Ice Drilling Design and Operations (IDDO)
Technical Advisory Board
April 21 & 22, 2009
University of Wisconsin – Madison
Room 351, Space Science and Engineering Building
1225 W. Dayton Street
Madison, WI USA

On April 21 and 22, 2009, the Ice Drilling Design and Operations (IDDO) group's Technical Advisory Board TAB) met to discuss technical issues presented in drilling rock and ice. The intent of the meeting was to obtain feedback from industry experts and incorporate this feedback into drill planning, design and operations. All members of the Technical Advisory Board were in attendance as well as personnel from IDDO and the Ice Drilling Program Office (IDPO).

Attendees

Name	Group	Organization Affiliation
Lou Albershardt	IDDO	University of Wisconsin-Madison - Contract
Mary Albert	IDPO	Dartmouth College
Charlie Bentley	IDDO/IDPO	University of Wisconsin-Madison
Robin Bolsey	IDDO	University of Wisconsin-Madison
Kristina Dahnert	IDDO	University of Wisconsin-Madison
Peter Doran	TAB	University of Illinois at Chicago
William Eustes	TAB	Colorado School of Mines
Steffen Bo Hansen	TAB	University of Copenhagen
William Harrison	TAB	University of Alaska
Mike Jayred	IDDO	University of Wisconsin-Madison - Contract
Tanner Kuhl	IDDO	University of Wisconsin-Madison
Don Lebar	IDDO	University of Wisconsin-Madison
Nicolai Mortensen	IDDO	University of Wisconsin-Madison
Marshall Pardey	TAB	QD Tech, Inc.
Alex Pyne	TAB	Victoria University of Wellington
Alex Shturmakov	IDDO	University of Wisconsin-Madison
Pavel Talalay	TAB	St. Petersburg State Mining Institute
Mark Twickler	IDPO	University of New Hampshire
Tony Wendricks	IDDO	University of Wisconsin-Madison - Contract
Frank Wilhelms	TAB	Alfred Wegener Institute for Polar and Marine Research
Kris Zacny	TAB	Honeybee Robotics Spacecraft Mechanisms Corporation

(Day 1 – 4/21/09)

Welcome

Charlie Bentley initiated the meeting by welcoming all in attendance and providing an outline for the meeting.

Purpose is two-fold:
1. Discuss 5-year Drilling Technology Plan
2. Discuss challenges presented by current drill systems and future plans and designs

Summary of IDPO/IDDO Structure (Bentley & Albert)

- Vision
- Mission
- Goals
    - Long/short term planning
    - Identify new technology
    - Provide needed equipment

- Enhance community communication
- Collaboration – Three organizations involved (Dartmouth College, University of New Hampshire, University of Wisconsin-Madison); The IDPO and IDDO have advisory boards that work to formulate 5-Year plans for each organization:
  - IDPO - SAB (Senior Advisory Board) – 5-year Science Plan
  - IDDO - TAB (Technical Advisory Board) – 5-year Drilling Technology Plan

In the U.S. ice drilling community, a Request For Proposal was needed from both a science organization and a logistics organization.

- U.S. drilling was previously planned from the bottom up, as there is not a nationally run drilling program.
- This new formulation and collaboration between IDDO and IDPO will help anticipate science needs and get drill systems started. This will ensure drills are ready when scientists need them and ensure their logistics requests are met as well. This should also prevent those interested from leaving this line of study due to previously overwhelming time and logistical constraints.
- Collaboration funded for 5 years.
- Future goal may be a top-down organization controlling data dissemination, core storage, drill development, etc.
- Scientists will initially contact IDPO regarding needs, at which point a letter of feasibility from IDPO will accompany the scientist's proposal to NSF.
- The IDPO and IDDO are encouraged to explore industry, foundations, etc. to gain additional outside funding.
- Additional information on these organizations, their efforts and the advisory boards can be found at http://icedrill.org.

Summary of IDPO-SAB Meeting (Albert)

- SAB Organizational Chart – a spread of scientific interests, but not broad enough.
- Charge to the SAB
  - Science drives the drilling: A draft of the 5-year Science Plan will be on the web for community review by the 2nd week of May 2009. A revised draft will be submitted to NSF by early June and return comments from NSF are expected by IDPO/IDDO by the 3rd week of June. Final revisions are to be approved by the end of June and the report submitted online by June 30, 2009.
    - Living document – will be updated yearly
- Elements of the 5-year Science Plan – three different, but closely related groups:
  - Climate - 200 year arrays (light, agile drills), 2k arrays (intermediate or agile drills), 40k arrays (intermediate or DISC drill, replicate coring), High-res records of last interglacial (intermediate or DISC, replicate, quick access), climate prior to 800k years ago (shallow wide-diameter, rapid access drills), pre-quaternary atmosphere (Koci drill), climate transitions
  - Ice Flow History & Response - influences of sediment & water on bottom of ice, geothermal flux, ice properties affecting sheet flow, exposure dating, grounding zone processes, basal ice composition and history
  - Sub-ice environment and habitat - deep time paleoclimate, basal biogeochemistry, geological & tectonic history, subglacial lakes

- SAB message to Drilling Technology
  - Produce good cores/holes
  - Light/mobile drills desired
  - Logistics should not impede science
  - Consider logistical demands, costs, other considerations in system design

- SAB Priority Drilling Needs
  - Maintenance of readily available/agile technology (Badger Eclipse, hand augers)
  - Two logging winches - 1km, 4km (the latter is higher priority)
  - Replicate coring (DISC drill)
  - Intermediate coring drill (Hans Tausen clone)
  - Access drilling concept (small hole) – access to bed
  - Prepare DISC for other/colder regions and review drill fluid considerations, as 141b depletes ozone and is out of production.

        - IDPO/IDDO will look to the Scientific Committee on Antarctic Research (SCAR) for a definition of ‘environmentally friendly’ fluid.
    - Access drilling (large hole) for rover deployment

<u>Drills for International Partnerships in Ice Core Sciences (IPICS) Objectives</u> (Bentley)

- The Oldest Ice Core
    - Transition from a 40k yr cyclicity to a 100k yr climate cycle
        - O_2 isotope graph from ocean
        - O_2 isotope graph from ice cores (likely site south of Dome A, Aurora Basin – 4700m thick ice)
- The 40k Network
    - Holocene (current warm period)
    - Last glacial-interglacial transition
    - Potential sites (Greenland, Antarctica)
    - Holes reaching, or planned to reach, 40k include: Dome C (1200m depth to 40k horizon), WSD (3000m), Camp Century (1200m), Dye 3 (1880m), GRIP (2100m), Renland (312m); fractions of total ice thicknesses range from 37% to 96%
    - Interest in intermediate drills, smaller/easier to transport than the DISC Drill
    - Hans Tausen drill – good for intermediate depths (1000m achievable in only 1 season); used near the bottom of several holes; this drill, shorter than the Epica drill, can handle difficult conditions/warm ice; very flexible system; no fiber optics
        - Shorter barrel provides better circulation in warm ice and combats melting in the borehole
- The 200 Year Array
    - Contributions to a quantitative assessment of recent climate change
    - Have not reached 400m with an open hole drill, not because of hole closure, but because of bad core quality and fracturing induced when nearing brittle zone. A small amount of fluid might help in this case.

<u>Discussion of Needed Drill Systems</u>

- **DISC Drill** (Shturmakov)
    - 122mm core
    - Large scale logistics
    - Need to develop low temperature capability (current temp potential is -40C or -50C)
        - Do we need to aim for -60C or is it only -58C (coldest known hole temperature, from Dome A).
        - Biggest issue is electronics and plastic components.
        - Consider operational temp vs. survival temp – could use internal heaters as with Mars applications. (Zacny)
        - How long is the drill actually at -58C once you begin tripping/drilling? A guaranteed capability to -40C could possibly be trusted down to -55C. (Wilhelms)
        - Istuk drill – seals were the issue at cold temps. Should replace Viton seals with Teflon/other, which performed well at Dome C.
            - Zacny will look into what types of seals/seal requirements were used on extraterrestrial applications.
        - Two onboard computers is DISC instrument sections spec’d to -40C but built to 0C. Sections tested to -60C and did not hold up. Will require redesign. (Mortensen)
        - Should present option of using -55C parts to the scientists, but clarify no guarantee they will go to -60C; this will substantially lower cost. (Wilhelms)
        - If using -55C components at -60C/-65C you may just reduce the part’s life, but able to swap in spares as opposed to designing an overly rugged system. (Zacny)
        - Could use a different drill for the first and coldest portion of the hole and then switch to the normal equipment (DISC Drill) at lower/warmer depths. (Wilhelms)
        - Expected temperature at WAIS bed is -2/-3C, but we are no longer going all the way to the bed
    - Drilling Fluid
        - DISC Drill – only enough 141b fluid for current hole and, potentially, some of the replicate coring of this hole. Smaller kerf this year could save up to 9% fluid.

        - 141b still available in South Africa. Will be used in Epica DML hole (EDML) to drill refrozen water. (Wilhelms)
        - Isopar density = .76, 141b density = 1.24, mixture density = .92; Need to find another densifier (Eustes)
        - Need to explore value of silicone oils; study published by Talalay; approximate cost is $1400/drum.
        - Necessity to find new fluids cannot be separated from the design of the drills. Need to consider logistical concerns as well – extra time/costs of reaming, transportation, etc. May find a cheap low viscosity fluid, but might need to transport more of it – this adds to overall cost. (Wilhelms)
        - Do the holes need to be clean (not allow microbes to grow) or sterile (a fluid with no DNA)? (Wilhelms)
            - Could sterilize fluid with UV lamps, but this just kills the organisms and doesn't dispose of the DNA
            - Filtration (costly) could get rid of these; fluid shouldn't be dirtier than the ice it's going through (Doran)
    - Altitude Capability
        - Some DISC surface components might not hold up (e.g. frequency drives) in East Antarctica; not a major concern at the moment. (Mortensen)

- **Deviation Drill for Replicate Coring** (Shturmakov)
    - WAIS hole will reach ~3465m with high resolution data
    - Four deviation holes likely with total core collection around 400m
        - Passive (whipstock) – will be started at the bottom of the hole (so as not to plug the entire hole if things go wrong).
        - Active (steerable drill, no whipstock)
    - Inclination of Vostok hole was 6%; drill became stuck at 3660m during 08-09 season; cable broke at termination; deviation drilling with the Kems drill started at 3600m using cutters with an outer edge; drilled down to 3620m; deviation would be difficult from a straight (completely vertical) hole. (Talalay)
    - Other deviation drilling was performed at Vostok, but used a thermal drill and a whipstock. (Talalay)
    - Almost impossible to remove the whipstock; use separate whipstocks for each deviation (Talalay)
    - Multi-lateral completion techniques/directional drilling techniques – mining applications will be discussed by Bill Eustes tomorrow.
    - No other electromechanical deviation drills in production right now. Might be explored at NEEM when main hole is complete. Bedrock coring will also be explored at NEEM, which likely has a frozen bed. (Hansen)
    - Minimum diameter of replicate core is 98mm. Could it be 50mm? (Pardey) Could look at sidewall coring from the mining industry. Minimum core length of 1m required, but each replicate hole will likely provide 30-40m of core.
    - Cannot damage sidewall due to logging requirements (Twickler)
    - Jeff Severinghaus discussing interest in replicate coring with the Japanese

Plans for Very Deep Drilling (1 million year ice or greater)
- Discussed at IPICS; Germany would like to be involved (Wilhelms)
- Chinese plan to drill at Dome A (flat, undisturbed ice at bed or a mountain basin with bad ice?). Logistical support unknown at this time.
- Need to strive for drilling several holes this deep/old. (Wilhelms)
- Australian project not successful this past season due to weather/landing conditions.
- U.S. involvement is not ironed out yet. (Twickler/Albert)
- Don Blankenship conducted an East Antarctic survey last season. (Bentley)
- Originally planned for another hole over Lake Vostok, but plans have been suspended due to funding; drill was stuck this season due to hole closure/discrepancy in fluid level. (Talalay)

Shallow (open-hole) Drills in IDDO Arsenal (Lebar)
- Hand Augers (SIPRE, PICO, Kovacs) – loaned to scientists
    - 79-140mm cores
    - Max 20m depth

  - Single barrel driven from surface by hand
  - Sidewinder drive – powered adaptor (hand drill) used with PICO and Prairie Dog (two-barrel adaptation of PICO hand auger)
  - Inserted cutters (disposable)
- PICO 4-Inch Drill (dry drill)
  - 104mm core
  - Max depth 300-350m - core quality degraded below this
  - Weight of unit: 450kg
  - Shipping weight: 1270kg
  - Double barreled, tethered with motor in sonde
  - Aging system
- Badger Eclipse Drill
  - Modified from IceField Instruments
  - 81mm core
  - Max depth 300-350m
  - Weight of unit: 360kg
  - Shipping weight: 900 kg
  - Double barreled, tethered with motor in sonde
- Dirty Ice "Koci" Drill
  - Cores in silty/rocky ice (dry drill)
  - 76mm core
  - Max depth 25+ meters; striving for 40 meters
  - Weight of unit: – 700kg
  - Single barrel motor driven from surface
  - Main challenge is refreezing ice cement
  - Similar to hand augers, but thinner kerf
  - Rock coring heads available (tried during 2006)
- Main Challenges
  - What are these drills capable of? Are they meeting expectations? What are the expectations?
  - >50% of core is rated as excellent. Trying to quantify these quality ratings – could depend on the drill or the driller.
  - Logistical/transportability concerns – need smaller winches (bulk of the system weight).
  - Eclipse systems/components are not interchangeable with one another, while 4-inch systems are compatible and interchangeable with one another. (Albershardt)
  - Tried a small amount of fluid in the bottom of a PICO 4" drill hole at WAIS Divide. Drilling unsuccessful the second season in the hole, despite using fluid.
  - Danes used a small column of fluid over the top of 'dry' drills
  - Eclipse drill could be used with optional seals and be submerged; more difficult to disassemble this configuration. (Albershardt)
- Associated Shallow Core Work
  - Danes planning for an array of shallow holes around the NEEM hole next Spring.
  - Compatible/interchangeable systems are important. (Hansen)
  - 200yr array is naturally linked internationally, as small national programs can do this work and link them internationally without the major logistical barriers. (Albert)
  - New Zealand Hans Tausen clone in development, hoping to go to 400m, but still able to drill shallow holes/coastal sites; Roosevelt Island will be comparable to Berkner Island. (Pyne)

RAM "Shot-hole" Drill (Bentley)

- Rapid Air Movement (RAM) drill - Large volume, high pressure access drill
- ~4in. hole diameter; Sridhar Anandakrishnan would like a smaller, 2.5in. hole
- Unique to IDDO at the moment
- Dual compressor system drills a 60m hole in 20 minutes, while a single compressor only made it to 20m
  - full potential expected at 90m
- Reel size should be evaluated in clones, as it is too tall for Herc flights when assembled
- During 2008-09 season, depths of only 45m reached at Thwaites Glacier due to firn conditions
- Could likely drill hard/blue ice, but has not been tested; additional testing limited by funding

- If unlimited hose was used, depth potential only limited by hole closure
- AWI building a similar drill for seismic work
- Could be used to install antenna arrays or do ice flow measurements

Access Drills (Lebar)

- 3 possible types - Hot water media, "Slim hole", "Quick hole maker" for coring
- Hot Water Drills
  - 150-750mm holes
  - 10's-1000's m depths
  - Proven technologies
  - Relatively fast
  - Melted ice is relatively non-contaminating
  - Water freezes – limited hole life/drill sticking issues
  - High fuel consumption – Large logistics burden, but could be practical; IceCube was 1 gallon of fuel per 44 gallons of water heated (Wilhelms)
- Slim Hole Access Drills
  - 50mm hole
  - 1000's m depths
  - Coiled tubing run to an injector (used in oil and gas industry)
  - Quick
  - Reasonable logistics
  - Contaminating drill fluid
  - Tubing size will greatly affect logistics (has to be one reel)
    - Bigger diameter tubing makes the system much heavier; fatigue limits on metal tubing - usually good for about 150 trips; used on North Slope in cold temps (Eustes)
    - Jointed pipe vs. coiled tubing – no clear winner on speed; difficult to transport large coiled tubing rigs via aircraft (Pyne)
    - 12000ft (4000m) current depth capacity of coiled tubing rig in Hawaii – system roughly 130,000 lbs.
- Quick Hole Maker
  - 125mm depending on core size
  - 1000's m depth
  - Quick – no trip times as with coring drills
  - Drill fluid needed for chip transport/hole maintenance
  - Contaminating drill fluid
  - Tight casing needed to maintain fluid column (Wilhelms)

(Working Lunch)

<u>Discussion of the 5-year Drilling Technology Plan</u> (Bentley)

- WAIS Divide: High resolution Antarctic climate record; abrupt climate change & greenhouse gases
  - International U.S. effort using DISC Drill
  - Timeline: Drilling 2009-10, 10-11; Borehole logging 2011-12 (1/2 season); Replicate coring 2011-12, 2012-13, 2013-14
  - Comments:
    - Could do borehole logging at the start at each season; only takes a few days to complete (Talalay)
- NEEM: Nature of the last interglacial; abrupt climate change
  - International collaboration between Denmark, U.S., others, using the Danish drill
  - Timeline: Drilling 2009, 2010, 2011; Borehole logging 2011?, 2012, 2013?
  - 3.5m cores if new 6m chip collection chamber can be filled (50% more chips expected)
- IPICS – Oldest Ice: Drivers of Earth's climate cycles; greenhouse gases
  - International collaborations (U.S. is interested, but not currently committed); objectives should be clarified during IPICS meeting this summer (Albert)
  - Need to solve drill fluid problem, then use current drill systems to drill this ice; This problem should be addressed immediately and not tied to a specific drill system or project. (Wilhelms)

- Comments:
    - Hansen will email Mortensen information regarding fluid used at NEEM
- 200 yr Arrays
  - Science requirements for the drill:
    - Core/hole diameter: 2-4”
    - Depth: up to 400m
    - Drill fluid: None or small quantities (pure Isopar)
    - Site considerations: -40 (surface temp); minimum time occupancy
    - Transportability: helicopter/twin otter, light traverse
    - International aspects: linked science traverses
  - Comments
    - Need planned development for these smaller drills; no more ad hoc development (Lebar)
    - Is the current number of drills sufficient?
      - Need one more Badger-Eclipse drill; need to make these systems interchangeable; permanently sled mounted and towed OR compatible with helicopter sling
    - Need to review the trench necessity for the Badger-Eclipse drill.
    - Should we add hand augers to this array? (Bentley)
      - Cannot get good annual resolution this way (Twickler)
- 2k Arrays
  - Science requirements for the drill:
    - Core/hole diameter: 2-4”
    - Depth: Up to 500m
    - Site considerations: -40 (surface temp); minimum time occupancy
    - Transportability: twin otter, light traverse
    - International aspects: could be international standardization on core diameter - much easier to analyze core in the field (DEP) and swap tools between countries with standardization
    - Intermediate drills, agile drills (Badger-Eclipse)
  - Comments
    - Hans-Tausen clone could work
- 40k Network
  - Science requirements for the drill:
    - Core/hole diameter: 4”
    - Depth: 1,000m (Hans Tausen clone), others up to 3,000m (DISC)
    - High quality core requirement
    - Drill fluid necessary
    - Site considerations: -40 (surface temp); occupy multiple seasons
    - Transportability: twin otter or herc
    - International aspects: Some sites may involve core sharing, others may be national efforts tied to part of the international spatial array
    - Replicate, intermed drill, cold DISC, winches
    - Hans Tausen drill clone sought by U.S. gas and chemistry communities
  - Comments
    - Should we be designing replicate coring devices that work with more systems than just the DISC Drill? (Albert) This would be a completely new R&D effort. DISC Drill was chosen as it already provides a platform to work with. (Mortensen)
    - Concerns with DISC replicate coring: whipstock, new screens, barrels, cutter heads, motors, etc.
      - Could explore replicate coring with the Hans Tausen clone drill; could be used in the DISC hole
      - 130mm diameter hole (Epica) is ideal (Wilhelms)
      - Could design DISC Drill replicate capability and use in other holes after reaming (Talalay); this presents logistical concerns (more drill fluid, transport, etc.)
      - Petroleum industry always uses the same size hole (Eustes)
      - U.S. community will likely only fund ONE replicate coring drill (Albert)
  - High priority in 5-year Drilling Technology Plan
- High-Resolution Records of Last Interglacial
  - Science requirements for the drill: High accumulation site, core or use access drill to rapidly reach 1,000m

        - Core/hole diameter: 4”
        - Depth: >1,000m
        - Site considerations: -40 (surface temp); several season occupancy
        - Transportability: Herc
        - International aspects: U.S. primary
        - Replicate, quick hole maker, cold DISC, winches
    - Comments
        - Get to more interesting depths at a faster rate
        - Faster to dry drill; use this for rapid access to intermediate depths (Hansen)
            - If you’re going to wet drill the upper portion of the hole, you need a means to circulate and transport the chips. (Pyne)
        - Could use the RAM drill for the firn, case the hole, and then use the RAM drill to go deeper (no longer losing air in the firn)
        - Would 3” core suffice, as it could be obtained more quickly? (Bentley)
            - Need 4” core for high-resolution gas studies. (Twickler)
- Evidence from the Ice Sheet Prior to 800k yrs
    - Science requirements for the drill: Blue ice (shallow, large-volume sampling); able to drill many holes (210) only keeping the bottom meter of core. Might require two drills/teams for simultaneous drilling.
        - Core/hole diameter: 10”
        - Depth: Up to 12m deep
        - Site considerations: no contamination near core
        - Transportability: Helicopter
        - International aspects: U.S. effort only at present
        - Old ice, but not IPICS “oldest ice”
    - Comments
        - Jeff Severinghaus has an approved grant for development of this technology, which IDDO will begin shortly.
- East Antarctica (core retrieval from deep ice only)
    - Science requirements for the drill: Limited time onsite, get to region of interest quickly
        - Core/hole diameter: Unspecified
        - Depth: 4km
        - Drill fluid: Likely
        - Site considerations: -60 (surface temp); fixed camp several years
        - Transportability: Herc or heavy traverse
        - International aspects: IPICS
        - Two possible approaches – need to determine how we know the age of the ice in both of these circumstances.
            - Use access drill down to 800k years then coring drill below (new means) – but there’s pressure from NSF to verify age/depth accuracy
            - Use coring drill the entire depth, moving rapidly through the firn and ice younger than 800k
        - Replicate, quick hole maker, cold DISC, winches
    - Comments
        - Will need to do preliminary coring at this site or have detailed radar data to determine your age model for the site and know where this ‘oldest ice’ begins.
        - If an access drill is used, you need to use optical logging and comparisons to other related holes to determine the age of your first cores.
- Pre-Quaternary Atmosphere
    - Science requirements for the drill: (e.g. Koci Drill – Beacon Valley)
        - Core/hole diameter: not specified – Koci is 3”
        - Depth: up to 40m
        - Drill fluid: None (not allowed) – use minimal ethanol for stuck drills
        - Site considerations: rock-ice mixture; environmental protocol in Dry Valleys
        - Transportability: Helicopter
        - International aspects: U.S. so far

- Comments
    - Ron Sletten (University of Washington) contracted a NZ company to drill permafrost (more sediment than ice) (Pyne)
    - Zacny and company will test a permafrost auger in the Dry Valleys this coming season; could be modified to take core; use compressed gas to flush chips. When ice melts and refreezes around cutters, percussion is used to break through (40-50Hz).
        - Zacny will add IDDO to this email information distribution list.
- Changes across climate transitions of rare isotopes, gases, micro-particles that have never been previously measured.
    - Subset of rapid access drills
    - Unlikely to arrive under 5-year plan.
- Bed Conditions
    - Science requirements for the drill: Ice flow history and response (ice streams); disposition of sediment and water affecting forces on bottom of ice, water pressure and amount
        - Core/hole diameter: 3.5" shot hole to firn-ice transition (Anandakrishnan – seismic work) OR 3" access hole 1-5km depth (Severinghaus)
        - Drill fluid: Necessary for those depths, cannot go into subglacial environments
        - Site considerations: variable down to -60C; Single year occupancy? Anti-contamination efforts.
        - Transportability: Helicopter, twin otter or light traverse
        - Access, narrow, quick hole maker, winches, agile drills
    - Comments
        - Not necessarily sampling the bed
        - Hot water quick access could work
- Geothermal Flux
    - Science requirements for the drill: New territory, has not been considered before; lots of access holes, coiled tubing drill; Hole-maker? Putting instruments in the ice near the bed and letting them freeze in.
        - Core/hole diameter: small
        - Depth: Up to 4km
        - Site considerations: variable down to -60, holes can freeze shut
        - Transportability: Herc or traverse
        - Access narrow, winches
- Properties of the ice that affect flow
    - Science requirements for the drill: temperature, fabric & texture, impurities, density, porosity, densification rate, bubbles, strain rate, water content, internal & basal plumbing; drill for making lots of access holes, up to 12 per season
        - Core/hole diameter: 3"
        - Depth: Up to 4km
        - Site considerations: -60C (hole temp)
        - Transportability: Herc or light traverse (several tuckers)
        - Access narrow, intermed drill, quick hole maker, winches
    - General Comments (aside from current topics)
        - Winch for 3-4km holes (heavy transport)
        - Winch for 1km holes (easy transport)
            - U.S. has a need for these winches but does not have them available – Clow winch is too logistically difficult
        - Need to account for offsets in payout accuracy (temperature, strain, hysteresis)
- Internal Layering (tracers of flow history)
    - Science requirements for the drill: Ultimate goal is one site per season, get to the depth of interest quickly, do not save core from upper depths
        - Depth: Up to 4km
        - Site considerations: -60C (hole temp)
        - Transportability: Herc or light traverse (several tuckers)
        - Intermed drill, quick hole maker, winches, agile drills
- Exposure age dating and sediment deposits
    - Science requirements for the drill:

    - Core/hole diameter: 3-4”, rock and sediment coring at bottom of borehole
    - Core length: 1m for rock, 10m for sediment
    - Depth: target shallow areas up to 1 km
    - Site considerations: surface down to -60C, bed 0-10C
    - Transportability: Herc or traverse
    - WISSARD small - extension of old Kamb-Engelhardt drill, used for lowering instruments
  - Comments
    - Easier with a 2.5” or 3” core – this would be approximately a 5” drill (Pardey)
    - Collected a 100mm diameter bedrock core with a 132mm drill (Talalay)
    - Contamination only a concern with a liquid bed (Twickler)
    - Likely a hot water drill, but could be an electromechanical drill if the bed is frozen (Bentley)
    - Could this be used to sample the bed at NEEM? (Hansen)
- Ice Core inferences of elevation history (stable isotopes, total gas, layer thickness)
  - Science requirements for the drill: limited time onsite, get to region of interest quickly
    - Core/hole diameter: 3-4”
    - Depth: Up to 4km
    - Site considerations: -60C; fixed camp several years
    - Transportability: Herc or heavy traverse
    - Intermed drill, cold DISC, winches
    - Two possible approaches, as discussed earlier under ‘East Antarctica’
- Processes that control the sub-ice shelf mass balance – access hole for oceanographic mooring and ROVs
  - Science requirements for the drill:
    - Core/hole diameter: 3-30”
    - Depth: Up to 1,000m
    - Site considerations: keep hole open for 5-10 days; possible environmental restrictions
    - Transportability: Traverse or herc
    - WISSARD Large
  - Likely included in the 5-year plan
  - Comments
    - Contamination is not an issue if you’re drilling near the ocean, where it will flush out (as opposed to contaminating the continent)
    - ROV– need to account for the cable and keep the hole open
    - WISSARD small
- Grounding Zone Processes
  - Science requirements for the drill:
    - Core/hole diameter: 3-30”
    - Depth: Up to 1,000m
    - Site considerations: keep hole open for 5-10 days; possible environmental restrictions
    - Transportability: Traverse or herc
    - WISSARD small
- Basal ice composition and history
  - Science requirements for the drill: get to desired depth quickly, do not use core from upper depths, ultimate goal is one site per season
    - Core/hole diameter: 3-4”
    - Depth: Unspecified
    - Site considerations: down to -60C
    - Transportability: Unspecified
    - Replicate, WISSARD small, intermed drill, quick hole maker
- Deep time paleoclimate
  - Science requirements for the drill: geological record, pre-ice sheet, in subglacial lakes and basins
    - Core/hole diameter: 3-4” + reamer
    - Hole kept open for specified number of days
    - Depth: through ice sheet 1-3km
    - Site considerations: sea level to 3km, 0C to -50C degrees

        - Transportability: Traverse or herc
        - WISSARD small, winches
    - Comments
        - ANDRILL-type project
- Basal biogeochemistry
    - Science requirements for the drill:
        - Core/hole diameter: 3-10”
        - Depth: Up to 4km
        - Site considerations: -60C surface, 0C to -10C at bed; differential movement of ice over the bed, maintain open hole for (n) days, possible environmental contamination issues
        - Transportability: Herc or traverse
        - WISSARD small and large
    - Comments
        - Looking at filtering down to 0.2 microns (Bolsey) – screens, filters, UV, extreme heat
        - Step levels for micron filters: 10, 1, .45, .2 microns
            - Might not need all levels/types of cleaning (Doran)
        - Commercial products available for swimming pools, hot tubs (Bolsey)
        - British plan to enter subglacial Lake Ellsworth in near future (next 2-3yrs)
- Geological and tectonic history
    - Science requirements for the drill: Access hole diameter to fit coring
        - Recover geological 2-3” core, 10m in length
        - Depth: Up to 4km
        - Site considerations: -60C surface, 0C to -10C at bed; differential movement of ice over the bed, maintain open hole for (n) days, possible environmental contamination issues
        - Transportability: Herc or traverse
        - Access narrow, intermed drill, quick hole maker, winches
    - Comments
        - Communicate to scientists what is doable and what is not. What’s available? (Albert)
        - A project requiring this depth at these temps would be a hot water project larger than IceCube. (Bentley)
        - Mix water and alcohol to keep the water from refreezing so quickly? How would this affect the hole wall? (Wilhelms)
- Subglacial Lakes
    - Science requirements for the drill:
        - Core/hole diameter: 3-10”
        - Depth: Up to 4km
        - Site considerations: -60C surface, 0C to -10C at bed; differential movement of ice over the bed, maintain open hole for (n) days, possible environmental contamination issues
        - Transportability: Herc or traverse
        - WISSARD small, deep access wide, winches
    - Comments
        - Simple gravity core would be the easiest place to start. (Pardey)
        - Hole not large enough for a piston core; British are designing a piston-coring device to go down hole – an electrical device not using an arm. (Pyne)
            - Piston coring systems available for use in a hole as small as 2” (Bolsey)
        - Depth of the lake is a critical consideration in choosing your technique. (Pyne)
        - In a 30” hole, you could design a 24” single pass drill that could collect a 2-3” core (Pardey)

General Overarching Ideas from IDPO-SAB

Desired (not in priority order)

1. Maintenance of agile coring/drilling capability
2. Two logging winches: 1km, 4km (4km highest priority)
3. Proposal for replicate coring
4. Proposal for purchase of intermed drill, possibly next year (Albert)
5. Conceptual design for access drilling – narrow

6. Conceptual design for cold DISC
7. Conceptual design for access drilling wide (WISSARD large and small)

Need to include logistics costs and other considerations in the planning stages (end to end planning).
- Community can then steer clear of heavy transport and limited use systems.

(Day 2 – 4/22/09)

<u>Technical Challenges – Individual presentations and discussions</u>

Clean Access to the Bed (Mortensen)

- Hot water systems preferable
  - Self-sterilizing
  - Filtered/sterilized water doubles as drill fluid
  - Ice used as source for the clean water
- Borehole can be made under-balanced
- Electro-mechanical drills do not have these advantages
- What can be done to improve cleanliness of other systems?
  - UV/X-ray irradiation
  - Heat treatment
  - Clean fabrication
  - Survey – establish bed depth to avoid inadvertent breakthrough; need payout accuracy
- Comments
  - Nice to avoid cleanroom scenarios (Mortensen)
  - Can have a Class 10000 clean room, but then have a Class 100 bench for assembly work (Zacny)
  - Only external parts need to be sterilized (Doran)
  - Thermal melter would be used for access right near the bed
    - Drill majority of the hole with high pressure hot water, but gently enter subglacial lake without high pressure hot water agitation (Mortensen)
- Doran Presentation - Lake Vida
  - ICDS (Kyne) assisted drilling through 60m of ice to the brine with Sidewinder and 4" PICO (Kyne)
  - Three-room structure onsite: Clean room, lab, access room
  - Parts cleaned with alcohol and solvent
  - Had to be both microbial and hydrocarbon clean; Teflon is ideal
  - UV lamps in floor access panel
  - Five 55-gallon drums of distilled water back-filled in hole before using thermal melter to break through
    - Distilled water began melting process (Pyne)
  - Melt water run through 10, 1, .45 and .2 micron filters
  - Filtration can clean hole rapidly
  - Preferable to clean equipment before sending it down hole, even though it will be continuously flushed with hot/filtered water (Doran)
  - Cleanliness difficult with a larger system (Wilhelms), but can have clean room in field (Doran)
  - Clean manufacturing is not necessary; clean shipping and storage should be attainable; any steps you can do ahead of time helps (Doran)
  - Doran will distribute copies of the paper he presented; should be able to correlate filter replacement with volume of water.
  - Issue is keeping the hose clean as it continuously goes in and comes out of the hole; could have clearance around the hole, but each ice layer you melt through presents a new level of microbes (Bolsey)
  - Not such a concern as to what microbes are coming out of the ice, as they are the same as those in the actual lake
    - Importance is in what we're introducing to the hole from the surface or from other contaminants on the equipment.
    - Also need to consider closing the hole and keeping it clean until it fully closes. (Doran)
  - How do we know we're drilling clean?
    - Have fluorescent microscope at surface and someone continuously sampling the water. Results of tests within one hour. (Doran)

        - Swabbing equipment is used more in space industry.
    - Could have automatic machines testing the water immediately after it comes out of the filter and the heat exchanger.
    - Microbiologist should be onsite testing this – get the scientists involved. (Albert)
    - Small amounts of glycol could be used - very dilute if it enters the lake
        - Need some sort of anti-freeze for the system (Pyne)
            - Propylene glycol (food grade) is biodegradable
    - Heat exchanger solves fire hazard issue.
    - Practical limit not yet reached with melting drills; IceCube is currently the deepest at 2450m.
        - Expect we could go 3-4k meters with longer hose. (Bolsey)
    - Cryobot systems only contaminate water directly bordering them as the hole closes above.
        - Could filter this 'bubble' around the melter periodically? (Wilhelms)
    - Dry heat sterilization (+100C) for 24-48 hours could work for hot water drills and melting drills.
    - Hot water hose will rapidly degrade when exposed to 130-140C water. (Bolsey)
    - Could set up active alcohol wipers for the outside of the hose at the hole entry point. (Pyne)
        - An alcohol bath could also work. (Doran)
    - Cannot always expect a clean interface between the ice and the bed. (Harrison)
        - When are you through?
        - Brine may come through fissures in the ice before you break through. (Harrison)

Hot Water Access – Keeping a Hole Open (Pyne)

- ANDRILL: Ice shelf 80-90m thick, sea depth 150m, access to the sea floor
    - 120L/min. at 95C
    - Tide moves ice shelf ~1.5m
    - Ensure pipe does not freeze into the ice sheet
    - Heated seawater-based polymer drill fluid run down through sea floor and back up through separate casings; returned to surface at -2C.
    - Only needed to ream once every 3 weeks
    - 6m cores
    - 1200psi - worried about heating sea water at this temperature; used heat exchanger
    - Made reamer that fits around the pipe; consists of two hose reels and two capstan winches all run and kept in balance with a PLC
    - Conical shaped hole, larger at surface
    - 600mm Reamer
    - Need a large contact heating tool to make the hole large at the bottom (lose your conical water flushing ability when you penetrate through to the sea water)
        - Newer 400mm Reamer – large conical spray assists with the bottom of the hole
- Comments
    - Experience shouldn't change much with greater depths; tools based on AWI tools that achieved >1000m.
        - Twisting of hoses could be an issue with greater depths
        - Maintain guide wire riser down to sea platform; guide wires anchored all along the way with stainless straps. (Pyne)
    - IVG hose similar to IceCube hose; different specs from thermoplastic hose
    - Possible to keep hole open with thin thermoplastic 'casing'; turn current on if hole begins closing (Zacny)
    - Cement the hole wall, then you could circulate an alcohol/water mixture without it attacking the wall. (Wilhelms)
        - Grease, antifreeze liner?
        - How much alcohol will attack the wall?
        - This could allow for deeper holes, as you wouldn't have to worry about freezing at the top.
    - Large holes will need continuous hot water reaming.
    - Want an antifreeze liquid liner substance slightly lighter than water (for accessing the bottom) so it doesn't run out. (Pyne/Wilhelms)
    - Could pump antifreeze substance out at the end and drill/melt out the liner for removal (Pyne)
        - Could send a melter ring down around the outside of the tubing liner (Pardey)
        - Could cut the liner tubing in several places and pull out the pieces (Doran)
    - Isolating types of tubing used in North Slope drilling to keep the permafrost from melting (Eustes)

Sampling the Bed Under Water

- Remote-operated sea floor drills – electrically powered through umbilical (Pardey)
    - Japanese drill – 5800m sea depth drilling of bed; 20m total core collection capability; 16hp
        - Depth record
    - Wire line sea floor drill – 150m depth capability (SolidWorks animation shown)
        - Remotely controlled from surface, but not automated
        - Fiberoptic communication, 70hp
        - Will be tested in Puget Sound in early May, bound for India
        - 5" hole (3.25"-3.75" core)
        - Weight of system: 12 tons
    - Video of ROV-based drill, operating in 1500m of water
        - L-shaped drill base attaches to ROV
        - Could be modified into a single-pass drill (1-1.5m core range)
        - System dimensions: ~9'L x 6.5'L x 9'H
        - 65% core recovery in this difficult area (Papua New Guinea); greater success than previous attempts.
    - Comments
        - Could design a stackable system (24" diameter or smaller) to deploy down a borehole. (Pardey)
- Mackay Glacier Tongue (Pyne)
    - Banded debris-rich basal ice and basal ice resting on submarine till.
        - Diamond-cutting rock is a different process than cutting "slicing" ice.
        - Surface-set and imbedded diamond bits skid on ice (contact melting?).
        - Cutting rock and ice mixtures requires a bit that works for both "hard" rock and "soft" ice.
            - Can use diamond bits, but they don't cut ice well; more melting of the ice than cutting.
            - No good multi-use bit candidates available.
            - Need a sharp fine edge to cut ice and a strong blunt edge to cut rock.
        - Fluid flow pattern is critical to pull the chips away from the cutting surface and out of the hole
            - "Sweeping across the face" (Eustes)
        - Poly Crystalline Diamond (PCD) Composite Bits
            - Pointed cube and triangular PCD inserts, but PCD's do not like variable hardness (ice to rock); tend to sheer off
                - May work if controlling bit weight and penetration rate
        - Under diamond is tungsten carbide that can still cut if it is exposed (Zacny)
        - Ice and Rock Coring Barrels
            - T2 style inner tube protects core from flushing and breakage
        - Can you achieve penetration under conditions of loose pebbles? (Zacny)
            - Limited by power/torque when encountering loose sand and pebbles; need to balance this torque so the entire rig doesn't spin, possibly with hydraulically-driven dogs. (Pardey)
        - Pictures of three styles of rock coring bits (Pardey)
        - Use rope threads as opposed to traditional threads, as they stand up much better to sonic drilling (Pardey)
        - If the bed is frozen, keep it frozen - you get better core this way (Pyne)

Chip Transport "Removal of cuttings in deep ice electromechanical drills" (Talalay)

- Chip transport of primary importance in deep ice drilling
    - Flow rates and outlet pressure varies widely among drill systems
    - Concentrations of chips in drill fluid (should be >5%) vs. concentrations of chips in chip chamber
    - KEMS drill vs. Epica drill
    - (Figure) Eight different images of chip chamber designs (a-h); a-f models likely only allow for 35% concentrations; g-h allow for much higher
        - 75% packing concentration is likely the maximum
    - Cutting distribution tested with artificially-colored ice

- Comments
    - Recommend to install central tube in DISC Drill screens to increase core length (Talalay)

- Danish drills have 30mm central tube wrapped in a filter; shaft is turning all the time (self-cleaning when it begins to plug), 1 turn per second (Hansen)

Keeping a Hole Vertical

- Keeping a hole vertical not of great importance (0-10 degrees ok) (Talalay)
    - Can deviate if necessary
    - Limit should be about 8 degrees or you risk losing your drill (Talalay)
    - Scientists would like inclination kept as small as possible for layer studies (Wilhelms)
- Is inclination due to drilling techniques or ice sheet behaviors? (Bentley)
- Ideal inclination is 0%, as with hot water drill systems (Pyne)
- Different length pins can be added to top of drill to stabilize it in the hole
    - Proper pins can bring the drill back to vertical .15 degrees per each 100m
    - Pins need to be above the drill's center of mass
- One armed bandit (Wilhelms)
    - Used only one cutter and two cutter positions as shoes
        - Successfully used at bottom of EDML hole (normally difficult at those warm ice depths)
        - Increases chip size
        - Decreases amount of heat created during cutting
    - Core quality was good with this method, as you didn't have to keeping breaking the core due to icing of the shoes and re-staring again; desire as low a pitch as possible.
    - Started technique at -5.9C hole temp; pressure melting begins at 2.2C; introduced ethanol water solution (EWS) (50%/50%) around 4.4C, just enough to cover the core barrel
        - Used only 1/15th of EWS previously used.
    - Used plastic flights that were not full kerf.
    - Dome F small edge design helped.
    - Inclination decreased, ended hole with less than one degree inclination.
- DISC Drill Inclination Graphs (Mortensen)
    - Inclination graph/3-D borehole model shown.
    - Ice sheet movement at WAIS Divide surface ~2m/yr.
    - Very light WOB used (20-50kg), but not negative WOB.
    - Graph from Japanese drills (two different drills, two different holes) signifies inclination might be due to ice sheet properties.
    - More difficult to drill on an ice divide, where orientation of crystal axis changes throughout the hole, as opposed to a dome. (Wilhelms)
        - Plot energy needed to drill as a function of depth to determine if the crystal structure is changing. (Zacny)
    - Core dogs that are freshly clean perform a different break than ones that are dirty (with reference to the DISC 2-for-1 and 3-for-1 core break method (Wilhelms)
        - Additional icing with this method not witnessed by DISC crew
- Pictures (Hansen)
    - Cutter angle geometry greatly affects inclination; pitch was not changed
        - 40 degree cutters increased inclination, but 42.5 degree cutters decreased inclination (GRIP)
    - Spring/hammer setup allows for negative cutter load (20-30kg); cutters essentially 'pull' the drill down
    - Centering pins correct for increasing inclination
    - EDML hole ended around 1.8 degrees inclination; North GRIP ended around 2.8 degrees inclination
    - Important: Use sharp cutters, use a sufficiently high pitch and monitor your inclination each run.
    - Double barrel drills (heavier) stay more plumb than single barrel drills;
        - Kems drill was off 6 degrees (double barreled)

Drilling in Warm Ice

- Switched to Hans Tausen drill in warm ice (Wilhelms)
    - Moved to EWS when production decreased to only 2 meters/day; 100mL of ethanol added per run
- Sequence of Events, NGRIP Warm Ice Drilling (2000) (Hansen)
    - Drill freed using frozen glycol pellets.
    - Ideal method for warm ice drilling has not been found; methods developed to finish the holes, but not ideal for speed/core quality.

- EWS solution used to re-gain penetration.
    - Amount of ethanol needed not known.
- Cognac bombs (bags filled with 2-3 liters of EWS) attached to outside of drill; ripped open by a rotating screw once cutting begins.
- Lessons learned
    - Initial slow feeding of drill is imperative for cleaning bottom of hole.
    - 40% ethanol shots, one or two each run, make drilling in warm ice possible.
- Comments
    - Need to refine this technique.
    - Coating (i.e. Teflon or more sophisticated) of cutter head surfaces to prevent icing.
    - Coarse chips are better and fine chips present a problem.
    - Coating on cutters and vacuum grease coating on inside of core barrel decreased the refreezing problem, but did not solve it during testing. (Zacny)
    - Coating available that can have a 'warming' pulse sent through it.
        - Used on windscreens and airplanes (Wilhelms)
    - Zacny will email coating company (Magnaplate) contact info to IDDO.
    - Ski wax tried on core barrels with some success. (Hansen)
    - Explore use of a thermal drill in warm ice. (Talalay, Hansen)
        - Connectors on Russian drill would need to be redesigned for pressure concerns; have only gone to 2075m thus far.
    - Strength of DISC Drill pump might increase hole temperature and exacerbate the warm ice issue (Mortensen); ice is a very good insulator, and any heat you put into the borehole remains there for a considerable amount of time (Wilhelms)

Sticking Drills at Vostok: Recovery and Deviation (Talalay)

- 52nd Russian Antarctic Expedition (RAE) – 19 days, 31 runs, 7.8m of core collected
    - Drill stuck at 3658m
    - Cable broke at cable/drill termination
    - Special gripping device designed offsite and then manufactured in the field
    - 80L of antifreeze added; glycol removed using a special barrel with disc valve
    - After recovery of drill, 55 runs from 3658 to 3666.5m completed (deepest hole yet)
    - 2nd problem – core barrel unscrewed and dropped to bottom; unable to retrieve; cable again broken at drill termination.
- 53rd RAE
    - 141b (densifier) evaporation issues
    - -3 to -4C temperature gradient at bottom of hole
    - January 2008 - additional densifier added, liquid level brought up and hole closed
- 54th RAE
    - Hole re-opened, fluid density raised, reamed
    - Drill not recovered
    - Deviation hole started at 3600m, currently at 3620m

(Working Lunch)

The following topics were briefly revisited after the lunch break and notes were added above under the appropriate sections:

- Return to "one armed bandit" and warm ice discussion above (Wilhelms)
- Return to Keeping a hole vertical (Mortensen)
- Return to Mackay Glacier Tongue discussion (Pyne)

Drilling in Rocky Ice (Kuhl)

- Modified concrete coring drill
    - Coarse feed used for drilling ice/sand, micro feed for drilling rock
    - Capstan winch used for adding standard PICO extensions
    - Carbide-inserted cutters worked for rocks of <160 degree kerf
- Ice cement definition: loose sand and pebbles not well consolidated in ice.

- Transported by one helo load; each individual piece transported by 2-3 people on the ground.
- 1-meter barrel gives you a 0.5m core, as the cuttings are transported up the borehole wall via outside flights and dropped back into the top of the barrel.
- Overpacking of the core barrel with chips was often used to retrieve the core; trying to move away from core dogs.
- Problems with melting and refreezing of debris on cutting surfaces and core dog cages; difficult to remove core.
- Generally drilling at 80-100rpm.
- Deepest hole was 28 meters; limited by pulling power of capstan winch and strength of fiberglass PICO extensions
- Down-hole vacuum worked very well, but slow to use; have to vacuum after every few cm of penetration
- Comments
  - Rock drilled was dolerite
  - Limited to a dry hole by environmental constraints
  - Could use air for chip transport, but this doesn't lubricate the hole; also need a fairly large compressor. (Pyne)
  - Limited by refreezing cuttings - takes a lot of energy to cut the rock and this heats up the borehole substantially. (Pardey)
  - Steep flight pitch on aluminum barrels worked better than shallow pitch HDPE flights on new barrels.
    - 25 degree pitch seems optimal
    - 70% of heat created during drilling is stuck in the chips – remove chips quickly to prevent melting in the hole (Zacny)
    - Percussion can increase penetration – breaks up icing around the bit (Zacny)
      - Percussion bits can be PDC or diamond-coated tungsten carbide

Deviation Drilling (Mortensen)

- Whipstock solution currently preferable
  - Sacrificial – part of it will be destroyed, made of material harder than the ice
  - Reaming tool may be required to make room for whipstock and allow drill to turn
  - Reaming tool takes place of core and screen barrels
  - Cannot permanently place anything in the borehole
  - Comments
    - Need more flexible outer barrel or more reaming. (Pardey)
    - Need to plug deviated holes? (Pyne)
      - Intend to drill on uphill side of original hole – gravity will always return drill to original hole. (Mortensen)
- Directional Drilling 102 (Eustes)
  - You either "pull it" or "push it" – which way is your bit pointing and which way are you pushing it?
  - Factors affecting bit trajectory
    - Gauge and placement of stabilizers – need to be touching the side of the hole (act as a pivot)
    - WOB
    - Rotary speed
    - Bit type
    - Formation anisotropy and dip angle of the bedding planes
    - Formations hardness
    - Flow rate – how fast you're pumping and cleaning
    - Rate of penetration
    - Hole diameter
  - Predicting Wellbore Technology
    - Trajectory can be determined by Force: magnitude and direction
    - BHA trajectory prediction is complicated by unknown values of force and opposing force vs. formation hardness
  - Data for Predicting Trajectory
    - Bit Tilt
    - Bit Side Cutting
    - Rate of Penetration – WOB, RPM
  - Side Cutting Force vs. Bit Tilt
    - Side Force – bent sub most effective
    - Bit Tilt – bent housing most effective

- Four BHA Responses
  - Positive side force and positive bit tilt
  - Negative side force and negative bit tilt
  - Positive side force and negative bit tilt – mostly likely for ice coring applications
  - Negative side force and positive bit tilt
- Principles of Trajectory Control
  - The Fulcrum Principle
  - The Stabilizations Principle
  - The Pendulum Principle
  - Additional stabilizers increase your chances of sticking in the hole
- Station errors
  - You don't know where you are – "ellipsoid of uncertainty"
    - As you drill deeper, your uncertainty grows.
    - You could intersect with and re-enter your old hole.
- Comments
  - 1-3 degree deviation over 100ft long radius is typical
  - Rate of curvature is a big factor in the amount of time it will take
    - If you're just looking for an angled deviation it will be quicker than if you need to get back to vertical (but have to have gotten far enough away from the main hole)
  - How to remove the whipstock from the hole?
    - Not desirable to drill through a whipstock. (Eustes)
  - Probability of collision with the main borehole
    - Accuracy of instrumentation is crucial.
  - Whipstock is most straight forward method, but should consider jetting bit, thermal bits
    - Talk to commercial directional drillers (Schlumberger, Halliburton); Eustes will forward these contacts to IDDO.
  - Could use stabilizers to bend/steer the drill in a certain direction
  - Full-hole whipstock is difficult
    - Could use a tubing/casing with a whipstock inside; oval hole in the side of the casing would allow the drill to deviate out (Pardey)
  - Ideally the drill will clean up the cuttings as it reams/travels; DISC Drill has enough fluid flow/vacuum power for this. (Mortensen)
    - Concern is that chips will fall onto/into the whipstock mechanism and hamper its operation or removal. (Eustes)

Intermediate Depth Drilling (Hansen) – not discussed

Hole Logging & Instrumentation (Mortensen)

- Concerns
  - Suggestions on downhole sensors for hot water drilling (WISSARD)
    - Difficulty in implementing communications wires in hot water holes
  - General purpose logging winch
    - Difficult to design a multi-purpose winch; design might fail because it was trying to do too much
    - Look at slim hole winch suppliers (350-450kg), based in Calgary and Edmonton (cold weather applications) (Eustes)
    - Normally loggers do not need much power (Wilhelms)
      - Contact Rochester Cable
    - Need logging community to meet and decide on common requirements for power needs, data rates, etc. OR do we provide a design for a very basic system and make the loggers adapt their systems to that winch?
    - Old PICO logger – which winch was used? (Harrison)
  - Borehole temperature measurement crucial during warm ice drilling
  - DISC drill experiences inaccuracy in payout measurement, presumably due to cable stretch.

Drilling Technology – Honeybee Robotics (Zacny)

- Space-related designs and drills – coring drills deployed from small robots/rovers

- Coring drill fully autonomous, 4kg, acquires 10cm long x 1cm diameter core
- Sniffer – heats cuttings and sends vapors from cuttings to mass spectrometer on top of system
- MARTE Drill – core 25 cm long x 1 cm diameter
- DAME (Deep) Drill – 'smart drill', executive autonomy and diagnostics
- CRUX Drill – rotary, percussive, and rotary-percussion capabilities
- Permafrost drilling in Arctic on Devon Island
    - Rate of penetration is a function of bit diameter
    - Difficult to keep everything frozen with dry drilling; can pump cold air down hole.
- Want core that hasn't been thermally altered
    - 70% of heat from drilling goes to the chips, 10-15% goes to the hole, 10-15% goes to the drill, 5% goes to the core
- "Drilling in Extreme Environments" – will be published 09/15/09
    - Contains many designs that could be applied to ice/rock drilling
- Keeping the environment frozen prevents introduction of bacteria to the environment
- Research Victor Petrenko (Dartmouth) – sending current through a barrel to instantly melt off outer ice (video)

Function of the TAB

Charlie clarified the primary role the TAB should play in its work with IDDO:

- Edit/comment on the 5-year Drilling Technology Plan
    - 5-year Science Plan not finalized until June 1st – Drilling Technology plan will be based off of that
- Many members open to phone conferencing - WebEx could serve a function