Institution: Plymouth University

Unit of Assessment: Earth Systems and Environmental Sciences (B7)

a. Overview

Plymouth has established an integrated and dynamic group of research staff with common interests in Earth and Ocean observation, detection and the quantification of environmental processes. This is underpinned by experimental approaches to understand global change drivers and subsequent elucidation of underlying mechanisms, ultimately leading to novel theories on how Earth and Ocean systems function and integrate. The continuity and enhancement of our established research has been achieved by a long term, coherent policy supporting existing research groups within the following:

- Biogeochemistry Research Centre (BGC).
- Centre for Research in Earth Sciences (CRES)
- Coastal and Ocean Science and Engineering Research Centre (COSE)
- Marine Biology and Ecology Research Centre (MBERC)

These Research Centres bring together staff with cognate interests from two Schools within the Faculty of Science and Environment, namely The School of Geography, Earth and Environmental Sciences (SoGEES) and the School of Marine Science and Technology (SoMSE). Our unifying research philosophy maintains that like-minded staff within research groups are the engines of innovative research within their specialist fields, and that strategic planning and investment within the four thematic areas maximise opportunities for developing world leading research. The University's Research and Innovation Strategy 2009-2012 focused the investment of resources in strategic priority areas, which encompassed all aspects of Earth Systems and Environmental Sciences activity. This built on previous research investment of £5M in new laboratory and office facilities and the recruitment of high quality researchers prior to RAE 2008. The University has significantly strengthened its infrastructure and instrumentation base post-RAE 2008. In 2010 £1.8M was invested to develop the Biogeochemistry laboratory facilities, with additional investment to enhance the instrumentation base underpinning research in BGC and CRES. The Electron Microscopy Suite was also significantly upgraded in 2010 with a £1.2M investment in instrumentation for elemental analysis and mapping. New laboratories for ecological and genetic experimentation have been built as part of a £1.87M renovation of MBERC facilities. In 2012 the new Marine Building, resulting from a £19M investment by the University, was opened by HRH Prince Philip. The University has also funded the building of a new research vessel (Falcon Spirit) which supports marine related research in Earth Systems and Environmental Sciences. In addition to extensive international collaborations we have strong and longstanding regional research links with the Plymouth Marine Laboratory (PML), Marine Biological Association of the UK (MBA), Sir Alister Hardy Foundation for Ocean Science (SAHFOS), North Wyke Research (formally a BBSRC Institute, now part of Rothamsted Research) and The Environment Agency, evidenced by many joint publications and research projects.

b. Research strategy

In line with the strategy for Earth Systems and Environmental Sciences research at Plymouth stated in the RAE 2008 submission we have:

1. Built on the strengths of the existing research groups and the synergies between them by creating larger but coherent research centres in four key areas and establishing the Marine Institute (MI) to act as an overarching and unifying body (representatives from each of the four research centres sit on the MI management group and all of its various sub-committees). This process included the formation of the MBERC, which provided an important additional strand of expertise in environmental biology/ecology within the Earth and Environment area.
2. Capitalised on emerging research themes and a regional funding stream to establish Wave Hub, a grid-connected offshore facility in South West England for the large scale testing of technologies that generate electricity from the power of the waves.
3. Continued a long established tradition to focus on the recruitment, mentoring and development of early career researchers.
4. Sustained investment in our instrumentation base (e.g., two new ICP-MS instruments, two

walk-in, highly-controlled environmental chambers for global change experiments) and fieldwork facilities (e.g. a new high-tech research vessel, the 13.6-metre catamaran RV Falcon Spirit and a Rapid Coastal Response Unit to measure coastal change during extreme storms (http://www.bbc.co.uk/news/uk-england-20695065).
5. Expanded the number of ISO 9001:2008 accredited laboratories to include the Biogeochemistry Research Facility (BRF) and the Environmental Fluids Modelling Facility (part of CRES). This ensures appropriate quality assurance for our environmental measurements in these areas and has contributed to our 2008 objective to achieve stronger European links.
6. Forged stronger European links through a variety of EU and ERC funded projects, with a successful strategy of attracting Marie Curie Fellowships.
7. Developed our environmental technologies portfolio (e.g., patent pending for BioDev).
8. Contributed to the public understanding of science (e.g., Prof. Iain Stewart's acclaimed BBC series "The Climate Wars: How Earth Made Us" and Prof. Camille Parmesan's UNEP policy brief "Biodiversity, Health and Well-being".

Looking forwards, the strategic five year vision for Earth Systems and Environmental Sciences research at Plymouth is to:

1. Support the research objectives of its four constituent research centres through focused resource maintenance and acquisition.
2. Further enhance our positive and supportive environment for early career researchers.
3. Maintain and enhance the excellent infrastructure and instrumentation base for obtaining high quality environmental measurements, which serve as platforms for innovative experimental designs. For example, the University is investing £4.65M in the redevelopment of its waterfront Marine Station at Coxside.
4. Target funding from a diversity of sources, including the EU, RCUK and industry.
5. Expand accreditation under ISO 9001:2008 to more laboratories.
6. Expand existing strengths by encouraging more staff to actively engage in external professional activities, including serving on national and international committees (e.g. UNEP and IPCC), professional bodies and editorial boards of high impact journals.

The key integrating themes for research at Plymouth are the behaviour and fate of chemicals in the environment and their impact on ecosystem health, the impact of climate change on the physical environment and on biological communities and the development of new technologies and methodologies for Earth and Ocean observation and experimentation. To enable the strategy to develop these themes, all four Research Centres operate within a supportive but devolved faculty and university structure. Good practice is shared between the Research Centres by regular meetings between groups of staff: e.g., the annual Marine Institute Conference and the open invitation research conferences organised by each of the Research Centres.

The University Research and Innovation Strategy emphasises that Research Centres should be the focal point for all research activities. The four cognate Research Centres listed above meet regularly with the Dean and Associate Dean (Research) of the Faculty of Science and Environment to discuss research strategy for Earth Systems and Environmental Sciences, including staffing needs, infrastructure requirements, grant applications and research student mentoring and monitoring. These meetings are supplemented by regular formal meetings of the Research Centre heads with the Heads of the two Schools responsible for staffing and resources in Earth Systems and Environmental Sciences (SoGEES and SoMSE). Day to day research activities are then driven by the Heads of the four Research Centres who are responsible for staff appraisal (now called performance development review), career mentoring (including research students) and research management (including feedback on grant applications). Each Research Centre also has its own strategy for achieving the overall vision and these are detailed below.

BGC was formed by a merger of the Petroleum and Environmental Geochemistry (PEGG) and Biogeochemistry and Environmental Analytical Chemistry (BEACh) research groups to create a 30 strong centre of excellence who meet fortnightly for seminars and hold an annual conference with international guest speakers. BGC staff were awarded two European Research Council grants for both Advanced and Junior Investigators (€3.8M), in addition to numerous other EU and NERC awards, local Business Ideas competitions and Plymouth University awards for best research team

and most innovative researchers. There are strong international (e.g., BP, Total, Chevron, Shell, Environment Canada, The American Petroleum Institute), national (e.g., The Royal Society of Chemistry, The Foreign & Commonwealth Office, DEFRA) and regional (e.g., Kernow Analytical Technology, Fine Tubes Ltd) linkages. Research themes are now focussed on organic and inorganic biogeochemistry in aquatic and terrestrial environments. The BGC vision is to design, develop and apply novel analytical techniques to investigate biogeochemical processes in aquatic and terrestrial environments and use the unique, high quality environmental datasets obtained to propose and test new environmental hypotheses. BGC prioritises the recruitment of early career staff and enhancing the already excellent instrumentation base for high quality environmental measurements. The strategy to achieve this vision is to target EU and private company support, in addition to NERC opportunities, in marine chemistry. In the international arena BGC members have been particularly successful with European Research Council (ERC) funding and are actively involved in several networks, including the international GEOTRACES scientific steering committee and the General Assembly (governing body) of the European Association of Chemical and Molecular Sciences. We will expand links with the European Environment Agency based in Copenhagen and the European Centre for Environment and Human Health in Cornwall as well as DEFRA and the Environment Agency in the U.K.

CRES was formed in order to build on externally recognised research excellence, create an inclusive research community, develop a cohesive research programme and encourage novel initiatives across the whole spectrum of the Earth Sciences. In addition to many EU and NERC awards, CRES members have received numerous funded invitations to give plenary and keynote lectures as well as enhancing the public understanding of science, including leading BBC science productions. CRES has expanded research in palaeo-magnetic and structural analysis of the middle and lower crust, especially in the ocean basins, developed the use of stable isotope analyses to understand a range of climatic and geochemical processes and are at the forefront of research into palaeo-ecology and marine ecosystems, including ocean acidification and extinction events. Strong collaborative links have been developed with the British Geological Survey, the MBA and industrial partners (e.g., Shell Exploration & Production; Midland Valley). We have also developed research into new areas, including the application of remote sensing in geodynamics, mantle geochemistry and explosive volcanism and its products. The CRES vision is to carry out fundamental innovative research in order to make major advances in Earth Sciences. We provide maximum flexibility for developing new interdisciplinary areas that are relevant to the well-being of the UK, in terms of understanding Earth processes (past and present) and how they shape the sustainable use of natural resources, generation of energy, natural hazards and reduction in terrestrial and atmospheric pollution. We are expanding our outreach activities to both lay and broader science communities: e.g., by playing a key role in the Space Science and Earth Observation initiative. Our strategy is to promote a broad ranging interdisciplinary approach, with research extending from geophysics and tectonics to palaeontology and geomorphology.

COSE was formed as an integrated centre covering the University's key research groups in physical oceanography (marine physics and coastal processes) and coastal engineering. These strong component research groups remain the engines of research and have weekly meetings of research staff and students with presentations and discussions. Since 2008 strong advances have been made in physical oceanography using facilities such as the new research vessel and coastal response unit. The COSE vision for physical oceanography is to build on its established national and international reputation and gain recognition as a world-leading centre for coastal and ocean research. COSE aims to understand and predict the functioning of coastal and ocean systems in support of appropriate management of resources and activities. This will be achieved by bringing together a coherent group of internationally recognised research staff from across the marine physical sciences, coastal geomorphology and engineering. COSE is the largest coastal science and engineering grouping in Europe, forming a key component of the University's 'marine and maritime' strategic priority subject area and underpinning future Marine Institute initiatives.

MBERC was formed following RAE 2008 and brings together researchers in marine biology and ecology to provide a strategic research focus. The centre has been highly successful in obtaining research funding (NERC, RCUK, the Royal Society, EU, Marie Curie, Leverhulme, DEFRA, Natural England and the Esmée Fairbairn Foundation). It holds weekly research meetings, at which graduate students and staff present research findings, and has hosted several key international

meetings (e.g., International Temperate Reefs Symposium 2011). The centre has excellent collaborative links with other marine research organisations in Plymouth (SAHFOS, MBA and PML), including joint staff appointments, publications and shared PhD students. Within the UK, links include the NERC Sea Mammal Research Unit, CEFAS, National Oceanography Centre, Scottish Association for Marine Science and British Antarctic Survey. During the REF period, we have increased our research capabilities by: (i) appointing a chair (Parmesan) who is an expert in global biological impacts of climate change; (ii) appointing five early career researchers; and (iii) expanding our research infrastructure. The MBERC vision is to carry out high calibre research on the fundamental biology and ecology of marine (and other aquatic) organisms in order to make a substantial contribution to understanding how ecosytems and their biodiversity respond to environmental change. We have the capability to investigate effects at all levels of biological organisation from the molecular/biochemical and physiological response of individual organisms through to effects on populations, assemblages and ecosystems. This diversity of expertise will enable us to seek funding for: (i) the investigation and mitigation of the effects of multiple environmental stressors on marine biodiversity and ecosystems (e.g., ocean acidification, temperature, hypoxia); (ii) studying the potential harmful effects of microplastics; and (iii) developing novel approaches to the management of coastal environments, including the benefits of Marine Protected Areas (DEFRA).

c. People, including:

i. Staffing strategy and staff development

The foundation of our academic-led research in Earth Systems and Environmental Sciences relies on the quality of the staff and the stimulation brought about by the recruitment of new staff and post-doctoral fellows as well as the training of PhD students. We actively promote a vibrant research culture by creating an environment in which new ideas can flourish with interaction across Earth Systems and Environmental Sciences. We will continue to focus on the recruitment (e.g., from Wave Hub funding), mentoring and development of early career researchers. New academic staff are rapidly embedded within a research centre by assigning a more experienced colleague as a mentor and giving a research seminar at the earliest opportunity. They are initially given light teaching and administrative loads and start-up funds are provided to help them establish their research careers. New staff attend lecturing and staff development courses run by the University. There are regular appraisal procedures for career development for all staff. High priority is given to enhancing and refurbishing infrastructure and analytical facilities in order to provide high quality support for early career researchers and established academic staff. Equality and diversity are embedded in our approach, both formally, via a staff training course, and as an integral component of our day to day Research Centre activities. For example, since 2009, the Faculty has held an Athena Silver SWAN Award in recognition of its work in achieving gender equality.

Mentoring of early career staff by senior researchers is an integral and formal part of our research strategy. A good example of the success of this philosophy is **Ussher**. He was recruited from Swansea University as a Chemistry BSc graduate in 2001 to study for a PhD in Chemical Oceanography and was then the nominated PDRF on a NERC grant. Following this he was awarded a one year lecturing post (as maternity cover) during which time a successful EU Marie Curie Outgoing International Fellowship application based in Bermuda was prepared to broaden his experience. During his lecturing post he achieved an accredited teaching qualification. As a result of his research potential and teaching experience he was successful in obtaining a full time academic position in the BGC in November 2012 and has now been awarded an EU Career Integration Grant to develop his own research programme. At a higher level, **Lohan** was recruited to an early career academic post from a postdoctoral position at UCSC, USA in 2005 and was promoted to Reader in 2010 and Professor in Marine Chemistry in 2012. Similarly **Hall-Spencer** was recruited as an RCUK Fellow in 2003 and was promoted to Reader in 2011 and Professor in Marine Biology in 2012. Our commitment to supporting early career researchers is further demonstrated by the recruitment of a Royal Society Fellow (**Kirby**) and two RCUK Fellows (**Howell and Calosi**) who are now permanent members of academic staff in MBERC. SWRDA Wave Hub investment was used to recruit Conley and Hosegood as physical oceanography staff in COSE and **Menegon** and **Pagli** were recruited in 2012-13 as members of CRES. Our new staff provide balance to our academic staff profile and contribute to enhancing our priority research areas as

well as reinforcing our strong interdisciplinary base.

The UK Concordat to Support the Career Development of Researchers is embedded within the research culture at Plymouth. This is augmented by a university-wide Researcher Forum which has developed from the Early Career Academic Forum and the Contract Researcher Forum with bespoke development workshops and a Supervisory Development and Mentoring programme to support good practice in supervision and research degree examining. Successful engagement with research and innovation and the promotion of equality of opportunity are embedded in the Performance Development Review process for all staff. All early career researchers have taken advantage of this combination of formal support with the informal mentoring that takes place on a daily basis within each Research Centre. Early career researchers are also prioritised for funding within Research Centres. The success of this process is evidenced by the specific examples above.

ii. Research students

PGR recruitment is driven by each of the four Research Centres, with the Graduate School providing administrative support. All studentship posts are formally advertised and applications assessed by a panel of staff according to a job description and person specification. Advertising for posts is done internally and externally by formal advertising and also via informal networks. Face to face interviews are required for all advertised posts. All staff on interview panels (for staff or students) must have successfully completed the University equality and diversity training course for interview panels. The chair of any panel must also have successfully completed the 2-day training course for chairing such panels. All our research students are rigorously selected on merit and carefully nurtured through their programme of study. They are assessed annually through written reports and we attach a high priority to research students presenting their work at national and international conferences. Their intellectual input is key to our overall research profile.

Monitoring of student progression is undertaken by senior researchers (in the designated roles of research co-ordinators) in each Research Centre in liaison with the Graduate School, which provides a unified regulatory and procedural framework. This includes the appointment of experienced supervisory teams and utilises a student focussed logbook for monitoring progress from initial registration through to completion. In addition, good practice is shared between Research Centres via formal meetings (with minutes) of research co-ordinators once each semester, with research student representatives present for part of each meeting. The student representatives raise issues on behalf of their peers and disseminate outcomes back to the research student community. The Graduate School has recently overseen the establishment of Doctoral Training Centres (DTCs) for Geography, Earth and Environmental Sciences and for Marine Science and Engineering. These (i) co-ordinate the provision of generic skills training programmes for the next generation of innovative researchers, (ii) provide a focus for a rigorous and vibrant research training culture, and (iii) oversee a strong mentoring system coupled with peer student support.

We have a Researcher Development Programme for research students and researchers, mapped onto the VITAE Researcher Development Framework. This covers the four key domains of development: i.e., Knowledge and Intellectual Ability, Personal Effectiveness, Research Governance and Organisation and Engagement, and Influence and Impact. The programme, pursued in conjunction with the Graduate School, aims to develop self-determination, self-management, assertive communication, team interaction, research conceptualisation, public communication and creative thinking in the next generation of researchers. The research student monitoring and mentoring provision at Plymouth is endorsed as compliant with the UK Concordat to Support the Career Development of Researchers and the European Charter for Researchers and in 2011 was recognised by receipt of the “HR Excellence in Research” Award from the European Commission**.** Examples of good practice include student organised, open access research conferences for each research centre in which the students run all aspects of the programme and present their research. We have an excellent record of career progression for our PhD graduates. Taking the 2012 cohort as an example, all 13 have progressed their careers in science since they graduated. Timothy Poate and Sian Rees are PDRFs at Plymouth, Anthony Bicknell is a PDRF at the University of Exeter, Gabriela Garcia Rubio is a PDRF at CICSE in Mexico, William Grecian is a PDRF in Glasgow and Valentina Laria is a PDRF in Galway. Kate De

La Haye works in teaching support and Stacey DeAmicis is a Teaching Fellow, both at Plymouth. Sedercor Melatunan is a Lecturer in the Faculty of Fisheries and Marine Science, University of Pattimura, Indonesia and Emhemed Alfandi is a Lecturer at University 7th April, Zawiyah, Libya. Charlotte Marshall and James Highfield work for Natural England, Thomas Roc is designing tidal turbines for International Power in Bristol, Daniel Gantenbein is a research scientist with Omya in Switzerland and Alison Turner works for a mining and exploration consultancy in Australia.

d. Income, infrastructure and facilities

Plymouth University offers excellent research support across a broad spectrum of marine related subjects linked via the Marine Institute (MI). The MI provides a coherent focus for marine-related research in Earth Systems and Environmental Sciences focussed on understanding marine and coastal systems and assessing environmental change. It operates through a range of local partnerships with PML, the MBA, SAHFOS, the National Marine Aquarium and the Flag Officer Sea Training (FOST) Hydrography, Meteorology and Oceanography (HM) School. It has worked with the former South West Regional Development Agency and University of Exeter to research the viability and impact of a £28M wave energy project (Wave Hub) off the coast of Cornwall.

With funding assistance from the Departments of Energy and Climate Change and Business, Innovation and Skills and the EU ERDF Competitiveness and Employment Programme, the University opened its £19M Marine Building in September 2012. This houses the Marine Institute, Marine Innovation Centre and state-of-the-art Coastal Ocean and Sediment Transport (COaST) wave tank facilities consisting of a 35m x 15.5m x 3m Ocean Wave Basin and a 15.5m x 10m x 0.5m Coastal Basin. The Ocean Basin builds on Wave Hub investment and a growing research base in marine renewable energy, designing and testing wave and tidal energy devices. The Coastal Basin provides a physical model capability to complement Plymouth's internationally-recognised strengths in coastal field measurements, coastal sediment transport and coastal change. The University has recently purchased the 13.6 m ocean-going research vessel RV *Falcon Spirit* to service Wave Hub projects and facilitate other coastal research work. The vessel has a replacement cost of £0.75M. Over the course of 2013 the University is investing £4.65M to completely redevelop its Marine Station site which is within walking distance of the main campus. This will provide greatly enhanced facilities for teaching and research, with more teaching rooms, a wet laboratory, aquaria, berths and equipment storage facilities to support boat-based activities. Our research strategy is endorsed by the University which has given high priority to enhancing and refurbishing analytical facilities. It has also invested in new facilities for ecological and evolutionary research, including molecular ecology and genomics, and behavioural ecology, as well as new technological advances that allow, for example, analysis of seafloor video footage and a High Performance Computing cluster (£0.25M) that supports advanced hydrodynamic modelling applications.

High quality environmental measurements are a cornerstone of our research investigations. We have therefore invested in ISO 9001:2008 accreditation of research laboratories, including a nutrient laboratory with a four channel segmented flow analyser and a specially designed trace metal clean facility containing a positive pressure cleanroom (Class 100), supported by a recently refurbished dust free laboratory with three Class 100 work stations and a specially designed room for acid washing. Within these laboratories we have a suite of analytical instruments for the detection of dissolved trace metals in natural waters (sub-nanomolar), including flow injection analysers with spectrophotometric, chemiluminescence and fluorimetric detection and voltammetric instrumentation which are used onboard ship and in the laboratory. We also have ICP-MS as well as ICP-AES and GFAAS facilities. Facilities for the analysis of complex mixtures of organic chemicals include novel high temperature gas chromatography-mass spectrometry (HTGC-MS) and HTGC-FID instruments (used to identify 'mystery' oil pollutants to national acclaim in 2013), a GCxGC-MS (the first of this model in the world to be installed and used for ground-breaking research on oil sands pollutants for Environment Canada); we also have more routine GC-MSD (2) and LC-MS^n instruments.

Our Microscopy Laboratory is designed for high precision work and includes a high magnification picking microscope and a transmission and reflectance microscope with a digital camera and imaging software. In addition, the Electron Microscopy Centre is equipped with both scanning and transmission electron microscopes with cryo-stage imaging of frozen, fully hydrated specimens and

an X-Ray micro-analysis suite providing full analytical capability, including quantitative elemental analysis and element mapping. Our Stable Isotope Mass Spectrometry analytical facility is equipped with an isotope ratio mass spectrometer, with modular attachments for carbonate oxygen and carbon and organic carbon stable isotope analysis. Research conducted using this facility has resulted in recent funding of £1.3M from NERC and the EU. The Palaeomagnetic Research Laboratory is equipped with a high sensitivity spinner magnetometer, two spinner magnetometers, a large-aperture archaeomagnetic spinner magnetometer and associated alternating field demagnetizer, an alternating field demagnetizer with a hysteretic remanence attachment, an anisotropy of magnetic susceptibility bridge with high temperature furnace and liquid nitrogen thermostat attachments, and a pulse magnetizer. We place emphasis on developing novel technologies including liquid chromatography coupled with mass spectrometry for palaeoclimate studies and Electron Backscatter Diffraction (EBSD) facilities for a new Earth Materials Laboratory.

We have bespoke facilities for the laboratory investigation of organismal responses including extensive controlled temperature (-20 to +30 ^{o}C) space, NERC-funded mesocosms for the manipulation of gas levels (to reduce seawater pH and hypoxic conditions), HEIF funded purpose-built, high resolution video-microscopes and microprobes for the measurement of small scale physiological responses and facilities for the detection of microplastics in marine sediments. We are developing a capability for monitoring stress effects at the molecular level, e.g. heat shock proteins, via funding from two NERC Biomolecular Analysis Facility grants. For field work, we have two remotely operated vehicles and a purpose-built sled that enable us to carry out detailed surveys and mapping of seabed habitats. The videos produced are analysed using our extensive analysis suite.

Recently announced grants awarded to staff demonstrate our core research strengths. In biogeochemistry, for example, research in marine trace metal cycling will be enhanced by a NERC grant to investigate “The supply of iron from shelf sea to open ocean” in collaboration with Co-I’s at University of Southampton and National Oceanography Centre (**Lohan & Ussher**; 2013-2016, £250k) and a EU Marie Curie Career Integration Grant to “Determine the impact of seawater chemistry on the solubility of atmospheric trace metals” (**Ussher & Worsfold**; 2013-2017 €100k). In physical oceanography, highlights are two NERC grants: “Surface mixed layer evolution at sub-mesoscales (SMILES)” with Co-I’s at PML, University of Cambridge and BAS (**Hosegood**; 2013-2016, £470k) and “Fluxes across sloping topography in the Northeast Atlantic (FASTNEt)” with SAMS (Lead Institution), NOC-Liverpool, NOC-Southampton, Bangor University, PML and BODC (**Vlasenko, Hosegood & Nimmo Smith;** 2011-2015, £580k**)**. A good example of inter-disciplinary research in chemical/physical oceanography is a NERC grant on “Seasonal controls on shelf-edge nutrient fluxes at the Malin Shelf (Autonomous Underwater Vehicles)” (**Lohan, Hosegood and Nimmo Smith**; 2012-2015, £125k). Within earth sciences new research will be underpinned by three NERC grants: “Clumped-isotopes on marine temperatures during the Cretaceous” (**Price & Grimes;** 2013-15, £396k), an Urgency Grant (**Cole**; 2013, £51k) to study “Explosive activity at Volcán de Colima, Mexico” and “Evaluating the evolution of modern marine ecosystems” (**Twitchett & Price;** 2010-14, £453k). In marine ecology, recently funded projects include “Impacts and implications of ocean acidification on key benthic ecosystems, communities, species and life cycles” (**Spicer & Calosi**; 2010-14; NERC; £200k); “Scaling empirically derived ocean acidification responses to naturally assembled systems” (**Hall-Spencer & Foggo**; NERC; 2013; £91k); “Assessing the effects of long-term ocean acidification at CO_2 vents off Methana Greece” (**Hall-Spencer**; EU; 2011-15; £122k) and “Microplastics in the marine environment” (**Thompson**; DEFRA; 2011-14; £255k).

Accreditation is a cornerstone of our consultancy and professional services strategy. A strategic investment of c.a. £2.5M is planned over the next five years in capital equipment (including a HR-ICP-MS, EDXRF, ToF-MS and EBSD) that will operate within our ISO 9001:2008 accredited environment and this will underpin research and consultancy. The major part of the investment will be to fund new instrumentation which will complement and enhance our facilities in the Analytical Research Facility (ARF), Biogeochemistry Research Facility (BRF), CRES, and our Electron Microscopy Unit. The Consolidated Radio-isotope Facility (CORiF), a radioanalytical facility with state-of-the-art gamma spectrometers and liquid scintillation counters, is another ISO 9001:2008 accredited laboratory that provides a range of contract analytical services in sediment geochronology, soil erosion and sediment budget studies, radioactively contaminated land and

tracer studies, radiochemical tracer studies and non-radiometric analyses. In addition, there is a commitment to invest in technical support and a full-time Quality Manager in order to further develop our ISO 9001:2008 accreditation capability.

e. Collaboration and contribution to the discipline or research base

Collaboration is embedded in our research philosophy and examples of discipline-based and cross-disciplinary initiatives in the national and international arenas are given below. Examples of international collaborations include:

- *Marine renewables*. Since the advent of PRIMARE, COSE researchers have rapidly developed an international reputation in research related to marine renewable energy. This is evidenced by: (i) its role as coordinator of the €1.9M SOWFIA project; (ii) its selection by Pacific Northwest National Laboratories (USA) as co-consultants along with the Wave Energy Centre in Portugal to the IEA Ocean Energy Systems Annex IV activities; (iii) its promotion to full member status of the SuperGen UK Centre for Marine Energy Research; and (iv) COSE members serving as expert panelists in international marine renewable energy activities such as the South East Asian Collaboration for Ocean Renewable Energy.
- *Climate change*. An example of collaboration in the field of climate change is the participation of Parmesan in a National Center for Ecological Analysis and Synthesis Working Group studying "Marine Impacts of Climate Change" from 2010-2013. The team of 18 scientists came from 5 countries (UK, Spain, Australia, Canada and USA) and results have been published in *Science, Nature Climate Change* and *Ecology Letters* **(Parmesan)**.
- *Ocean acidification*. Research on the effects of ocean acidification by MBERC staff has been carried out through several collaborative projects including: a NERC OA Benthic Consortium (with PML, MBA, CEFAS, and Universities of Southampton, Bangor, Hull, St Andrews, Glasgow and Herriott Watt) **(Calosi and Spicer);** the EU FP7 MedSeA project (with the University of Palermo and the Stazione Zoologica di Napoli, Ischia) **(Calosi and Spicer)**; and the NERC UK Ocean Acidification research programme (with the Universities of Southampton and Bangor and CEFAS) **(Hall-Spencer and Foggo**).
- *Marine chemistry*. Collaboration in marine chemistry include a partnership with the Universities of Oxford and Southampton on two 'UK GEOTRACES' projects to determine trace metal biogeochemical cycles in the South Atlantic and sub-tropical Atlantic. These were funded by a NERC consortium grant (NE/H004475/1, £3.5M and NERC standard grant (NE/G015732/1, £1.2M) (**Lohan**). Collaboration with the Bermuda Institute of Ocean Sciences (BIOS), on trace metal biogeochemistry in the Sargasso Sea and atmospheric and oceanic time series studies at the Tudor Hill and BATS sites was funded initially by an EU Marie Curie Outgoing International Fellowship (2009-2012) and is now supported by a Marie Curie Career Integration Grant (2013-2017) and a joint PhD studentship (**Ussher, Worsfold, Lohan**).
- *Physical oceanography*. Collaboration with leading European marine research centres from 28 countries in the framework of the landmark €90M EU MyOcean/MyOcean2 initiative to create regional operational Monitoring and Forecasting Ocean Centres was part of the GMES - Global Monitoring for Environment and Security- strategy. Within this initiative, Plymouth was responsible for implementation of the NEMO ocean model for the Black Sea (**Shapiro**). Further collaboration took place within the €10M PERSEUS (Policy-oriented marine Environmental Research for the Southern European Seas) project to assesses the dual impact of human activity and natural pressures on the Mediterranean and Black Seas. Plymouth was responsible for assessing effects of shipping activities and exchanges between polluted shelves and deep sea (**Shapiro**).
- *Sediment transport*. COSE researchers are internationally recognised for their research into sediment transport and hydrodynamic processes in the swash and inner surf zone, in part through extensive collaboration with a number of international research groups: University of New South Wales (Turner), University of Delaware (Puleo), Deltares (Roelvink) and University of Bordeaux 1 (Senechal and Castelle). These collaborations have involved several large international measurement campaigns including Truc Vert, France (2008), Delta Flume, Netherlands (2008), Perranporth, England (2011, 2012), Loe Bar, England (2012) and Delta flume, Netherlands (2012) (**Masselink, Russell, Conley**).
- *Marine ecosystems*. CRES researchers (**Twitchett & Price**) lead a NERC project in the Co-

evolution of Life and Planet programme studying the controls on the structure and function of Mesozoic marine ecosystems collaborating with Oxford; Southampton; Leeds; Madrid and Florida. **Twitchett** was also Co-PI of a project on the restoration of marine ecosystems following the Permian-Triassic mass extinction, IGCP 572, funded by UNESCO/IUGS and Co-I of an Australian Research Council Discovery/QEII Fellowship grant with Curtin University of Technology, Western Australia.

- *Ocean drilling programme*. CRES scientists also participated in three recent Integrated Ocean Drilling Programme (IODP) international collaborative research expeditions (**Morris** was the Lead Shipboard Palaeomagnetist on Expedition 335 "Superfast Spreading Rate Crust 4" and Expedition 345 "Hess Deep Plutonic Crust; and CRES PDRA Dr Debbie Wall-Palmer was the Shipboard Micropalaeontologist on Expedition 340 "Lesser Antilles Volcanism and Landslides").

As an example of interdisciplinary research, Rowland was awarded a European Research Council funded Advanced Investigators Award (OUTREACH project (2009-14) agreement no. 228149) of €2M. This project integrates organic geochemistry with ecotoxicology to characterise the chemical composition and toxicity of individual chemicals within the 'supercomplex' mixtures of organic pollutants resulting from oil spills and oil sands operations. Such chemicals are presently outwith the recently imposed EU REACH regulations. Thus far the project has resulted in > 20 scientific papers and GB, US and Canadian provisional patents, plus many invited lectures The work impacts on the research and policy decisions of Environment Canada and the American Petroleum Institute, for whom Rowland is now a consultant. This has led to further collaborative projects with Shell Global Solutions and BP USA (on oil industry research), and the Maritime Coastguard Agency, RSPCA and RSPB (on chemical spill research) (**Rowland**).

An example of collaboration with end users is a NERC-RNLI Partnership grant (2008-12) on the 'Dynamics of Rip Currents and Implications for Beach Safety' that supported a PDRA and a Knowledge Exchange Fellow. This work received additional funding from the Met Office, Bournemouth Borough Council and RNLI to extend the work to beaches with structures, such as groynes, which create strong rip currents. An output of the Partnership grant was a National Rip Current Warning system for the UK developed in collaboration with the Met Office (**Russell and Masselink)**.

Staff have made substantial contributions to the wider research environment and demonstrated leadership in the academic community. Examples of involvement in the committee structure of learned societies include: President of the Scientific Committee on Ocean Research (SCOR) (**Burkill**); Member of the Board of Life Sciences, U.S. Academy of Sciences (**Parmesan**); Chair of the European Association of Chemical and Molecular Sciences Division of Analytical Chemistry (2011-2016) (**Worsfold**). Examples of membership of working parties and steering committees include: IPCC ocean acidification working group (funded by UNESCO, 2011-present; International Council for the Exploration of the Seas (ICES) Working Group on Deepwater Ecology (2005-present); and United Nations Environment Programme (UNEP) representative drafting guidelines for deep-sea fisheries management in the High Seas (2008-present) (**Hall-Spencer**); Chair, International Sub-Committee on Cretaceous Stratigraphy (2013-) (**Hart**); Member of GEOTRACES Scientific Steering Committee (2010-) (**Lohan**); Member of the Programme Committee of the Division "Tectonics and Structural Geology" of the European Geosciences Union (EGU) (2008-2011) (**Menegon**); Committee to Advise the US Global Change Research Programme, U.S. National Academy of Sciences (**Parmesan**); Palaeontological Association Council Member (2006-) **(Twitchett).** In addition, staff have presented to government bodies, e.g. presenting evidence on marine microplastics to the UK Parliamentary Select Committee on water quality (**Thompson**).

Research excellence has been recognised by the following awards: "2013 Distinguished Scientist" by the Texas Academy of Sciences; 2010 T Reuters ranked 2nd most-highly cited author in "Climate Change" for the previous decade (1999-2009) **(Parmesan)**; 2010 University of Plymouth World Class Researcher Award (**Hall-Spencer**); Jean Baptiste Lamarck Medal, April 2011 (EGU), Gryzbowski Foundation Award 2011, Honorary Membership, The Micropalaeontological Society 2010 (**Hart**); Challenger Fellowship Award for Marine Chemistry 2008 (**Lohan**); Leverhulme Trust Fellowship 2011-2012 (**Price**); European Research Council

Advanced Investigators Award 2009-14 (**Rowland**); James Lee Wilson Award for "Excellence in Sedimentary Geology by a Young Scientist" 2011 (**Twitchett**); Japanese Association for Flow Injection Analysis Honour Award 2008 (**Worsfold**). Staff also have formal status as **Visiting Scientists** overseas, e.g. Visiting Professor and Blaustein Fellow in the Department of Geological & Environmental Sciences at Stanford University, USA (**Rowland**); Visiting Scholar (2011) in the School of Earth and Environmental Sciences, James Cook University, Australia (**Price**); Adjunct Faculty Member, Bermuda Institute of Ocean Sciences, Bermuda (**Ussher**).

Staff are engaged in all aspects of journal publishing and peer review, including **editorial roles**. Associate Editor, Ocean Acidification (**Hall-Spencer**); Special Publications Editor and Board Member, Cushman Foundation, Editorial Board of Revue de Paléobiologie and Paläontologische Zeitschrift (**Hart**); Associate Editor, Limnology and Oceanography Methods (**Lohan**); Associate Editor, Ocean Dynamics, Editorial Board of Estuarine Coastal and Shelf Science (**Manning**); Editorial Board of Conservation Biology **(Parmesan)**; Editorial Board of Marine Geology (**Masselink);** Editorial Board of Cretaceous Research, Proceedings of the Geologists' Association (**Price**); Associate Editor and Special Guest Editor, Organic Geochemistry (**Rowland**); Editorial Board of Micropaleontology (**Smart**); Lead Editor for themed issue of Philosophical Transactions of the Royal Society B entitled 'Plastic, the environment and Human Health' (**Thompson**); Associate Editor, Paleontological Research (**Twitchett**); Editorial Board of Nonlinear processes in Geophysics, Editorial Board Advances in Geophysics and Environmental Mechanics (**Vlasenko**); Editor, Analytica Chimica Acta; Editorial Boards of Analytical and Bioanalytical Chemistry, Journal of Environmental Analytical Chemistry and Environmental Chemistry (**Worsfold**). As examples of **participation in peer review**, **Bilton, Fitzsimons Grimes, Hall-Spencer, Morris, Price, Rowland, Rundle, Stokes, Taylor, Vlasenko and Worsfold** are/or have been members of the NERC peer review college and **Worsfold** has chaired all of the NERC/ACTF Analytical Science and Technology Studentship Assessment Panels (2010-1013). Staff also review proposals from several international agencies such as the National Science Foundation (USA).

As would be expected, staff have been invited to give many plenary and keynote lectures at international conferences in the assessment period. Examples are the 22nd V.M. Goldschmidt Geochemistry Conference 2012, Montreal, Canada (**Belt & Rowland**); the 14th Glossop Lecturer, 2013 (**Griffiths**); IPCC WG1 & WG2, Okinawa, Japan (2011) (**Hall-Spencer**); the Royal Swedish Academy 300 year celebration of Linneaus and the Intergovernmental Climate Change Conference (COP15) in Copenhagen (**Parmesan**) and the 5th International Marine Debris Conference in Hawaii 2011 (**Thompson**). Staff have also had senior roles in the organisation of several international conferences, including Co-Convenors of the International symposium on the Cretaceous system, 2009 (**Hart & Price**) and Co-Chairs of the World's largest coastal research conference, the International Coastal Symposium, which was hosted by Plymouth in April 2013 with 500 delegates (**Masselink & Russell**).