Science and Technology of Deep Subglacial Explorations on Earth, Mars, and Europa

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Introduction. The deep subglacial domains of Earth, Mars and Europa are of increasing interest from a wide range of perspectives spanning ice sheet physical processes to astrobiology. Exploring these domains is challenging in an equally wide range of ways including simple access, scientific instrumentation, logistics and navigation, and communications, which we will address in varying depth.

Earth ice sheets. On Earth, the basal properties and processes of ice sheets and glaciers have long been interesting on the bases of the role of terrestrial ice in the climate system and the record of past climates contained in the ice. At present the ice sheets of Greenland and Antarctica are changing at rates considered impossible a few years ago, and these changes are stimulating a wave of research into physical processes at work in the basal and lateral boundaries. At the same time, recent discoveries of bed bioweathering in temperate glaciers has been of interest in both geomorphology and extremophile biology. We have built and deployed the Ice Borehole Camera system into the basal layers of Ice Stream C in West Antarctica and have demonstrated the general utility of image data; the information collected suggests a specific process of basal freezing as well as discovering a surprising subglacial water-filled cavity.

Mars polar caps. On Mars the polar caps are scientifically important, although the present-day Mars exploration program plan does not reflect this situation. The polar caps are interesting because: This is where we know there is water; the caps contain the best recent climate history data sets obtainable; the basal ice is sufficiently warm to contain appreciable amounts of interstitial liquid water which is in contact with possibly soluble mineralogic material; the basal domain and bed are protected from atmospheric and cosmic-ray effects, and, finally, the bed is arguably the seafloor of an ancient Mars ocean where life may have flourished. Recent remote sensing data has provided additional detail to the picture of the polar caps, but has left many unknowns, including their mineralogic composition, age and mass balance. An approach to polar cap subsurface exploration is the use of a Cryobot, or thermal probe, for access. We have been involved in the development of a Cryobot, and we will describe the objectives and status of our Cryobot development work.

Europa. On Europa, a device functionally similar to the Cryobot will be required for exploration in the deep subsurface, including access to the subglacial ocean, but miniaturization, instrumentation, sterilization, energy source, chemical vulnerability, autonomy, communications, etc will be significantly different. In the context of Europa subsurface exploration, we are today simply learning some basic skills and discovering some realities for doing work in subglacial environments, and in our Earth work and Mars preparations we may learn how to ask certain scientific questions concerning the subglacial as a habitat.

Water Ice. The theme common to these explorations of Earth, Mars, and Europa is subsurface water ice, possibly as ice-rich deposits, as a site for scientific investigations. Of significance are: The presence and interpretation of interstitial inclusions (mineralogic, gas or gas hydrate, and liquid water), the stratified-accretionary nature of most large ice masses, and the role of ice and water in climate. Ice as a habitat is a central question for planetary exploration, and may be of significance in terrestrial ice. The capability, for example, of sea ice microbes to alter the freezing point of their immediate brine inclusion surroundings, if realized in deeper layers of the Europa ice shell, would result in more liquid water than local temperature would suggest even for salty ice. This increased liquid water could significantly alter physical properties such as the mechanical strength of the ice as well as providing habitat.

Science. The science motivations for the deep subglacial are astrobiological, geochemical, glaciological, and climatological. Of course astrobiology itself includes these other study areas in its periphery as the nature and history of the habitat are crucial pieces of information in understanding current status.

Measurements in Ice. In the course of understanding ice in its roles as planetary feature, habitat and record keeper, the ice itself is of little interest beyond the interpretation of the grainsize and orientation. The measurement emphasis is on the inclusions in the ice, generally found on grain boundaries. Measurements of interest are geochemical compounds and redox potential, biochemical compounds, analysis of mineralogic and gas inclusions, stratification, crystal grain size and orientation, and temperature. We are in planning for adapting instruments for Cryobot deployment for scientific examination of the subglacial environment, e.g. cameras, Raman spectrometers, UV spectrofluorometers, and miniature chemical analyzers.

Technology. We are engaged in the development of a Cryobot, a robotic device for descent in ice sheets; our immediate goals are for in-situ scientific access to terrestrial ice and subglacial lakes, and the longer-term goals are the Mars polar caps and the Europa ocean. We will describe our perceptions as to the long-term goals of glacial in-situ technology, and we will provide data recently acquired in West Antarctica by the Ice Borehole Camera, a testbed for the science bay of the Cryobot. Other technology developments are required from other teams, e.g. instrumentation, sediment coring methods, strategies for acquiring ice samples, etc; we are not doing it all, and we have no plans to attempt to do it all.

NASA Program. This collection of science objectives and technology development projects, when taken with the activities and interests in other elements of Earth and planetary explorations, speak to a multiyear sequence of integrated and coordinated science and technology elements with the exploration of the Europa ocean as the ultimate objective. These elements would include Earth science projects from both extremophile biology and climatology, comet studies, Mars polar cap surface surveys and subsurface explorations, and, finally, Europa in-situ missions. Each phase would accomplish science in its site as well as technology development and test for the following phase. A crucial issue is how this might be funded, and the answer is that it will require going to congress with a request for a budget augment. To accomplish this aggressive program in the current budget level would mean gutting the planetary program as it is now defined, and that procedure would cancel very exciting flight programs that have been carefully thought out and are well considered by the planetary science community. Can we get new funds in a deteriorating economy? No one can predict the mood of congress or the executive, but it is clear that the discovery of the Europa ocean has reached out decisively to both the public and the scientific communities, and it is equally clear that the exploration of the Europa ocean is on a very long term back burner at the current rate of investment.

In Summary. We have entered a branch of exploration that has never been seriously examined in the past: oceans, ice and life on other planets. There is some urgency in the task of putting forward the science and technology of this exploration. We have addressed a small part of this exciting program, and we plan to be part of the approach, in collaboration with other US and foreign institutions.