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Subglacial Lakes of Antarctica

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(1) Water has slowly gathered into low-lying areas beneath the vast East Antarctic ice sheet over the ages. These accumulations (Figure 1) range in size from shallow, icy swamps (Price *et al*, 2002), to bodies of water just slightly smaller than the major African rift valley lakes (Kapitsa *et al*, 1996). The temperatures and pressures in these environments are similar to those in the world's deepest oceans (~–4°C). (Cowen *et al*, 2003).

(2) Sub-glacial environments are unique laboratories found nowhere else on Earth. They are analogous to times in the Earth's evolution when it is believed that the planet was encased in ice (the Precambrian "Snowball Earth"). Many believe these deep freezing conditions presented a major threat to the continuation of life on Earth, (Hoffman *et al*, 1998). Similar environments that may support life beyond our planet are known on other ice-covered worlds in our solar system eg Europa, Mars (Chyba and Phillips, 2001; Franck *et al*, 2000; Gaidos *et al*, 1999; Kargil *et al*, 2000; Jakoysky *et al*, 1998).

(3) Sub-glacial environments are ecological experiments that have been taking place for more than 35 million years. At that time Antarctica was first becoming encased in ice. Beneath the ice sheets, energy from the sun is not available to support life. The energy for life in these dark places is provided by the slow flow of the overlying ice and heat emerging from deep in the Earth's interior. For millions of years, these environments have been isolated from weather, the seasons, and climate change. These unique histories provide an unparalleled opportunity to advance our understanding of how life, the environment, and the evolution of our planet have combined to produce the world as we know it today.

(4) The most extensively studied location is Subglacial Lake Vostok, the largest, oldest and most stable sub-glacial lake yet discovered on Earth. Lake Vostok is located under the vast East Antarctic Ice Sheet directly beneath the Russian Antarctic Station, Vostok. It has been speculated that the lake has been isolated from with the atmosphere for 35 million years. As the ice sheet flows over Lake Vostok, material and water are introduced and removed from the lake. It is now estimated that the entire contents of the lake are re-placed every ~50,000 years (Jouzel *et al*, 1999; Bell *et al*, 2002, Studinger *et al*, 2004). It is also believed that the water in the lake circulates much as water in lakes at the Earth's surface (Wuest and Carmack, 2000). To understand the evolution of the lake, it will be important to study the ice melting and freezing cycle, the geological setting, the flux of heat from below and the dynamics of the ice sheet flowing above.

(5) Small bubbles of air are captured in the Antarctic ice sheet as snow slowly turns into ice. Subsequently these time capsules are preserved inside cages of water molecules known as gas hydrate (Hondoh, 1996; Uchida *et al*, 1994). The trapped gases molecules are released into subglacial lakes as the overlying ice sheet melts. Once the lake water can no longer dissolve any more gas, gas hydrate itself will begin to accumulate within the lake (Lipenkov and Istomin, 2001; McKay *et al*, 2003). The gas hydrates form interesting habitats for microbial organisms and will be an important consideration in plans to enter and sample the lake and its sediments.

(6) The fundamental biochemical molecules and reactions that define life as we know it, can only survive within a specified range of temperature, pressure, nutrient supplies, and energy sources. The temperature limits on life are now believed to be between –13°C to

+121°C. Pressure by itself does not appear to preclude life at least within the pressures encountered on Earth. Some bacteria, such as in the deep ocean, actually require elevated pressures to exist and cannot grow when brought to surface conditions (Yayanos, 1995). The limits of life controlled by water activity, nutrient or energy limitations, ionizing radiation, and as unusual forms of elements such as gas hydrate are unknown. However, there is a minimum requirement for energy, regardless of its form or source, for the chemistry and processes of life to occur. Subglacial environments are grand experiments that are responding to isolation from the sun that will provide insight into the evolution of life.

(7) The fundamental geophysical dynamics of planet Earth produce the enclosed basins and topographic lows where water can gather. Lake Vostok rests along a major tectonic boundary (Studinger *et al*, 2003). The history of earthquakes in the region indicates that the deep subsurface beneath Lake Vostok has been recently active. Active faulting, deep mantle advective flow and development of hot springs are expected. Sediments at the bottom of subglacial lakes will most likely record the formation and onset of Antarctic glaciation and the evolution of the chemical environment within the lakes since isolation from the atmosphere.

(8) A wide range of nations is actively studying subglacial environments. Areas of scientific interest include the chemistry and biology of frozen lake water recovered from the base of the Vostok ice core (Russian, France, US), geophysical surveys of the ice sheet and the surrounding environments (US, Italy, Britain, Germany) and models of various components of these complex systems (Canada, Switzerland, Denmark, Germany).

(9) In 1999, SCAR sponsored a seminal workshop in Cambridge, England and subsequently an international Group of Specialists (Subglacial Antarctic Lake Exploration Group of Specialists – SALEGOS) was established by SCAR in 2000 in Tokyo (see Table 1 for membership). SALEGOS was tasked to refine, expand and advance the 1999 workshop's scientific objectives; develop the critical requirements/criteria for lake(s) selection; provide scientific guidance and input to COMNAP deliberations on logistics and drilling technologies for subglacial lake entry and sample retrieval; develop a set of objectives for technology developments related to the science objectives as opposed to only entry and retrieval; consider and recommend organizational strategies/models for managing an international exploration program; delineate information gaps and the sequence or timing that is needed to progress toward the ultimate goal of lake entry and sample retrieval; *c*onsider the environmental ramifications and how the Environmental Impact Assessment (EIA) process needs to be applied for support of subglacial lake exploration and the role of other SCAR and Treaty bodies; and recommend a series of SCAR activities to facilitate and promote the exploration of subglacial lakes (Priscu *et al*, 2004). The SALEGOS has now addressed its terms of reference and is progressing Subglacial Lake Exploration to a SCAR Scientific Research Program.

(10) International scientific and public interest in what might lie under the vast Antarctic ice sheet in these previously unknown dark and remote environments, has been and remains high. As summarized above, the initial phases of exploration have already begun and international planning continues. The promise of new and exciting exploration and research in Antarctic subglacial lake environments addressing some of the most basic questions, such as the evolution of our planet, the controls on climate, and the limits to

life, will only be realized once we have fully explored these sites. Many nations have begun individual and bilateral studies of these inaccessible environments, analyzing samples from the Vostok ice core and remote studies from the ice surface. Working jointly SCAR and CONMAP are the leading international bodies capable of providing leadership in this important scientific frontier. International cooperation, partnerships, shared logistical costs, and major technological developments will be needed to ensure not only an optimal scientific return on our investment but also to ensure that these environments are explored and sampled in ways that preserve them for future generations.

Figure 1. Location of Sub-glacial Lakes in Antarctica. Lake Vostok indicated in black, other lakes in blue. Siegert et al (1999). Red Stars indicate seismic events close to Vostok Station.

Figure 2. Schematic Cross Section of *In-Situ* Observatory for Lake Vostok

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