Institution: University of Cambridge

Unit of Assessment: B 07 - Earth Systems and Environmental Sciences

1. CONTEXT*:* Our overall research policy is to pursue fundamental research at the cutting edge of a wide range of ever-expanding frontiers in Earth Sciences. An intrinsic part of this strategy is a commitment to supporting and enabling impact from this research. Our work has significant impact in a number of areas but it is particularly important to the energy industry and for policy makers working in the area of natural hazards and climate change; we also have a strong record of contributing to public understanding in these areas and in thinking on the evolution of life.

1.1 Beneficiaries of our research

Economic prosperity: We make a significant contribution to economic prosperity by commercialisation and exploitation of our scientific insights, particularly through the influence of our research on the exploration and production activities of **multi-national oil-related companies** notably Schlumberger, Shell, BP, Exxon, Hess, Tullow and BG (impact case A, "Imaging Below Basalts"; impact case B, "Sedimentary Basins"; Impact case C, "Enhanced Oil Recovery").

Beyond hydrocarbons, through our work in mineral sciences we engage with a variety of other industrial beneficiaries including companies in the nuclear industry, Rolls Royce, and the two Korean companies, Samco and Samsung. Of particular note is the influence that our work on carbon capture and storage has had on the activities of Shell (impact case E,"CO_2 Leakage").

We have a long tradition of working with companies producing **scientific instruments,** this has led to new instrumental developments or enhancements after discussing novel approaches to long-standing problems, or ways of addressing new problems. A recent example of such interaction led to commercialisation of a new product, a scanning spectrometer system, described in impact case D ("Volcanic Gas Fluxes").

Income is generated from a range of **software products** developed through our research; one of these has provided the salary to employ a programmer for over 20 years, and another has been distributed to 17 countries over 6 continents by Cambridge Enterprise, a company wholly owned by the University which facilitates consultancy and provides indemnity and liability insurance to university staff in return for a small percentage fee.

Government agencies and policy-makers: Through our research into earthquake and volcano **hazards** we are engaged with groups responsible to their governments in many different countries, including Almannavarnir (Icelandic Civil Protection Department), the China Earthquake Administration, the Geological Survey of Iran, Bihar State Disaster Management Authority and the Scientific Advisory Committee to the Government of Montserrat. Our staff contribute to **policy development** through membership of the Board of the Parliamentary Office for Science and Technology of the House of Commons (POST) and on the NDA Environmental Safety Case Independent Panel. Our work on **climate science** has contributed to the development of policy by the IPCC. In the UK one of our staff chairs the Programme Advisory Group of the NERC Ocean Acidification Research Programme which feeds into DEFRA (the Department for Environment, Food & Rural Affairs) and DECC (the Department of Energy & Climate Change).

The general public and society at large: Many aspects of our work capture the public imagination and interest. By engaging with them and the media we help inform and contribute to contemporary debate, thereby inspiring the next generation of researchers.

2. **APPROACH TO IMPACT**

Our approach to impact is to promote the fundamental advances we make in understanding how the Earth works with an awareness of industrial and policy need through the many contacts we maintain; this happens both at open meetings designed to attract key industry representatives and policy makers and by regular meetings with commercial partners. Our staff are encouraged to convene suitable meetings and to accept invitations to speak to appropriate audiences in order to disseminate their work. Regular engagement with both senior industry staff (e.g. Head of Technology or Chief Scientist of multi-national companies) and other staff who are budget holders for specific technologies, ensures that we are acutely aware of the current issues facing our partners and are able to highlight advances which may be of direct relevance to their concerns. There are famous examples where this approach has revealed new insights or produced new techniques that were not necessarily anticipated but which are very relevant to industry; e.g. the understanding of sedimentary basin formation by extension, which originates in this department. A recent example, provided by the breakthrough in sub-basalt imaging described in impact case A ("Imaging Below Basalts") involving Schlumberger (and others), is one of several

collaborative projects with the Schlumberger Gould Research Center, which was established in Cambridge specifically to benefit from strong collaborative links with the University. Because the companies involved in these projects are multi-national the impact is often global in reach.

Commercial recognition of the success of this approach is visible in many ways including: our privileged access to commercial datasets which we use for basic research (e.g. seismic data acquired by our partners at £M cost); representation by our staff at high levels in industry e.g. one of our staff sat on BP's Technology Advisory Council (2001-2008) and another was non-executive chairman of Shell (albeit 2004–05, outside the period covered by the REF); 12-20% of our research grant income is derived from industrial sponsors over each of the previous 4 years, amounting to over **£2M** during this period, even though contractual agreements for this research usually involve the results being publically disseminated; c. 20% of our research students are funded by industrial partners, and several of these have regularly funded students over a ten-year period, with the resulting research frequently making a direct contribution to their business and often leading to students entering employment with the them. The regular supply of staff to these businesses provides further opportunities for knowledge transfer.

2.1 ***The Cambridge Earth Sciences Industrial Associates scheme*** offers a good example of how this approach works in practice. We have cultivated and nurtured relationships with our commercial partners, particularly with companies in the energy sector, to produce a well-established and successful knowledge-exchange mechanism. This allows them to draw regularly on our new insights and breakthroughs, informing their approach to existing and potential challenges, and thereby augmenting their own problem-solving capacity. The scheme was initiated in 1991 and has led to close and enduring personal links. Although the membership has varied, there are currently 7 multi-national oil-related companies participating, each paying a subscription; these funds allow us to take advantage of strategic opportunities and to fund pilot research projects which can lead to further impact. We invite our Associates to an annual meeting presenting our recent research, typically attended by 20-30 company representatives who are key members of their research, exploration and development teams. There is extensive opportunity for discussion with Department members leading to frequent interaction with subscribers to the scheme between these meetings. The members of the scheme are kept abreast of research projects, new directions and technique developments, this privileged early access to our latest ideas gives them a real commercial advantage over their competitors. They recognise the importance of our research programme by making available ship time, proprietary software packages for data handling and high-quality proprietary datasets. We frequently make a real contribution to industry understanding of their commercial data when we use these datasets for our basic research. The value that one scheme member places on our approach is clearly shown by BP's decision, in 2010, to invest **£4.35M** in the Department of Earth Sciences to endow a new Professorship in Quantitative Earth Sciences; this is the latest in a series of commitments that BP have shown to our work.

2.2 ***The BP Institute***, (BPI) which is hosted by the Department of Earth Sciences, provides another example. High-level discussions with the company led to the Institute's foundation in 1999 through an initial endowment of **£22M** to support 5 academic posts, one of which is at professorial level. The Institute has developed an international reputation for its research in multiphase flow and, whilst BP continues to offer us interesting problems and data for people to work on, the Institute's intellectual independence is contractually guaranteed, enabling it to concentrate on research that fits its academic interests and capabilities. BP have a representative, who regularly works from the site, in a boundary-spanning role acting as a technological facilitator, with a clear understanding of the problems faced by BP and the individual skills of the researchers in Cambridge. Through courses, seminars and visits to BP's offices our researchers meet up to 100 BP staff each year, leading to formation of very effective knowledge-led networks. In 2010 BP added a further **£3.93M** to the BPI endowment, a testament to the value it places on this initiative.

In 2001-2008 one of our staff sat on BP's Technology Advisory Council. Another acted as an advisor on the 2010 Macondo Gulf oil spill; our research into the fluid mechanics of mixing has been critical to informing BP about the processes occurring in the Gulf of Mexico water column and has changed the way that BP carries out risk assessments and planning for deep-water drilling worldwide. The BP Institute's work has led to a **spin-out company** (Breathing Buildings) and to several joint **patents**.

2.3 ***Public engagement:*** We aspire to listen to and understand current public attitudes and concerns directly by interactive engagement. The annual **Cambridge Science Festival**, part of the

University's contribution to National Science week, provides an excellent opportunity for engagement and members of the Department are directly involved in this hugely successful community event; it is attended by 30,000 people from a very wide geographic area. We maximise the impact of the **Sedgwick Museum** which is an integral part of the Department and a major regional museum providing an ideal venue for public engagement and outreach. The museum's staff are experts in increasing the public accessibility of science and helped to establish the University's "Rising Stars" public engagement course. The museum visitor numbers increased from 61,000 pa in 2007-8 to 90,000 pa in 2011-12 and the evidence base of visitor profiles shows that it attracts people of all ages and backgrounds. Dedicated display space is used to showcase the Department's research and PIs regularly include funding to support this in research grant applications; an example is a large exhibition (supported by over £500k from the Heritage Lottery Fund) commemorating the geological work of Charles Darwin for the bicentennial celebrations in 2009, which incorporated recent research conducted in the Department on the Galápagos.
The **University's External Affairs and Communications Office** provides an excellent service for disseminating research results to the general public through both the University website and the local, national and international media. Our staff also regularly present their science through television, radio, and newspaper interviews. Several have written popular articles and books and have contributed to events such as the Hay Festival.

2.4 Engagement with Government agencies and policy-makers: In part through the need, over many years, to obtain permissions for field work and field experiments overseas, our researchers have established extensive contacts in international bodies and governmental agencies in a range of countries. Some of these personal relationships have developed into direct contacts with policy makers in overseas government thereby providing an avenue for communicating our science. An example is our work on major **earthquakes**, particularly in Iran, which has led to improved understanding of the vulnerabilities of communities at risk, and close interaction with those responsible for advising governments, aiming to improve resilience and to develop evidence-based policies for the concentration of resources.

Much of our work on **radioactive waste management** is in conjunction with the UK's National Nuclear Laboratory, this connection enables technology dissemination through our part in international customer meetings and workshops involving other international organisations, such as the IAEA. Collaborations with British Antarctic Survey on climatic and environmental change and ice sheet dynamics feed science output to DECC.

2.5 Staff mobility and reward: Our graduate students and early career researchers are highly sought after by both small and medium geoscience businesses (e.g. Galson Scientific and Equipoise - both established by our former graduate students) and multi-nationals (BP made offers to over 35% of the applicants from Cambridge Earth Sciences in 2012-13).

Our staff 's commercial involvements are influential in Senior Academic Promotions: in the last promotions round the award of a chair to the lead on impact case B ("Sedimentary Basins") was supported and strengthened by references from senior partners in industry, and three of the most commercially active members of BPI were rewarded by promotions.

3. STRATEGY AND PLANS: We will continue to develop our highly successful Industrial Associates scheme for engagement with the commercial sector; we will showcase the work of our younger staff in order to maintain and develop the scheme into the future. Much of this work is connected with the University's **Energy@Cambridge** strategic research initiative; we will endeavour to use this initiative as a springboard, with the help of collaborators retired from senior positions in industry, to foster new commercial interactions.

We are committed to developing our links with **government agencies and policy-makers** and are approaching this in several ways. An example is provided by our work on earthquake hazard. As this research extends into new geographic areas we have developed new links through the **Cambridge Central Asia Forum**, which has already enabled us to make a number of governmental connections in central Asia. Other initiatives include a recent RCUK award to collaborate with social scientists, in which the Overseas Development Institute is a partner. By collaborating with bodies experienced in the communication of scientific knowledge to policy-makers we hope to translate our research into more effective earthquake mitigation, improved infrastructure and enhanced crisis management.

We have developed other links with policy-makers by capitalising on the expertise of staff in different parts of the University, for example the **Cambridge Centre for Carbon Capture and**

Storage which promotes the University's work in that area is coordinated by the Judge Business School; this connection has helped to secure a large contract from the Department of Energy & Climate Change to extend our work on CCS which is influencing policy in this part of DECC. We play a central part in the recently established **Cambridge Centre for Climate Science** which has similar objectives for the promotion of research in Climate Science. This will be enhanced by the recently formed Cambridge-BAS innovation hub (£3.3M) co-funded by NERC and the University's HEIF5 allocation. We also anticipate increasing benefits from the knowledge-sharing events organised by the University's **Centre for Science and Policy,** which provides an overview of the policy landscape and helps to connect researchers with policy-makers and business leaders. They also provide a Professional Development program on the policy-making process and the practicalities of engaging with it, which is of value for early career researchers.

The Department has a strong enterprise culture, enhanced by the recent appointment of a **Knowledge Transfer Facilitator (KTF)** embedded within the School of Physical Sciences, who will provide a focal point for commercial partners who have yet to develop strong direct links with our staff. Through familiarity with both our research staff and commercial partners, the KTF will help build productive new links in addition to organising consultations and arranging exploitation agreements. This role will complement the University's **Research Facilitators** who already act to alert staff of opportunities for exploiting their research. By employing **specialist staff to support impact developments** we intend to improve our effectiveness. The KTF provides one example of this, but we have also employed specialist staff to act as web-designers for projects in which communication with society at large is an important component (e.g. the Templeton-funded 'Map of Life' project). Specialist **science writers** have also been employed for the ambitious public outreach activity involved with the Templeton project & it is clear that there is scope to improve the transfer of knowledge by extending this approach into other areas, leading to the production of accessible **publications,** targeted at non-specialist audiences, based on the cutting-edge research we have published in international peer-reviewed journals.

The University's Public Engagement team supports staff communicating their research to the public and the University's professional development programme provides training in communicating with the media. Our researchers understand the importance of developing these skills, and one of our senior academics has recently spent several months seconded to the BBC as a **British Science Association Media Fellow.** We also recognise the value of professional media communication so we work regularly with the **University's Office of External Affairs and Communications**, and increasingly with **'The Naked Scientists'**, who produce science podcasts and an internet science radio show; their programmes reach multi-million audiences per week, and their pod-casts are downloaded typically 600,000 times a month.

4. RELATIONSHIP TO THE CASE STUDIES: Impact cases A ("Imaging Below Basalts", involving Schlumberger and others), B ("Sedimentary Basins" involving BP) and E ("CO_2 Leakage" with Shell) demonstrate the effectiveness of our strategy to facilitate the transfer of our research by developing close working relationships with our major industrial partners. The last of these has influenced commercial investment into the trials necessary for large-scale CCS projects. The other two cases have had significant impact on the exploration and production of oil and gas, and led to major changes in practice worldwide. In each case the translation of our fundamental research into economic impact arose through the Department's Industrial Associates group.

Impact case C ("Enhanced Oil Recovery"), based on research carried out at the BPI on the behaviour of fluids in production reservoirs held in unconsolidated sands, led to the development of new technology which we have jointly patented; the significantly increased oil recovery from reservoirs of this type has led to considerable financial benefits for the oil industry. Our close connections with BP through the BPI, has resulted in a highly effective mechanism for developing economic impact, which formed the basis of the knowledge-transfer process in this and several other cases, including some which are too commercially sensitive to include in this submission. Impact case D ("Volcanic Gas Fluxes"), and our research on earthquake hazards, provide good examples of the importance of communicating the implications of our findings to policy-makers, government agencies and NGOs, and have demonstrated the importance of our strategic decision to develop close working relationships which facilitate the communication of our research to those with the authority to translate it into policy decisions of global relevance.