Searching For Ice And Ocean Biogenic Activity On Europa And Earth

Joan Horvath’, Frank Carsey ’, James Cutts[a], Jack Jones’, Elizabeth Johnson*,
Bridget Landry *, Lonne Lane* , Gindi Lynch’,
Ken Jezek[b] , Julian Chela-Flores[c] , Tzyy-Wen Jeng[d] and Albert Bradley[e]

*Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Drive, Pasadena CA 91109
[b]Byrd Polar Research Center, Ohio State University, 1090 Carmack Rd, Columbus OH 43210
‘International Centre for Theoretical Physics, Office 275, P.O.Box 586,
Strada Costiera 11,34136 Trieste, Italy.
‘Abbott Diagnostics Division, Abbott Laboratories, Abbott Park, IL 60064
‘Woods Hole Oceanographic Institution, Woods Hole, MA 02543

ABSTRACT

One of the more likely places in the solar system for the existence of extraterrestrial life forms is the Jovian moon Europa. It has been postulated that a volcanically-heated ocean is likely to exist underneath Europa’s icy surface. If a detailed remote-sensing reconnaissance of Europa determines that an ocean does exist under the ice, then in-situ measurements will be needed to directly explore the Europan ocean and the ice that lies above it. In order to make quantitative measurements of the Europan environment, a lander spacecraft capable of penetrating the surface ice layer by melting through it is proposed. This vehicle, dubbed a “Cryobot”, will be designed to carry a small deployable submersible (a "Hydrobot") equipped with a complement of instruments. The design of an instrument package to search for life across the wide range of thermal and pressure environments expected on Europa, the issues in sample handling, and long-term reliability for a potential multi-year transit through the ice all present difficult design issues. Opportunities for performing investigations of deep, submerged Antarctic lakes on Earth are described which would test the Cryobot/Hydrobot system while collecting intrinsically valuable terrestrial science data.

Keywords: Europa, exobiology, instrumentation, submersibles, ice probes

1. BACKGROUND

Observations of the icy Jovian moon Europa by the Galileo spacecraft were acquired at the same time that the scientific and public excitement over the meteoric findings suggesting life on Mars peaked. These events have served to stimulate conceptual planning for a mission to Europa to search for signs of life in the water presumed to underlie its thick surface ice. Since substantial ice covers are also found on Earth, and there is a long history of research into these ice sheets, ice caps, floes, and glaciers, it is useful to examine the scientific and technical benefits in a joint study program for both planets. The planetary exploration program and terrestrial glaciology and oceanography

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● Further author information -
JCH (correspondence): Email: joan.c.horvath@jpl.nasa.gov Telephone: 818-354-7431 Fax 818-393-1366
FDC: Email: fdc@pacific.jpl.nasa.gov Telephone: 818-354-8163 Fax: 818-393-6720
JC: Email: james.a.cutts@jpl.nasa.gov Telephone: 818-354-4120 Fax: 818-354-8333
JJ: Email: jack.jones@jpl.nasa.gov Telephone: 818-354-4717
LJ: Email: liz@puddy.jpl.nasa.gov Telephone: 818-354-0926
BML: Email: bridget.m.landry@jpl.nasa.gov Telephone 818-393-7884
LL: Email: arthur.l.lane@jpl.nasa.gov Telephone 818-354-6186
GL: Email: gindi.lynch@jpl.nasa.gov
JCF: Email: chelaf@ictp.trieste.it Telephone: (int.+39 40) 2240392 Fax: (int + 39.40) 224163
TJ: Email: jengtx.add@notes.abbott.com Telephone: 847-937-8880 Fax: 847-938-7072
AB: Email: abradley@ whoi.edu Telephone 508-289-2448

programs have numerous objectives and requirements in common. Here, we examine scientific objectives and observational technologies likely to be of interest to terrestrial and planetary science over the next decade and outline an integrated development program for those technologies, where appropriate.

2. TERRESTRIAL ICE SCIENCE

Studies of ice sheets and caps are generally devoted to reconstruction of past climates or to understanding the current state of the ice cover, i .e., mass balance and stability, from the perspective of possible catastrophic changes in sea level. The climate studies focus on the chemical composition and dust character in the annual layers laid down by snow deposition. These analyses can go back for over 250,000 years in the case of the East Antarctic ice sheet, which is over 4 km thick in its central regions. Studies of contemporary processes concentrate on obtaining observations at depth of ice temperature, velocity, and rheology. In general there remains strong interest in measuring ice sheet chemical and physical properties over space and time.

New information about the extent and depth of the large (nearly the size of Lake Ontario) subglacial lake discovered near Vostok Station, East Antarctica, is sparking renewed interest in, that site and others. The lake is covered by approximately 4-km thick ice, The lake water chemistry and lacustrine sediments may contain a record of early ice sheet development, since the lake may have been isolated for significant geological time. There is also speculation that the lake may provide a suitable habitat for simple life-forms and that it may be volcanically heated. If so, it might provide an excellent simulator for Europa's oceans.

3. PLANETARY ICE STUDIES

Jupiter and Saturn each possess satellites covered with ice. Jupiter's moon Europa is particularly intriguing because of its position in the Jovian system. Europa is strongly tidally flexed due to the influence of Jupiter as well as other nearby satellites, This flexing is thought to be the mechanism leading to volcanism on Io, a nearby Jovian satellite, and it is speculated that Europa has volcanic activity beneath its ice as well. Europa's cracked icy surface (Figure 1) is therefore thought to cover an ocean of volcanically-heated liquid water.

A primary goal of an early mission will be to determine whether Europa's ice does in fact cover a liquid ocean, and, if so, the depth below the surface of this ice-water interface, Current estimates of the ice thickness range from 1 to 100 km. Surface conditions on Europa are estimated to be a temperature of approximately 100 K and a pressure of 10^{-11} bar, Acceleration due to gravity on Europa is 1.7 m/s^2. The conditions at the ice-water interface would depend upon the actual ice thickness; if the ice is 100 km thick pressures would be approximately 2 kbar and temperature would be 270 K. Under these conditions the entire ice sheet is most likely composed of Ice 1, the most common form of water ice on Earth under normal conditions.

The smallest of the four large Galilean satellites of Jupiter, Europa has a mean density of 3040 kg/m^3, a value intermediate between those for icy satellites, such as Ganymede or Callisto, and the rocky satellites, such as Io or the Moon. Schubert et al.[1] proposed that if Europa were composed of a simple mixture of water ice and rocky material similar to that of Io or the Moon, then it would have a bulk water content of at least 5% by mass. Further, if all the water ice were concentrated in a single surface layer its depth would exceed 100 km. Observations of Europa made by the Voyager 1 and 2 spacecraft revealed that the surface is predominantly composed of water ice, with considerably fewer impurities than are present on Ganymede or Callisto.

Of particular interest to the scientific community is the possible existence of extraterrestrial biological activity due to presence of liquid water under the icy surface. Several scientists[2,3] have calculated that based on radioactive heat sources and heat transported by conduction, Europa could have a water mantle a total of 100 km thick comprised in part of a liquid water layer 50 km deep. However, other authors have opposed this idea because their calculations show that such a water layer would freeze in a very short time compared to the age of the satellite[4]. Peale et al? and Cassen et al.[6] calculated the rate of tidal heating in an ice shell above a liquid water layer on Europa, They suggested that the heating rate was large enough to prevent the ice from thickening and a liquid layer could therefore be maintained under the ice crust,

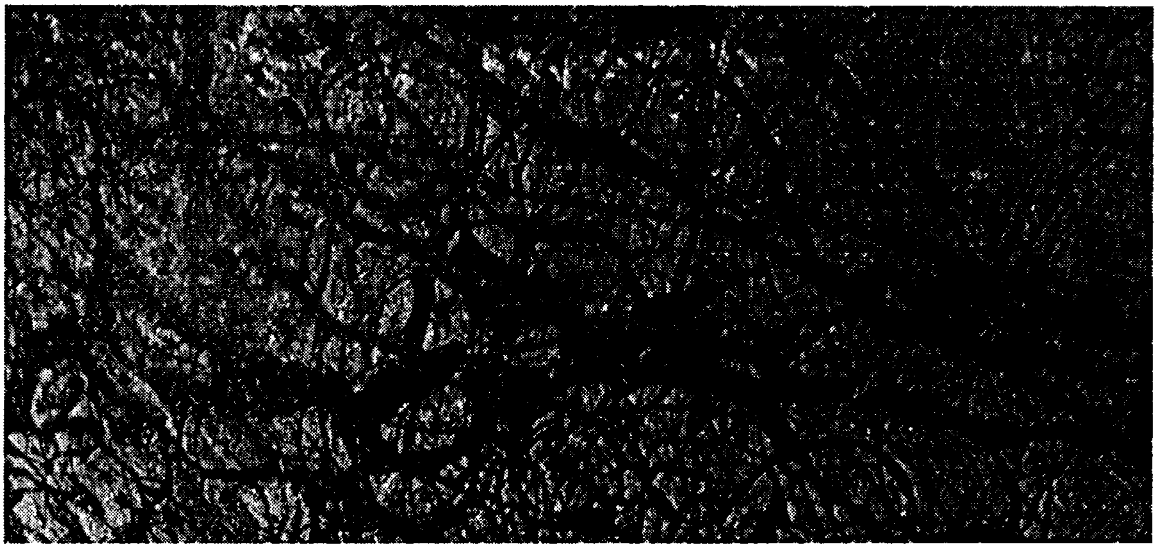

Figure 1. Visible image of Europan equatorial zone taken 27 June 1996. Image size 'approximately 360 x 770 km, 1.6 km resolution.

To date, these results prove inconclusive because the calculated structure depends largely on coarse-resolution data. Observations of the surface indicate that the surface is relatively young compared to that of Ganymede and Callisto, as evidenced by the low number of impact craters. This evidence supports the water layer models[7,8] as does theoretical work by Stevenson 9 Images taken recently using instruments on board the Galileo spacecraft show the surface to be severely fractured with large areas of the icy surface separating from the nearby material. It is thought that the dark bands and ridges are a mixture of slushy ice and rocky debris[10]. The arrangement of individual plates, some of which appear to have rotated in position, suggest the existence of some lubricating layer beneath the surface at least at the time at which fracturing occurred. It is not yet known whether this layer is, or was, composed of a liquid or softer slush.

4. PLANETARY LIFE SCIENCE

Any study of Europa or other icy body will have as a prominent scientific objective the search for life. This search is motivated by analogy with anaerobic life found in abundance in undersea volcanic vents on Earth, or, in fact, virtually anywhere liquid water is found[11]. If Europa does indeed have a liquid water ocean beneath the outer ice crust as a result of interior volcanic heating, then it is possible that hydrothermal vents located on the seafloor may provide the necessary conditions for simple ecosystems to exist. Such vents rue found in terrestrial oceans and support many species of marine life, some of which are uniquely found at hydrothermal vent sites. Generally a vent community will extend tens of meters from the vent, Most vents have a finite lifetime of the order of ten to twenty years before becoming inactive, at which time the local biological activity ceases, When a new vent forms, simple bacteria present in the water become the basis for a new vent food chain which can extend to tubular worms, mollusks and crabs. The water ejected from hydrothermal vents is typically rich in sulfur and other minerals. These bacteria extract all nutrients directly from sulfur via chemosynthesis, making sunlight and oxygen unnecessary.

In order to determine if these conditions (or others that might support life) are repeated beneath the Europan surface, it will be necessary to embark on an extensive survey of the satellite using a variety of scientific tools. It seems unlikely that remote sensing techniques alone will be sufficient to determine with any certainty the existence of a subglacial ocean, unless current theories regarding the ice thickness are incorrect. Thus, some combination of orbiter mission and lander missions are needed to satisfy the demands of a complete Europa study.

5. OBJECTIVES FOR AN EUROPA-EARTH ICE PROGRAM

We indicate here the objectives for the joint program, keeping in mind that some objectives do not apply in both environments.

5.1. Europa

Major scientific questions to be answered about Europa are: Does Europa have an ocean? If so, what is Europa's physical oceanography? Does the ocean have currents? What is the chemistry of the ocean/ice and the mineralogy of the core? Is this ocean composed of liquid water, or some part brash ice or slush? Was them' ever open water? What geological processes have been at work on Europa, and how active are these forces? How often is the ice surface resurfaced, and what is the mechanism (impact cratering, cryovolcanic resurfacing, or others?) Are biological processes at work, or were there some at work in the past? If so, which ones, and how do they affect observable quantities? What might some habitats be, and what would be the best ways to detect these organisms?

5.2. Earth

Several major scientific questions that can be addressed in an integrated Earth-Europa program are: How do the profiles of specific anions, cations, and dust over regions of Greenland and Antarctic ice sheets(as well as certain ice caps of South America and Asia) vary within depositional basins? What is the structure of horizontal profiles of temperature in the active layer for continuous and intermittent permafrost areas of North America, Europe and Siberia? What are the temporal and spatial changes in oceanic vent chemistry, thermal character and biological communities? What evidence is therein subice hike bottom sediments regarding the existence of subglacial lake life-forrns?

6. THE EUROPA-EARTH PROGRAM

At the outset, there needs to be an emphasis on an inexpensive mission to characterize the interior of Europa. Significant data can be obtained with an orbiting spacecraft with only a radio transmitter, needed in any case for communications. Very detailed analyses of the interior of a planet can be obtained with an orbiting spacecraft derived parameters would include the moments of inertia and the coefficients of various harmonic expansions, which in turn are related to the interior structure.

In the case of an object that is tidally stressed, measurements of oblateness at minimum and maximum tide yield significant information on interior structure. An array of seismometers on the surface would tell definitively whether there is water through analysis of P and S wave transmission. Significant further evidence could be obtained by an imaging spectrometer, which could derive ice compositions since the behavior of the ocean and ice would depend on the existence of CO_2 and/or hydrated ammonia. Another potentially powerful instrument is a radar mapper to make more detailed analyses of ice thickness distribution.

An ideal approach to the examination of Europa, including the presence of life, would consist of staged deployments, each of which is crucial to the success of the following phase. Clearly the shortest route to obtaining information on the composition of the Europan "ocean" is to sample the surface material which is thought to have originated at depth and become distributed on the surface by eruption-like processes. To accomplish its goals the orbiter would deploy remote sensing instruments and drop penetrating probes, and the in situ vehicles would all carry a progressively more complex in situ chemical laboratory (ISiCL), discussed in detail below.

In the following sections, the key in situ observational tools of the Europa-Earth Program are described in a preliminary fashion.

- The In Situ Chemical Laboratory (ISiCL) will perform chemical analyses of melt and ocean water, including assays for biotic molecules.

- Instrumented "Impact Penetrators", akin to those being constructed now for deployment on Mars, are dropped from orbit to penetrate the upper layers of ice and perform chemical and physical analyses.

- The **Cryobot** probe, which melts its way through the Europan ice cover, acquires chemical information en route with the **ISiCL,** and transports the Hydrobot to the Europan Ocean. (Figure 2.)

- The Hydrobot (also shown in Figure 2), is a self-propelled underwater vehicle for exploration and analysis of the Europan ocean.

Concepts for a variety of sample return missions have been proposed. One proposed mission could be flown early on to collect surface samples that had been thrown up into orbit by a large **impactor.** The sample collector would pick up dust thrown out many kilometers by the **impactor** and return it to Earth. The samples could then be examined on Earth for evidence of biological activity. Others would be launched later or perhaps flown in concert with one of the following in situ analysis missions," The following sections describe a set of potential missions. These missions have not been integrated into existing roadmaps, but are an indication of how Europan missions might be flown based purely on integration with Antarctic tests.

6.1. First mission: orbiter deploying impact penetrators. (Launch: 2001+)

The major objectives of the orbiter, from the perspective of this program, are to generate a good estimate of ice thickness, to determine the surface relief, and to obtain information on the chemical constituents of the surface, especially in **regards** to understanding the composition of the darker areas. Some of this reconnaissance will be performed by the Galileo orbiter in 1997-8.

The instruments required for these analyses include an altimeter and an imaging spectrometer. The mission duration should be long enough to include a tidal excitation event so that short-term deformation of the surface ice can be observed if measurable at the limits of spectrometer resolution. Finally, the orbiter may need to carry surface **penetrators,** similar to those planned for Mars, to examine the structure of the Europan surface material and possibly to be part of a seismic network to fine-tune the ice thickness estimates. These **penetrators** will not be discussed further in this paper, but maybe a good precursor of the cryobot.

6.2. Next mission: shallow Cryobot melter probe. (Launch: 2005+)

The key requirement of the Europan campaign is accomplished by descending through the Europan ice and into the ocean below to search for signs of life. However, there are sufficient engineering challenges in this that a **pathfinding** mission is needed. This mission would land a **penetrator** whose objective is a shallow, 10-500 m melt into the surface, with descent limited by a cable or by a short-lived heat source, The probe should penetrate deeply enough to get below the "gardening layer" on Europa's highly-irradiated surface and obtain data uncontaminated by external effects. The shallow probe would be equipped with the **ISiCL.** Measurements would include a surface density profile and size distribution for the topmost layers, and tests for remaining trace **organics** right at the surface. **Organics** that imply a metabolic pathway are of particular interest, i.e., ethanol, **butanol,** and acetate. The lander also should image the surface to determine its smoothness and hardness, and might carry a hydrophore or seismometer to determine ice motion.

Finally, the lander should deploy a radar or equivalent system to determine accurately (within 10%) the ice thickness distribution over its geographical range. The development of **Cryobot** probe technology for use in the Europan **and** Earth deployments is a key part of this program and will be discussed in more detail below.

6.3. The Cryobot/Hydrobot mission (Launch: 2010+)

The deep-penetrating **Cryobot** with its Hydrobot is the ultimate deployment of the Europan program. By the time of its deployment the ice thickness will be known, the density and strength of the upper layers will be established, the technology of the melting probe will be proven on Earth as well as on Europa, and the **ISiCL** will be fully developed and tested in both environments. The submersible will be designed to answer the question: "How similar is this ocean to those on Earth, and has life evolved along a pathway analogous to the one we know at present on **Earth?"**

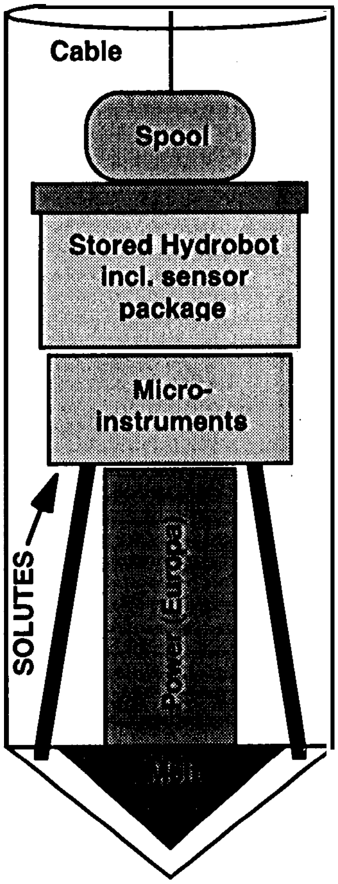

Figure 2. Cryobot/Hydrobot schematic.

6.4. The Earth program

The Earth program is planned to take advantage of technology development for the Europa project, but is not strictly constrained by those developments. In particular, it will require at least some modification of the Europa devices for Earth use. In general, the Europa developments that will find application on Earth are probes similar to the Philberth-type "Cryobot" melting probe used in Greenland (see the discussion under Technology Roadmap), the Hydrobot, and possible penetrators using the ISiCL. The ISiCL is an important concept for Earth as well as Europan application, but the modifications required for terrestrial 'use may be extensive, In general, the technology is transportable even if the actual devices are not. Some potential earth applications follow.

6.4.1. "Extremophile" life

"Extremophiles", life forms that live in extreme environments, are of intense interdisciplinary scientific interest.[12] These extremophiles can metabolize at temperatures below the freezing point of water and can live in "starvation survival" mode for extended periods of time[13]. Life in hot environments, saline environments, and so on has been observed on Earth, and significant industrial use has been made from substances extracted from these life forms or their metabolic products. A search for new extremophiles, and an understanding of how these creatures fit into known evolutionary schema, will be a primary focus of any Earth exploration.

6.4.2. Ice sheet and glacier structural profiles

Recent ice sheet drilling programs have provided astonishing information on climate change over the past 100,000+ years. These data sets have also presented questions on such topics as the poleward/equatorward shifts of atmospheric circulation patterns during climate changes of the past. While of unquestionable value, major drilling programs arc so expensive as to be nearly prohibitive. With a suitably modified Cryobot, rapid vertical profiles of key chemical constituents and particles can be made far more cheaply, once the device is developed. Specifically, a series of Cryobot deployments in the West Antarctic ice sheet could use chemical tracers to identify annual layers and dust contaminants to determine the source of the air masses from which the snow was derived This would gain a far better understanding of the mean transport conditions of the glaciation and interglacial, with an emphasis on the time required for changes in regime. In general, air-dropped penetrators or widelydistributed cryobots could give invaluable information for climate change studies that are currently prohibitively expensive.

7. TECHNOLOGY ROADMAP

It will be crucial that a careful list of technology requirements on both Earth and Europan sides of the program be developed, as well as timing that fits with ongoing programs on both sides.

7.1. The In-Situ Chemistry Laboratory (ISiCL)

Both Earth and Europan exploration can benefit from maximum possible in situ chemical analysis. There are areas of interest distinct to Earth or to Europa, as well as some in common. In both cases, basic technology development in sample handling, reduced mass and power, and increased reliability and sensitivity of basic instrumentation will be key. Instrumentation that will be on the surface of Europa will need to operate in a severe radiation environment. On both Earth and Europa, ice instrumentation must withstand cold temperatures and the wet, variable-pressure conditions inherent in operating in ice. A development program for this instrumentation will need to be undertaken as soon as the science requirements are clearly understood.

In situ chemistry measurement requirements for ice include particle size distributions, chemical constituent concentrations emphasizing a few key cations and anions, and isotopic distributions. It is likely that the emphasis will differ for Earth and Europa. On Earth chemical species will be selected to reflect variables that characterize past climate states, Detection of “life” and the evolutionary stage it has reached will be one of the primary goals of a Europa exploration program, It is, however, difficult to determine what chemical form “life” might take under Europan ice. The planetary program has performed most of its work looking for life in dry environments, and we will look to researchers used to a wet, biotic environment for instrument concepts.

7.2. The Cryobot

The Cryobot would be transported to the Europan surface, presumably by a landing vehicle which would then serve as the communications station for transmitting data to Earth. For the second Cryobot mission, a miniature submersible Hydrobot will be carried through the ice and into the ocean. Both of these missions would deploy the I! iCL, but possibly in different versions.

The Cryobot is an adaptation of the late 1960’s Philberth probe[14]. These are cylindrical probes approximately 2 m in length and 10 cm in diameter. Housed inside the metal casing are banks of electrical heaters which cause the probe to descend vertically through the ice driven by gravity. The trials of two such probes were conducted at Station Jarl-Joset, Central Greenland, in 1968 with mixed success, and the idea has evolved somewhat over time. Although the principles involved were sound, technical problems with the heating elements caused both probes to fail before reaching the intended depth. These probes were powered electrically via a wire spooled from the rear of the probe which became fixed in the refreezing meltwater. Extreme adaptations of these probes have also been used to melt through rock[15]. In the case of a Europa Cryobot version of this probe, thermal energy would most likely be provided by an onboard power source. It is calculated that a descent rate of approximately 0.2-1 km per month is achievable, assuming water ice with a 100 K surface temperature. Greenland Philberth probes descended in much warmer ice at 1.5 to 3 km per month. How the devices would work in cryogenic ice with possible contaminants, low pressures, and with smaller-scale vehicles is another challenge, currently being addressed by experimental work at Caltech and at Leicester University in England.

Communication with the Cryobot/Hydrobot through ice and water is not a simple engineering problem. One solution is to connect the Cryobot/Hydrobot to the landing vehicle via an umbilical cable. The cable is stowed on-board the Cryobot and played out to allow for the slow descent through the ice. The ice will freeze up behind the Cryobot as it descends. Materials compatible with a wet cryogenic environment will be needed for the cable.

Additionally, data cannot be stored on board the small communications package left on the surface, Due to the intense radiation flux, all data would be corrupted in a short time period. Similarly, a vehicle cannot be left in orbit for prolonged periods. Therefore, data will be processed on board the Cryobot/Hydrobot and then sent directly to Earth (relay options to other lander or orbiter vehicles maybe explored as well), The layer of ice above the Cryobot should serve as adequate radiation shielding for it and the Hydrobot.

7,3. The Hydrobot

The Hydrobot is a small submersible which is released from the Cryobot and then autonomously explores the subglacial ocean. Once at the ice/water interface the Cryobot ceases to descend and the Hydrobot is released to explore the ocean. By terrestrial analogy it is unlikely that this interface will be smooth or continuous. Therefore, the deployment mechanism for the Hydrobot must include sufficient intelligence to determine whether the liquid ocean has been reached. The major constraint on the probe is that it must be small enough to fit within the Cryobot yet still accommodate the instrument package and communication system, which potentially could include many kilometers of cable. This small Hydrobot also must be capable of withstanding extreme hydrostatic pressures. Even if the probe is deployed in a region with few or no active hydrothermal vents, samples of the ocean floor could still be examined so that any dead organic matter present could be detected. Engineering tradeoffs need to be made to determine whether the Hydrobot should communicate with or without a cable; if without, it could use the housing of the Cryobot as a recharge and data release station. The use of the sonar acoustics for data transmission to the Cryobot housing will be examined further.

The Hydrobot requires sufficient buoyancy control to permit movement through the ocean to the desired depth and some degree of horizontal searching through use of currents, presumably driven by volcanic heating or uneven cooling at the upper surface. Even a modest flow of 0.01 m/s would result in the probe traveling of the order of 1 km/day. Active propulsion at modest speeds (0.1 m/s) is possible and might be attractive.

The Hydrobot would have an instrument package that might include: a hydrophore to listen for volcanism, a device to look at backscatter of particulate, measurements of temperature and salinity (or conductivity), a current meter (assuming that currents exist), a sonar imager for navigation and mapping, and a visible imaging system, which is highly desirable, especially near vents.

A modification of the ISiCL laboratory would test for volatiles typical of hydrothermal fluids: high concentrations of H_2, H_2S, CH_4, and CO_2 relative to "normal (Earth) seawater" (whatever this implies on Europa), The age of the vent and the degree of phase separations of its effluents will drive concentrations of these volatiles. Vents tend to be acidic, (as low as pH = 2.5) and a simple pH measurement would give a first indication of the presence or absence of vents. From this data one could estimate the phase of evolution Europa is currently experiencing relative to the postulated evolution of Earth's oceans.

The Hydrobot's version of the ISiCL instrumentation would determine whether the ocean exhibited one set of requirements for "life we would recognize": liquid water, and then possibly a carbon source, a nitrogen source, and phosphorous and sulfur. The ISiCL instruments could perform microscopic DNA fluorescence and send images of fluoresced DNA back, as this may be used to detect the degree of evolution of microorganisms, if any. If organic compounds existed, instruments could determine whether left and right enantiomers are in a racemic mixture[16] (equal amount of the left and right enantiomers) or whether there is a bias toward one of them, as is seen in terrestrial biochemistry (chirality). It has been proposed that very unbalanced handedness would most likely be produced by self-reproducing organics, i.e. "life". A particular challenge in the design of the instrumentation will be to determine which chemical reactions can ***only*** be mediated by life, and which methods will test for these reactions unambiguously.

8. TERRESTRIAL TEST SITES

It is explicit in this program that the measurement systems and vehicles designed for Europa can be tested in terrestrial environments, and that in the course of those tests scientific projects can be supported with data sets not otherwise obtainable. The test program will focus on several specific science/testing campaigns.

8.1. Vostok Lake and similar water bodies beneath ice sheets

Vostok Lake is a body of water several hundreds of meters deep located above the bedrock and 4 km below the surface of the Antarctic ice sheet near the Russian station at Vostok. Since heat input is assumed at the bottom, there is the potential for life in unique forms in the water and sediment, since life in the lake may have been evolving independent of other terrestrial life for significant periods of time. There is also the very real prospect of significant interference with those life forms by the entry into the lake water of a contaminated or chemically active probing system. These are also issues in probing the ocean beneath the ice on Europa; hence, it is logical to address the technology required for both of these programs, and to test planetary program procedures and devices in the Vostok environment. The Vostok Lake exploration techniques can be tested by using the probe to melt through one of the ice shelves of Antarctica and into the ocean beneath, or alternatively to use a similar but less-pristine lake in Greenland for tests. There will be a thorough design, review, and approval process for this probe in order to best safeguard affected ecosystems.

It is currently postulated that there will be at least two Vostok missions. A first would consist of a Cryobot outfitted with a camera where the Hydrobot will eventually be installed, for an initial look at the water below the ice. This would be followed by a second mission with a full Hydrobot, as similar as possible to that planned for Europa. Vostok missions would be powered by electricity produced on the surface and transmitted down the Cryobot cable.

8.2. Ice sheets

The great ice sheets of Greenland and Antarctica contain our best climate data for the past quarter-million years, and they also have significant potential impact on human life and affairs in an altered climate. Thus, they are the sites of extensive study. Recent core studies have been of great significance in determining the nature of climate change over the past 100,000 years, and numerous questions have been generated by preliminary core analysis. Repeating the drilling that obtained these cores is not practical in view of the great cost, largely logistical, in these projects. However, the scientific motivation is strong to obtain more profile data in other regions of the ice sheets. Here the refined Philberth probe could be of importance in allowing profiling of selected chemical species and/or dust particles at a fraction of the current deployment cost, while at the same time providing a proving ground for the probe design that will eventually go to Europa.

8.3. Oceanic vents in the mid-latitudes and polar regions

Earth's oceanic vents, where volcanic gases are released at the seafloor, are interesting in their own right as sites of unique life-form development. They are highly relevant to the Europa program as they are a reasonable model of what is expected on the seafloor of Europa as a consequence of tidally-induced volcanism. Probes designed to examine and report on the life-forms at the Europan vents should be tested at Earth's vents, and, at the same time, information of the temporal changes in vent communities and properties could be acquired at far less cost than required for a manned submersible.

9. CONCLUSIONS AND RECOMMENDATIONS

We have noted that there are strong motivations to deploy a sequence of instruments in orbit, upon the surface, and through the upper ice layer of Europa in search of life. This program involves extensive development and testing here on Earth. Terrestrial glaciology needs technical development to extend its reach during this period of cost constraints. The applications of this technology include studies of lateral variability in ice sheets, profiles of glaciers, deployments of instrument networks on sea ice, a search for extremophiles, and other topics. There are significant elements common to the programs to study ice on Earth and on such planetary bodies as Europa. Therefore, an integrated program should be examined and defined in detail and presented to the appropriate government agencies, private interests, and candidate foreign participants.

Specifically we recommend that a challenging but affordable Europa mission sequence similar to that described above be examined and approved, and a timeline of the missions be proposed. At the same time, a terrestrial long-term glaciology and biology program should be defined which would benefit from the technical advances called for in the Europa missions. Finally, from the examination of the Earth-Europa science objectives there are key technology developments required. In stating these, we assume that numerous and challenging elements of the program will be addressed outside this program. Among these are: The Europa orbiter, a communication system to move data from on or below the Europan surface back to Earth, navigation and control which will deploy the various probes where they can best work, power systems, radiation protection, and the like, Emphasizing those developments specifically related to the ice and ocean requirements, we see the need for:

- The In-Situ Chemical Laboratory (ISiCL)
- Impact-Penetrator precursor vehicle(s).
- The Cryobot and its surface station.
- The Hydrobot.

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