# Geophysical exploration of a West Antarctic subglacial lake

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**Introduction and aims.** It is now an established hypothesis that Antarctic subglacial lakes house unique forms of life and hold detailed sedimentary records of past climate change (e.g. Siegert et al., 1996; Siegert, 2000). A necessary prerequisite to *in-situ* measurement of these environments is a detailed knowledge of the glaciological and topographical setting from airborne and ground-based measurements.

Only Lake Vostok, the mega subglacial lake in East Antarctica (Siegert et al., 2001), has been examined in detail by airborne geophysical techniques (Studinger et al., 2003). However, the Subglacial Antarctic Lake Exploration (SALE) group of specialists set up by SCAR to consider and recommend mechanisms for the international coordination of a subglacial lake exploration programme state that "*the size of Lake Vostok makes it very difficult to characterise in a meaningful way (e.g. seismic exploration of the lake will take many field seasons to complete)*" (SALE, 2003; Siegert, 2002). Hence, it is now thought that investigation of smaller subglacial lakes is "*a prudent way forward"* (Priscu et al., 2003).

This proposal aims to undertake geophysical exploration of a small subglacial lake near the Ellsworth Mountains in West Antarctica. Geophysical data will be used to model ice flow, heat transfer and water circulation within 'Subglacial Lake Ellsworth'. The outcome of the project will be the first full characterisation of a subglacial lake, and the establishment of an appropriate candidate for future exploratory research.

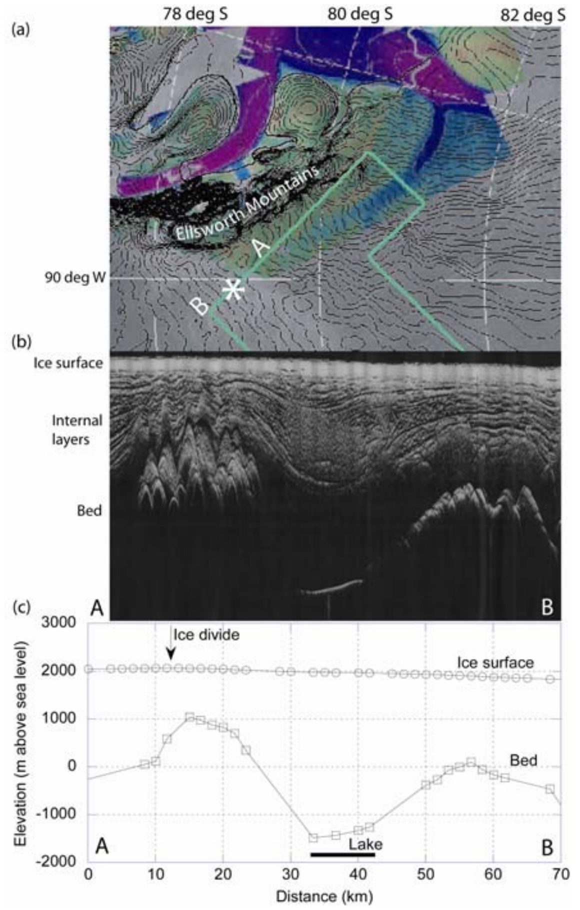


**Figure 1.** The Ellsworth subglacial lake. (a) The location of the lake (*), InSAR ice velocity and ice sheet surface elevation. (b) Raw RES data. (c) Digitised RES data.

**The subglacial lake.** Eight lines of evidence collectively prove the existence of Lake Ellsworth. (1) Radio-echo sounding (Figure 1) reveals a strong, flat, specula return that could only come from an interface with a significant dielectric contrast, which has no roughness at the scale of the radio-wave. Such an interface is best explained by the ice-water surface of a subglacial lake (Siegert et al., 1996). (2) Small scale changes in the slope of the reflector are apparent, which are similar to those observed in Lake Vostok and are symptomatic of a lake beneath. (3) The ratio of the slopes of the ice-water and ice-surface interfaces, averaged over the lake, is at the amount required for the lake to be in hydrostatic equilibrium with the ice sheet. This, in combination with the point above, means that our target lake passes every criterion used previously to identify subglacial lakes. (4) The slope of the ice-water interface is also noticeably less than the surrounding topography, inferring strongly that the water depth of the lake is several tens, possibly hundreds, of metres. (5) Internal ice sheet layers, observed above the lake (Figure 1), converge in vertical section with the lake surface (Figure 1). Ice flow modelling that we have undertaken shows this is only possible if the ice base above the lake is melting at a rate of several cm per year. Hence, the internal layer pattern is consistent with the production of subglacial meltwater. (6) Thermo-mechanical ice-sheet models of West Antarctica predict that the bulk of the ice base is at the pressure melting point. Such models certainly expect melting beneath 3.4 km of ice, which is the ice thickness above our target lake. (7) Thermodynamic calculations reveal the heat required for subglacial melting above Lake Ellsworth now and at the last glacial maximum (LGM) is 54 and 46 mW $m^{-2}$, respectively. The basal heat flux calculated in West Antarctica from temperature gradients in boreholes is ~70 mW $m^{-2}$. Hence, basal heating at the level expected is sufficient for the subglacial lake to exist both now and at the LGM. (8) Regional radio-echo sounding shows that our lake occupies a distinct subglacial bed depression; a topographic requirement for subglacial water to pond.

**Objectives.** To fulfil the project's aim, the following objectives are required. (1) To undertake a ground-based RES survey of Lake Ellsworth and its locale. (2) To use RES data to define the outline of the lake and its glacial/topographic settings. (3) To undertake a seismic survey of the lake. (4) To use seismic data to define the lake's bathymetry and the sediments across the lake floor. (5) To use new data visualisation techniques to view RES and seismic data. (6) To use numerical modelling to quantify ice flow across the lake, heat transfer within the lake (including rates of melting/freezing) and lake water circulation.

**Methodology.** *Objective 1.* RES is a well-established method of measuring the thickness and subglacial conditions of large ice sheets and is certainly capable of measuring the subglacial lake in question, as is demonstrated in Figure 1. As Lake Ellsworth is only ~10 km long, we anticipate that a ground-based survey can be accomplished well within in a full single season. Rippin (named PDRA) has several years of field experience using radar to measure ice sheets and glaciers. *Objective 2.* RES data acquired in (1) will be processed to reveal the lake outline and topographic setting. Corr, Siegert and Rippin have several years experience in processing RES data. *Objective 3.* A comprehensive ground-based seismic survey of the lake will be undertaken. This will require a full season in the field and will occur in parallel with the RES survey (1). We will acquire ~60 km of seismic reflection data from several transects across the lake. Woodward, who has over 8 years experience of seismic and radar acquisition, including Arctic and Antarctic field seasons, will undertake the fieldwork, and field preparation will be assisted by Smith who has more than 15 years experience of deep-field, polar seismic acquisition. *Objective 4.* Seismic data will be processed to reveal the bathymetry of the lake. Data will also be scrutinised with a view to extracting information about the sediment thickness across the floor of the lake. *Objective 5.* Data from (1) and (3) will be interpreted using new 3-D dynamic data visualisation techniques. Martin Jakobsson (collaborator) has extensive experience of such techniques. *Objective 6.* Results from (2) and (4) will be used as inputs to three numerical models that will help us to quantify the lake system. First, we will model ice flow over the lake. Hindmarsh has a model that utilises internal ice sheet layers to constrain the flow, to accurately determine ice flow processes and rates of surface ice accumulation and basal melting/freezing. Second, Payne will model the heat transfer between the lake and ice required for the lake to exist. This study will also investigate how former ice configurations may have affected the lake's size and extent. Third, we will model water circulation with code being developed as part of an existing NERC project to Siegert.

**Timetable.** The project will last for three years. It is hoped that Objectives (1 and 3) will take place within the first year. This will leave the remainder of the project to complete objectives (2) (4) (5) and (6).

**Expected results, outcomes & deliverables.** The outcome of this project will be the first detailed characterisation of a subglacial lake. This project is the first phase of a long-term ambition to undertake *in-situ* measurements of the lake. The results of the project will make it possible to plan such exploration by the end of the decade. A consortium of researchers from the BAS and the universities of Bristol, Aberdeen, Cranfield, Leicester, Northumbria, Southampton (SOC) and Surrey will meet on 1st September to formulate a plan for the *in situ* exploration of Lake Ellsworth following the completion of this project.

**Request for resources**. Funds to undertake a 3 month field season (with four people), and a 1 month field season (2 people) are requested. Funds for a PDRA are also requested to assist with the first field season and to process field data. The PDRA will help to plan and undertake the RES survey and, after the fieldwork, will process the RES data. This PDRA will be employed for the full three years of the project. The PDRA will require a PC. Funds for software are sought to enable the 3D dynamic visualisation of data (Jakobsson, collaborator). The seismic recorders BAS have been using for the past ~12 years are now beyond their serviceable life. We therefore request funds for a new recorder suitable for this project. Funds are also sought for a new ground-based RES system, based on the University of Washington's design, plus 9 months of technician time to assemble the equipment. Funds for computer software, to process RES and Seismic data are sought. A modest amount of travel money is required for PIs and PDRAs to meet on a regular basis, to meet with the collaborator (Jakobsson, in Stockholm) and to disseminate our work to the international community (including SALE members).

**References**

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