Methods for measuring the physical, hydraulic, and chemical characteristics of waste rock

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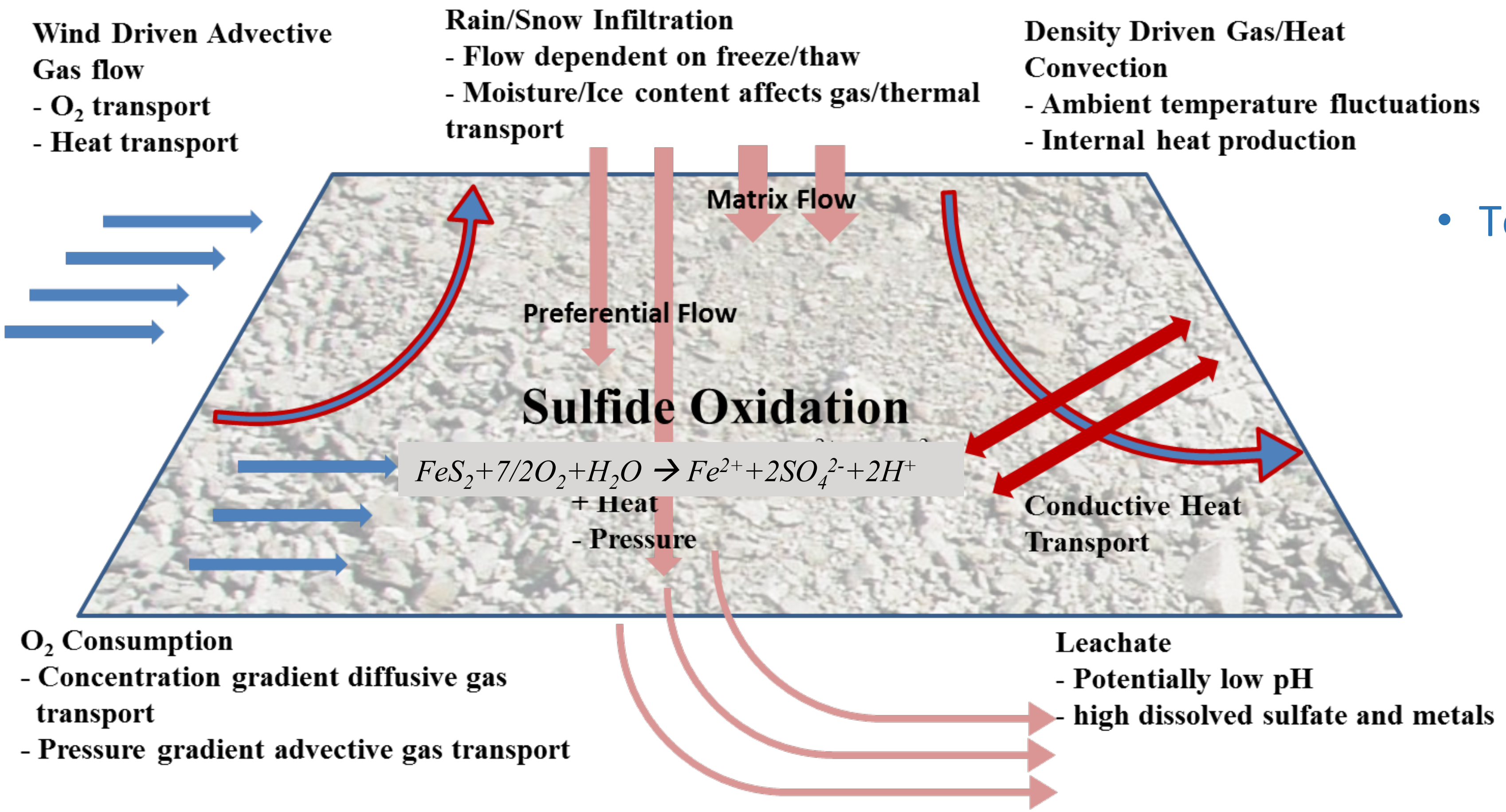
Outline

- Over the past 15 years research groups at UW, UBC, UA and Carleton U have been making a range of measurements to evaluate sulfide oxidation and ARD in waste-rock dumps
- Review of several instruments/techniques that we use to collect water samples, and to evaluate water, air and heat movement
- Describe some of our experience in installing, maintaining and using these instruments and data

Processes that affect sulfide oxidation

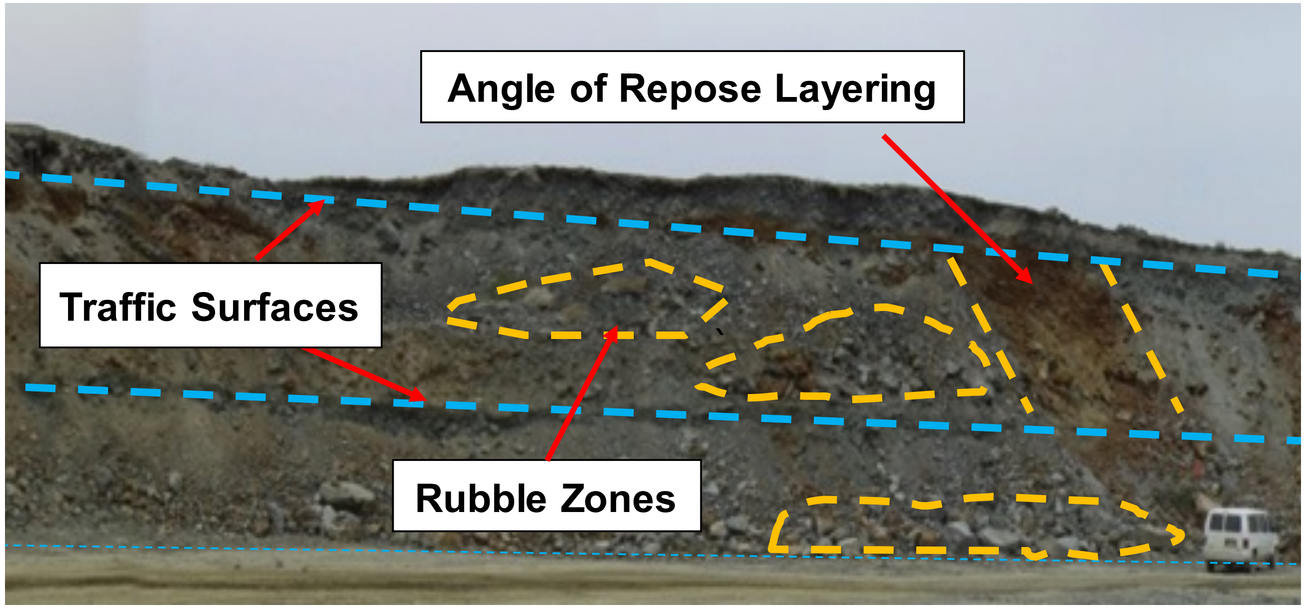


Amos *et al.*, App. Goech. (2015)

- To evaluate, we need to understand
  - Hydrogeologic characteristics
  - Gas composition and transport characteristics
  - Thermal characteristics
  - Physical characteristics
  - Water chemistry of the unsaturated zone

Waste rock investigations

- Challenges
  - Large footprint, large thickness
  - Heterogeneous
  - Grain size ranges from fines to boulders
  - Internal structure: traffic surfaces, rubble zones, tip-face bedding and voids affect gas and water transport
  - Technically difficult to install instruments



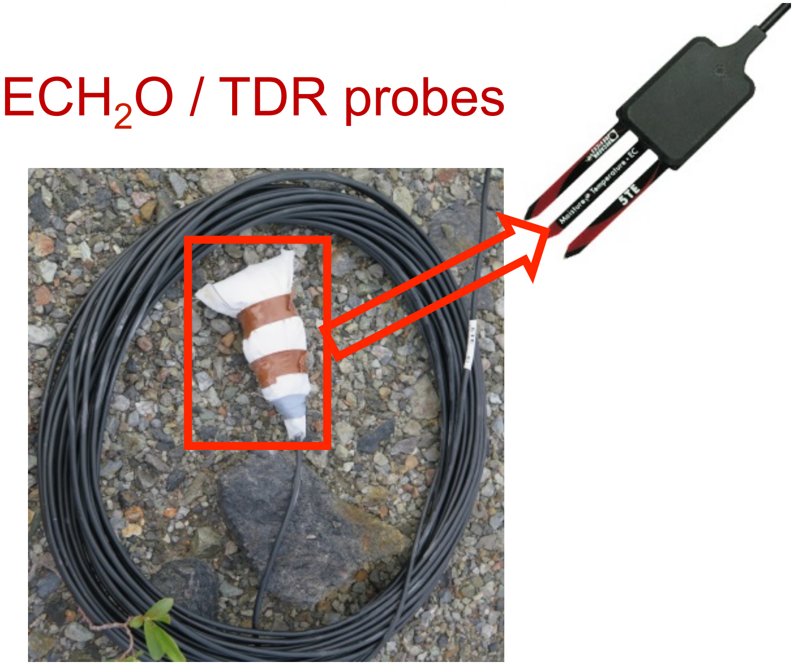
- Usual methods for installing instruments in WRD
  - Packsack drill (Pionjar™) to make narrow instrument holes
  - Hand-excavate or use excavator to make test pits, then backfill around instruments
  - Place instruments on exposed WRD surfaces that are eventually buried
  - Place instruments in drilled boreholes that are backfilled

Monitoring Instruments

SWSS (soil-water solution sampler)

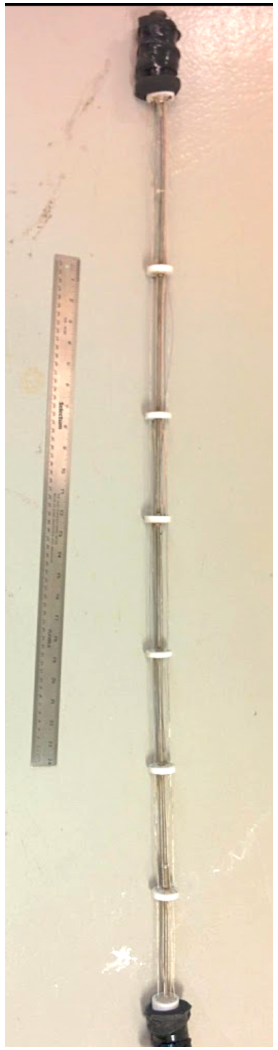
Soil tensiometers

ECH$_2$O / TDR probes



Gas sampling tubes

Air permeability & thermistor

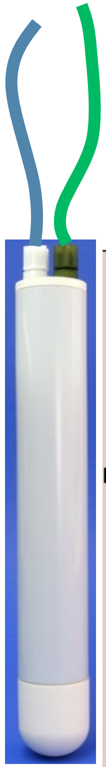


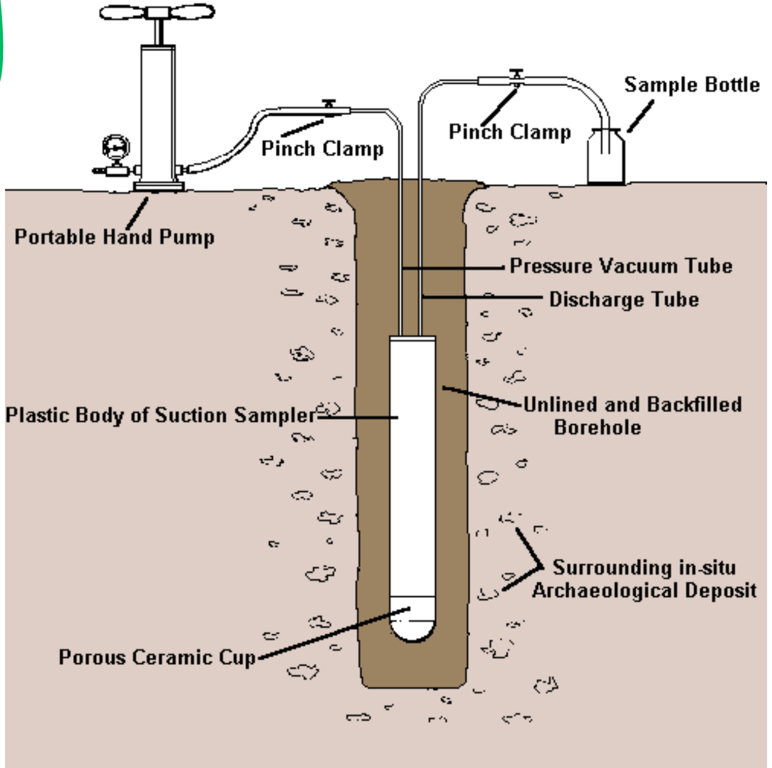
Thermal conductivity

Unsaturated zone water samples

- Soil water solution sampler (SWSS) or "suction lysimeter"
- Sealed body with a fine porous cup, pressure/suction & sample tubes
- Attached to PVC standpipe in borehole or in test pit, then backfill
- Use hand pump to apply vacuum to porous cup to draw water from matrix for sample collection
- Success requires good hydraulic contact between WR matrix and cup
    - Pack around cup with silica flour or matrix fines
- Allow 6-72 hr collection time under vacuum
- Use N_2 pressure to push sample up to surface, 20-200 mL per sample
- Shallow and deep SWSS available
    - \$150 – 350 (< 15 m, no check valve)
    - \$800 (15–90 m, with check valve)
    - Soilmoisture Inc., SoilMeasurement Inc., Campbell Sci.

Pressure/vacuum and sample tubes extend to surface



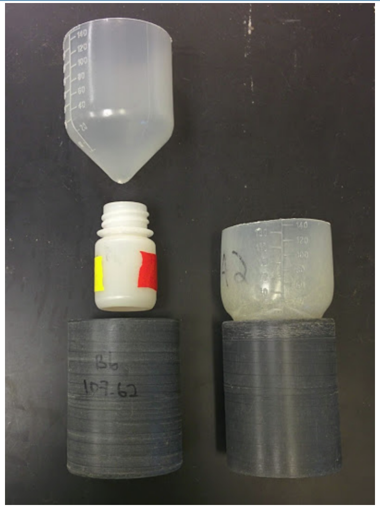


Nylon sock with silica or matrix fines

Unsaturated zone water samples

- Centrifuge extraction of water from matrix samples
- Requires 1-2 kg of waste-rock matrix material from test pit and borehole core samples
- Fines are best (*e.g.*, predominantly < 1 mm)
- Extracted sample is a single snapshot in time
- Not a method for continually monitoring water chemistry
  - However, it can provide insight where conventional porewater samples (SWSS) not available

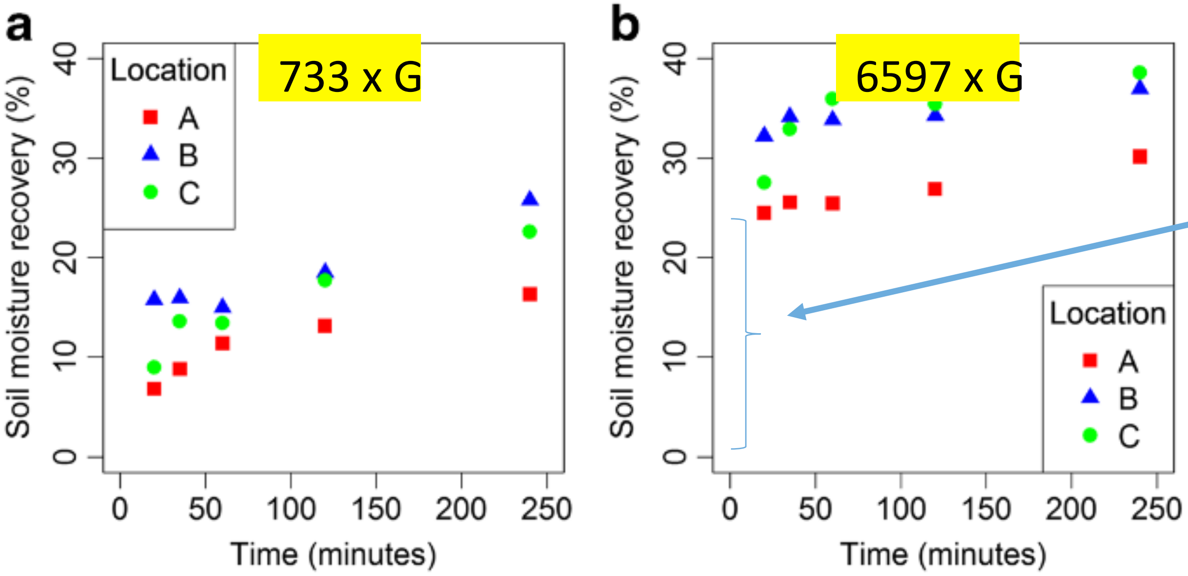
Centrifuge tube, stand & water sample bottle



Six position rotor with 110 g samples

Centrifuge extraction

- Soil moisture recovery is a function of time and rotational speed (G)
- At high G (*e.g.*, 8500 rpm), most of the recovery occurs in first 15-30 minutes; lower G effective for wetter samples
- Waste-rock matrix with 5-10 wt% moisture content typically provides 2-6 mL water per 100 g solids
- Typically combine multiple subsamples for sufficient volume for analysis (pH, metals, anions)
- *Careful to respect load and RPM limits of centrifuge*



Approximately 80% of the recovered water releases in first 15 minutes

Fraters *et al.*, Environ Monit Assess (2017)

Pore gas sampling

- *In-situ* measurements of pore gas O_2 and CO_2
- Measure O_2 to identify zones of sulfide oxidation and gain insight on gas-transport characteristics
- Measure CO_2 for evidence of acid generation and carbonate mineral dissolution
- Bundles of 1/4" x 1/8” PE tubes terminating at different depths

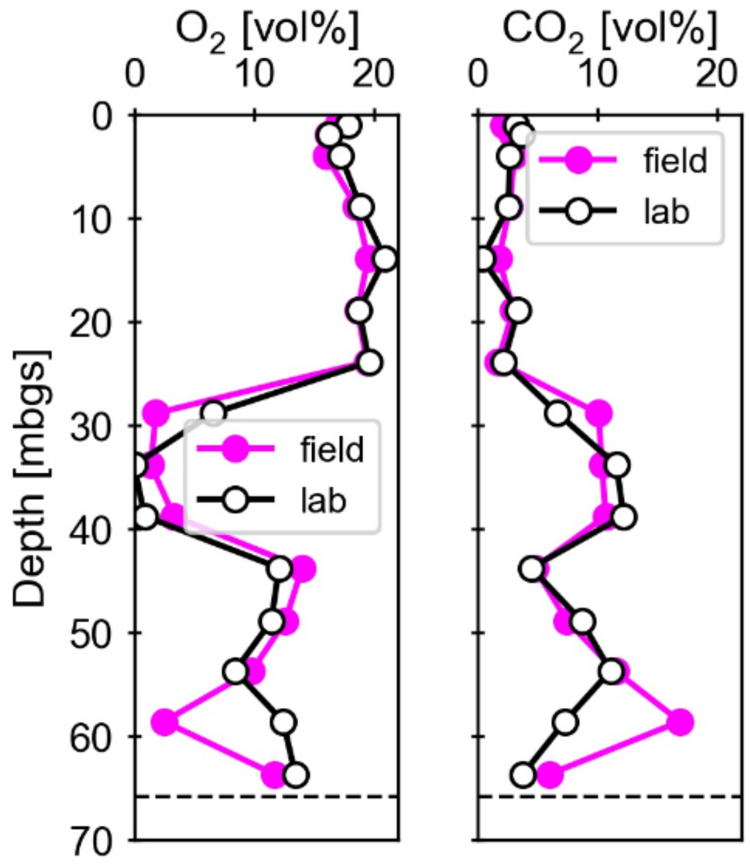
in Pionjar drill hole, test pit or borehole

- Backfill test pit with excavated material; borehole with sand

and enough bentonite to isolate sample points

- Inexpensive materials
- Use a portable O_2/CO_2 meter to monitor until O_2 bottoms out and CO_2 reaches maximum (*e.g.*, Quantek, Nova)
- ***Alternative: sample into a vacuum vial then measure with GC***

Comparison of field meter result *vs.* gas sample collected and analysed by GC



Atmospheric values

Active sulfide oxidation consuming O_2

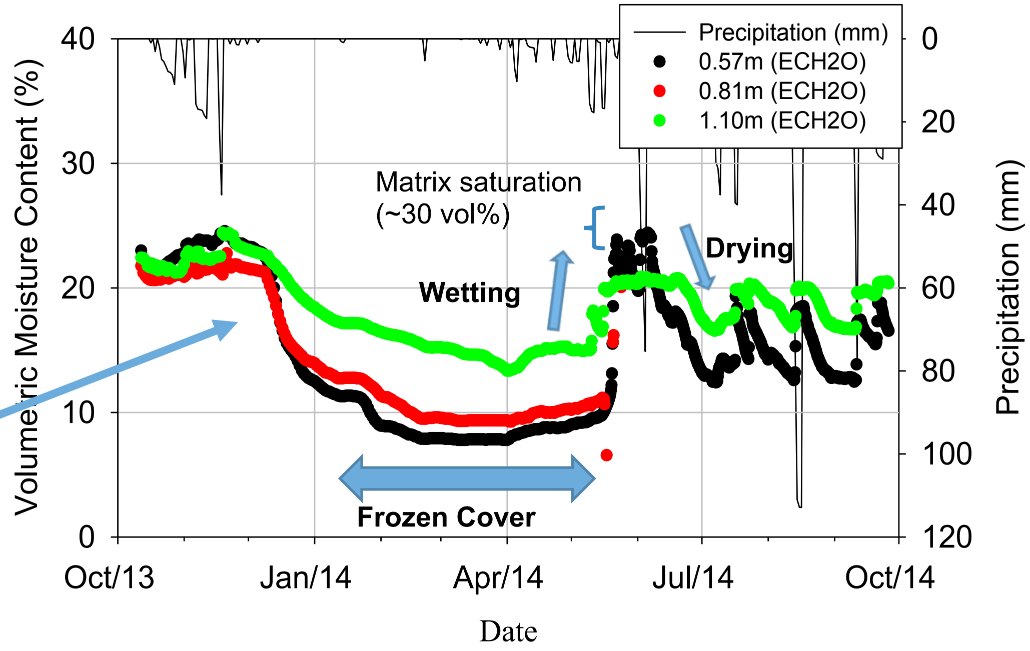
Acid dissolution of carbonate minerals→ CO_2

Custom-built 20-port portable O_2/CO_2 sampler

Moisture content (*in-situ*)

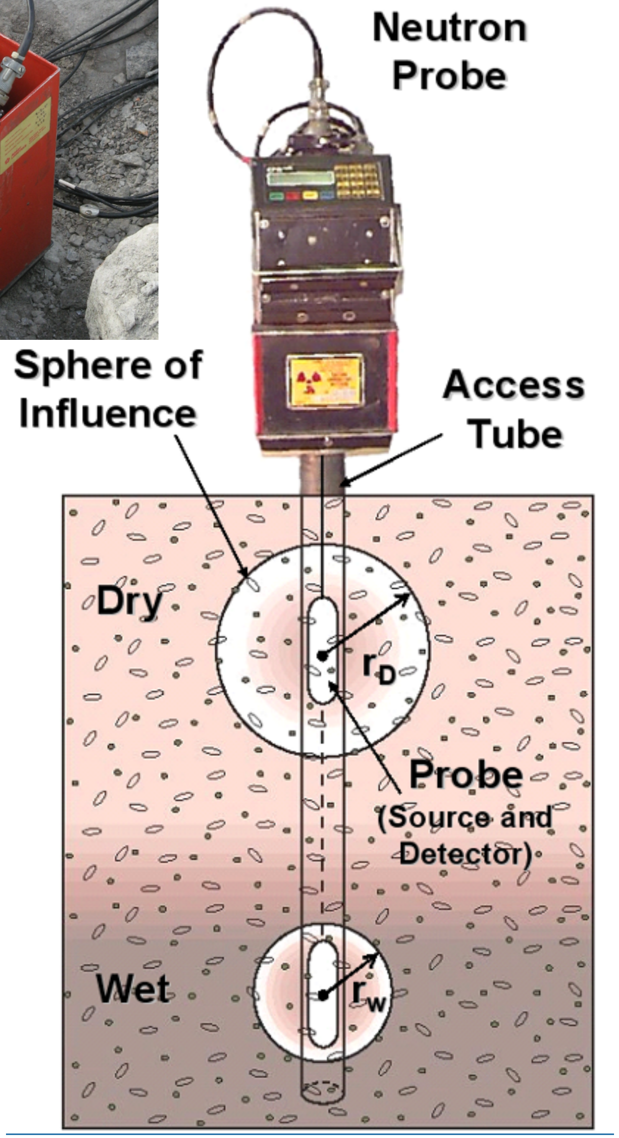
- Volumetric water content (VWC) sensor (TDR and ECH2O probes) and a datalogger
- Both measure the dielectric constant of the matrix and this is correlated to the moisture content
- Reliable readings require good contact with the WR matrix
  - For test pits and Pionjar holes, directly push into fine WR matrix
  - For boreholes - place sensor in pouch of silica flour or fine drill sand, attach to PVC well pipe, lower into borehole with instrument string, and backfill
- No maintenance
- *Life of a few years for capacitance type (ECH$_2$O)*
- Cable length to >100 m
- Several brands and models

Continuous datalogging shows wetting and drying events



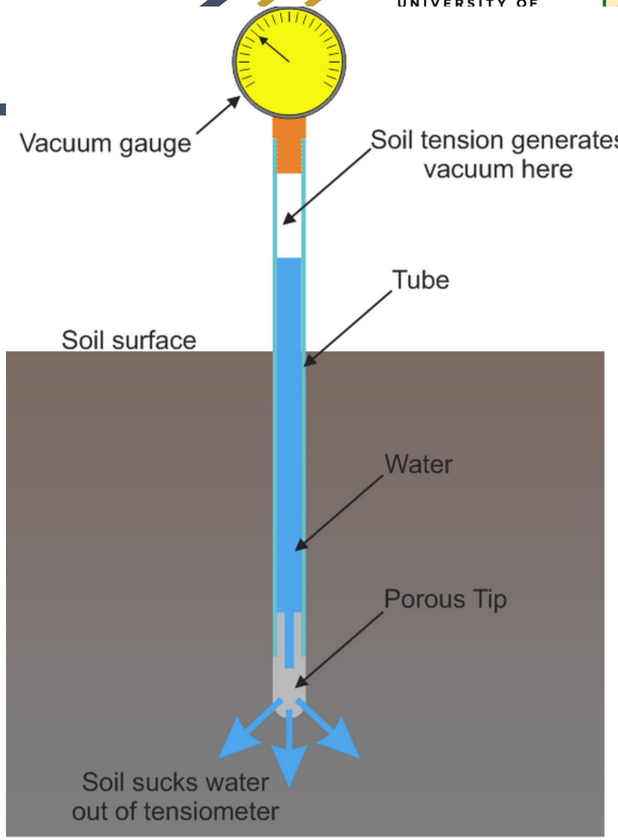
Moisture content (*in-situ*)

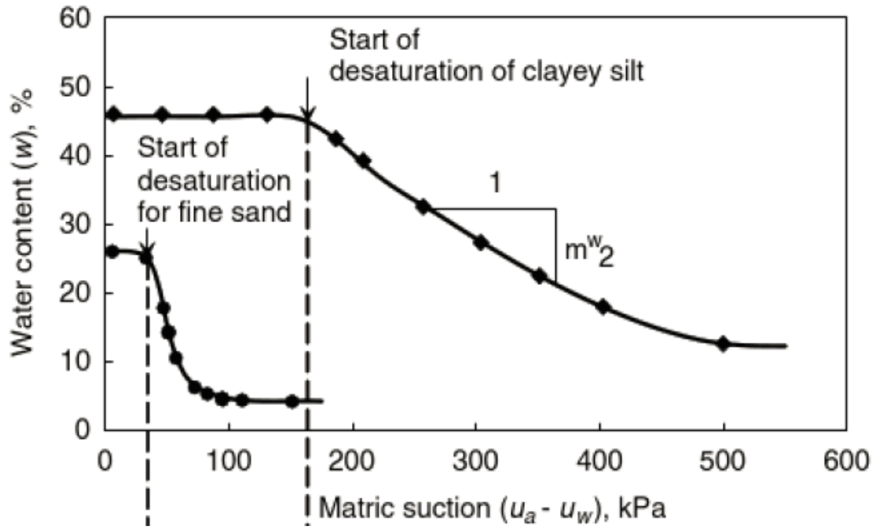
- Neutron probe volumetric water content (VWC)
  - *The probe contains a source of fast neutrons, and the gauge monitors the flux of slow neutrons scattered by water in the matrix materials*
- Use of the probe requires aluminum access tube (2”) that has direct contact to WR (*i.e.* not in a backfilled borehole)
- Procedure is quick and easy, and can give a high level of moisture vs. depth detail
- *Not for all sites: complications for transport and storage of radiation devices*



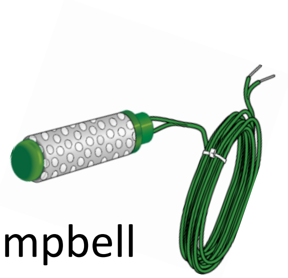
Soil water tension (vadose zone)

- Tube tensiometers to measure matric suction (+ moisture content) → help understand unsaturated hydraulic conductivity and conditions when water will flow
- Water filled tube, ceramic cup & gauge. WR matrix absorbs water out of the ceramic cup, creates a vacuum in the tube, gauge reads the suction
- Nest of two or three depths to give vertical hydraulic gradient
- Tube tensiometers, shallow depths only (< 2 m); must be maintained (refilling, must not freeze)
- MUST have direct contact to WR matrix
- $400 w/gauge; $800 w/transducer + datalogger cost
- Buried remote matric potential sensors – *low maintenance, greater depth*; slightly less accurate; $200-400 ea





Soilmoisture



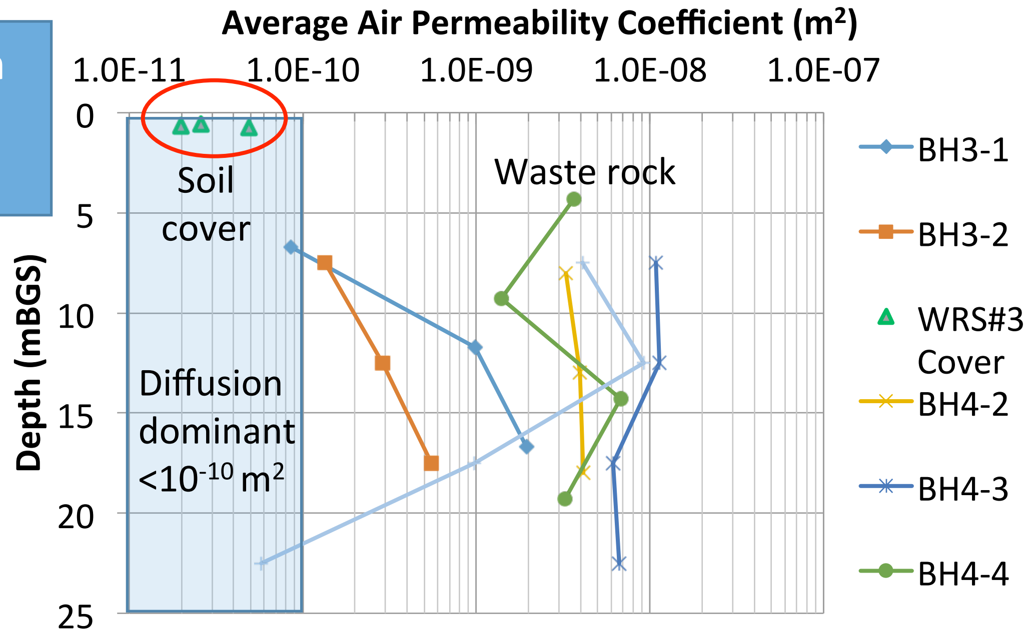
Campbell Science

Metergroup TEROS

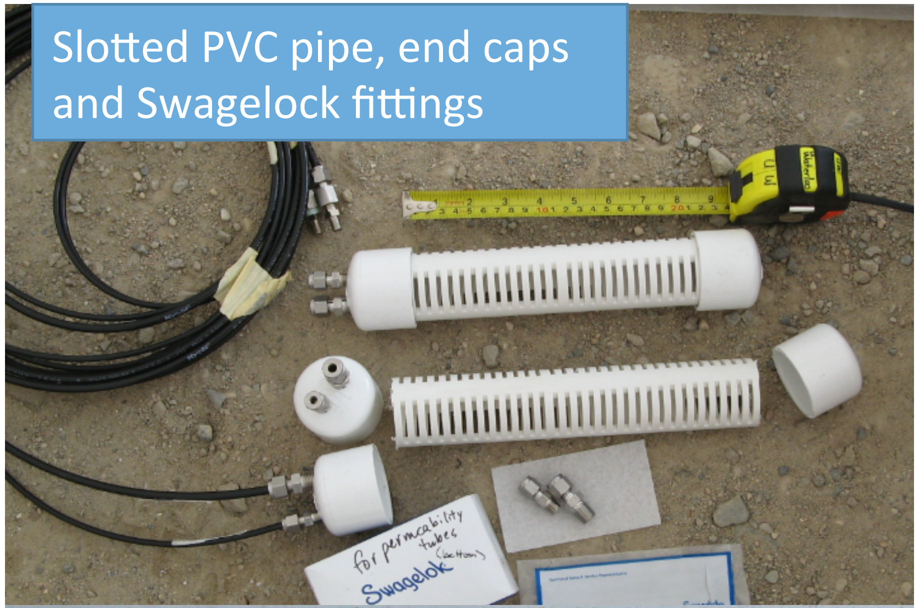
Waste-rock air permeability

- Perforated permeability ball or cylinder ("sensor") placed in borehole or excavation and buried
- Sensor is attached to surface by two lengths of nylon tubing
- Inject N_2 through one line; monitor pressure with the other line
- Use custom datalogger to control and monitor flow rate of N_2 and pressure reading at the sensor

WRD with 0.5 m soil cover



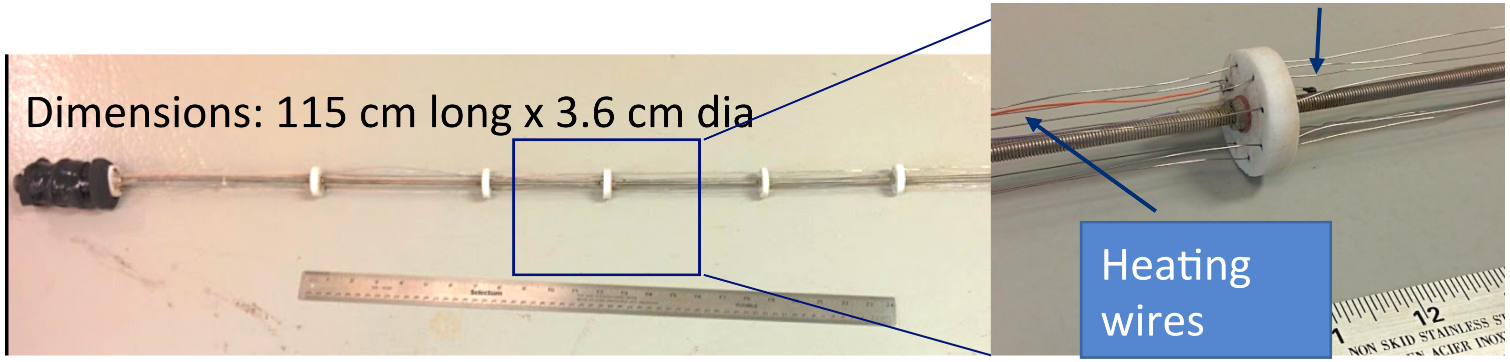
Slotted PVC pipe, end caps and Swagelock fittings

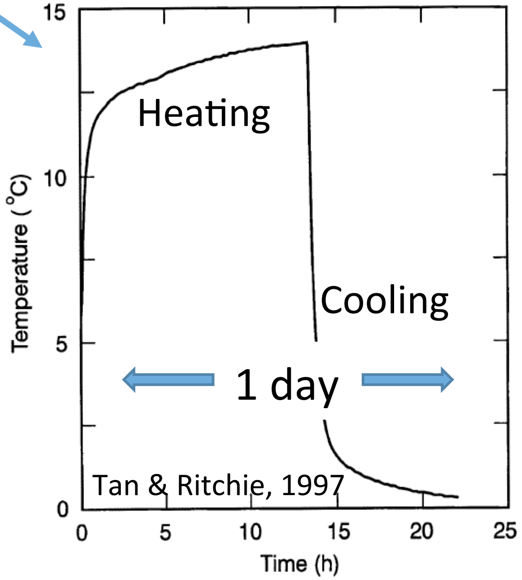


Thermal conductivity

- Insight into heat transport characteristics of the WR, presence or absence of ice and water
- <u>Thermal conductivity probe</u>: custom assembly of several heating wires and thermistors
- Take measurements every few meters along the length of a 2-4 inch PVC standpipe access port in a borehole or buried in a WRD
- Custom-built datalogger controls and records heating and cooling response
- Temperature recorded during 13 hr heating and 10 hr cooling (1 depth/day) cycle is used to calculate the thermal conductivity
- TC doesn't vary much between waste rock types (0.6 to 5 W $m^{-1}C^{-1}$) but is sensitive to WR heterogeneity, moisture content, ice

Thermal conductivity probe

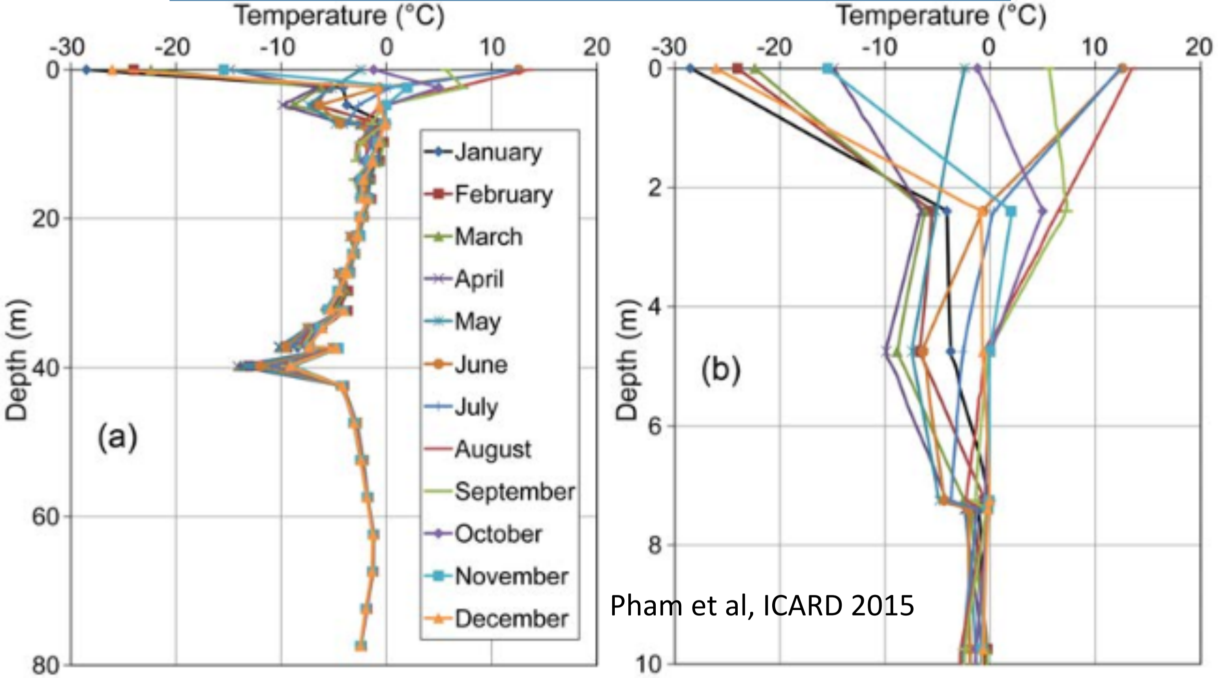




Subsurface temperatures

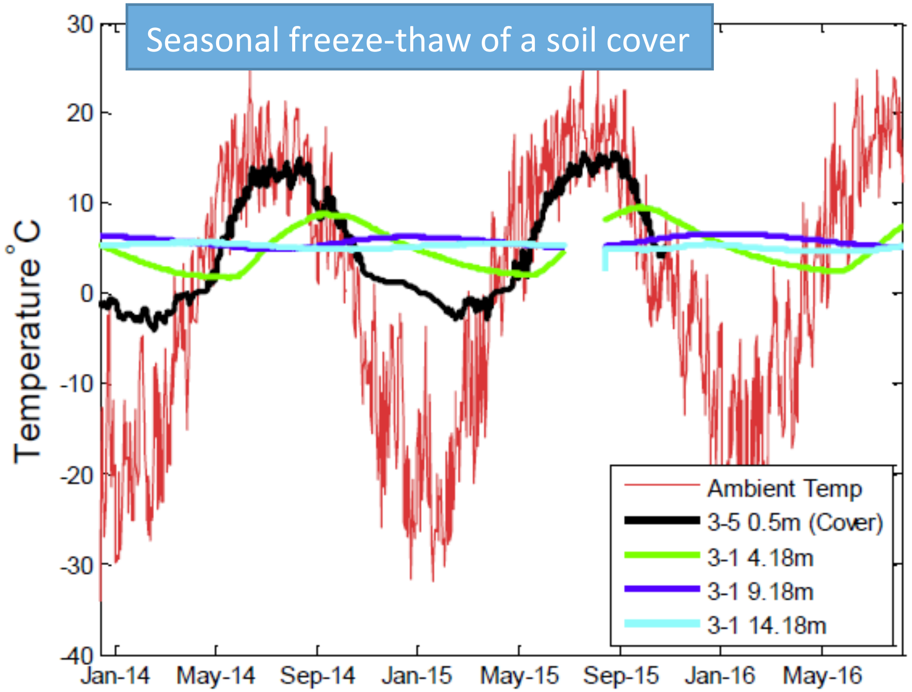
- Multipoint thermistor strings – continuous monitoring at multiple depths, or move the string from one location to the next and use a portable reader/ammeter
- Rough cost: $15/m of cable and $110/thermistor bead
- Single point thermistors – inexpensive but slow, tedious to get detail
- Certain moisture sensors record temperature (cost savings)

Permafrost region waste rock with 4.5 m active zone



Pham et al, ICARD 2015

Seasonal freeze-thaw of a soil cover



Hand excavations and installation with portable gas drill (*e.g.*, Pionjar)

- Limited to shallow depths (<2 m) and narrow diameter instruments (<5 cm)

+ Can be done any time, easy to do, minimal planning
+ No heavy equipment costs, inexpensive
+ Reliable installation method, poses few challenges
+ Minimal disturbance of WR matrix, so instruments equilibrate quickly
+ One or two instruments per Pionjar hole; a few per test pit

Excavator test pits

- Effective to about 3-4 m depth

+ Relatively inexpensive, *e.g.*, 9 x 9 m x 3 m deep = < $5000
    - Mobilization may impact cost
+ Reliable instrument placement
+ Sampling opportunities

- Waste rock is extensively disturbed near the instruments
- Regular sampling to monitor re-establishment of moisture, gas and chemical equilibrium

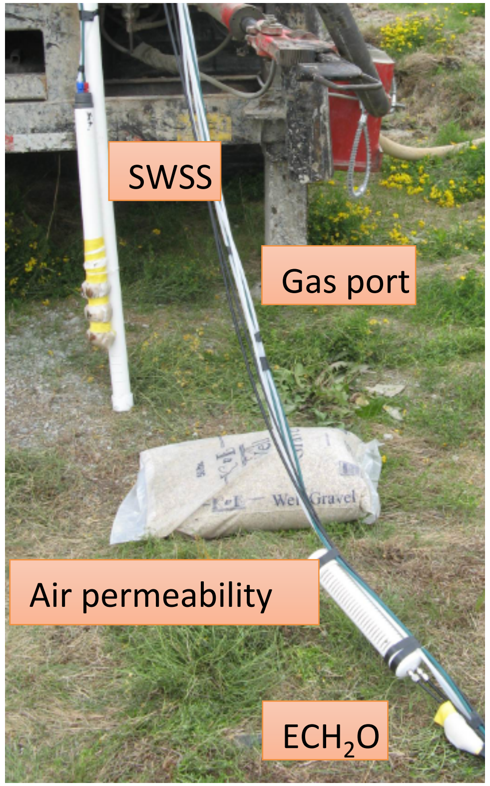
Instruments placed on active WRD surfaces

- Placed on dump face or driving surface during waste rock deposition

+ Installation includes knowledge of nearby waste-rock characteristics
+ Can modify placement to obtain best coverage and reliable installation
+ Good chance for success in locations that would be challenging by other methods (*e.g.*, base rubble zones)
+ Minimal use of heavy equipment keeps costs low

Instrument string for WRD surfaces and boreholes

- Assemble bundles of instruments ahead of time to minimize standby costs
- Bundle = Multiple instruments terminating at different depths (SWSS, gas, air perm, moisture, thermistor)
- Build with borehole dimensions in mind.



Instruments placed on active WRD surfaces

- Instruments, wires and tubes <u>must be protected</u> using rigid and flexible PVC pipe, small waste rock
- Logistic challenges: <u>Equipment</u> operators must be careful
- Some instrument damage has to be expected
    - Install redundant points to account for inevitable losses
- Takes time for WRD to wet up and for representative geochemical, gas and moisture patterns to develop
- Regular monitoring to tell when equilibrium reached

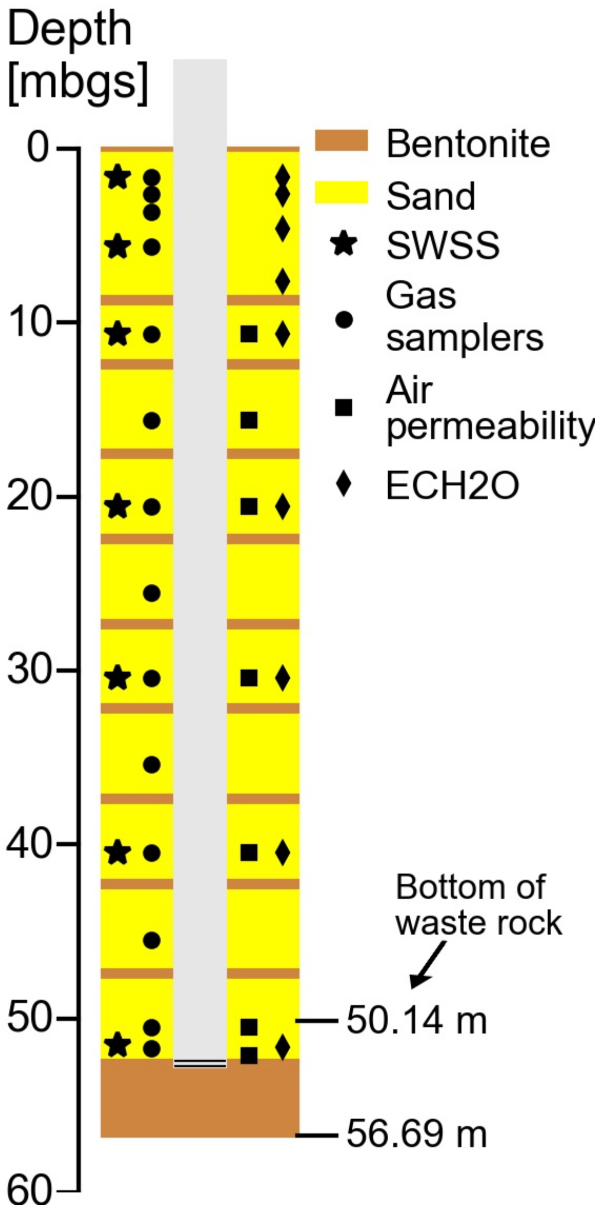
Borehole drilling

- *e.g.*, Dual rotary air, sonic drilling
- Drill hole, retrieve cuttings/core, place instruments, backfill as casing pulled
- Backfill with drillers silica sand at instrument depths
- Bentonite layers between instrument depths
- Lots of instruments can fit in a typical 15-20 cm diameter borehole
- Fast: DR = 25 m/day; Sonic = 40-80 m/day

Example:

20 cm dia x 55 m hole

- 10 ECH_2O
- 15 gas ports
- 7 SWSS
- 7 permeability
- 1 thermistor string
- 30 cm bentonite layers



Borehole drilling

- Expensive
  - Dual rotary air, *e.g.*, $300 per meter, some cuttings, no core
  - Sonic *e.g.*, $1,000 per meter, 100% core recovery, but it is heavily pulverized
- Ideally avoid drilling methods that use water. When water is used, it can affect water chemistry, moisture, temperature, conductivity values
  - Sonic generally doesn't use water or air
  - Compressed air used for DR cutting return may temporarily affect pore gas
- In all cases, monitor over time to identify when sample points have equilibrated with surrounding materials
- Core log from sonic drilling can help correlate water chemistry and sensor readings

Thank you

- Questions?

Acknowledgements

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