Technology Requirements for Subglacial Research

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Mackay Glacier SW Ross Sea
• Subglacial Environment(s)
• A System Science Approach
• Science Requirements
• Subglacial Access
• Sample Recovery
• Subglacial Observatories
Subglacial lake exploration
Subglacial Environments
from the Earth, the ice to the ocean

Life in Extreme Environment
Ice Grounding Zones
Ice Shelf Processes
Sub Ice Shelf Circulation
Basal Ice
Subglacial Hydrology
Sediment & Geology
Subglacial Volcanism
Subglacial Sediment & Geology
Subglacial Hydrology
Analogy to extraterrestrial life
Ice Sheet Evolution
Ice Stream Dynamics
Structural evolution of the Antarctic Plate

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Subglacial Geology

Sedimentary Basins

Ice bed interaction
- bed properties (soft-hard)
- properties of subglacial till
- bed rock erosion and rock comminution

Subglacial geomorphology
Tectonic setting and structural evolution of the Antarctic Continent
Subglacial volcanism and distribution of geothermal flux
Ice sheet evolution inferred from exposure dating
Ice-Ocean Interphase
Ice good insulator

melt

Geothermal flux

freezing
Vertical profile @ shear margin

Firn layer

Glacial ice

Basal ice

Bed

0 m
~ 30 m
110-120 m

Water level before and after break through to the basal water system

102.10 m
1022.1 m
1023.0 m
1024.7 m
1032.5 m
1033.9 m

1.5 m cavity

individual sediment strikes
thin layers
thick frozen on debris
clear ice
Clear Basal Ice and entrained debris
Laminated Layers
Thick Debris Layers
**Base of the Ice**

- **crystal boundaries**
- **ice edge**
- **fine debris above clear ice layer**
subglacial hydrological system

Shear margin
channelized system

Ice Stream
distributed system

resupply

ground water
subglacial hydrological system

channelized system
distributed system
subglacial lakes

Drainage to ocean

Byrd Subglacial Basin

WRT

UpC 2.5k
ROV Sampling hotel with integrated oceanographic mooring and back drill system

Tether with englacial temperature and tilt sensors

Traversable drilling system

Ice thickness 200 to 700 m

Water column 0 to 500 m
estimated total water depth 400 to 700 m

~ 2 km

How To Study?
Data from Remote Sensing

positive and negative mass balances for different regions of WAIS

-- Joughin & Tulaczyk (2001)
-- Rignot & Thomas (2002)
An active West Antarctica subglacial water system near Siple Coast grounding lines

Fricker et al., 2007
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ROV

~ 2 km

Drilling - Point Measurement
Geochemical tracers of physical processes
• Insitu Measurements
  - Geophysical
  - Geochemical
• Sample Recovery
• Long Term Observatories
• Remote Long Term Observatories and Sample Acquisition
Subglacial Requirements

• Similar to Deep Ocean
• Off shelf equipment
  - bulky but suitable
• Often simple rearrangement is possible to fit down a borehole
Custom rearrangement of individual components
Surface component wind and solar power and data telemetry station preferably satellite based

Ice thickness 200 to 700 m

Tether with englacial temperature and tilt sensors

Tethered winch system

Programmable profiling between tethered winch system and ocean floor.

Water column 0 to 500 m estimated total water depth 400 to 700 m

Heated wet connector or electrical power and data transfer through tether

Intelligent tethered winch system, which can be programmed through telemetry link

Negatively buoyant CTD probe lowered and raised by tethered winch system probe possibly equipped with heating element to avoid ice formation or to remove ice on sensor

Surface Buoy

Ice

ocean

Profiler

housing electronics batteries

downlink

wire rope

weight

modem

motor

sensors
Sample Recovery

instrument maintenance

• Long term deployment and recovery
• Borehole redrilling
• or ROV supported recovery, maintenance
Power & Data
- strengthened, fiber optic + power cables in neutrally buoyant umbilical tether

Navigation
- Doppler velocity log (2 Doppler current meters)
- gyro (FOG) compass

Imaging
- high-definition camera
  + HMI lights (broadcast quality images)
- 3 lower-resolution cameras
  + 4 quartz lights (piloting, down-hole viewing)
- digital still camera (high-resolution still images)
- vertical scanning sonar (long-range imaging)
- triple laser-beams (sizing and volume of objects)
Geophysics
- multibeam swath mapper (lake floor morphology)
- high-resolution sub-bottom profiler (geological history)

Oceanography
- CTD (salinity, temperature)
- Doppler current meter (water velocity)
- water sampler (calibrations)

Biology
- DO meter (dissolved oxygen)
- fluorometer (live organic material)
- water sampler (microbes)
- sediment corer (macro- and micro-biota)
- ice corer (microbes)
Sedimentology
- transmissometer (suspended particle concentration)
- laser particle size analyzer (suspended particle sizes)
- shear vane probe (sediment strength)
- sediment corer (particle size, composition, structure, fabric)
- ice corer (glacial debris)

Glaciology
- DO meter (dissolved oxygen from streams)
- thermistor probe (in situ ice temperature)
- shear vane probe (sediment strength)
- ice corer (ice chemistry, structure)

Recoverable Samples
- water sampler
- ice corer
- sediment corer
- sample mailbox
Deployment – Tech. Challenges

ROV – Design
Multi disciplinary platform for subglacial research

Safe deployment and recovery
ROV – Design & Construction

Solidworks design
Computer based design and prefabrication testing

Challenge through ice deployment
- 4 segment heat treated aluminum frame
Safety features

- Hydraulically powered latching mechanism releases after power failure, allowing retrieval after irresolvable power loss.
digital computer controlled
ROV control
Data transfer via fiber optic

Power supply
digitally controlled
3600-VAC 3-phase and
1500-VAC single phase

25 HP 3 phase
hydraulic motor

24, 12 and 5 V DC
Instrument
240 V AC
Lights
ROV control
LabView program
2 screens with tab function for fast scrolling

*Operation Modes:* remote operated autonomous survey rudimentary on ice data processing

=> targeted investigation incl. sampling in ROV mode
Deployment - Tech. Challenges

Smart soft coiled tubing
hot water drill system

- Deployment
Recovery
Hole Maintenance During Operation
through ice deployment with smart soft coiled tubing HW drill

- Ice thickness 200 to 700m
- Water column 0 to 500 m
- Estimated total water depth 400 to 700 m
- ~ 2 km

- Traversable drilling system
- Tether with englacial temperature and tilt sensors
- Sampling hotel with integrated oceanographic mooring and back drill system
- ROV
Smart soft coiled tubing HW drill
Injector System I
Smart soft coiled tubing HW drill Injector System II
Smart soft coiled tubing HW drill

Umbilical Hose I

- Fiber Strengthened Hose
  - Thermo-plastic tubing (FiberSpar – Smart Hose)
  - Rubber hose (pot. producer Swan hose)
- Conductor wiring (electrical power)
  - Electrical power supply for
    - for ROV and sensor operation
    - electro mechanical rock or ice drilling
- Fiber-optics (life stream data transfer)
  - Life stream data return
  - higher drill control
  - precise depth determination
  - ROV and sensor operation
Drilling and Traversing Technology

Integration of ROV, Science Equipment and Drill System into Coherent Traverse System

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Traverse Design and Drill Integration

Additional features not shown
Lift or crane for additional instrument and ROV deployment
Anchor and tie down points for additional winch systems (sed corer, sensor string deployment, etc.) or science and drilling equipment.

Mandatory Safety Features: fall arrests around borehole and hard helm area

ROV workshop
MECC

ROV and coring winch system
MECC

Injector with gooseneck

Hose spool

Lift

HPU
Traverse Design and Drill Integration

- ROV + Coring winch system
- Heater unit
- ROV and drill workshop
- Drill & ROV Command
- Mechanical workshop
- Kitchen
- Water reservoir
- Fuel
- Back-up generator
- Control lines
- Fuel
- Hot Drill Water
- Cold Drill Water
- Electric
- Heat
- B-up

Science labs (clean + sed)
- Temp controlled Science Storage
Extra Curricular Activities

- sediment coring,
- rock coring
- single point CTD measurement
- placement of englacial temperature and strain sensors strings,
- tethered automated multi year CTD sensor system.
Oceanographic Mooring System

Ice-ocean interphase observatory
Autonomous tethered CTD profiler
Autonomous ocean flux crawler
max diameter 50 cm

i) CTD
   a. conductivity (salinity)
   b. temperature,
   c. pressure
ii) doppler current meter
iii) transmissometer
iv) laser particle size analyzer
v) rosette water sampler
in addition we are currently considering to include
vi) a micro mass spectrometer for low molecular weight gases (e.g. N2, O2, and CO2) (Tim Short, Univ. Southern Florida)
vii) prototypes of geochemical sensors.
Summary

Manageable technological challenges
Complementary ROV-AUV operation
Multi-disciplinary investigation
providing synergies
maximizing science output
enabling earth system science in an
integrative approach
combining
Glaciology, Geology,
Oceanography and Biology
Antarctic Peninsula

Size of Rhode Island

The Peninsula’s fringing ice shelves are retreating, in response to recent warming.

Image courtesy of Ted Scambos, National Snow and Ice Data Center, University of Colorado. Data from MODIS on NASA’s Terra Satellite, via the Distributed Active Archive Center.
increased grounding-line melting

-- Rignot & Jacobs (2002)
Antarctic Peninsular ice shelves show climatic sensitivity

Wordie Ice Shelf breaks up gradually
Larsen Ice Shelf breaks up catastrophically in 2003

What is future of RIS?
Subglacial Lake Vostok

Exploring unknown areas with ROV/AUV