Institution: University of Bristol

Unit of Assessment: 17 – Geography, Environmental Studies and Archaeology

Title of case study: Fragile subglacial environments get formal protection as a consequence of Bristol research

1. Summary of the impact

As research led by Professor Martin Siegert at the University of Bristol between 2001 and 2006 has shown, a complex, dynamic and living world exists beneath the thick ice sheets of Antarctica. These pristine aquatic environments are likely to be subject to international exploration and study for decades to come. Siegert and his team not only furthered scientific understanding of subglacial lake systems but also highlighted the potential damage to these environments during direct exploration and demonstrated the need for a formal code of conduct to protect them from contamination or undue disturbance during such work. The research was instrumental in achieving the adoption by the Antarctic Treaty Consultative Meeting in 2011 of a code of conduct presented by the Scientific Committee on Antarctic Research. The code, which is binding on the 50 nations that are signatories to the Treaty, identifies subglacial environments as being of special scientific interest and provides clear guidance to scientists on accessing these fragile ecosystems responsibly. Prior to this agreement, given that traditional deep-ice drilling techniques involve kerosene-based antifreezes, the ecosystems within subglacial lakes and their downstream catchments were in danger of being seriously compromised.

As a consequence of his research on subglacial lakes and in recognition of the impact of his work, Siegert was awarded the 2013 Martha T. Muse Prize by the Tinker Foundation (value $100,000).

2. Underpinning research

Nature of research findings and specific contributions:

Martin Siegert, Professor of Geosciences at the University of Bristol, has led multidisciplinary research programmes investigating the subglacial lakes of Antarctica and involving collaborations with researchers from around the world. Siegert's expertise is in glaciology and geophysics, and programmes he directed were crucial in demonstrating the need for a code of conduct when exploring subglacial aquatic environments. The specific contributions of Siegert and the other key researchers are provided below.

Antarctic subglacial lakes were first regarded as coupled physical, biological and chemical systems following an international collaboration on Lake Vostok in 2001 (Output [1]). Samples were taken from the underside of the sheet ice above Lake Vostok, which consisted of ice refrozen from lake water. The samples showed the lake to be a viable habitat for microbial life, and allowed inferences to be drawn about the chemistry of the lake water.

In Output [1], Siegert led the overall work and provided expertise in the physical processes component of the research. Martyn Tranter, Professor of Geography at the University of Bristol, provided expertise in terms of the chemical processes. A. Salamatin (Kazan State University, Russia) and J.R. Petit (The National Centre for Scientific Research (CNRS), France) contributed expertise on the physical environment. J.C. Priscu (Montana State University, USA) and J.C. Ellis-Evans (British Antarctic Survey) led the biological component of the research.

In 2003, Siegert and Tranter further developed the 2001 research at Lake Vostok to reveal the likely hydrochemical conditions experienced in the lake (Output [2]). The authors noted that the conclusion that Lake Vostok supported microbial life was highly applicable to other subglacial lakes.

The size and distribution of the 145 known Antarctic subglacial lakes was compiled in 2005 (Output [3]). This inventory of subglacial lakes demonstrated their presence across the bulk of the Antarctic continent, in both East and West Antarctica.

For Output [3], Siegert used his expertise in analysing geophysical data to determine the locations of subglacial lakes to create the inventory of these lakes in Antarctica. The other authors provided data that contributed to the inventory, but the compilation was led by Siegert. The inventory was updated in 2012, and now contains information on 379 subglacial lakes (Wright and Siegert, 2012 Antarctic Science, 24, 659–664, doi:10.1017/S095410201200048X).

In 2006, satellite observations of the ice surface sinking and lifting over time were shown to relate to the locations of a series of subglacial lakes at the centre of the East Antarctic ice sheet (Output [4]). Siegert related these ice-sheet surface elevation changes to rapid discharge from a subglacial lake; the distance between the discharging lake and the receiving lake was over 200 km. This work revealed for the first time an active subglacial hydrology in Antarctica and showed how subglacial lakes may be connected rather than isolated. This insight provided evidence that contamination of one lake from *in situ* exploration would risk contamination of an entire drainage system.

In Output [4], D.J. Wingham (University College London) used satellite observations to identify the ice surface changes central to this output. However, Siegert provided the subglacial context for the changes based on his geophysical and glaciological knowledge. It was this information that ultimately led to the impact.

The research summarised above was funded by Natural Environment Research Council (NERC) Grant NER/A/S/2000/01144 (Modelling the physical and chemical dynamics of Antarctic subglacial lakes) [Outputs 1-3] and by the NERC Centre for Polar Observation and Modelling [Output 4].

3. References to the research

Outputs:

[1] Siegert, M.J., Ellis-Evans, J.C., Tranter, M., Mayer, C., Petit, J.-R., Salamatin, A. and Priscu, J.C. Physical, chemical and biological processes in Lake Vostok and other Antarctic subglacial lakes. *Nature*, 414, 603-609. (2001).
DOI: 10.1038/414603a
Citations* = 94

[2] Siegert, M.J., Tranter, M., Ellis-Evans, C.J., Priscu, J.C. and Lyons, W.B. The hydrochemistry of Lake Vostok and the potential for life in Antarctic subglacial lakes. *Hydrological Processes*, 17, 795-814 (2003).
DOI: 10.1002/hyp.1166
Citations = 35*

[3] Siegert, M.J., Carter, S., Tabacco, I., Popov, S. and Blankenship, D. A revised inventory of Antarctic subglacial lakes. *Antarctic Science*, 17 (3), 453-460. (2005).
DOI: http://dx.doi.org/10.1017/S0954102005002889
Citations = 114*

[4] Wingham, D.J., Siegert, M.J., Shepherd, A.P. and Muir, A.S. Rapid discharge connects Antarctic subglacial lakes. *Nature*, 440, 1033-1036 (2006).
DOI: 10.1038/nature04660
Citations = 144*

*Citations as of 10th October 2013 on ResearcherID

Research grants referred to:

Modelling the physical and chemical dynamics of Antarctic subglacial lakes. Funded by the NERC (November 2001 for 3 years). £140,588. NER/A/S/2000/01144. PI: Martin Siegert.

Centre for Polar Observation & Modelling. Funded by the NERC (December 2000 for 5 years, extended to 2 further years). £2,139,203 for the first 5 years, plus £1M for a two-year extension. PIs: D.J. Wingham, J.A. Dowdeswell, J.C.R. Hunt, J.L. Bamber, D.L. Feltham, S.W. Laxon and M.J. Siegert.

4. Details of the impact

Background:

Policy and international relations with respect to Antarctica are regulated by the Antarctic Treaty System, and new policies are agreed by the 50 signatory nations at the Antarctic Treaty Consultative Meetings (ATCM). Matters relating to science are recommended to the ATCM by the Scientific Committee on Antarctic Research (SCAR).

Antarctic subglacial aquatic environments are continent-wide features beneath thick ice sheets that are of significant scientific interest and will likely be a major focus for international exploration and study for decades to come. To advance knowledge of these environments, it is necessary to carry out direct measurement and sampling. This must be done in a manner that does not adversely affect these pristine and ancient systems. Prior to 2011, access to subglacial environments had been achieved by using either hot-water drilling or ice coring. In those experiments little consideration was given to subglacial lakes as unspoilt environments and viable but fragile ecosystems (Evidence source [a]). The research conducted by Siegert and his colleagues furthered scientific understanding of subglacial systems in Antarctica and demonstrated the need for a code of conduct when exploring them.

Nature of the impact:

Siegert's research demonstrated that subglacial lakes are viable habitats for microbial life [1, 2], that they are widespread across the Antarctic continent [3] and that they can be connected hydrologically across large distances in even the most stable parts of the central East Antarctic ice sheet [4]. In combination, the work reveals a large, complex, dynamic, living subglacial environment.

"These papers were crucial in improving our understanding of the sub-glacial system of Antarctica as a pristine, potentially fragile ecosystem that required formalised protection during direct measurement and sampling," said Dr Michael Sparrow [a], Executive Director of SCAR.

The US National Academy of Sciences (US-NAS) undertook an independent assessment of the exploration of subglacial aquatic environments with the intention of defining a set of standards for responsible exploration of these ecosystems. The report, published in 2007, cites Siegert's research heavily (13 papers by Siegert were referenced in the text 57 times) [b]. It even uses a figure from Siegert *et al.* [3] as its cover page. However, despite the scientific influence of this report, it was not initially a major influence on policy decisions [a].

As a result of the US-NAS report, SCAR convened an Action Group (which consulted with subglacial aquatic environment specialists from around the globe and from a wide range of disciplines) to develop a formal code of conduct for SCAR members, but also for use by members of the Antarctic Treaty. The code of conduct was heavily influenced by the US-NAS report as well as by reports from the SCAR Subglacial Antarctic Lake Environments Scientific Research Program [c, pg 3], of which Siegert is a contributing member.

"Again, Siegert's work was instrumental in forming SCAR's judgement on how and why subglacial environments can be protected," said Sparrow [a].

In June 2011, at the XXXIV ATCM in Buenos Aires, a Code of Conduct on the exploration and research of subglacial aquatic environments was formally adopted [a, c], binding Antarctic Treaty members to undertaking such work in a clearly defined and responsible manner.

In December 2012, Siegert led a NERC-funded* UK team to undertake the first direct measurement and sampling of a subglacial lake – Lake Ellsworth in West Antarctica. The work was fully compliant with the code of conduct, and the research plan was commented on favourably by the ATCM and published in the peer-reviewed literature (Siegert et al., Clean access, measurement and sampling of Ellsworth Subglacial Lake. Reviews of Geophysics, 50, RG1003, doi:10.1029/2011RG000361, 2012). While the fieldwork was unsuccessful this time, plans are currently underway to undertake a second attempt in full accordance with the Code of Conduct.

For his innovative research on Antarctic subglacial lakes, and recognition of the impact it has had, Siegert was awarded the 2013 Martha T. Muse Prize by the Tinker Foundation (http://www.museprize.org/news.html).

**Direct measurement and sampling of Subglacial Lake Ellsworth: a multidisciplinary investigation of life in extreme environments and ice sheet history. Funded by the NERC (1 October 2009 for 5 years). A consortium Grant, involving the University of Bristol, the British Antarctic Survey, the National Oceanography Centre, Durham University, the University of Edinburgh and Aberdeen University. Total award: £7,925,275 (£6,244,620 FEC). PI: Martin Siegert.*

5. Sources to corroborate the impact

[a] Sparrow, M. (Executive Director, SCAR). Letter to M. Siegert. 5th November 2012.

[b] National Research Council (2007) *Exploration of Antarctic Subglacial Aquatic Environments*: *Environmental and Scientific Stewardship*. Committee on the Principles of Environmental Stewardship for the Exploration and Study of Subglacial Environments, Polar Research Board, Division of Earth and Life Sciences. National Research Council of the National Academies. The National Academies Press Washington, D.C. 152pp. [http://www.nap.edu/catalog/11886.html]

[c] *SCAR's code of conduct for the exploration and research of subglacial aquatic environments.* Agenda item CEP 8c, paper IP33. Antarctic Treaty Consultative Meeting, Buenos Aires, 20th June – 1st July 2011. [http://www.scar.org/treaty/atcmxxxiv/ATCM34_ip033_e.pdf]