AN INTERNATIONAL PLAN FOR ANTARCTIC SUBGLACIAL LAKE EXPLORATION[1]

John C. Priscu
Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana 59717

Robin E. Bell
Lamont-Doherty Earth Observatory, Palisades, New York 10964

Sergey A. Bulat
Division of Molecular and Radiation Biophysics, Petersburg Nuclear Physics Institute, St. Petersburg, Russia

J. Cynan Ellis-Evans
British Antarctic Survey, Cambridge, United Kingdom

Mahlon C. Kennicutt II
Geochemical and Environmental Research Group, Texas A&M University, College Station, Texas, 77843

Valery V. Lukin
Arctic and Antarctic Research Institute, St. Petersburg, Russia

Jean-Robert Petit
LGGE-NCRS BP96, F-38402 St. Martin D'Hères, Cedex, France

Ross D. Powell
Department of Geology, Environmental Geosciences, Northern Illinois University, DeKalb, Illinois, 60115

Martin J. Siegert
Bristol Glaciology Center, School of Geographical Sciences, University of Bristol, Bristol, UK BS8 1SS

Ignazio Tabacco
DST-Geofica, Via Cicoconara 7, 20129 Milano, Italy

[1]This paper was accepted for publication in February 2004. We wish to thank two anonymous reviewers whose comments improved the manuscript, and Slawek Tulaczyk who provided facilities and logistics for our meeting in Santa Cruz. We dedicate this manuscript to the late Mario Zucchelli, whose energy and ebullience as the host of our first meeting in Bologna, Italy set the tone for all further deliberations.

Polar Geography, 2003, **27**, No. 1, pp. 48-62.

Abstract: Discovery of at least 100 subglacial lakes beneath the vast East Antarctic Ice Sheet has focused international attention on the challenges presented by the way we conduct science in such unique and inhospitable settings in an atmosphere of increasingly stringent environmental concerns. Exploration of subglacial environments will require careful and detailed planning, organization, and international cooperation. To this end, the Scientific Committee on Antarctic Research (SCAR) convened an international Group of Specialists (Subglacial Antarctic Lake Exploration Group of Specialists—SALEGOS) to develop a detailed assessment of the needs and critical milestones to be accomplished during the implementation of a subglacial exploration and research program. This paper surveys the progress and recommendations made by SALEGOS since its inception regarding the current state of knowledge of subglacial environments, technological needs and challenges, international management, the portfolio of scientific projects, and "clean" requirements for entry, observatory deployment, and sample retrieval.

INTRODUCTION

Liquid water lakes were identified beneath the ice sheets of Antarctica in the 1960s and 1970s (e.g., Robin et al., 1970; Oswald and Robin, 1973). The largest and most well known of these lakes is the 250 km long Lake Vostok. The majority of Antarctic subglacial lakes are much smaller, having lengths of around 10 km. All subglacial lakes are located beneath ice in excess of 3.5 km thick, and are likely to have water depths of the order of tens to hundreds of meters. The age of subglacial lakes is dependent on two factors—the age of the ice sheet and the age of the basal ice. The age of the ice sheet determines when the lake was first established. For Lake Vostok this may be as much as 15 million years ago. The age of basal ice, which melts into subglacial lakes, dictates the age of the lake water. For Lake Vostok this is of the order of 1 million years. Subglacial lakes are therefore significant bodies of water, isolated from the atmosphere for, possibly, millions of years. It has been hypothesized that Antarctic subglacial lakes contain microbial life, and because the habitat is extreme and ancient, these microbes may be unique. To date, no direct measurements have been made in any subglacial lake. Such work is, however, the only way to identify and understand life in these extreme environments.

Subglacial lake exploration has caught the imagination of the scientific community and general public around the world. Interest in the lakes has been growing over the last decade and scientific information about subglacial environments has increased enormously in the last few years. A number of workshops (e.g., SCAR 2001) have considered the scientific value and assessed the scientific advances to be gained from an exploration of subglacial lakes. There was consensus that an exploration program and its scientific objectives were worthy of the financial and logistical support that will be needed to accomplish the goals of a subglacial exploration program. Consideration of the details of an exploration program is an important next step in the realization of such a major program. To further these discussions and provide explicit plans for the development of subglacial programs, the Scientific Committee on Antarctic Research (SCAR) formed a Subglacial Antarctic Lake Exploration Group of Specialists (SALEGOS) to consider various aspects of subglacial exploration and research. The Group was formed at SCAR XXVI in Tokyo in July 2000 and includes 10 members representing five countries. The membership of SALEGOS (comprising the 10 authors of this paper) was organized by the executive committee of SCAR. The expertise of SALEGOS membership covers a wide range of scientific disciplines and includes extensive experience in managing complex Antarctic projects. Funds were made available from SCAR to organize a series of meetings in which matters relating to the organization of subglacial lake exploration were discussed. Reports from each meeting were made available to scientists outside of the group of specialists, and the public, via the SALEGOS website [http://salegos-scar.montana.edu/]. This report provides an update on the activities of the Group.

HISTORY OF SUBGLACIAL LAKE EXPLORATION

The early history of the discovery of Antarctic subglacial lakes set the stage for the formation of SALEGOS. The history of subglacial lake exploration occurred in three stages: discovery and serendipity (1960–1979), deliberation and assessment (1994–2001), and action (2001 to present—see Table 1). The discovery and serendipity phase began in the mid-1950s with recognition of the possible presence of liquid water accumulation several kilometers below the vast East Antarctic Ice Sheet by various investigators (e.g., Robin et al., 1970). While recognized as a novelty, interest in the lakes was minimal for many years to follow. Attention was again brought to the lakes in the early 1990s when more compelling information regarding the existence of a very large lake, Lake Vostok, was provided. This evidence was based on a re-examination of previous airborne radar survey data and seismic experiments as well as the acquisition of new ice surface altimetry from space. It was soon recognized that Lake Vostok was only one of many lakes under the East Antarctic Ice Sheet (Siegert et al., 1996; Fig. 1). The period of deliberation and assessment included several workshops to summarize what was known about subglacial lakes and to determine whether there was sufficient scientific justification to commit the needed resources for their exploration. This phase ended with growing public and scientific interest in subglacial lakes and a consensus that the scientific knowledge to be gained by subglacial lake exploration warranted a concerted international effort. The 1999 SCAR International Workshop on Subglacial Lake Exploration held in Cambridge, England (SCAR 2001) developed a draft science plan for subglacial lake exploration, including consideration of the technology challenges. The workshop report established scientific goals for an exploration program, assessed the exploration technologies needed to attain the goals, suggested the stages required for a phased-in exploration program, established guiding principles for subglacial lake exploration, and produced a set of recommendations to facilitate further planning. The principal scientific goals and requirements set forth by the Cambridge Workshop Report (Table 2) formed the basis for further deliberations by SALEGOS.

The current stage of subglacial environment exploration and research is considered to be the "planning and action" phase, where concrete and explicit plans are being developed to implement actual exploration of subglacial environments. This stage is being spearheaded by SALEGOS, whose task is to address such specific issues as lake selection criteria, potential technologies for clean lake entry and sample retrieval, international management models, and a time-line for implementation. In its deliberations SALEGOS decided that the development of specific and explicit science portfolios would be a useful model to move planning efforts forward. The portfolio approach is intended to encourage wide participation in the program by allowing

TABLE 1

Brief Chronology of Antarctic subglacial Lake Research

Stage 1: Exploration and Serendipity
• **1961.** Russian pilots observation of unusually flat areas on the ice surface.
• **1964.** Kapitsa and Sorochin undertake a seismic experiment at Vostok Station. These data are later used to confirm the water depth of Lake Vostok (Kapitsa et al., 1996).
• **1963–1964.** SAE seismic data collected that provides first evidence of liquid water lakes under the ice sheet.
• **1973–1975.** Radio-echo sounding confirms a lake under Vostok Station.
• **1994.** International workshop in Cambridge, UK formalizes Vostok data.
Stage 2: Deliberation
• **1994.** Discovery of Lake Vostok first reported, SCAR, Rome, Italy.
• **1998.** "Lake Vostok: Scientific Objectives and Technological Requirements: An International Workshop," St. Petersburg, Russia.
• **1998.** Lake Vostok Workshop: "A Curiosity or a Focus for Interdisciplinary Study," Washington, DC, USA.
• **1999.** "Workshop on Subglacial Lakes," Cambridge, UK.
• **2000.** SCAR forms Subglacial Lake Group of Specialists (SALEGOS).
• **2001.** "Subglacial Lake and Deep Ice Exploration: Canadian Expertise and International Opportunities," Ottawa, Canada.
• **2001.** "Life in Ancient Ice Workshop," Oregon, USA.
• **2001.** "Subglacial Lakes: Biology and Decontamination Issues," Amsterdam, Netherlands.
Stage 3: Planning and Action
• **2001 (November).** First meeting of SCAR SALEGOS, Bologna, Italy.
• **2002 (May).** Second meeting of SCAR SALEGOS, Lamont-Doherty Earth Observatory, Palisades, New York, USA.
• **2002 (October).** Third meeting of SCAR SALEGOS, University of California, Santa Cruz, USA.
•**2003 (March)** NSF workshop "Lake Vostok: Defining a Technology Roadmap for Exploration and Sampling," Stanford University, California, USA.
• **2003 (April).** Fourth meeting of SCAR SALEGOS, Chamonix, France.

interested parties to identify a role they might play in the larger program. The portfolio approach also divides a rather complex program into smaller and interrelated but independent objectives and milestones that can be accomplished in an orderly fashion. Each portfolio has its own set of technological, environmental, and logistical requirements that will need to be considered in a detailed management and implementation plan. While several discrete subprojects are identified for planning purposes, it is not intended that these are necessarily a linear progression of steps, but several objectives may well be pursued in parallel at the same time.

The proposed SALEGOS project time line (Fig. 2) is primarily related to the types of sampling methodologies needed and the types of samples required to conduct the

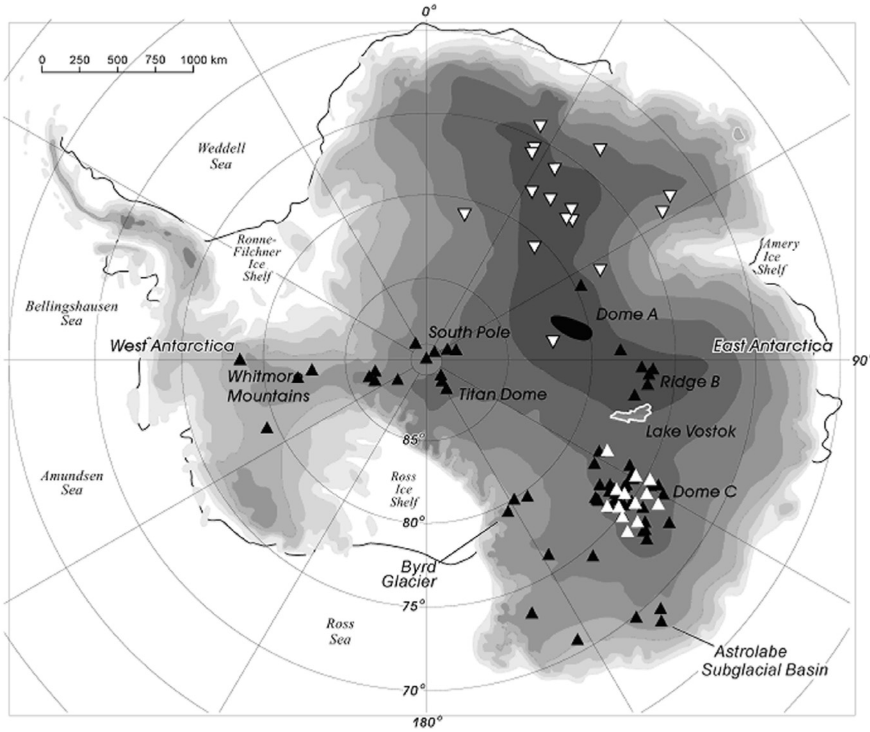

Fig. 1. Map of the Antarctic Ice Sheet showing the locations of Antarctic subglacial lakes. Italian (white triangles), Russian (upside down white triangles), and SPRI (black triangles) lakes are included (Lake Vostok is shown as an outline rather than a triangle). The ice-sheet surface is contoured at 500 m intervals (after Drewry, 1983). Adapted from Dowdeswell and Siegert (2002).

experiments of interest. The most readily available technologies are remote sensing techniques that are already being used in ongoing studies. More challenging objectives require lake entry and the most challenging objectives require sample retrieval. Within the objectives that require sample retrieval, water and shallow sediment retrieval are less challenging than recovery of deep sediment cores. Reasonable time frames to accomplish the proposed objectives were short (0 to 3 years), medium (3 to 6 years), long (6 to 9 years), and very long (9+ years) term. The outcomes of SALEGOS deliberations provide an initial attempt at a "needs" analysis based on the goals and objectives of subglacial environment exploration and research as laid out in the 1999 Cambridge Workshop Report (SCAR, 1999).

The deployment of *in situ* observatories is seen as an important step in subglacial exploration that is relatively tractable given current technology. There are several examples of where the exploration of subglacial-type environments have been planned, and the resulting documents from these plans are relevant to future investigations of subglacial lakes (e.g., Aamot, 1967; Philberth, 1966; French et al., 2001; Zimmerman et al., 2001). Observatories will be essential to gathering a time series of basic physical and chemical measurements that can be used to plan the more complex program involving sample retrieval. The first generation of observatories are

TABLE 2

Principal Scientific Goals and Requirements to be Addressed by Subglacial Lake Exploration[a] and the Scientific Portfolio Developed by SALEGOS

Goals
• To determine the form, distribution, and activity of life in the lake water, the sediment below, and the ice above.
• To recover climatic information contained in ice overlying the lakes and sediment underlying the lakes.
• To understand the origins of subglacial lakes and their impact on the evolution of life under the ice.
• To determine the extent and hydrological dynamics of the sub-ice lake system.
Requirements
• The program must be internationally coordinated.
• The program must be multi- and interdisciplinary in scope.
• Non-contaminating technologies and minimum disturbance must be fundamental considerations in program design and execution.
• The ultimate goal must be lake entry and sample retrieval to ensure the greatest scientific return on investment.
• The best opportunity for attainment of important interdisciplinary scientific objectives is the study of larger lakes; therefore, Lake Vostok must be the ultimate target of a subglacial exploration program.
Portfolio items
• Remote studies: Accreted ice, modeling, and remote sensing.
• Deployment of remotely operated *in situ* observatories.
• Survey and inventory subglacial lakes to understand them as systems.
• Studies of subglacial lake processes and histories.

[a]Modified from SCAR, 2001.

envisioned as a static (or vertically mobile) string deployed in selected locations of each lake basin. The instrument strings would be fitted with a host of sensors that would yield the vertical structure of the water column and provide first-order properties needed to advance modeling efforts. These observatories would return time-series data on such parameters as temperature, conductivity, redox, and selected gas concentrations. Such data will allow circulation models to be refined and provide important information on redox couples that could potentially support life. Spatial and temporal gradients of bioreactive chemical species may also lend the first clues to how biological organisms make a living in subglacial environments. These data are essential for constraining risk and planning for sample return programs. Sample return would focus to a large degree on the identity and diversity of life forms in the lake, *in situ* growth and metabolic rates, the presence of unique biochemical and/or physiological processes, and the evolutionary history of subglacial environments through analysis of their sediment record.

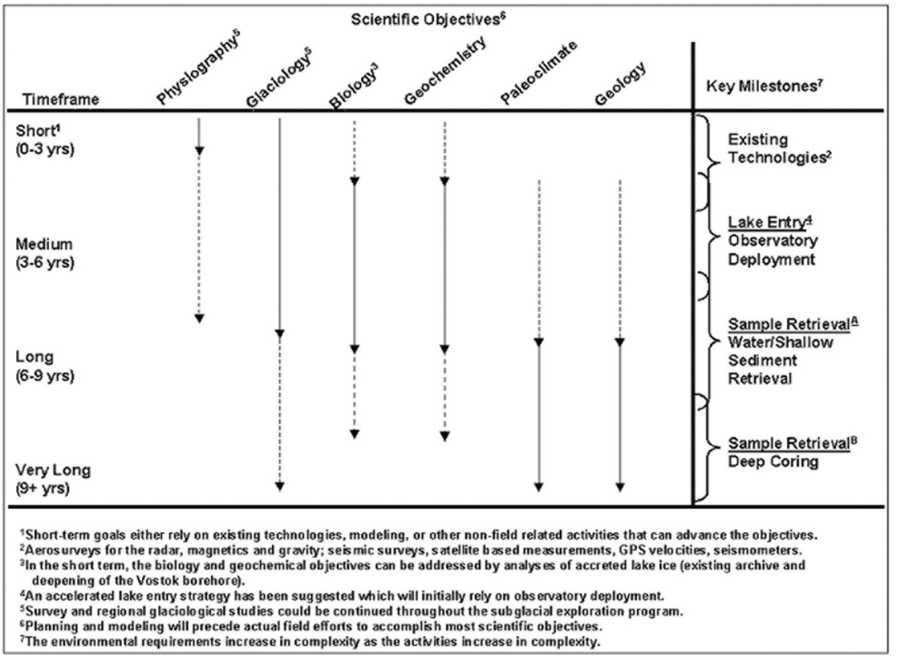

Fig. 2. SALEGOS assessment of the timing of subglacial lake exploration and key technological milestones.

SITE SELECTION

Potential study sites must be critically evaluated before sampling programs can be initiated. While SALEGOS endorses the concept that the greatest scientific return may result from large lakes such as Lake Vostok, it acknowledges that the scientific advances could be gained from investigation of smaller lakes. Lake Vostok is the only subglacial lake to have been characterized in any meaningful sense to date, as it is the only subglacial lake to have been investigated in a systematic manner (Bell et al., 2002); no other lake has been investigated by seismic, interferometric SAR or ice-coring methods (Petit et al., 1999, Siegert et al., 2001). While large lakes may be an ultimate target, testing technologies, developing methodologies, and performing experiments in analogue settings (frozen subaerial lakes, glaciers, ice shelves, or grounded ice sheets) or smaller lakes would be a prudent way forward.

The great size and density of information that exists on Lake Vostok does not mean that other lakes will not yield important scientific information. Moreover, as more data are collected and analyzed, more lakes, some of them quite expansive in their own right, are being identified. Analysis of airborne surveys made between 1967 and 1979 (Robin et al., 1977, Siegert et al., 1996, Dowdeswell and Siegert, 1999) revealed that at least 70 subglacial exist in East Antarctica. Dowdeswell and Siegert (2002) characterized subglacial lakes into three main types: (1) lakes in subglacial basins in the ice-sheet interior; (2) lakes perched on the flanks of subglacial mountains; and (3) lakes close to the onset of enhanced ice flow. The majority of subglacial lakes are located within 200 km of ice divides in the major Antarctic ice sheets (Fig. 1). The bedrock topography of the ice-sheet interior involves large subglacial basins separated by mountain ranges (Drewry, 1983). The lakes in the first category are found mostly in and on the margins of subglacial basins. These lakes can be divided into two subgroups. First, there are those located where subglacial topography is relatively subdued, often toward the center of subglacial basins. Second, some lakes occur in significant topographic depressions, often closer to subglacial basin margins, but still near the slow-flowing center of the Antarctic Ice Sheet. Where bed topography is very subdued, deep subglacial lakes are unlikely to develop. Lake Vostok is the only subglacial lake that occupies an entire section of a large subglacial trough. Other troughs, such as the Adventure Subglacial Basin, contain a number of smaller lakes.

"Perched" subglacial lakes are found mainly in the interior of the ice sheet, on the flanks of subglacial mountain ranges. In several cases, small (<10 km long) subglacial lakes have been observed perched on the stoss face of large (>300 m high), steep (gradient >0.1) subglacial hills. At least 16 subglacial lakes occur at locations close to the onset of enhanced ice flow, some hundreds of kilometers from the ice-sheet crest (Siegert and Bamber, 2000).

About 20 other lakes have also been reported recently by Popov et al. (2002), who analyzed radio-echo sounding (RES) data collected between 1987 and 1991 by Russian Antarctic Expeditions in central Antarctica between Enderby Land and 90°S. Radar surveys carried out in 1999 and 2001 by the Italian Antarctic Program (PNRA) over Aurora and Vincennes Basins and over Belgica Highlands, revealed 14 subglacial lakes to be added to the original Siegert inventory (Tabacco et al., 2003). This Italian survey also defined the boundary conditions of a relatively large lake (Subglacial Lake Concordia) located in the Vincennes Basin, at 125.15°E, 74.0°S. The ice thickness over Lake Concordia ranges from 3900 to 4100 m, the surface area is greater than 900 km^2, and the water depth is estimated to be about 500 m in its central part. Lake Concordia could be an excellent candidate for future study of the subglacial lake environments. Preliminary data also exists for another large lake (estimated to be about 200 km long and 50 km across) approaching the size of Lake Vostok (G.L. Leitchenkov and R.G. Kurinin, unpubl. data). This lake occupies the sector of East Antarctica between 20°W and 30°E from 81°S to the South Pole. RADARSAT images of Antarctica shows a large and remarkably smooth ice surface area striking NW-SE with the center at 82.5°S, 18°E which looks similar to that of Lake Vostok. Further data collection and processing are required to confirm the existence of this second large lake. The high density of lakes in the Dome C region implies that they may be hydrologically connected within the same watershed and would be an important system to study from the standpoint of subglacial hydrology and biological and geochemical diversity.

Importantly, any strategy for subglacial lake exploration need not be based on the assumption that all studies are conducted in the same location at the same time. In fact, some scientific objectives will require the study of multiple sites to be successful. This is in part due to the recognition that all subglacial environments are not "created equal" and that in fact there is a diversity of environments populated by a large number of individual lakes, many with unique attributes that will allow for specific hypothesis testing. For example, if the strategy were focused on finding life in subglacial lakes, exploration of any of a number of lakes may suffice, though certainly different evolutions and histories for lake biota may create the opportunity for different ecosystems in different locations. If paleoclimate investigation were the sole theme, exploration should occur in the regions most sensitive to past climate changes. Finally, if geological evolution was the primary reason to explore subglacial environments, drilling through the thinner ice to bedrock and sediments on either side of a lake might prove more instructive and less costly than recovery of sediments from beneath a lake. Clearly, the criteria and final site selection itself will need to consider a wide range of variables, but attainment of scientific objectives should be the paramount consideration.

As subglacial environment exploration moves forward, the criteria for selecting among the many possible study sites becomes an important consideration in planning efforts. Questions that should be addressed in such a site selection process are:

- Does the lake provide the greatest likelihood for attaining the scientific goals?
- Can the lake be characterized in a meaningful way (e.g., size, postulated structure)?
- Is the lake representative of other lakes and settings?
- Is the geological/glaciological setting understood?
- Is the lake accessible (what is the closest infrastructure)?
- Is the program feasible within cost and logistical constraints?

Siegert (2002) examined the inventory of Antarctic subglacial lakes (Siegert et al., 1996) in order to ascertain which lakes were best suited to exploration, given the questions listed above. The conclusion was that while exploration of large lakes, such as Lake Vostok, is a long-term priority, smaller lakes that can be characterized more easily should also be considered for exploratory research.

The recognition of a range of subglacial environments where water may accumulate suggests that distinct evolutionary histories and settings most likely exist—as discussed above, all lakes are not created equal. This "population" of subglacial environments will increase the power of field experiments by providing a range of similar and contrasting environments to study the evolution of life under the ice. Therefore, subglacial environment exploration and research will entail the investigation of a range of settings, not just a single location or lake.

ENVIRONMENTAL ISSUES

One of the more contentious and important issues facing the development of a subglacial lake exploration program is stewardship of the environment. Critical testing, verification, and monitoring for potential contamination during all phases of the scientific program will be necessary. This will require a deliberate and careful scrutiny of all of the methodologies employed, from ice drilling to sample recovery, both from an environmental and scientific standpoint. Contamination may arise not only from the possible introduction of chemicals (toxic, nutritive, or otherwise) into the lake but also from the potential for the introduction of non-indigenous microorganisms. Redistribution of water and sediments within the lakes must also be minimized during any *in situ* operations. SALEGOS recognized the importance of these issues and invited experts with planetary protection expertise to the Fall 2002 meeting. It is clear that lessons can be learned form the experiences of planetary protection during space exploration that can be adapted to the challenges of subglacial exploration (Race et al., 2003). Analogies drawn between the list of environmental issues encountered by both projects include: cleanliness of equipment and sampling arrays; transfer of material during operations such as the introduction of drilling fluids or microbes into the lake during drilling; the need for monitoring of operations to ensure compliance and quality in all phases of the program; clear guidelines on the decision path and responsibilities when difficulties are encountered; and contingency planning for unforeseen events or developments.

Important considerations during planning include: attempts to better understand perceptions of risk; development of a risk communication plan; plans to deal with potential lawsuits and liability issues; and programs for public education and engagement in the project. Complete documentation of and transparency in the decision making process is also essential since the project is sure to attract both scientific and public debate. It is also clear that in projects at the frontiers of knowledge and technology there is uncertainty in the process and unforeseen events will likely occur. It is expected that the project will be highly scrutinized, possibly challenged and perhaps even opposed. Planning must be flexible and allow for incremental decision-making as our understanding of science and the project develops over a period of many years. Among the key lessons learned from space exploration are to: (1) integrate environmental issues early in planning; (2) use objective groups for advice and oversight; (3) communicate early and often to all stakeholders including the public; (4) pay attention to consensus building (both nationally and internationally); and (5) apply previous experiences, tailoring them to the specific needs of each project.

Following on from the lessons of planetary protection, SALEGOS suggested that it would be prudent to have an independent scientific body (such as the U.S. National Academy of Sciences) consider the 30-year history of planetary protection of space studies and provide guidance on how these lessons can be applied and adapted in preparing environmental protocols for subglacial exploration. SALEGOS further recommended that SCAR contact the Committee on Space Research (COSPAR) and explore ways that these two international organizations could work together to provide the scientific community with advice on these issues. COSPAR, which was established by the International Council for Science (ICSU), coordinates international cooperation in the conduct of space research. COSPAR is analogous to SCAR.

While there are analogies with planetary exploration missions, it is not intended to infer that subglacial lake exploration should be subjected to an equivalent degree of concern or precaution. Subglacial lakes by their nature are Earth-bound and have been subjected to the steady input of earthly organic materials and microbes for thousands if not millions of years. Cleanliness requirements need to be developed within this context, as pointed out in space exploration policies. Restrictions and requirements must be realistically developed in the context of the specific activities involved, the target of exploration, and the mission's objectives. For space missions, research and development is continuing to refine new technologies for use in detecting and quantifying contaminant levels and to improve cleaning and sterilization techniques that are satisfactory for life detection missions. Subglacial lake exploration can be informed by these experiences.

INTERNATIONAL MANAGEMENT AND ORGANIZATIONAL STRATEGIES

SALEGOS concluded that plans for existing large-scale international projects in Antarctica could be adopted for a subglacial exploration and research program. A review of past and present projects indicated that the management plan for ANDRILL (The Antarctic Drilling Program; http://andrill-server.unl.edu/structure.htm) dealt with many of the same challenges that subglacial exploration is facing and the management model could be used as an appropriate guide for developing organizational strategies for subglacial research. The ANDRILL program builds on the lessons learned from programs such as EPICA (the European Project on ice coring in Antarctica; for details see http://www.esf.org/), the Cape Roberts project (see http://www.antarcticanz.govt.nz/Pages/International/CapeRoberts.msa), ODP (the Ocean Drilling Program; http://www-odp.tamu.edu/), and others.

An organizational plan for subglacial research must begin with a way for SCAR nations to become more involved with the development of the science objectives for subglacial environment exploration and research. There are many scientists interested in seeing a subglacial exploration program become a reality, but at the moment SALEGOS is the only organized group trying to develop an international infrastructure to conduct such a program. Although scientists are continuing to conduct site survey work, accreted ice studies, and remote sensing and modeling, most other objectives will require lake access. One way to move planning forward is to establish an international scientific infrastructure to oversee program development and carry forward the goals established by SALEGOS and previous workshops. This group would provide leadership in promoting the science to be conducted during an exploration and research program. As the Terms of Reference of SALEGOS are currently being realized, SALEGOS encourages the formation of an independent body that is recognized by all nations and by a broad range of international scientists, to steer the scientific direction of the program. There is a need to initiate "grassroots" support within each nation to promote the study of subglacial environments. These activities could be coordinated with and compliment SCAR's activities.[2]

A PLAN FOR THE TRANSITION OF SALEGOS TO A SCAR SCIENTIFIC PROGRAM GROUP (SPG)

SALEGOS is presently the only organized group attempting to develop an international plan for a subglacial environment exploration and research program. This Group has generated momentum since its inception and has addressed and formalized many of the challenges that are necessary for the development of an international and multidisciplinary program for subglacial research. It is the judgment of the SALEGOS membership that the Group's Terms of Reference (Table 3) have been met and the Group of Specialists has served its original intent. Therefore, SALEGOS recommends disbandment after its current budget period in 2004. However, SALEGOS also recognizes that SCAR has an interest in further fostering international cooperation to accomplish subglacial environment exploration and possesses the expertise to

[2]See the recommendation on the transition of SALEGOS to a SCAR Research Program below.

TABLE 3

The Terms of Reference for SALEGOS

1. Refine, expand, and embellish the Cambridge 1999 workshop's scientific objectives.
2. Develop the critical requirements/criteria for lake(s) selection.
3. Provide scientific guidance and input to COMNAP deliberations on logistics and drilling technologies for subglacial lake entry and sample retrieval.
4. Develop a set of objectives for technology developments related to the science objectives as opposed to only entry and retrieval.
5. Consider and recommend organizational strategies/models for managing an international exploration program.
6. Delineate information gaps and the sequence or timing that is needed to progress toward the ultimate goal of lake entry and sample retrieval—are there milestones along the critical path and what are they?
7. Consider the environmental ramifications and how the Comprehensive Environmental Evaluation (CEE) and Environmental Impact Assessment (EIA) process needs to be applied for support of subglacial lake exploration and the role of other SCAR and Treaty bodies [Group of Specialists on Environmental Affairs and Conservation (GOSEAC), Committee on Environmental Protection (CEP)].
8. Devise a series of SCAR activities to facilitate and promote the exploration of subglacial lakes such as targeted workshops.
9. Be a proponent of subglacial lake exploration with National Antarctic Programs to garner the financial and logistical resources needed for the program.

continue to serve in an advisory role to the developing international program. It was further recommended to SCAR that SALEGOS be developed to a SCAR Scientific Program Group entitled "Subglacial Antarctic Lake Exploration (SALE)". Membership on the program committee should be open to all SCAR nations, especially those with an interest in subglacial exploration. The initial core members should draw on the current SALEGOS membership for continuity with a request for each interested National Committee to review its membership on the committee. Appointees should be selected based on a combination of national representation and expertise in relevant disciplines; therefore, more than one national from a country may be appointed a member of SALE.

The designation of SALE as a SCAR Scientific Program Group will provide a focus for the following activities.

1. Encouraging and facilitating communication and collaboration between scientists and technologists worldwide involved in subglacial environment exploration. This would be achieved by organizing workshops and symposia to present new results, exchange of ideas, sharing and compilation of information, assistance in the coordination/planning of activities, and maintenance of a website.

2. Advising the international community on all facets of scientific and technology issues relevant to subglacial lake exploration including environmental concerns and safeguards.

3. Promoting collaboration, data access, and data sharing to facilitate and expedite data syntheses needed for developing and revising the science and technology agenda for subglacial environment exploration.

4. Summarizing and reporting the results of these efforts to the scientific and wider community on an ongoing basis.

5. Encouraging adherence to the agreed guiding principles of subglacial environment exploration of international partnering, interdisciplinary emphases and focus, and minimal disturbance and stewardship of the environment.

6. Be an advocate for subglacial environment exploration in all venues including national Antarctic committees, scientific communities, and the public.

CONCLUSIONS

Water has accumulated beneath the thick East Antarctic Ice Sheet over the millennium, forming subglacial environments ranging in size and form from Lake Vostok, an expansive body of water the size of Lake Ontario, to shallow frozen swamp-like features the size of Manhattan. Although similar in size to these more familiar landmarks, subglacial environments in Antarctica remain virtually unexplored. Over 100 lakes, shallow and deep, have now been identified, suggesting that the subglacial environment is an immense interconnected, hydrologic system that has been previously unrecognized. While the full aerial extent and the interconnectedness are not yet fully known, the potential drainage system identified is larger than that of the Mississippi River basin in the United States. These environments have formed in response to a complex interplay of tectonics and topography, with climate and ice sheet flow over millions of years. Sealed from free exchange with the atmosphere for 10 to 35 million years, subglacial environments are analogues to the icy domains of Mars and Europa that hold the greatest promise for the presence of life beyond Earth.

Tantalizing evidence from ice cores taken from the overlying ice sheet indicates that it is very likely that locked within these subglacial environments are unique ecosystems. Any subglacial life within these ecosystems must be adapted to the low temperature and high pressure coupled with the tortuously slow delivery of nutrients and gases from the overriding ice sheet. These settings are probably the most oligotrophic on the planet and may harbor uniquely adapted organisms with novel metabolic traits. Seismic, geochemical, and genomic studies point toward the influence of local tectonics in setting boundary conditions under which these subglacial systems have evolved.

Approximately 35 million years ago, the climate of Antarctica shifted the entire continent from a tree-covered region into a region locked beneath 3 to 4 km of ice. Recovering a record of this major climatic shift has remained elusive. The subglacial lake region rings the nucleation point(s) of the East Antarctic Ice Sheet and has tremendous potential for containing paleorecords of these major shifts in climate. Numerous, targeted drilling efforts around the perimeter of the continent have consistently failed to recover these crucial paleoclimatic records that are essential for understanding the evolution of global and regional climate. Clearly, the Antarctic subglacial environment remains one of the last unexplored frontiers on our planet and its exploration will certainly change the way we view the Antarctic continent. In order to understand the complex interplay of biological, geological, chemical, glaciological, and physical processes within subglacial environments, an interdisciplinary approach to research and study is essential. The overarching scientific objectives for subglacial environment exploration and research endorsed by SALEGOS are to: (1) understand subglacial environments and their impact on the origins, evolution, and maintenance of life beneath ice sheets; (2) determine the form, distribution, and functioning of biological, chemical, and physical systems in subglacial environments, including the sediments, the water, and the overlying ice; and (3) recover and decipher the climatic information contained in the sediments in lakes and the ice sheet sealing the lakes.

The aims and objectives of subglacial studies can only be accomplished by an integrated series of interlocking phases of discovery and exploration. It is envisioned that the program will take at least 10 years to accomplish and will require a period of sustained international coordination of the best scientists and technologists available.

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