Report of the Subglacial Antarctic Lake Exploration Group of Specialists (SALEGOS)

Meeting - 2

Lamont-Doherty Earth Observatory, USA

23-24 May, 2002

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Lamont- Doherty Earth Observatory, USA, 23-24 May, 2002

Dr. John Priscu, Convener, welcomed the members of SALEGOS to Lamont-Doherty Earth Observatory of Columbia University. He thanked Dr. Robin Bell for the invitation to host the meeting and to her staff for making all of the necessary arrangements. Dr. Bell welcomed the Group. Dr. Bell indicated that her staff was available as needed to assist SALEGOS.

The following members of the Group were present: J. Priscu (Convener), M. Kennicutt II (Secretary), R. Bell, S. Bulat, C. Ellis-Evans, R. Powell, JR Petit and I. Tabacco. Members V. Lukin and H. Miller were unable to attend and sent their regrets. No invited guests or observers were present. The addresses of GoS members are attached (Appendix A).

1.0 Adoption of Agenda and Appointment of Rapporteurs.

The agenda of the meeting was discussed and accepted. The agenda is provided in Appendix B. Rapporteurs were appointed to assist M. Kennicutt II, SALEGOS Secretary, in recording the meeting's discussions. During the first day of the meeting, 23 May 2002, R. Powell, R. Bell, JR Petit and C. Ellis-Evans recorded the discussions. During the second day of the meeting, 24 May 2002, S. Bulat, I. Tabacco, R. Bell and M. Kennicutt II recorded the discussions.

2.0 Standing Items

2.1 SALEGOS Membership

SALEGOS membership was evaluated to ensure that appropriate expertise was available to adequately address all aspects of the SALEGOS Terms of Reference (TOR). All agreed that if the need should arise for discussions of topics outside of the Group's expertise, appropriate experts would be invited to attend and advise SALEGOS. It was determined that additional expertise in glaciology was needed and a list of potential candidates will be developed and forwarded to the SCAR Executive Committee for approval and selection.

2.2 SALEGOS Terms of Reference (TOR)

The Terms of Reference for SALEGOS were again considered. The progress of SALEGOS will be assessed and monitored based on fulfillment of the TOR. Progress will be routinely summarized in meeting reports. The following is a brief assessment of progress to date in addressing the TOR presented in SALEGOS Report -1:

1) **Refine, expand and embellish the Cambridge 1999 workshop's scientific objectives.**

Extensive detail was provided in the SALEGOS Report – 1 on specific timelines and how the scientific objectives would be accomplished in a coordinated manner. It was also discussed that more detail would be useful for these timelines emphasizing discipline based objectives. Given the framework provided in the first report these more detailed assessments of scientific objectives could be easily integrated into the timelines matching scientific objectives with technological milestones. Coordination of these various "needs" assessments, provide a detailed blueprint for implementation of a subglacial lake exploration program. In general, SALEGOS felt that the scientific objectives as expressed in the Cambridge workshop were clear and required little additional discussion. It was also recognized that the national authorities within each country will set the scientific agenda and there will be a need to harmonize and coordinate these efforts.

One future action item for SALEGOS is to develop similar timelines on a discipline-by-discipline basis to provide additional details for planning purposes.

2) **Develop the critical requirements/criteria for lake(s) selection.**

This TOR has not been discussed by SALEGOS. Site selection criteria were proposed in the Cambridge workshop. These criteria will be considered and revised as needed at a future SALEGOS meeting. Objective, agreed criteria for lake selection are important for site selection decisions. SALEGOS still endorses the concept that the greatest scientific return would result from a Lake Vostok campaign.

3) **Provide scientific guidance and input to COMNAP deliberations on logistics and drilling technologies for subglacial lake entry and sample retrieval.**

The SALEGOS Report – 1 provides a 9+ year timeline for technological requirements and milestones. The report provides a discussion of "clean technologies" used in planetary exploration, environmental assessment requirements, an approach to ice drilling and its support requirements, and a discussion of applicable technologies for sensing lake environments. SALEGOS will continue a dialogue with COMNAP to determine if the guidance being provided is sufficient to convene a workshop on technology and logistical requirements for subglacial lake exploration as recommended by the Cambridge workshop. A joint forum will be conducted in Shanghai, China with SCAR and COMNAP to advance these issues.

4) **Develop a set of objectives for technology developments related to the science objectives as opposed to only entry and retrieval.**

A first technology "needs" assessment was presented in SALEGOS Report – 1. SALEGOS will continue a dialogue with the scientific community and COMNAP to determine how these issues can be advanced.

5) **Consider and recommend organizational strategies/models for managing an international exploration program.**

Models for the management of a subglacial lake exploration program are discussed in SALEGOS Report - 2. Experiences learned from programs of similar scope and magnitude will be important for providing guidance on how a successful international exploration program might be organized.

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?**

A preliminary "needs" assessment was provided in the SALEGOS Report – 1. These "needs" assessments will continue to be refined and revised during future SALEGOS meetings.

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)].**

This issue was considered during the first SALEGOS meeting. It was recognized that the choice of lead nation will be a major determinant in the environmental requirements for subglacial lake exploration since national legislation generally stipulates the required procedures. It was also recognized that environmental planning should involve several documents addressing various phases of the program and that one overall CEE was not realistic or desirable. These discussions are reported in SALEGOS Report-1. SALEGOS is constituted to assess and evaluate various aspects of subglacial lake exploration and does not endorse one approach or another. The partners will decide the ultimate approach to environmental assessment of subglacial lake exploration.

8) **Devise a series of SCAR activities to facilitate and promote the exploration of subglacial lakes such as targeted workshops.**

A joint session with SCAR and COMNAP is planned for July in Shanghai, China. Three members of SALEGOS will also participate in an upcoming drilling technology workshop (FASTDRILL). Other recommended activities are discussed in SALEGOS Report - 2.

9) **Be a proponent of subglacial lake exploration with National Antarctic Programs to garner the financial and logistical resources needed for the program.**

Communication of the importance of subglacial lake exploration is being pursued through various activities such as broad dissemination of SALEGOS reports, dedicated sessions at scientific meetings, press conferences, and publication of a book on subglacial lakes. Other promotional activities are discussed in SALEGOS Report - 2. SALEGOS members are the best situated to be proponents of subglacial lake exploration in their respective countries and are encouraged to do so.

Significant progress had been made in addressing the SALEGOS TOR. The TOR provides a guide for deliberations and setting of agendas for future SALEGOS meetings.

2.3 Discussion of SALEGOS Meeting 1 – Report

SALEGOS members were asked for comments on SALEGOS Report -1. M. Kennicutt explained that the reports were intended to be as informative as possible. SALEGOS reports will include inter-sessional materials that are not discussed at the meetings. However, these additional materials are circulated for comment by SALEGOS members. The committee agreed that this was an effective way to proceed given the limited number of meetings scheduled for SALEGOS. In general, the response to the SALEGOS Report - 1 was very positive. The Convener noted that the SCAR Executive had been complimentary of the quality and content of the report. Others reported that the meeting report had generated increased interest and encouraged continued discussion and planning for subglacial lake exploration in their countries. SALEGOS Report -1 has also been extensively used by the media to update the public on progress toward the development of a subglacial lake exploration program.

3.0 Update on Research Progress

Members of SALEGOS provided brief updates on recent developments in subglacial lake research.

3.1 Lake Dynamics, Origins, and Geology

The recent work of R. Bell and colleagues at Lamont-Doherty Earth Observatory have documented the formation of accretion ice along the shoreline of Lake Vostok and the subsequent export of significant volumes of lake water from the system along the eastern shoreline. The ramification of these observations include (a) relatively short residence time for the lake water (~13,000 years) (b) that most of the existing accretion ice samples were formed along the shoreline and may not be representative of open lake condition and (c) over 250m of accretion ice still persists at the base of the ice sheet to the east of the lake.

Other work from Bell's laboratory (headed by M. Studinger) suggested that Lake Vostok has formed atop an over thrust continental margin, recently reactivated. This model explains the distinct morphology, gravity and magnetic signals on either side of Lake Vostok as well as the relatively thin crust determined using seismic receiver functions. The evidence for recent reactivation includes the line of seismic events along the eastern marine of the lake and several hundred kilometers both north and south and the $^3He/He^4$ signal presented by JR Petit.

Bell's laboratory has also been involved in delineating physical boundary conditions for other subglacial lakes. Work conducted by A. Tikku and colleagues showed that another lake, Lake Concordia, an 800 km^2 lake lies about 100 km northeast of the European Dome C camp. The description of this lake is key, as this lake appears to have basal processes such as melting and freezing that are similar to Lake Vostok. These processes are believed to be critical to the maintenance of a subglacial ecosystem and have previously only been documented in Lake Vostok. This lake may be an ideal target for early subglacial lake exploration.

3.2 Accreted Ice Studies

S. Bulat provided a research update on the molecular biology of Vostok accreted ice performed in collaboration with French scientists. They contend that the Vostok ice core (both glacier and accreted ice) is incredibly pure in regard to dissolved organic carbon (DOC) and microbial content. Very low DOC concentrations (less than 24.7 ppb) were found in both accreted and glacier ice suggesting that autotrophic rather than heterotrophic life would exist in the lake. They reported that bacterial biomass in both accreted and glacier ice is less than 50 cells ml^{-1} of melt water, close to the detection limits of Polymerase Chain Reaction of 2-8 cells ml^{-1}. In addition, they suggested that microbes would be inactivated due to oxidative DNA degradation by dissolved oxygen during passage through the ice. In the glacier ice, there is 10 times less O_2 than fresh water at standard conditions. However, they believe that there is still sufficient oxygen present during the long (1000 kyr) transit from the surface to the base of the ice sheet to degrade DNA. This may explain the lack of a definitive detection of DNA in glacier ice. The glacier-released microbes, whether alive or decayed, should represent a very low input to the waters of Lake Vostok. Also, they postulate that an excess of dissolved oxygen exists in the lake water (2 to 100 times as high as the O_2 concentration in fresh water at standard conditions) is unlikely to be subjected to significant microbiological consumption. Excessive oxygen concentrations may even be a constraint on life in the lake (oxygen toxicity).

By comparing the external (contaminated) surface of ice cores with the internal portions of the core from 3 accreted ice samples, Bulat and colleagues believe that 64-100% of the isolated prokaryotic clones were contaminants (Figure. 1). So far only three of the sequenced bacteria are believed to be indigenous to Lake Vostok (Figure. 2). The closely related DNA signatures of the suspected indigenous bacteria are typical of, or related to, thermophiles. One of them is a known extant species from hotsprings and is capable of growing as a chemolithoautotroph oxidizing H_2 and reducing CO_2 at reduced oxygen tensions. The two other taxa are unidentified in the current databases but show relatedness to bacteria associated with hydrothermal vents and nearby surficial sediments. Among them are thiosulfate oxidizers and anaerobic methanotrophs. These findings led them to suggest that mesothermophilic chemolithoautotrophs might be present in Lake Vostok, most likely in anoxic sediments that might be associated with hydrothermal activity.

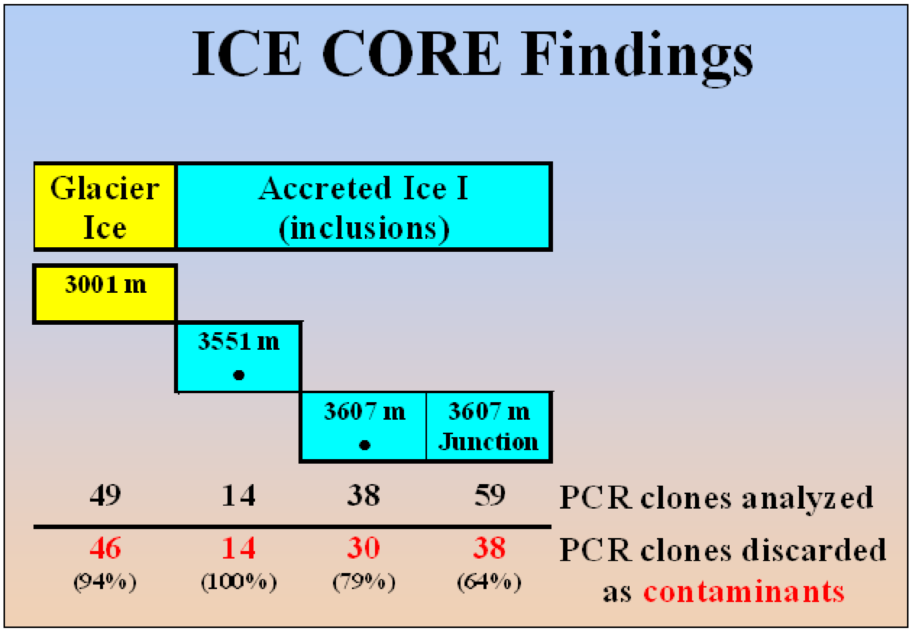

Figure. 1. Russian-FrenchVostok ice core molecular results showing the PCR clones disregarded (Bulat et al. 2002).

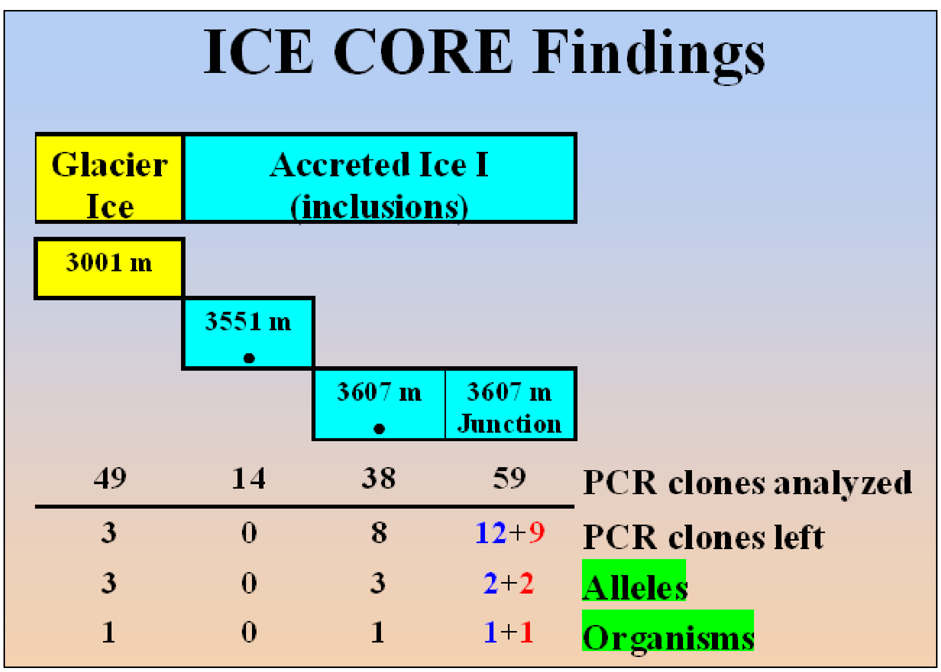

Figure 2. Russian-French Vostok ice core results showing remaining clones, allele number and organism number (Bulat et al. 2002).

Research being conducted by J. Priscu and colleagues on Vostok ice takes a more holistic approach to core analysis. Their work is based on an interdisciplinary approach involving molecular biology, scanning electron and epifluorescence microscope detection of bacterial cells and other particles, transmission electron and molecular detection of viruses and associated host bacteria, geochemistry, life in solid ice and mineralogy. Priscu's lab has now processed 12 Vostok ice cores including both glacial and accretion ice with this interdisciplinary approach and will be publishing their data soon.

As noted by other investigators, Priscu and colleagues employ stringent decontamination protocols and include numerous controls in all aspects of their research. Researchers in his laboratory are now using GC/MS to determine the penetration of drilling fluid into the Vostok cores using samples collected from a dry borehole (BH5) and one where kerosene based drilling fluid (TC-1) was used (borehole 5G). A comparison of bacterial density in three ultrapure water washes (each removing about 30% of the core by weight) for a number of Vostok 5G cores is presented in Figure 3. This figure shows two important items: 1) the outside of the core is clearly highly contaminated by bacteria, and 2) the asymptote achieved in the final sample indicates that the inner 30% of the core is relatively free of bacterial contamination. DNA fingerprinting (TRFLP) and scanning electron microscope examination of selected cores corroborate this contention.

3.3 Paleogeobiology

Deep ice cores obtained in Greenland and Antarctica have been used for paleoclimate studies. Analyses of these cores include: stables isotopes for radioactive or cosmogenic compounds; studies of composition of gas entrapped in air inclusions; and chemical characterization of aerosols and heavy metals. Owing to the very low concentrations (10^{-9} to 10^{-15} g g^{-1}) of chemical constituents in the cores various analytical techniques were specially developed and adapted to yield reliable results. Stringent decontamination techniques were also developed and tested and are now routinely used.

Studies of biological communities in ice using modern techniques are relatively new and offer a potentially new field of study – paleogeobiology. The availability of long ice cores and samples of accreted ice from the Vostok ice core has greatly increased interest in this area. Similar to the limitations encountered during studies of the chemical content of ice, the biological content of ice samples is also low making such studies difficult at best. Development of robust ice core decontamination techniques, including adequate controls during each step of the protocol, is critical for producing unequivocal results and must be pursued. The assistance and expertise of biologists who are familiar with stringent sterile lab environments should be enlisted. Sensitive methods will be needed for future subglacial lake exploration. The assistance of chemists who are experts in utilizing stringent clean, but not necessarily sterile, environments to work on extremely low amounts of matter should be enlisted. Cross-verification of techniques between different labs for decontamination of ice core, as well as tests for decontamination of artificial ice samples containing low concentration of a series of known bacteria, should be considered.

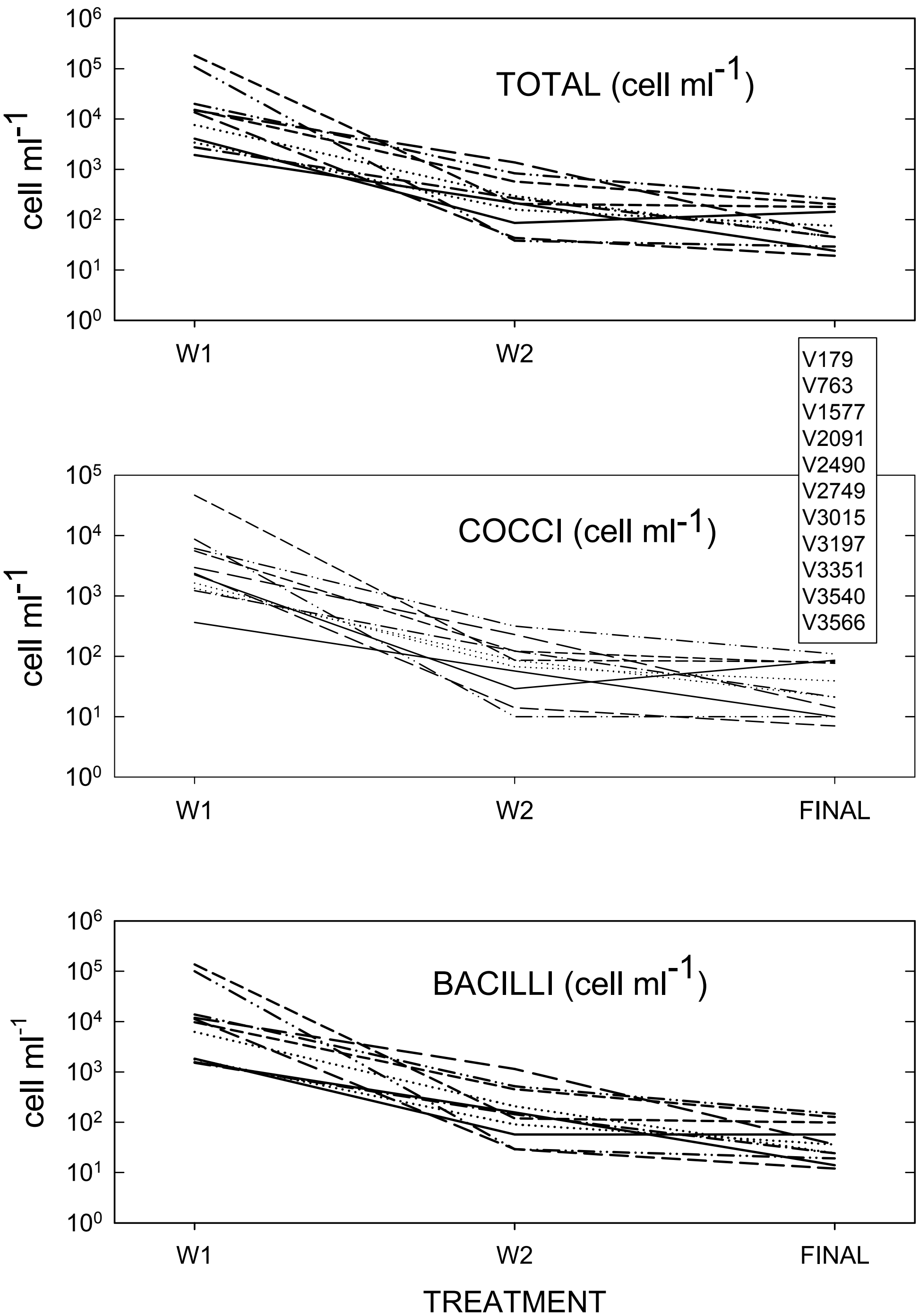

Figure 3. Bacterial cell concentration (cocci, bacilli and total) as a function of depth within cores from borehole 5G. Samples were obtained by ablating approximately 33% of the core with ultrapure water with each of 2 washes (W1 and W2). The inner 33% (Final) is considered a "clean" sample. Bacteria were counted following Syber Gold DNA stained samples by epifluorescence microscopy. Core depths are presented in the inset.

4.0 International Support for Subglacial Lake Exploration

The discussion of international collaboration focused on two issues. First, development of a science plan that enables a wide spectrum of nations to participate (see Section 7.0 below). Second, how to more fully engage the scientific community in subglacial lake exploration. The Group discussed strategies that would encourage National Antarctic Programs (NAPs) to actively develop subglacial lake research programs. It was agreed that wide and timely dissemination of SALEGOS reports was one method of communication. It is important that the SALEGOS members keep NAPs briefed on all deliberations.

It was also agreed that the forum provided by the joint meeting with SCAR and COMNAP in Shanghai (July 2002) was important for communicating the interests and needs of the subglacial lake exploration community to NAPs and MNAPs.

Another mechanism to generate interest in the program is to develop sessions on subglacial lakes at national and international scientific meetings such as the one held at the spring American Geophysical Union (AGU) meeting in Washington DC (June 2002). The format for this meeting was oral presentations, posters and a press conference that is available as a web cast (http://www.connectlive.com/events/nsfolpa/ and http://www.nsf.gov/od/lpa/news/02/vostok_webcast_images.htm). An open forum was also held during the AGU meeting to discuss all aspects of subglacial lake exploration. To engage a broader audience, especially more European scientists, special sessions on Lake Vostok will be scheduled for the American Geophysical Union (AGU)/European Geophysical Society (EGS) meeting in Nice, France in the Spring of 2003 and the International Geophysical Society (IGS) meeting in Milan, Italy in the summer of 2003.

Timely publication of research findings in peer-reviewed journals is important in maintaining interest in subglacial lake exploration. All investigators are encouraged to publish their results as soon as feasible. Subglacial lakes have also garnered much interest in the popular literature and media and scientists are encouraged to participate in these important outreach activities.

A steering committee within the US NSF Office of Polar Programs has been established (http://www.nsf.gov/od/opp/antarct/subglclk.htm) and charged with developing a plan to organize and hold a workshop or series of workshops that will involve development of an implementation plan for studying Antarctic subglacial lakes. The workshops will be structured to bring out the interplay between science goals and technology requirements. The scientific goals should define the requirements but the state of the technology may proscribe the goals. The workshops will include appropriate international and interagency participation and should at a minimum identify, discuss, and make recommendations concerning the following topics:

- primary and secondary scientific goals
- associated instrumentation requirements
- level of biological isolation required for each approach for meeting the various goals

- technology R&D necessary
- sequence in which science goals should be attacked
- logistics requirements
- site selection criteria, taking into consideration logistical constraints and scientific goals
- any other topics deemed significant by the committee

Initial discussions are taking place to possibly engage the US National Academy of Sciences through the Polar Research Board to evaluate the state of the art of clean technologies for entering and working in subglacial lakes.

SALEGOS encourages Antarctic programs in other countries to form similar planning groups. Program planning is now advanced enough to begin the formation of Scientific Steering Committees on a country-by-country basis (or based on alliances such as being considered by the European Union). These Steering Committees would serve as the focus for individual country planning, act as proponents of the program within national Antarctic programs, and act as their nations representatives in international coordination and planning activities.

5.0 International Management - Organizational Strategies

The Group discussed various models for the international management of subglacial lake exploration. R. Powell provided background on the discussions and planning efforts for ANDRILL. SALEGOS concluded that the ANDRILL plans dealt with many of the same challenges that subglacial lake exploration was facing and thus the ANDRILL model (Figure 4) could be used as an appropriate guide for possible organizational strategies for an international subglacial lake exploration program. The ANDRILL program builds on the lessons learned from programs such as EPICA, Cape Roberts, ODP and others.

The general organizational approach is to form an international scientific steering committee, set-up a science management office, and establish an operations management group. Each of these organizations has specific responsibilities related to the management and oversight of the program. These three organizations are closely coordinated and must be structured to work effectively together. SALEGOS considered the role of each of these bodies and a summary of a possible structure for a subglacial lake exploration program is described below.

Scientific Steering Committees (SSC) provide guidance and direction for the overall scientific program, generate funding for science within each partner's national programs, provide scientific input and advice to field operations, and liaise with relevant organizations in each partnering country. As mentioned above, one model is for each partner to have a National Scientific Steering Committee (NSSC) to address these responsibilities internally in each country or alliance. Representatives from national steering committees would then be selected to represent national interests on an International Scientific Steering Committee (ISSC). Membership should also provide representation of the wide range of disciplines needed to accomplish the scientific objectives. The balance between national representation and scientific expertise will need to be decided by the partnering countries. The ISSC liaises with the Science

Management Office (SMO) and the Operations Management Group (OMG). The ISSC facilitates and promotes subglacial lake exploration. In the ANDRILL model, the ISSC is designated to hire the contractor to manage operations including approval and oversight of the drilling and environmental assessment contracts. The ISSC has funds provided by partner countries to develop common facilities, conduct site surveys as needed for specific drilling targets, and assesses drilling capabilities. The ISSC schedules the drilling plan and prioritizes drilling projects. The ISSC oversees publications, manages the program's portfolio of projects, and promulgates the formula to balance funding and scientific representation in the program. The Science Management Office (SMO) is seen as the operational arm of the ISSC and co-ordinates operations on a day-to-day basis. In ANDRILL, the SMO consists of a manager, a secretary/business manager, and a staff scientist. The manager is a member of the ISSC.

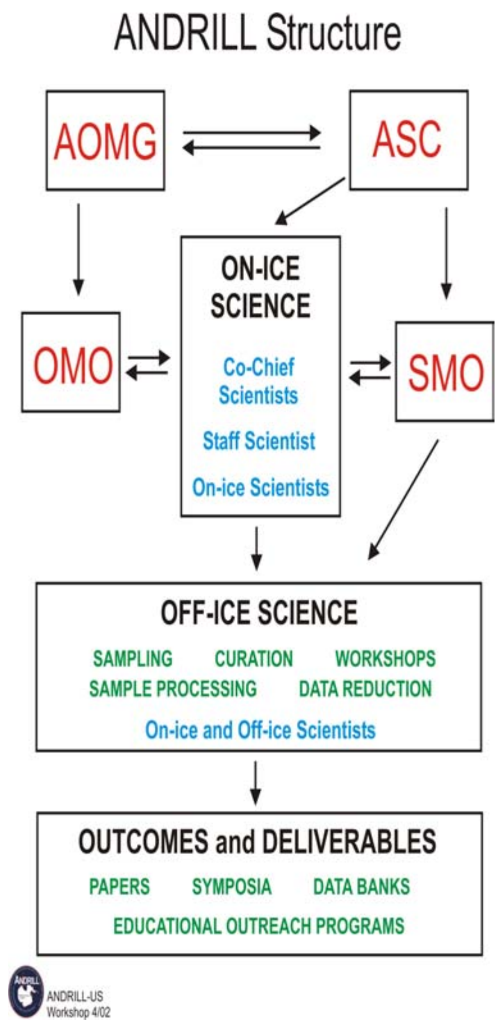

Figure 4. Science and management structure for the ANDRILL project.

The Operations Management Group (OMG) includes the logistics coordinators of the partner countries. The OMG manages logistics and non-scientific support. One national operator is usually selected to establish the program operations management office. The lead operator manages all operations including drilling, camp services, and on-site science facilities. The lead operator convenes and reports to the OMG. The lead operator develops the operational plan in consultation with the OMG, the SMO, and the ISSC. OMG responsibilities include: defining the requirements of project technical objectives, estimates costs, conducts bidding for operations and drilling activities, assesses environmental requirements, prepares and executes a logistical support plan, applies for any statutory approvals, assesses and manages risk, assesses safety requirements, procures all necessary materials and personnel for field campaigns, conducts and oversees field operations, and closes out the project sites at the end of the field campaigns. The OMG also co-ordinates the design and acquisition of the drill rig and associated facilities. The OMG oversees and manages the contract for drilling operations, facilities, and technical support. The lead operator manages the national contributions for operations and drilling costs and regularly reports to the ISSC and the SMO.

This model has been successfully used for international programs of this size and scope and provides guidance for the formation of an international program for subglacial lakes. Various other models can serve as useful examples of how large international science programs are structured and managed such as the Ocean Drilling Program. The partners must negotiate the ultimate structure and delegation of responsibilities. Cost will be borne by individual national contributions and it is expected that the level of participation in the scientific, management, and decision-making aspects of the program will reflect the relative magnitude of each partner's financial contribution. In-kind contributions (i.e., services, equipment, facilities, etc.) will have to be negotiated among the partners.

6.0 Subglacial Lake Exploration – Cost Estimates

A key consideration for the development of a subglacial lake exploration program will be realistic estimates of the cost of such a program. SALEGOS examined programs of similar scope to provide an estimate of the costs that might be associated with a subglacial lake program.

ANDRILL - The projected costs for ANDRILL (2001-2011) operations is $13 million USD (with contingency and escalation included). The science budget is estimated to be close to $10 million dollars over the term of the project. Based on these estimates, on average the ANDRILL program is estimated to cost $2 to 3 million USD per year.

EPICA (European Project for Ice Coring in Antarctica) - Ten (10) European nations are participating in this project that was started in 1996 and expects to have a ten-year lifetime. National contributions come mostly through National Antarctic Programs and the EU. The EU is providing ~ 40 % of total program cost. The objective of the project is to reconstruct climate form deep ice cores drilled at two different locations in Antarctica. For the DOME C drilling site, National Antarctic Operators from France and Italy (IPEV and ENEA) have taken responsibility for the logistics. For the Droning Maud site logistical operations are the responsibility of the National Antarctic Operators of Germany (AWI) and Norway. A Steering Committee under the umbrella of the European Science Foundation is responsible for the overall program with a science group coordinating the scientific efforts, a drilling group is responsible for drilling technology, and a finance panel oversees national contributions. Total estimated cost at present (with 90% of the field work complete) is 40 million EURO (~$39 million USD) with 85% for logistics.

Cape Roberts - Researchers from seven nations – Australia, Germany, Italy, the Netherlands, New Zealand, the United Kingdom and the United States – participated in the Cape Roberts Project, a geological drilling program designed to recover sediment by using land-fast sea ice as a platform off the coast of the Ross Sea, Antarctica. The project was formally initiated in May, 1992 with three drilling seasons (1997-1999) and was completed with the publication of the last science report volume in 2002. There was a total of about 70 drilling crew, scientists and support staff in Antarctica for each drilling season, although many more scientists participated in the project “off-ice”. Although slightly different, the overall operational structure was similar to that of ANDRILL, which was described in more detail above. Operational and science costs were kept separate. The final operational budget for the project was $6.2 million USD. No final tally has been made of the science research costs as they were awarded by the respective funding agencies of each nation’s Antarctic Program to each participating scientist.

GRIP (Greenland Ice Core Project) - This project was funded by 4 countries (Denmark, France, Switzerland, Germany) with some smaller contributions (some in-kind) from other countries and at a later stage additional funding from EU. The science program was organized by the ESF and a Scientific Steering Committee. The Steering Committee decided on the overall objectives and the detailed use of the ice core, its distribution and the division of science between the partners. To organize and carry out the fieldwork a Project Office was established at the University of Copenhagen. Total cost of acquisition and curation of the ice core was on the order of 7 million EURO (~$6.8 million USD).

Programs of similar scope and magnitude cost, on average, about $2 to 4 million USD per year suggesting that a total cost for subglacial lake exploration program of a duration of ten years to cost between $20 and $40 million USD with costs split roughly 50/50 between logistic and science costs. Specialized facilities (on site and home laboratories), technological development, unique equipment (such as sensor strings, robotics, autonomous vehicles, ROVs), and other specialized sample recovery or processing equipment will require additional resources. These costs are difficult to estimate but might require an additional $5 to 10 million USD bringing the program cost estimate to as much as $50 million USD over ten years.

SALEGOS recommends that more precise cost estimates be requested for various components and possible scenarios as described below. One approach is to contract a professional project management and planning consultant (as has been done for ANDRILL). However, to effectively proceed with this activity, SALEGOS believes an operational management group (OMG) and an ISSC must be convened in order to provide the consultant with adequate advice and details for realistic and accurate cost estimates.

7.0 Subglacial Lake Exploration Program – A Scientific Portfolio

In discussions of possible structures for a program for subglacial lake exploration, it was concluded that to ensure wide participation, each interested national program should be able to identify a niche or role that they could fill. This niche could include participation in scientific investigations and/or logistical or technology efforts. It was also clear that the overall exploration program needed to be designed as a series of components that can accomplish significant milestones along the way. In order to maintain interest in the program and to ensure adequate resources to accomplish the scientific objectives, key shorter-term objectives need to be defined and a plan developed to progress toward short term as well as long term objectives. This approach recognizes that subglacial lake exploration, as SALEGOS envisions it, has a series of supporting and interconnected scientific objectives that require different levels of technological advances and developments, financial resources, and logistical support. In order to advance the science of subglacial lakes, a portfolio of components with self-contained objectives and requirements was seen as a useful way to proceed. While the ultimate goals of subglacial lake exploration will be best accomplished by completion of the entire portfolio of components, significant advances can be made by completion of individual components as the program proceeds toward longer term and more comprehensive objectives. This approach also provides for regular assessment of progress in the context of continued availability of resources (i.e., there are logical stopping points if circumstances dictate this decision) and for active management of the program so that goals, objectives, and implementation plans can be revised as new information is acquired. This is particularly important in regard to subglacial lake exploration, since the current information for making important programmatic decisions is limited. This also allows for the addition of new portfolios or components that might not have been envisioned in the original planning exercises.

To begin the development of a subglacial lake exploration scientific portfolio, SALEGOS developed an outline for several components with discrete objectives, logistical needs and technology requirements. At the present time, the following components are envisioned recognizing that site surveys and remotely sensed data collection and lake characterization is currently on-going and will continue into the future:

a) Remote Studies- Accreted Ice, Modeling, and Remote Sensing
b) Deployment of Remotely Operated *In Situ* Observatories
c) Subglacial Lakes as Systems
d) Subglacial Lake Processes and Histories

SALEGOS notes that even though these components are presented as discrete projects, they are intricately inter-related and each component compliments the objectives of the others. In addition, these components could be conducted in parallel and it is not intended that they necessarily be implemented in a step-wise or chronological order, even though some studies may rely to some degree on information or technologies provided by other components. Nor is importance or impact inferred by the order of the components. In the "best-case" scenario, all components would be implemented simultaneously with independent timelines realizing that implementation is primarily controlled by the availability of financial resources and logistical support.

7.1 SALE Portfolio 1 – Remote Studies – Accreted Ice, Modeling, and Remote Sensing

It is recognized that many of the overarching scientific objectives of subglacial lake exploration will require lake entry and sample retrieval; however, much can be accomplished before these more complex activities take place. In addition, pre-lake entry studies will focus scientific planning for the more challenging phases of lake exploration and allow for more meaningful hypotheses to be drawn. This portfolio has four components: 1) accreted ice studies, 2) the study of analogue settings, 3) continued remote sensing surveys, and 4) modeling.

SALE Portfolio 1A – Vostok Borehole and Ice Core Studies ─ In lieu of actual lake entry, accreted ice and associated studies are the primary mechanism to increase our understanding of subglacial lakes. The existing accreted ice and possible newly cored ice are the only surrogates for lake water. A primary scientific objective is to infer what type of life, if any, is present in the lake based on materials encapsulated in accreted lake ice. A second objective is inference of lake chemistry from the chemistry of accreted ice and the presence and character of any debris being contributed by the ice sheet. SALEGOS recognizes that Lake Vostok accreted ice (especially that closest to the lake) is exceptionally clean in terms of organic carbon and microbial content suggesting that decontamination methods must be implemented when working on accreted ice to ensure the veracity of the resultant studies. An inter-comparison of decontamination methods was recently launched by NSF (April 2002). There are two potential sources of accreted ice for study: 1) ice already retrieved and archived and 2) new ice cores from continued deepening of the existing bore hole. Accreted ice studies are already in progress and have been summarized in SALEGOS reports and the periodical literature. It has been suggested that ice drilling, down stream of the lakes, might provide a chronology of lake evolution by sampling of accreted ice that was extruded from the lake over time. These areas, where ice is transported out of the lake accreted on the base of the glacier, might be reasonable targets for fast access drilling technology tests. Issues related to deepening of the Vostok borehole to obtain more accreted ice are discussed in Section 8 of this report.

SALE Portfolio 1B – The Study of Analogue Settings ─ It has been recognized that the study of analogue settings is probably the most efficient way to begin to develop and test the technologies needed for subglacial lake exploration. Analogue settings may include frozen lakes, ice shelves, glaciers, ice sheets without underlying lakes, and the shallow sections of ice sheets over lakes. Logistically these locations may be easier to access for initial testing and proof of technologies. Environmental protocols can be tested at these locations that are less sensitive to disturbance than subglacial lakes. Localities in the northern and southern hemispheres should be considered. This is also a place where some partners could take on specific tasks commensurate with their ability to financially participate in the program. As a value added, it is recommended that these analogue studies have their own scientific objectives in addition to testing protocols and methods for subglacial lake exploration. In this manner multiple objectives can be accomplished.

Lessons should also be garnered from other programs attempting similar operations such as drilling through ice, casing through water columns and recovery of sediment cores such as Cape Roberts, ANDRILL, FASTDRILL, SHADRILL, and ODP/IODP. These programs will encounter challenges similar to those expected during subglacial lake exploration. The lessons learned in these programs will be important for planning and should be incorporated into planning activities. Liaisons should be established with these other programs to stay abreast of their progress.

SALE Portfolio 1C- Remote Sensing Surveys of Subglacial Lakes **─** Several countries are conducting remote sensing surveys of subglacial lakes (i.e., USA, Italy, and Russia). These surveys will be critical to expanding the inventory of possible study sites and increase our understanding of the range of possible subglacial lake environments. Specific goals for this task are outlined below in Section 7.2. It is strongly recommended that these surveys continue including aero geophysical (laser altimetry, radar, gravity and magnetic surveys) and ground based seismic surveys to map and characterize the geological setting, morphology and structure of lakes.

SALE Portfolio 1D – Modeling of Subglacial Lakes and Systems **─** An important component of pre-lake entry studies is modeling efforts to predict lake dynamics including interactions with the overlying ice sheet, estimates of the trophic and oxygen status of the lake, important reduction/oxidation couples that drive certain metabolic reactions, estimations of water residence time, and lake age estimates based on the residence times. It is also important that ice sheet dynamics be modeled as well as the subglacial hydrologic system to determine if there is communication among the lakes and what is the potential drainage basin or watershed for particular lakes or lake systems. Models and predictions of the important geological processes and climate variations over the history of the evolution of lakes will provide an important framework for understanding and interpreting detailed studies of lake systems and their functioning. This would also include coupled ice sheet-climate modeling, as well as reprocessing of historical data to glean as much information as possible from the studies that have already been done. The discovery of many lakes was based on the reanalysis of data collected in the past.

7.2 SALE Portfolio 2 – Deployment of Remotely Operated In Situ Observatories

This component is an embellishment of the accelerated lake entry scenario presented in SALEGOS Report -1. There are four objectives for this component of the exploration program: 1) a "proof of concept" that lake entry is feasible with acceptable disturbance, 2) provision of seminal information on the basic water chemistry and thus the environmental setting of subglacial lakes, 3) a determination of the physical/chemical conditions and distributions in the lake which may be indicative of the presence of life, and 4) life detection. This portfolio can be accomplished by completing four components: *in situ* lake observations, survey and inventory of subglacial lakes, "down ice hole" studies, and modeling.

The drilling and entry technology necessary for lake entry should become part of the broader international assessment of ice coring capabilities needed for other independent or complimentary programs that have a need for new and innovative ice drilling and coring technology. Workshops and task forces are assessing these needs and developing a plan for future capabilities (e.g., FASTDRILL). It is important that the needs and capabilities required for subglacial lake exploration be part of these wider plans. The following is excerpted from a US NSF OPP report to COMNAP on drilling developments:

"Through its drilling contractor, Ice Coring and Drilling Services (ICDS), the NSF is currently supporting two drill development efforts with potential applications to subglacial lake exploration. The first of these efforts is the development of a compressed-air mechanical shot-hole drill capable of rapidly drilling to depths of roughly 100 meters. This drill is being developed for use as part of an ice-dynamics study of the onset area of ice stream D in West Antarctica and will be used for a large-scale seismic study to be conducted during the 2002-2003 field season. This drill system could be used for production shot hole drilling in support of large-scale seismic surveys of subglacial lake sites.

The second major effort being supported by NSF is the development of a very large-scale hot water drill, which produces a 60-cm diameter hole and is capable of drilling to a depth of 2.5 kilometers in approximately 40 hours. This drill system, called WOTON, is being developed as part of the preliminary work in preparation for a large, multi-year drilling effort at South Pole Station in support of ICECUBE, a kilometer-array neutrino detector project. While the WOTON system itself is very specialized and may not have direct use for sub-glacial lake exploration, significant knowledge that could have applications for lake-access drilling in the future may be gained in the area of large-scale, hot-water drilling."

SALE Portfolio-2A - In situ Lake Observations – The technological requirements for this phase of exploration can be addressed mostly with existing methodologies and equipment. The science objectives can be accomplished by a "one-way" lake entry to deploy a string of sensors in a lake. It is proposed that a string of sensors be developed to provide a profile of the lake's environment. Also the distal end of the sensor array would be fitted with a probe and camera to provide shallow penetration of the underlying sediments, if they are present, and for visualizing and characterizing sedimentary parameters. The deployment package would be kept simple to meet the requirements of the size limitations of the entry hole.

The entry hole could be allowed to freeze behind or be maintained open for a relatively short period of time. This suggests that hot water technologies could be used eliminating environmental concerns about the introduction of drilling fluids and other foreign materials. Current technology can achieve the entry objectives and environmental concerns would be minimized. Arrays of sensors are already proven for use in the deep sea in similar extremes of temperature and pressure and should be directly applicable or relatively easily adapted to subglacial lake needs. The sensors and drilling technologies are robust and could be subjected to chemical cleaning techniques used in planetary exploration to accomplish the goal of clean entry.

The sensor array(s) would be left in place to monitor the lake chemistry providing an important time series of data. Information would be transmitted to a surface collection point. Because the package to be deployed will be simple, the "on the surface" support facilities can be minimized. A means of collecting and string data transmitted from the observatory and a reliable source of power for long term monitoring would be required. Solar panels and wind generators as commonly used in Antarctic Automated Geophysical Observatories would suffice. No sample retrieval is proposed, limiting the need for special precautions or on-site laboratory facilities.

Initial lake entry is an important first step and would install a real time observatory in a lake. For initial lake entry attempts, lakes close to existing infrastructure and facilities could be targeted to test and improve the techniques. If a "light-weight" drilling apparatus is designed, it could be moved from location to location and ultimately several lakes might be instrumented to begin to establish the range of lake environments that might exist, but the important first step is lake entry itself. The data collected would provide important information about the oxygen conditions of lakes, whether lakes contain fresh or salt water, whether bio-reactive chemicals are distributed in a way consistent with the presence of life, if lakes are optically pure or turbid, if lakes are stratified, and if chemicals are partitioned within a lake between the water and underlying sediments. For specifics on the types of sensors envisioned see the SALEGOS Report - 1.

There are technological issues that may need to be addressed. To minimize the introduction of foreign materials into the lake during entry, a water lock system may need to be developed. If this is determined to be the technique of choice, a finishing drill may be needed to complete the ice drilling from the water lock into the lake proper. Engineering designs and specifications need to be developed in detail.

SALE Portfolio 2B – "Down-Ice Hole" Studies — Other aspects of this component might include targeted ice coring on the way to the lake to establish biological/geochemical information on one possible source of lake water and biota, the overlying ice. The trade off between time lost and these coring operations would need to be assessed (this also requires an open hole as well). It might be feasible to conduct appropriate "down ice hole" science for other objectives such as down hole logging of ice properties. It is unclear whether down hole logging of ice holes provides relevant information to address the scientific objectives or if it is feasible. These issues will require further research.

7.3 SALE Portfolio 3 - Subglacial Lakes as Systems

This component envisions the study of multiple lakes and includes the necessity for sample return. The scientific objectives are to understand the processes which control the development of lakes (tectonics, morphology, domes), determine if subglacial lakes are part of a major subglacial hydrologic and/or ecological system, ascertain if the finding from the Vostok ice core studies are representatives of other subglacial lakes, document the diversity of lake settings and environments, and assess the controls on bio-diversity in subglacial lake ecosystems.

This component is envisioned as an extension of the accelerated lake entry component. Multiple lakes would be entered and instrumented. In addition limited sample retrieval would be necessary beginning with water column profiles and possibly surface sediment sampling. Technological requirements would be the same as for accelerated lake entry; however, the hole would need to remain accessible for the retrieval of samples. The lessons learned from sensor arrays would assist in lake and site selection and discrete sampling would be augmented by those sensor deployments found to be most useful in the accelerated lake entry phase. If financially feasible, multiple "light weight" portable drilling rigs should be made available for coordinated entry into multiple target lakes.

The following types of tasks are considered as being necessary to address the objectives of this component of the exploration program. As mentioned above, improved inventories and surveys of the complete range of subglacial lakes are needed. As a first order attempt to understand regional hydrology, modeling can provide useful insight into the extent of regional lake systems, the aerial extent of the watershed of the systems and how, or if, subsurface flow is an important phenomenon. Emplacement and long-term data collection from observatories in a series of lakes will be important, creating a network of observatories across the entire area where lakes occur. As mentioned above, lake entry and sample recovery will be key. Chemical and isotopic tracers will be valuable in understanding whether there is communication among lakes and defining the overall dynamics of subglacial lake systems. These datasets will also be important for understanding the subglacial sediment systems and constraining their possible origins. To date, extensive lake sediments have only been documented in Lake Vostok.

As outlined in the Cambridge workshop report and the first SALEGOS report, a range of technological advances will be necessary in order to implement the sample return components of the program. The reader is referred to the technological timelines provided in SALEGOS Report -1. These include technologies for sample collection, return and processing but also for the development of the appropriate protocols and methodologies, particularly for the detection of possible unusual life forms. The more complex arrays of equipment that will be deployed down the ice hole will also require more exhaustive and diverse cleaning procedures.

SALE Portfolio-3A - Survey and Inventory of Subglacial Lakes ─ In order to select an appropriate lake (or lakes) for entry and sensor deployment, a more complete understanding of the population of lakes that exist is needed. Therefore a recommended component of the *in situ* lake-observing scenario is the continuation of remote sensing surveys of lakes. There are two conclusions that can be reached from our current knowledge of subglacial lakes: 1) the more we look, the more lakes we find and 2) all lakes are not created equal. These are important conclusions in that we now have a significant population of lakes to choose from for study. Clearly, different lake settings may indicate differing modes of origin and possible different life forms. On a first order, this infers that there may be a range of lake environments that differ considerably in their characteristics and, therefore, their origin, evolution, and resident biota. Data from a number of lakes will provide a powerful tool by documenting contrasts across a large population of lakes. It will also provide important clues to the origins and evolution of lakes and their relationships to the overlying ice sheet and the regional geological and plate tectonic setting. Therefore, additional information is needed about the characteristics of the full suite of subglacial lakes including – water depth, physiographic size/dimensions, geologic setting, the presence or absence of sediments, the velocity of ice in the areas (residence time), the accumulation rate of ice, and the hydrology of the subglacial lake environment. These continuing surveys will improve the "inventory" of lakes, assist in identifying sites for locating *in situ* observatories, identify potential sites for sample return missions and can help in defining potential geological setting and possible origin/formational setting of lakes.

7.4 SALE Portfolio 4 – Studies of Subglacial Lake Processes and Histories

As this component of lake study is the most complex and the most likely to be addressed in the later stages of an exploration program, SALEGOS did not spend extensive time in developing details for this scenario. This scenario reflects the conclusion of the Cambridge workshop that Lake Vostok is the ultimate target of study and that many of the more complex scientific issues can best be addressed in larger lakes that are expected to more fully express subglacial lake processes. By the time that this component of the program is implemented, the entry, sensor, and sample return technologies being used should be well tested and mature. Our understanding of subglacial lake processes will be greatly improved by previous studies in the lakes. This phase of subglacial lake exploration should include a range of components and activities including multiple observatories in larger lakes, sediment coring, water return, and regional surveys of the geophysical, geological, and glaciological setting. This component will study internal subglacial lake processes complementing the studies of subglacial lakes as systems. The scientific objectives in the broader sense for this, the penultimate phase of subglacial lake exploration, is provided in the three overarching goals listed in the Cambridge workshop: 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 lake and the sediments underlying the lakes; and to understand the origins of subglacial lakes and their impact on the evolution of life under the ice. While limited sample return will be accomplished under other components, this will be the main phase of sample return especially the most challenging sample return efforts such as retrieval of long cores of sediment. Due to the increased complexity of these operations, the environmental assessments and requirements will also increase in complexity.

Process studies will develop an understanding of the origins of the lakes and the water in them, the evolution of the lakes over time, the structure and functioning of subglacial lake ecosystems, and the influences of regional tectonics and climate on lake formation, persistence, and creation, and controls on the maintenance of or change in the lake's chemical/physical environment. This will be the most technologically challenging phase of subglacial lake exploration. It will include requirements for water and sediment retrieval, emplacement of long-term observatories, three-dimensional characterization of lake water and sediment environments, deep sediment coring, and sophisticated on-site facilities for physiological and other experiments. The latest robotics and autonomous vehicles would be needed to accomplish the scientific objectives. Drilling requirements may be significantly different from previous studies and require larger access holes for entry of instrument packages as well as routine access to the lake itself.

The full details of this phase of subglacial lake exploration will only be known after significant additional information is collected. Lake selection and site selection within lakes will be critical to accomplishing the scientific objectives. An understanding of the range of potential subglacial environments and an understanding of the subglacial lake system including its hydrology and watershed dynamics will be key to understanding how lakes internally operate. Many of these details will only become clear as the exploration program is implemented.

8.0 Other Business

8.1 Deepening of the Vostok Borehole – Additional Comments

Following recommendations during SALEGOS meeting – 1, the Convener of SALEGOS solicited comments from 5 experts related to the Russian proposal to deepen the existing borehole over Lake Vostok (four responded). Based on these responses and deliberations by SALEGOS, a letter was sent to the SCAR Executive summarizing the conclusions (see Appendix C).

JR Petit led a follow-up discussion of the issues related to the proposed borehole 5G deepening at Vostok Station. The basic question is whether the risk of contaminating Lake Vostok with materials contained in the existing hole is balanced by the scientific knowledge that would be gained from the analysis of additional accreted lake ice. It was also considered whether the risk of contamination can be minimized thus assuring that deepening of the boreholes would not contaminate the lake. The areas of concern are three fold: transport of contaminants along ice crystal interfaces, diffusion through permeable ice, and hydro-fracturing or crevasse formation. JR Petit suggested that all of these outcomes were unlikely due to the following factors. First, there would be little or no fluid water at the crystal interfaces at these pressures, temperatures and the expected high purity of the accreted ice from the lake. Therefore transport along veins would not be expected. Secondly, the size of the ice crystals at these depths is large and diffusion through these materials would be quite slow. It was suggested that one monitor of ice quality, as the hole was deepened, would be to monitor the size of ice crystals to see if they decrease toward the lake surface. Third, hydro-fracturing or development of crevasses would only occur if there were bubbles or impurities in the ice or if pre-existing fractures were encountered. At these depths bubbles are unlikely as most gas is in the form of clathrates. Any pre-existing fractures would be expected to quickly anneal at these depths and pressures.

The properties of the ice between the current depth of penetration and the lake surface are unknown. Various precautionary approaches have been proposed to reduce the risk of lake contamination. There was agreement that in the interim, until a lake is actually penetrated, that accreted ice provides the only potential clues to the lake environment.

8.2 Decontamination Comparison Studies

JR Petit and S. Bulat informed SALEGOS about a meeting (U.S. National Science Foundation, Arlington, VA, 17-18 April 2002) that was recently held with scientists and Antarctic agency representatives from France, Russia and the United States to discuss utilization of recently returned samples of Lake Vostok accretion ice. These samples of accretion ice (belonging to all three countries) are currently stored at Laboratoire de Glaciologie et Geophysique de Environnement (LGGE) in Grenoble, France. During the two-day meeting, the scientific importance of these ice core samples was discussed and potential areas for research were outlined. A specific plan was developed for the allocation of samples among the three countries for establishing a mechanism for formal international collaboration between French, Russian and US scientists. To facilitate comparison of biological results, an experiment was designed to allow for the controlled evaluation of two different decontamination methods from Russian and US laboratories. The importance of effective ice core decontamination procedures needed for ice chemistry and biology was agreed. The following is an excerpt from the US NSF OPP meeting report entitled "France-Russia-United States Collaborative Program on the Lake Vostok Ice Core: Samples 3612 to 3623 of the Accretion Ice":

While analytical methods for characterizing the geochemistry of the ice are fairly well standardized and data from different sources are readily accepted, decontamination is a controversial issue for comparing biological results from the ice. Presently, a variety of decontamination methods are used prior to biological testing of the ice. Because of the wide variation in results on how much and what kind of life is present in the ice from the Lake Vostok site, it was agreed that an international inter-comparison of decontamination methods is warranted. A plan for such a study was devised. Biologist S. Bulat will visually inspect and select a small piece (e.g., 15 cm length) of the Russian allocation of the accretion ice. The ice core segment selected will be cut vertically to produce two one-quarter sections of the original core. One replicate piece will be sent to a biological laboratory in the US (selection of the US lab will be made by NSF/OPP) and S. Bulat will analyze the second replicate. Each laboratory will decontaminate the quarter section of the core using their preferred method. After decontamination, a small aliquot from each lab will be forwarded to an independent laboratory (US or France) for measurement of DOC and ion concentrations. If there are no significant differences in the chemical composition of the decontaminated samples, then the remainder of the sample in each biology laboratory will be split so that one half can be analyzed by each group for comparison of the presence of nucleic acids and organisms.

It was also suggested that preliminary complementary studies could be done with artificially seeded laboratory-made ice cores. In this case, ice cylinders are formed in the freezer with a dilute suspension of one species of microbe and then a second species is spread over the ice surface to mimic a contaminant. Both taxa can be easily tracked during the decontamination procedure to determine efficiency of contaminant removal.

8.3 Subglacial Lake Book

Plans for a book on subglacial lakes were tabled until further discussions could determine interest and readership.

8.4 Shanghai Meeting

A joint forum with SCAR and COMNAP will be conducted on Saturday July 20, 2002. A tentative schedule of speakers was agreed upon and will be forwarded to SCAR and COMNAP Executive Committees for review.

8.5 NSF – "Life In Ancient Ice" Workshop

A "Life in Ancient Ice" workshop, supported by the National Science Foundation, was held June 30-July 4, 2001, and brought together 35 participants from 6 countries (the United States, Germany, Russia, Australia, Israel, and Denmark). The talks focused on the biology of ice and permafrost, with topics including the source of samples, techniques for studying life from sub-zero environments, the taxonomy of recovered organisms, and the evolutionary and astrobiological implications of the research. Key points in the discussion included the quality of samples, access to samples, decontamination issues, viability of organisms, taxonomy of organisms, and data coordination. A discussion of future research directions concluded the meeting. Princeton University Press will publish the workshop presentations. The final report for the workshop can be found under "workshops" on the SALEGOS website: http://salegos-scar.montana.edu/.

8.6 Logistical Considerations

Logistics will be a critical component of any subglacial lake exploration program and may control the timing of each phase of the program. Recently the US-NSF reported to COMNAP on two issues related to the possible support of a subglacial lake program and edited summaries are provided as information:

(a) ***Aircraft Support*** *- During the 2000-2001 austral summer season the NSF conducted tests of a Basler-Turbo DC-3 aircraft to assess the potential applications of the aircraft for deep field support. The aircraft, chartered through Leading Edge Aviation of Missoula, Montana, was used for a variety of deep-field missions during the 45-day charter period. The aircraft was tested in a variety of snow, temperature and altitude conditions, the most extreme being in support of the Automated Geophysical Observatory (AGO) network on the Antarctic plateau. The tests were wholly successful, and the aircraft shows significant promise as an alternative to the LC-130 Hercules for medium-lift air support situations and for passenger transportation to deep field sites.*

(b) ***Overland Science Traverse Capabilities*** *- The NSF has recently purchased a second Caterpillar Challenger 55 tractor to be used in support of West Antarctic research being conducted as part of the International Trans-Antarctic Scientific Expedition (ITASE). Over the past 3 years the United States has been developing the capability to use over-snow traverses as a means of conducting scientific explorations over a large area. The unique feature of traverse capability is that the entire traverse (vehicles and support equipment) can be transported to a remote site via LC-130. The traverse itself can be configured to support a variety of types of research and might be well suited for extended surveys of subglacial lakes. A tentative plan for enhancing US traverse capabilities can be found under the "US Research" heading on the SLAEGOS website http://salegos-scar.montana.edu/.*

8.7 Planetary Exploration Technologies

The US National Aeronautics and Space Administration (NASA) hosted a workshop to evaluate the relevance of exploring extreme Earth environments to the exploration of Mars and Europa (http://astrobiology.arc.nasa.gov/extremes). Four sessions provided overviews on: 1) the science of extreme environments; 2) deployment platforms, robotic systems, and trends in automation; 3) instrument development activities; and 4) future opportunities. NASA research and development activities will contribute to the range of technologies available for subglacial lake exploration.

9.0 Meeting Schedule

The following schedule of meetings is proposed:

Meeting 1 Bologna, Italy, 29-30 November 2001 - **Complete**
Meeting 2 Lamont –Doherty Earth Observatory, 23 – 24 May, 2000 - **Complete**
Meeting 3 Shanghai, China, 20 July 2002 – Presentation to SCAR/COMNAP (not an official Group meeting)
Meeting 4 TBA, Autumn 2002 (perhaps adjacent to the FASTDRILL workshop planned for 3-4 October 2002)

Meeting 4 St. Petersburg, Russia- May or June, 2003 proposed

The SALEGOS meeting schedule will be revised as the committee proceeds with its deliberations. Hearing no further items, the meeting was adjourned.

Appendix A

Committee Members and Contact Information for Participants SALEGOS Meeting 2

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Appendix B

Agenda for SALEGOS Spring 2002 NY Meeting

Dates of meeting: 23-24 May 2002
Venue: Lamont-Doherty Earth Observatory of Columbia University, Lamont Hall
Tel. 845 - 365 - 8827; FAX 845 - 365 - 8179; website: http://www.ldeo.columbia.edu/what/index.html

Meeting details DAY 1

23-May Thursday

9:00	9:15	Welcome/Introductions; Appointment of reporters: C. Ellis-Evans; R. Bell; R. Powell; J-R Petit; C. Kennicutt	J. Priscu
9:15	9:30	Opening Remarks	J. Priscu
9:30	9:45	Overview and discussion of Meeting I report	M. Kennicutt, J. Priscu
9:45	10:40	Update research progress; ~5 min per person	J. Priscu
10:40	11:00	COFFEE	
11:00	12:00	SALEGOS strategy for encouraging national operators to develop subglacial research programs (European involvement?)	C. Ellis-Evans, R. Bell, J-R Petit
12:00	13:30	LUNCH ON CAMPUS	
13:30	15:00	Outline a general operational structure for international agreements required.	J.C. Ellis-Evans, J-R Petit
15:00	15:30	COFFEE	
15:30	16:30	Discuss scientific guidance and input to COMNAP deliberations on logistics and sterile drilling technologies for subglacial lake entry and sample retrieval.	R. Powell, I. Tabacco, J-R Petit
16:30	17:00	ANDRILL update	R. Powell
17:00	17:30	General Discussion; SALE WEB site	Everyone
17:30		Closing remarks, adjourn	J. Priscu
19:30		Dinner to be announced	

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Meeting details Day 2

24-May Friday

9:00	9:15	Updates	J. Priscu
9:15	10:30	Consider and recommend organizational strategies /models (Cape Roberts model, etc.) for managing an international effort.	R. Powell, J-R Petit
10:30	11:00	COFFEE	
11:00	12:00	Agree on a set of recommendations to present to COMNAP in Shanghai. Fate of SALE?	J. C. Ellis Evans, R. Bell
12:00	13:00	LUNCH ON CAMPUS	
13:00	14:00	Discuss themes and agenda items for the next SALE meeting and for the town meeting planned during AGU, Washington, DC (Tuesday, 6:30 PM)	M. Kennicutt, S. Bulat
14:00	14:45	Discuss expert opinions regarding the Russian plan to extend the depth of their 5G borehole by 50m	J. Priscu
14:45	15:00	COFFEE	
15:00	15:45	Discuss plans for deep accretion ice samples returned from Vostok Station during the 2001-2002 field season and outcome of Vostok Ice planning workshop (Washington April 17-18, 2002) on deep accretion ice cutting and sharing	S. Bulat, J-R Petit
15:45	16:15	Finalize plans for a book (select a publisher; decide on editorship and authorship) on subglacial lake research.	J.C. Ellis-Evans, J. Priscu
16:15	17:00	Review SALE membership; General Discussion	Everyone
17:00		Closing remarks, adjourn	J. Priscu
19:30		Dinner to be announced	

Appendix C
Expert Opinions on the Russian Plan to Core an Additional 50 m from the Vostok Deep Borehole 5G

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Dear Bob,

SUBJECT: Russian plan to take an additional 50 meters of accretion ice from borehole 5G

The Russian Antarctic Expedition presented plans at our last SALEGOS meeting to retrieve an additional 50 meters of accretion ice from the deep Vostok borehole during the 2002-2003 season. Details of this plan are outlined in the SALEGOS report from meeting-I (Bologna, Italy 29-30 November 2001). The Group agreed that the scientific justification was adequate to endorse a deepening of the Vostok borehole to provide additional accreted lake ice for coordinated international studies. However, the Group did not feel that appropriate experts were present for a valid technical and environmental judgment to be made. I, as convener, was tasked with obtaining statements from geophysical and glaciological experts concerning environmental issues. I presented five experts (only four responded) with the Russian plan to deepen the Vostok borehole by another 50 meters. The letter sent to each expert follows:

Dear Colleague:

You may know that the Russian program is planning on taking another 50 m of accretion ice from borehole 5G (leaving 80 meters between the bottom of the borehole and the ice/water interface). SCAR has requested that SALEGOS provide recommendations concerning the scientific and environmental issues that surround such a venture. There was a unanimous consensus that more accretion ice, particularly the very clear ice below 3608 m, will have important scientific ramifications. However, the environmental issues remain unresolved. I was tasked by the GOS to obtain the judgment of experts on this issue. In this respect, would you please send me your formal evaluation of the environmental issues that you feel may result from increasing the depth of the 5G borehole. Specific items you should address (but are not limited to) are:

1. What is the probability of drilling fluid permeating the additional 80 m, thus contaminating the lake water?

2. What is the probability that the same mechanical properties of the accretion ice previously collected (the clear ice between 3608 and 3623 m) exist to the lake water interface?

The response from each individual is attached (because several experts requested to remain anonymous I imposed anonymity on all). Based on the advice and comment from these recognized specialists and discussions among the Group of Specialists, we are unable to arrive at a consensus on the risk of contaminating the lake during a deepening of the existing hole. This is primarily due to a lack of adequate information about the properties of the ice to be drilled and an inability to quantitatively predict ice behavior at these great depths and unusual conditions. One expert suggests that based on experience with drilling-induced hydrofracturing that any fracture once initiated would propagate long distances. Grain boundary percolation of contaminants also raises concerns about lake contamination, as the expectation is that increasingly warm temperatures will be encountered as the lake surface is approached. Other experts propose various preventive activities that might reduce the risk of lake contamination. While recognizing that the Russians are world leaders in ice drilling, the general consensus of other experts is that additional assessment would be needed before the risk of lake contamination can be adequately determined. The precautionary approach would seem prudent but we defer to SCAR to determine what the next steps might be. I suggest that the SCAR Executive convene a meeting in Shanghai to discuss these issues in detail and develop clear and tractable guidelines that can be presented to the Russian program.

Sincerely,

John C. Priscu
Professor of Ecology and Convener of SALEGOS

RESPONSE EXPERT #1:

Drilling closer to the lake at Vostok raises some concerns if high confidence in lake isolation is required. Possible contamination paths include: 1) grain-scale infiltration; and 2) hydrofracturing. Quantitative estimates of the probability of either are likely to be difficult to obtain, but both are worth considering.

Hydrofracturing would be generation of a crack or crevasse that penetrated to the lake. Basal crevassing is a well-known phenomenon on ice shelves, and basal crevasses have been observed in grounded ice of the Siple Coast as well. The crevasses are opened by the deviatoric stresses of ice flow, aided by pressure of subglacial water. There certainly are deviatoric stresses in the ice at Vostok, and the ice must be very close to or fully in floating equilibrium hence with high-pressure basal water, so it is likely that any fracture once initiated would propagate for some distance. (Many papers exist on the propagation of water-filled crevasses, and I can supply references if required; recent work by C.J. van der Veen is relevant, and the original papers were by J. Weertman. Work by K. Jezek is also relevant.) Drilling-induced hydrofracturing was observed on ice stream B during hot-water drilling operations conducted by H. Engelhardt and B. Kamb--during penetration, a drop in water level occurred coincident with sudden appearance of a radar reflector emanating from the borehole, followed by loss of the reflector over time, interpreted as hydrofracturing and then freeze-up. The stress concentration associated with drilling, especially if the borehole is overpressurized, is thus of concern.

The other issue is grain-scale percolation. Fluids are known to exist in subfreezing ice, along two-grain boundaries and especially at three-grain junctions, and an interconnected network is inferred. Fluid would exist even in pure ice owing to the thermodynamic effects of surfaces, but impurities greatly increase the possible volume of the fluid. Both premelting and impurity-derived fluid increase in volume as the temperature increases, diverging as the melting point is reached. Thus, drilling to somewhat warmer ice approaching the lake level may greatly increase the mobility of any contaminants moving along the liquid network. A reasonably complete theory of this phenomenon was recently published by A. Rempel et al. in *Nature*, from a team led by John Wettlaufer, and they probably can limit the likely velocity of contaminants in such a system.

RESPONSE EXPERT #2:

1. What is the probability of drilling fluid permeating the additional 80 m, thus contaminating the lake water?

To leading order, the way to look at this is the same as how we convinced ourselves that advection of intercrystalline water was slow relative to diffusion in the Greenland ice core (Rempel et al., Nature, vol 411, 568, 2001). We "homogenized", or made an "effective theory" for the ice sheet and then provided a very generous upper bound on the flow of interstitial (i.e., potentially contaminating in your case) water. We calculated the ice flow speed V via Dansgaard-Johnsen. The fluid moves at a speed U relative to the ice matrix. The non-hydrostatic component of the pressure gradient is GradP in a coordinate frame moving with the ice, and we calculate the (isotropic) scalar permeability k using details of geometry and crystal size and hence can write

U = -(k GradP)/mu, where mu is the water viscosity.

We take mu(T= - 10 deg C) = 0.0026 Pa s and with vein radii of a micron and mm size crystals we find k = 0.01. Now, the generous upper bound comes from actually saying that GradP is of order the hydrostatic value 10^4 Pa/m and we find U = microns/yr. Again, these are Greenland conditions at GRIP.

Now, you can look in that Nature paper (attached) and find a simple formula for the anomalous diffusive velocity which you can relate to your drilling site to see how much diffusion will occur over that remaining depth.

In any case, there is natural diffusion down through that ice of soluble impurities that have nothing to do with drilling, so the lake is being "naturally contaminated" by an unavoidable process.

2. What is the probability that the mechanical properties of the accretion ice collected 3608 and 3623 m (the clear ice) are present to the lake water interface?

That's a tough one because I don't know e.g., what the gradient in crystal size is and I don't know the salinity of the lake. In any reasonably brackish water there is an unavoidable growth instability that makes the accreted ice a two phase two component material, with orthotropic fabric and hence mechanical properties. Calculating that requires a lot of information about growth history. A theory was given in a paper written about 10 yrs ago ("Directional Solidification of Salt Water: Deep and Shallow Cells", Europhys. Lett., 19, 337, 1992), and more recently on buoyancy driven convection of the interstitial liquid ("The phase evolution of young sea ice", Geophys. Res. Lett. 24, 1251, 1997).

RESPONSE EXPERT #3:

Rationale

The project is to obtain an additional 50m of ice by drilling at Vostok below 3623 . The remaining ice thickness to the lake water will be about 75 m. At the bottom of the hole, (~3675 m) the ice temperature will be about 1.5°C below the melting point.

It was suggested the 220 m of accreted ice at Vostok forms an ice massif blocked against the Eastern edge of the lake, and overridden by the moving glacier. At the interface (around 3540 m depth) a shear layer is likely active.

The risk that the drilling fluid (kerosene and HCFC –freon substitute- mixture) can contaminate the lake water exists :
-if we assume the filled bore hole could be crushed against the edge and damage the integrity of the hole,
-if we assume the ice is permeable to drilling fluid.

As Vostok is situated a relatively short distance (2-4 km?) from the lake edge, and the glacier move by 3 m/a, it is expected the integrity of bore hole could be maintained for several years. Over a longer period (century or more) this risk may be real and should be evaluated.

The presence of ice veins with liquid may exist at the grain boundaries in regions where impurities are concentrated. Theses veins could exist at temperature below the melting point.

While comparison with other ice types is usually done, accreted from Vostok lake is significantly different from sea ice, lake ice, temperate glacier ice: no gas, low conductivity, very low impurity content (the ice is clear below 3609 m), and crystals are very large.

Results obtained from X-ray diffraction experiments carried out on large single crystals from accreted ice indicate a very low lattice distortion. *Abnormal grain growth* seems at the origin of the quality and size of these ice crystals. To grow such large crystals, the grain boundary energy must be low. If this is true, it implies that the impurities are not concentrated at the grain boundary but are embedded in the ice lattice. Therefore, the very large size of crystals and the high quality of grain boundaries could be an obstacle for continuous movement of liquid along triple junctions. However, the permeability of accreted ice could be higher for very deep ice soon after the formation of accreted ice when crystal size is relatively small.

Suggestions to prevent lake contamination follow:

1. A geophysical survey (by precise inclinometry and hole diameter measurements) of the borehole should be done in order to detect and evaluate the rate of deformation of the hole.

2. Stringent control of the pressure of the drill fluid at the bottom of the hole should be made to prevent excessive over-pressure that may facilitate the fluid to escape from the borehole (over-pressure may facilitate fluid penetration into the ice or even produce a so-call “hydrolic fracture”).

3. A backup system to remove the drill fluid from the borehole should be available in an emergency. Lowering the fluid level by several hundred of meters will allow rapid closure (in a few weeks) of the ice at the bottom of the borehole.

4. Continuous measurement of the crystal size from an ice slice (according to the axis of the core) should me made as cores are extracted. If layers are detected with small crystals (~ centimeter in size) drilling should stop.

RESPONSE EXPERT #4:

I have read the material that you gave me, and I have some thoughts on it. Basically, I feel that the Russians are rushing into this whole thing a little too quickly, unless I am missing or overlooking something. In the "expert conclusion" paper (the paper where they plan to drill to lake water and then re-core the ice) I had the sense that the original proposal lacked some quantitative analysis that should have been addressed before the proposal was submitted. For instance, they talk about measuring the pressure difference at the drill head once the have penetrated to the lake. They need to know this before the drill head reaches the lake surface. This pressure difference could be calculated ahead of time with a high degree of accuracy. Assuming they know the compressibility of the drill fluid and ice, this can readily be done. I don't understand the problem they are having with this - it is a simple calculation. However, they should know the pressure difference before they penetrate to the lake surface, since a large difference could produce failure of the ice around the hole at the bottom where they plan to seal the lake water from the hole above the drill head at first penetration.

Another issue they did not address is the time required for the lake water, once it has risen up in the hole, to freeze. This could take a LONG TIME, since freezing requires conduction of heat from the hole, and the temperature gradients will be extremely small (on the order of 0.01C/m vertically and 0.1 C/m radially). In one sense, this is good, since it gives them time to extract the drill head from the hole, but this long period also creates a problem discussed below. The freezing rate could be estimated so that they would have an idea of how long to wait before drilling again.

They do not seem to have tried to estimate the amount of contamination that will occur in the lake water before it freezes after it has moved into the drill hole. They indicated that after the lake water freezes in the drill hole, they will drill again to extract this ice for analysis. However, it will be contaminated by the drill fluid that was there during the original drilling. His drill fluid will have diffused into the ice round the hole, and once the lake water is in the hole, the fluid will diffuse back toward the hole and eventually mix with the lake water. So the question is: is this ice from the lake water any good for analysis? The drill fluid will contain organic materials and probably micro organisms that may make this ice less useful for analyzing the life forms that may exist in the lake, let alone the chemistry of the lake water. I am not a biologist, so maybe I am out in left field on this. At any rate, they should b e able to estimate the amount of contamination from the drill fluid that is left on the hole wall and in the ice directly adjacent to the hole. To do this they should first determine the rate at which the water will freeze and then calculate the rate of diffusion into the hole. This can be done.

The process they propose for drilling to the lake surface appears to be risky to me. As far as I'm concerned, a very rigorous analysis and some testing needs to be done before they are given the go ahead on that part of the project. Drilling another 50 m appears OK to me, though.

Overall, I think they were somewhat conservative in estimating the rate at which the drill fluid will penetrate the ice. At the depths they are talking about, the ice is large grained, under heavy pressure, not severely deformed and virtually bubble free. This is much different than sea ice and lake ice that they used as a benchmark. In this regard I think they are on the safe side.

Below is my paragraph about their request to drill another 50 m. It does not contain much of my remarks above.

COMMENTS SPECIFIC TO THE RUSSIAN PROPOSAL TO DRILL AN ADDITIONAL 50m:

The request to drill another 50 meters to retrieve additional lake ice appears to me to be a fairly safe undertaking. First, I feel that they have probably overestimated the diffusion rate of the drill fluid into the ice. Using sea ice and lake ice as a comparison to the ice just above Lake Vostok is probably not realistic. The ice above Lake Vostok is not severely deformed, very dense, has little bubble and impurity content, and is under a high state of hydrostatic pressure. In addition the large grain volume/grain boundary surface ratio also will impede diffusion. Consequently I feel that the contamination rate due to this process will be quite low. In addition, I agree that water inclusions at this level are not a significant possibility for the reasons discussed in the proposal analysis.

Beyond that, I am of the opinion that the proposed drilling to the lake surface should be approached with great care. Even though the Russians are world leaders in ice drilling technology, the proposed project impresses me as risky, since there are issues that need to be resolved before this project commences. The final pages of the “Expert conclusion” have raised many of the same concerns that I had and made some recommendations that should be followed.