White Paper – Antarctic subglacial lake exploration

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Convenors of the 7th International Meeting on Antarctic Subglacial Lakes, Chicheley Hall, 30-31 March 2015

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Summary

It has been 20 years since Subglacial Lake Vostok was hypothesised to harbour a unique microbial community that evolved in isolation over millions of years, and contained ancient records of past climate. Subsequent research made it clear that testing these hypotheses is possible only through direct measurement and sampling of the lake water and sediment. SCAR has been a valuable integrator for international discussions on how to explore subglacial lakes, and in 2011 it produced a formal 'code of conduct' on subglacial access, accepted at the Antarctic Treaty Consultative Meeting in Buenos Aires, which subglacial exploration programmes must adhere to.

In large part due to the SCAR's role in facilitating and encouraging this area of research, including the influential "code of conduct", three nations obtained funding and moved forward with subglacial research programs. In February 2012, Russian scientists punctured into the top of Lake Vostok using the existing ice core at Vostok Station. This feat was repeated in January 2015, allowing lake water to freeze within the borehole and subsequent coring of the frozen sample. In December 2012, a British attempt to access Lake Ellsworth, a deep-water lake at the centre of West Antarctica, was halted when a purpose-built clean deep-ice hot-water drill experienced technical difficulties. A month later, US scientists successfully undertook the clean access and sampling of Subglacial Lake Whillans, a shallow 'active' lake at the edge of West Antarctica, revealing a thriving microbial ecosystem in the lake-water and sediments and confirming initial hypotheses regarding life beneath the Antarctic ice sheet.

With a first phase of subglacial exploration now complete, 60 researchers from 12 nations gathered in the UK Royal Society's Chicheley Hall on 30-31 March to discuss first results and to plan future work (Siegert et al., 2015).

Three priorities for future research were identified:

(1) technology for clean, reliable deep-ice access and subsequent *in situ* data acquisition is a pre-requisite for subglacial lake exploration;

(2) a variety of subglacial environments should be considered for exploration for the full extent subglacial biodiversity, and cross-correlation of climate records, to be evaluated; and

(3) international cooperation is desired for scientific optimisation, allowing the sharing of logistics, equipment and samples.

Targets for future exploration include deep-water lakes at the ice-sheet centre, hydrologically 'active' lakes closer to the continental margin, and other environments including former subglacial lakes now covered with thin ice and deep sedimentary basins where extensive groundwater may exist.

Such investigations are only possible with considerable engineering and logistical support.

Antarctic Roadmap Questions

The meeting at Chicheley Hall provided a unique international opportunity to collectively provide input into the COMNAP process to lay the ground work for the development of future subglacial exploration missions. To this end, attendees completed a questionnaire relating to their scientific ambitions and preferred programme arrangements required to meet them. The result, albeit from a subset of a much larger community, yielded an interesting degree of close agreement on one hand, and contrasting views on the other, relating to specific aspects of subglacial exploration. A summary of the findings from this questionnaire exercise is provided below.

Attendees were first asked to list which of the horizon scan questions they plan to address. The top four answers were as follows (numbers refer to the order of questions as in Kennicutt et al. (2014)):

> **#26. How does subglacial hydrology affect ice sheet dynamics, and how important is this linkage?**
>
> **#27. How do the characteristics of the ice sheet bed, such as geothermal heat flux and sediment distribution, affect ice flow and ice sheet stability?**
>
> **#34. How will the sedimentary record beneath the ice sheet inform our knowledge of the presence or absence of continental ice?**
>
> **#47. How do subglacial systems inform models for the development of life on Earth and elsewhere?**

Collectively these questions demonstrate the multidisciplinary nature of the research and the globally relevant results that can be gained from subglacial lake exploration using a combination of geophysical survey, clean subglacial lake access measurement and sampling, down borehole measurement and sediment drilling; all of which have extensive logistical and engineering requirements.

A second set of questions related to the location where their research is thought best conducted in terms of scientific deliverables and logistical ease. Although there were numerous responses for subglacial lakes Vostok, Ellsworth and Whillans, the largest number of respondents commented that a variety of settings was required to fully answer the questions, and not restricting only to subglacial lakes. Indeed clean sampling of sedimentary material away from subglacial lakes was described by several attendees as being an interesting way of answering the top four questions. That the community did not focus on one particular lake, indicates that there is no consensus on the 'best suited' lake for exploration at this stage. Only by the exploration of multiple subglacial targets, across the Antarctic continent, can the full diversity of these systems at the ice sheet bed be comprehended and their importance to the Earth system determined.

The third set of questions concerned the technological advances needed for clean lake access. Clean access is critical to protect samples and *in situ* measurements from contamination, and to address the important issue of environmental stewardship. Given that numerous lake exploration probes have already been designed, built and tested, the majority of responses focused on equipment not yet configured, such as down borehole profiling systems, deployment of long-term *in situ* observatories, and coring of benthic sediments. There was an overwhelming consensus that clean, reliable deep-ice hot-water drilling is currently the best way to access subglacial environments, and general agreement that procedures for this type of subglacial access now exist. Despite the overall concurrence that hot-water drilling is the best access method, procedures and protocols for monitoring cleanliness of boreholes, and devices passed within them, need to be further established.

The final set of questions focused on whether international collaboration was required to undertake subglacial lake exploration in future and, if so, what the nature of such collaboration should be. While some level of cross-national collaboration was almost unanimously regarded as being desirable, only half the responses thought it essential. Although some favoured the idea of a single major international programme, funded by several nations, the majority of respondents spoke to the advantages of retaining a multiple target approach with specific programmes led by individual nations. Within this context, international collaboration should be enhanced through academic and knowledge exchange between programmes, and through sharing of samples to ensure reproducibility of results. With the emphasis on informal cooperation rather than managed collaboration, there was agreement that SCAR can, and should, retain a role in promoting and coordinating subglacial lake exploration research. This final decision was in large part based on the fact that SCAR has been a leader in defining the scientific importance of subglacial research and developing clean access protocols to both protect the environment and maintain a high level of sample integrity.

Through more than 20 years of perseverance, much has been learned about technology, logistics and subglacial science from recent missions to Lake Vostok, Lake Ellsworth and Lake Whillans. All three programmes have a good record of both cross-project dialogue and collaboration, and all have been very open to demonstrate both successes and failures.

Experience from these three programmes, in addition to insights from the debate at Chicheley Hall, now allow us to respond to each of the three ARC challenges, as follows.

Challenge 1: Extraordinary Logistics Requirements

Missions to Lakes Whillans and Ellsworth demonstrate that sophisticated equipment and substantial loads can be transported via over-snow traverses from the ice –sheet margin, where logistic hubs exist – to the ice sheet interior.

For the case of Lake Vostok, the use of a major permanent interior ice station made the research possible. However, sampling site proximity to deep field stations is rare and seasonal camps supported by ski equipped aircraft such as those for the Ellsworth and Whillans projects will be required to access and sample the majority of subglacial lakes. The deep-field logistics model developed at these sites has been demonstrated to work well.

Challenge 2: Technology

Technology development is an important component of subglacial research. Clean, rapid, reliable access through thick ice to the subglacial environment is a requisite.

The method of access at Lake Vostok, via an existing borehole used to obtain ice cores for palaeoclimate research represents a significant challenge in terms of cleanliness. These boreholes are kept open through the use of many tons of organic drilling fluid, which can be detrimental to the collection of uncontaminated samples and can cause irreversible damage to the subglacial environment if released. SCAR’s Subglacial access Code of Conduct must be considered when forming and using deep boreholes filled with organic fluid near the basal ice environment.

In contrast to Vostok, both the Lake Whillans and Lake Ellsworth programmes used purpose-built hot-water drills, designed and tested to provide a high level of clean access. The successful Whillans drill cleanly penetrated 800 m of ice in a little over a day and provided a 0.5 m diameter borehole for sampling water and sediments for 24 hours. The unsuccessful Ellsworth drill aimed to reach ~3 km, around 1 km further than any previous hot-water ice drill, but failed to link a reservoir of subsurface water with its main borehole preventing further drilling. Much experience has been gained from these national projects, and the scientific community believes that, with modification, it is entirely feasible to use hot water drilling to explore even the deepest and most remote subglacial lakes.

Sampling technology is also an area where advances have been made. Obtaining samples cleanly, and returning them to the ice surface without contamination is essential for this work. Such operation is not easy, given the depths and pressures involved, the temperature differences between the bed and the ice surface and the fact that the ice sheet itself has its own chemical and biological signature that must not be confused with actual samples of subglacial water. These hurdles have been addressed in both the Lake Whillans and Lake Ellsworth programmes.

Finally, it is important that a temporal record of measurements be obtained from *in situ* observatories for a true understanding of contemporary ecosystem dynamics and how these processes will respond to global changes. Development of such observatories has been initiated through the Lake Whillans and Lake Ellsworth programmes.

Challenge 3: Infrastructure

Infrastructure is a key element of deep-field subglacial research. Thus far, successes have been demonstrated, in terms of the deployment of staff, equipment and samples to the ice sheet interior, and the development, operation and dismantling of temporary deep-field research stations (involving a full array of accommodation, laboratories, ski-way for aircraft, communications, health and safety etc.). Such work needs a considerable level of planning, and currently only a handful of nations would be able to provide the logistical back-up required to service such operation.

Kennicutt, M., et al. (2014). Six priorities for Antarctic Science, *Nature*, 512, 23-25.

Siegert, M., J. Priscu, and I. Alekhina (2015), The future of Antarctic subglacial lake exploration, *Eos, 96*, doi:10.1029/2015EO032249. Published on 10 July 2015.

Details of responses

The following responses to specific logistic and engineering questions by the group of experts who convened at Chicheley Hall are provided below (in order of popularity). Results from this poll and ensuing discussion provide a unique international opportunity to collectively provide input into the COMNAPs Antarctic Roadmap Challenges Project and lays the ground work for the development of future subglacial exploration missions.

What technological advances are needed in terms of scientific measurement and sampling?

- New *in situ* small sensors (permanent) = 37%
- Clean technology for the sampling of sub-bottom sediments = 27%
- HWD and borehole sensors = 20%
- State-of-the-art geophysical equipment for airborne research, inc. AUVs = 17%
- 3D seismic reflection = 13%
- Reliable access to the bed = 10%
- ROV's = 10%
- Groundwater flow techniques = 7%
- permanently deployed sensors = 4%

What technological advances are needed in terms of lake access?

- Clean access = 27%
- HWD = 27%
- Increased transportability = 20%
- Repeatable fast bed access = 13%
- Clean drilling fluids for coring = 4%
- Keeping boreholes open for longer = 4%

What technological challenges are needed in terms of ensuring cleanliness?

- Further development of reliable rapid access using HWD = 40%
- We have this sorted now on HWD = 22%
- Better control and planning of all steps of the operations = 17%
- Using heat drilling (neither coring nor HDW) = 4%
- Sediment coring (especially casing) = 4%
- Clean labs on site = 4%

What form of international partnership would you like to see to implement such work?

- Cooperation, not full on international project = 30%
- Shared logistics, technology and science = 27%
- International team (ANDRILL Project) = 20%
- A SALE type SCAR group = 10% [nb. in discussions, it was unanimously agreed that a SCAR-led forum for international exchange and dialogue was desired to guide future development of research].
- Sharing samples = 7%

Is this partnership essential or desirable?

- Essential = 40%
- Desirable = 40%
- No response = 20%