Proposed subglacial Antarctic lake environment access methodology

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Summary In oil well drilling, there is a concept referred to as "Drilling with Casing"; a process where the tubular that is utilized to drill the hole is also used to case the resultant borehole without the removal of the tubular from the borehole. This method is proposed to be modified for SALE access, where coiled tubing, composed of steel or a lighter weight composite tubular, would be used to drill through the ice with hot water to a point close to SALE. The size of the borehole created by the hot water would only be of sufficient clearance to allow passage of the tubular downward. When the tubular was in position, then the hot water inside the tubular would be displaced with a non-freezing fluid. The water around the tubular would gradually freeze, but the incompressibility of the fluid inside would prevent the tubular from collapsing as the water froze. This tubular could be placed quickly with a small surface footprint and used as a permanent conduit to the lake.

Citation: Fleckenstein, W., W., and Eustes, A., W (2007), Subglacial Antarctic Lake Environment Access Methodology: A Keystone in a Changing World – Online Proceedings of the 10th ISAES X, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 033, 4 p.

Introduction

The broad goal of Subglacial Antarctic Lake Environment (SALE) exploration is to access the lake water and underlying sediments without undue contamination, obtain a variety of in situ physical, chemical and biological measurements and retrieve water and sediment samples for study in a laboratory setting (SALE Workshop, 2006). The obstacles to overcome include depth of SALE, uncertain nature of the ice-water interface, remote nature of surface access points, adaptation of acceptable contamination protocols, and specific tool development.

It is proposed to divide the SALE exploration into two parts. First, the access hole will be constructed with hot water drilling. The access hole diameter will be designed to allow passage of the tubular used for hot water drilling, then this tubular will be displaced with a non-freezing fluid and frozen in place. The incompressibility of the non-freezing fluid will balance the closure stresses of the surrounding ice and prevent the collapse of the tubular, which may then be non-rigid. This access hole will then be a permanent conduit to SALE.

Access Drill Technology

A variety of systems have been used to bore holes in ice (Bentley and Koci, 2006; Splettstoesser, 1974; Mellor and Sellman, 1974). Surface driven rotary rigs with continuous, jointed pipe are similar to industrial drilling operations, but have the largest logistical footprint and have proven impractical for Antarctic operations. Surface rotary drilling with wire line core retrieval (RISP wire line drill, Cape Roberts drill, ANDRILL) allows cores to be retrieved through the drill pipe with wire line obviating the need to pull the core barrel to the surface for core recovery. These drills are capable of drilling at 100 meters per day but require the well bore to be filled with a non-freezing drilling fluid.

Wire-line electro thermal (ET) drills penetrates ice by melting, but requires an antifreeze liquid to be added to the melt water to prevent refreezing. Wire-line electromechanical (EM) drills consist of an assembly deployed on wire-line with a motor to turn core bit and barrel and a pump for circulating cuttings to a screen storage area. The core is cut and retrieved (with cuttings) by pulling the assembly to surface. The borehole is created by continuously cutting and pulling the core to the surface with the wire-line. The borehole must be filled with a non-freezing fluid of sufficient density to prevent ice closure. There is significant experience with EM drills, including the current KEMS drill (in use at Lake Vostok), EPICA, JARE, and ICDS DISC drills.

Hot-water drills use a very hot water under pressure sprayed from a nozzle to melt a hole in the ice (Tulaczyk et al, 2002; Engelhardt et al, 2000; Clow and Koci, 2000). There is also a wealth of experience with hot-water drills including the Cal-Tech and Univ. of Alaska drills, RISP drill and BAS drills, AWI, ANARE and AMANDA drills, and the Ice Cube EHWD. Hot water drills are very rapid, using melt water in the well bore to balance the closure stresses present in the ice. Holes are very straight and are the most efficient way to drill large bore holes – typically 1 gallon of fuel produces approximately 30 gallons of melt water. Hot water drills are very rapid in rates of penetration and can create a 2500 meter borehole in less than 2 days. The firn ice layer must be cased off to allow water returns to surface; or, a pump must be lowered below the firn ice layer to allow circulation to surface.

Other technologies have been used to drill boreholes in the ice, including flame-jet drills, steam drills, electric hot points and compressed air drilling systems. These systems have niches in ice drilling, but are of limited use in deep ice bore holes.

Drilling Fluids

The process of SALE access and sampling will require the use of several types of drilling fluids (Gundestrup, 1988; Talalay and Gundestrup, 1999; Talalay and Gundestrup, 2000; Talalay and Gundestrup, 2000; Gosink, 1989; Gosink et al, 1989; Gosink et al, 1994; Gerasimoff, 2003). The deepest hole drilled with air is approximately 900 m at Dome C. To prevent hole closure in deep boreholes in ice, the hole must be filled with liquid of approximate density of 920 kg/m^3. The ideal hole fluid will not react with the ice, has a low viscosity at low temperatures, is not dangerous to crews or the environment, and is inexpensive.

The four fluids that have been primarily used in ice drilling operations are: water, petroleum fuels, non-aromatic hydrocarbons, and N-butyl acetate. Water is the most desirable fluid to use, since it environmentally the cleanest fluid in use, has no health concerns for workers, and is readily available at any glacial location. Water must be heated or combined with an antifreeze compound to be useful. The interphase heat transfer between the heated water and the surrounding ice is complex and must be managed to provide a workable hole diameter throughout the life of the well bore. As soon as the hot water circulation ceases, the well bore begins to freeze shut.

Petroleum fluids such as diesel, jet fuel and kerosene are relatively inexpensive, depending on the market price for petroleum products, but have health and safety issues due to the presence of aromatics. Non-aromatic hydrocarbons such as Exxsol or Isopar are available from which the aromatic hydrocarbons are largely removed, reducing both flammability and human health hazards. However all petroleum fluids have too low of a density to balance the closure stresses and must have a densifier added. The primary densifiers used included per(tetra)chloroethylene, trichloroethylene, Freon, and HCFC-141b. These densifiers each have undesirable characteristics. Per(tetra)chloroethylene and trichloroethylene are possible carcinogens and inhalation of the vapors affects the central nervous system. Freon is a banned under the Montreal protocol and HCFC-141b is being phased out under the Montreal protocol. All densifiers and petroleum fluids suffer from varying degrees of separation over periods of no fluid movement and may harbor microorganism colonies, due to their organic nature.

N-butyl acetate was introduced as an ice coring fluid after a survey of 250,000 compounds (Gosink, 1989). N-butyl acetate has the advantages of proper density and low viscosity at low temperatures, but has serious health and environmental hazards. N-butyl acetate is well known as finger polish remover. Silicone oils show great promise, due to their ideal density ranges and inert nature to the environment and humans but historically have not been used because of expense and high viscosity at low temperatures.

Drilling with Casing

Casing is defined as the tubular which is placed in the well bore after it is drilled. It is used to support the borehole and provide sealed conduit from the top to the bottom of the well bore. Drilling with casing is the process for using the tubular which drilled the well to remain in the well bore as the casing (Tarr and Sukup, 1999). Normally, the annular area between the casing and the well bore must be filled with cement or another grouting material, to provide an impermeable barrier to flow in the casing to open hole annulus. When the drilling with casing operations reaches the desired depth, cement is pumped down the casing, through the drill bit at bottom and back to the surface, in a manner similar to conventional well cementing operations. The casing itself is manufactured from carbon steel, plastic, or stainless steel (based on American Petroleum Institute (API) specifications); and is designed to the stresses and exposed environment that the casing will experience during its service life.

In conventional drilling with casing operations, the casing is rotated at surface to provide rotation at the bottom of the hole to the drill bit. The casing is jointed with a connection approximately every 13 meters. Drilling fluid is pumped down the casing, past the bit, and up the casing annulus to remove drill cuttings from the well bore. If it is undesirable to rotate the casing, a down hole motor powered by the drilling fluid (a “mud motor”) may be placed at the bottom of the casing. The bit is rotated by the hydraulic mud motor. In either case, if the bit wears out prior to reaching the desired depth, the bit must be brought to the surface and replaced, which significantly reduces the advantage of using the casing for drilling.

Drilling with Casing Adaptation to SALE

The process of drilling with casing could easily be adapted to SALE access. Ice is a very homogeneous medium to drill. There exists a significant international experience with drilling in ice. Unless there is a desire to recover an ice core for study, the simplest method of drilling a hole in the ice is with hot water. The use of hot water has many advantages for SALE access. There have been many successful boreholes of various diameters drilled with hot water. The design and operating parameters are well known. There are no moving parts in the borehole to wear out. Hot water is environmentally benign, easily obtained at location, and capable of rapid rates of penetration. Hot water drilling is similar to coiled tubing drilling in oil and gas operations; consequently, many of the tools needed are commercially available, or can be adapted to hot water drilling. Coiled tubing operations have been successful to 6,000 meters in oil and gas operations. That experience will be of assistance in SALE access boreholes that are approximately 3,500 meters in depth.

The current state of the art in hot water drilling is the Enhanced Hot Water Drill (EHWD) used in the ICE CUBE project at the South Pole. A purpose built drill is used to drill through the firn layer, normally about 50 meters down. A Rodriquez well is used to provide start-up and make-up water during drilling operations. Once the firn layer is cased, drilling continues using hot water pumped down a large diameter, jointed hose, using a weight stack on bottom to keep the well bore straight. A high pressure nozzle at the bottom of the string helps with the melting process. The discharged water which is now cooler flows back up the hole to the surface where it is reclaimed, reheated, and reused. It is necessary to separate the drill system into many components to facilitate shipping in the cargo hold of a C-130 plane. A similar design is proposed for SALE access.

Once the borehole has been drilled to a desired depth near the SALE, there are several options. The tubular may be frozen in place after being the water inside has been displaced with a non-freezing fluid, to resist the collapsing stresses of the ice surrounding the tubular. The non-freezing fluid density could be greater than, equal or less than the density of water, but there may be several advantages to choosing a simple, single fluid less dense than water. If the fluid is less dense than water the chances of contaminating SALE are less. The fluid chosen, due to its near incompressibility, will prevent collapse of the tubular during freeze-in, but will exert a positive pressure at the surface. The exact surface pressure at the top of the column of non-freezing fluid will depend upon the density of non-freezing fluid. The second option would be to breach the ice above SALE with the tubular and lower the end of the tubular some distance into SALE, prior to freeze in of the tubular.

Once the non-freezing fluid is in place in the tubular and a surface pressure containment valve structure is in place, the use of a lubricator will allow this point to be used as a permanent access point for SALE through the thin layer of ice between the bottom of the tubular and solid/liquid interface. This final completed surface pressure containment structure is commonly called a "Christmas Tree" or wellhead and is the standard method for accessing the subsurface in oil and gas wells. The wellhead is able to withstand a range of pressure and harsh operating conditions, such as on the North Slope of Alaska at Prudhoe Bay, in the North Sea, and in Siberia. Sampling and measurement tools, and coiled tubing can access the well bore through the use of a pressure lubricator. The layer of ice between SALE and the bottom of the frozen in tubular may be refrozen between SALE access operations, preventing lake contamination, or the tubular extended some distance downward into SALE prior to freeze in, allowing minimal ice to form within the access tubular. A short distance of ice to be penetrated below the permanently placed tubular will simplify final penetration and sampling efforts, within the range of distances that thermal devices have been used.

The process of sterilizing the tubular prior to SALE access is accomplished using various biocides and/or other sterilizing techniques as required by the scientific community. The advantage in the method described in this document is that there is no access to the SALE until conditions in the tubular meet the scientific criteria for cleanliness. Then and only then, would ice cutting-tools, such as a thermal melter or a wireline conveyed mechanical core drill, be run into the clean tubular through the lubricator to the bottom and start drilling or coring. Then the tools would drill beyond the bottom of the tubular to enable direct access the SALE.

This method of SALE access will address two issues of Environmental Stewardship: protecting the environment by minimizing alterations and allowing uncompromising sampling of water, over multiple seasons, if desired. By drilling using hot water, a hole that is designed only to allow passage of the tubular used to drill, the fuel necessary to heat the water will be minimized. Using the tubular to drill and case the hole will minimize logistical support costs, particularly since the tubular will be mobilized to location, but will never be removed. The use of a tubular to line the borehole will prevent fluids in the well bore from contaminating the surrounding ice, and allow greater flexibility in controlling fluid flow to and from SALE.

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