Rock Sampling using the Ultrasonic/Sonic Driller/Corer (USDC) for In-situ Planetary Exploration

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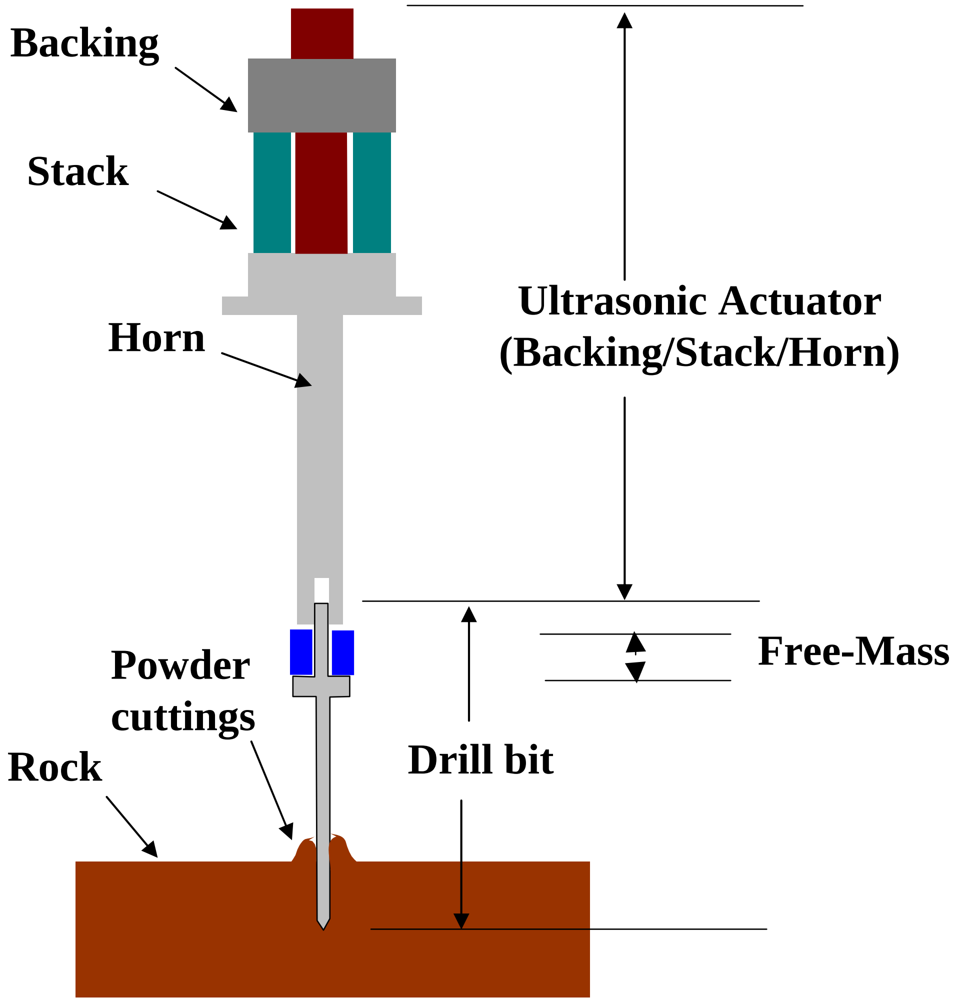
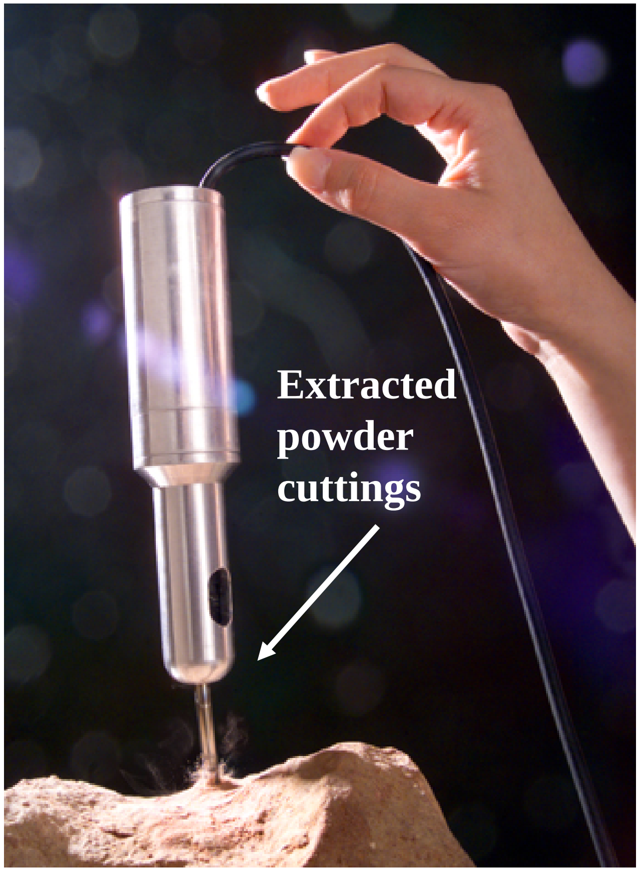
Ultrasonic/Sonic Driller/Corer (USDC)



2000 R&D 100 award



Applications of the USDC

Quiet concrete drill

Powdered cuttings sampler

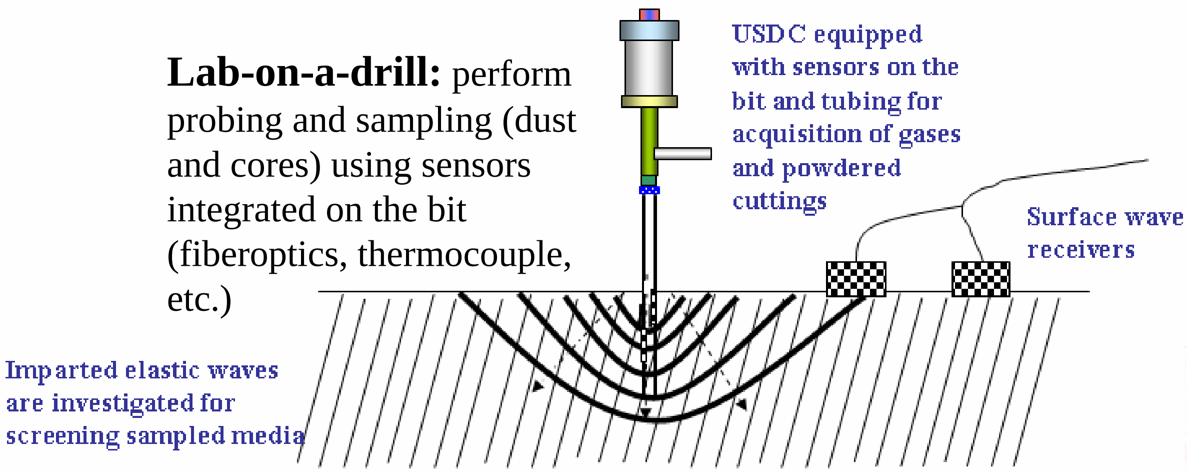
2000 R&D 100 award

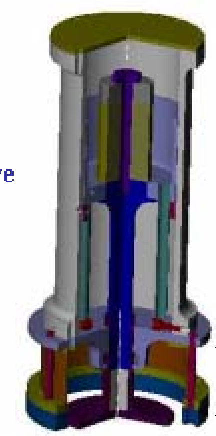
Simple feasibility tests was made operating the USDC from the Sojourner and the FIDO robotic arm

Ultrasonic Gopher for deep drilling

Proto-flight unit

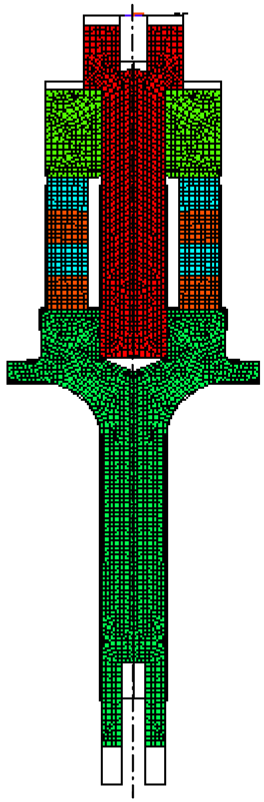
Lab-on-a-drill: perform probing and sampling (dust and cores) using sensors integrated on the bit (fiberoptics, thermocouple, etc.)

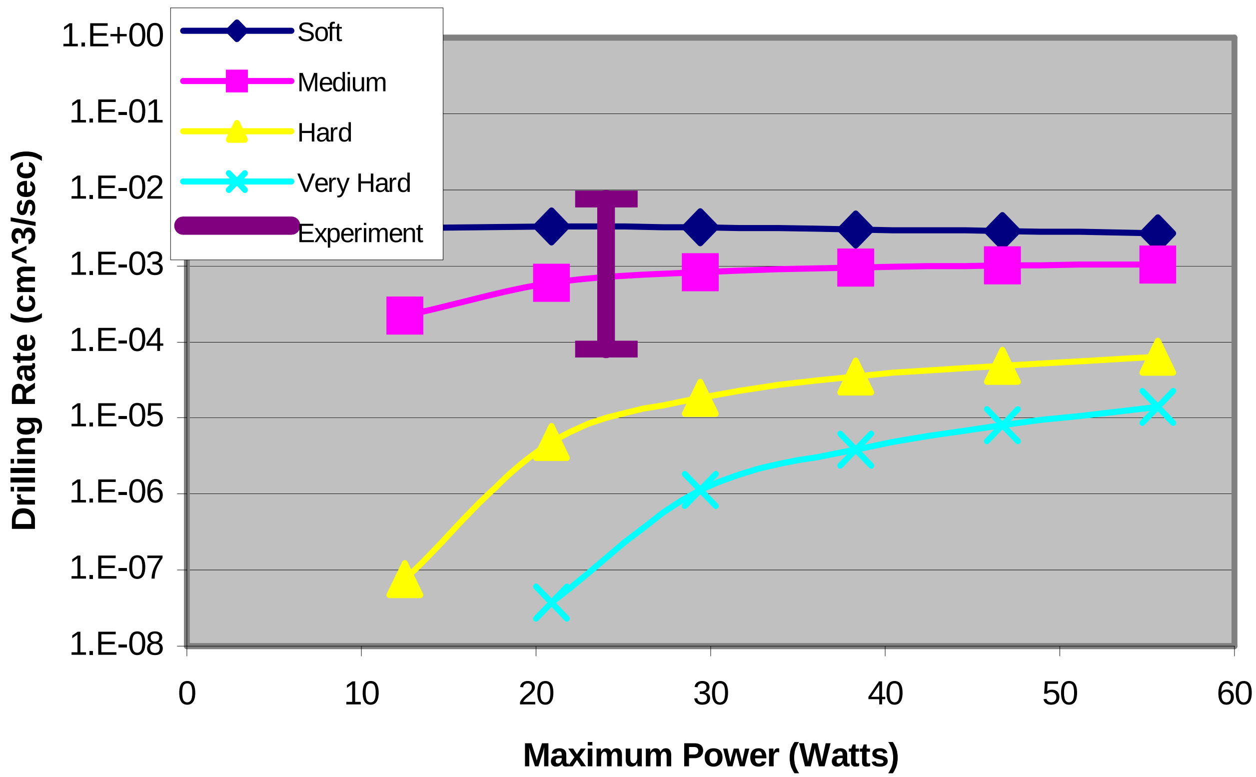




Ultrasonic Rock Abrasion Tool (**URAT**)

Drilling rate for different maximum power

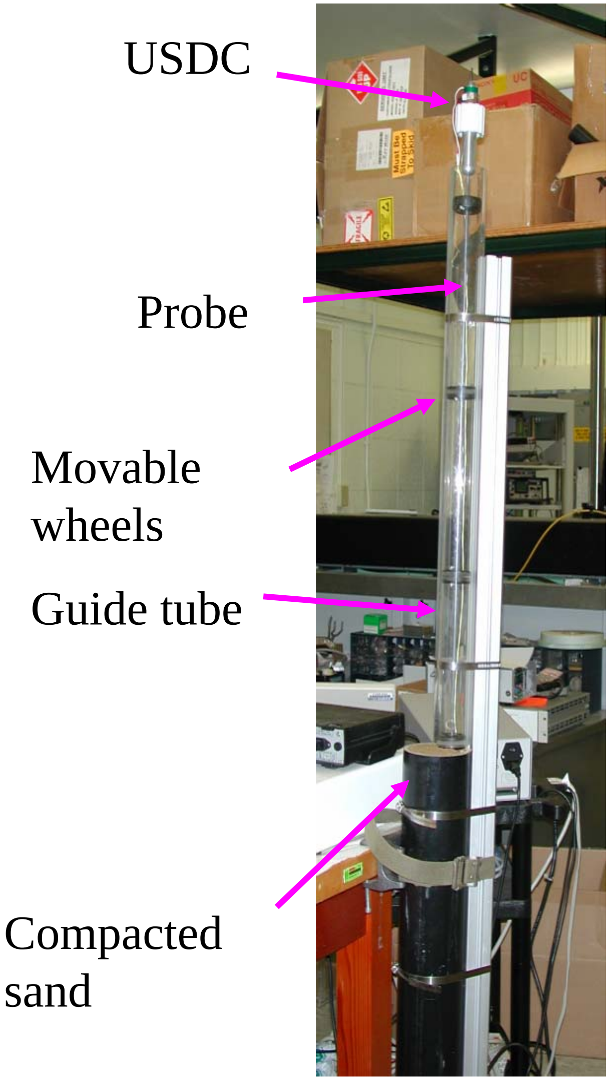




The average power is maintained at 10 watts by duty cycling the power supply

Note: The range described by the error bar was determined experimentally from a variety of rock samples.

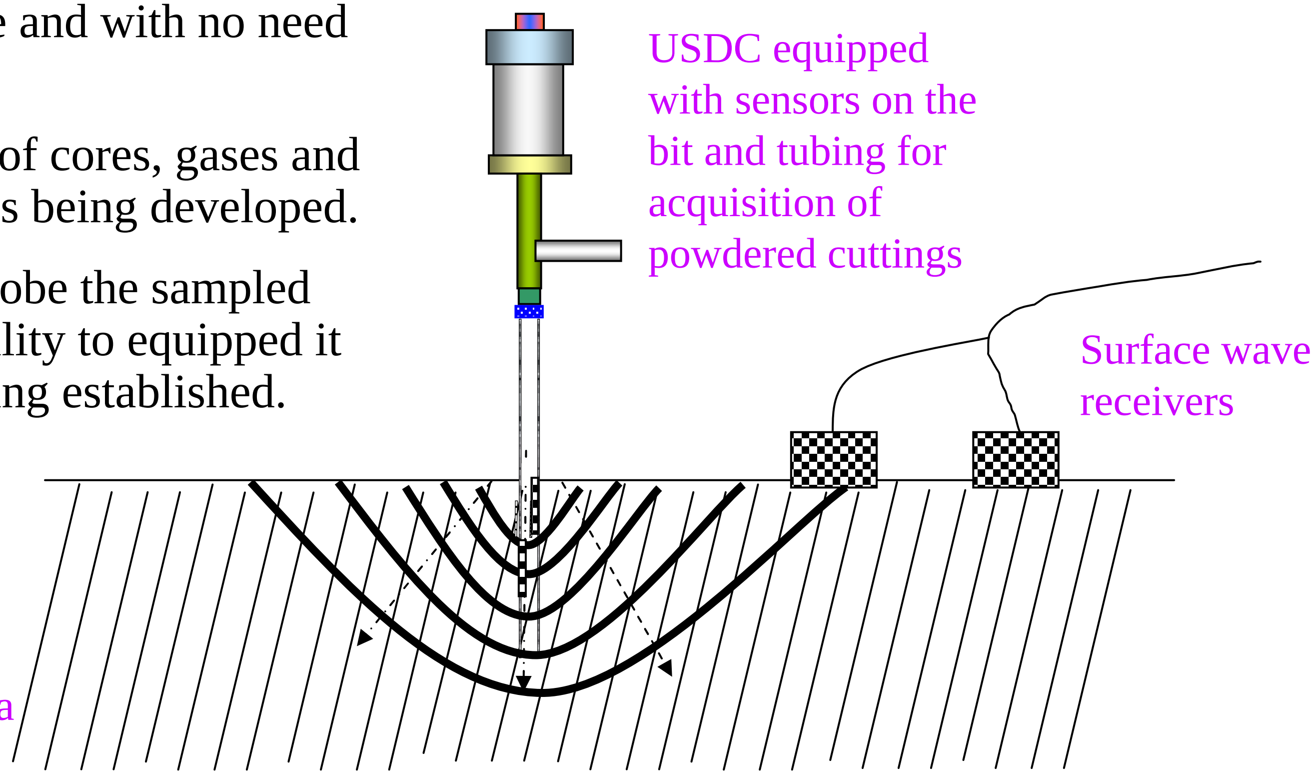
Soil penetrator and test bed



- Using 7 lb preload at ~70W and 20% duty cycled power, we reached a depth of 3-ft (~90-cm) in 30-40min.
- Since we used duty cycling the net drilling time is only about 6-8 minutes.

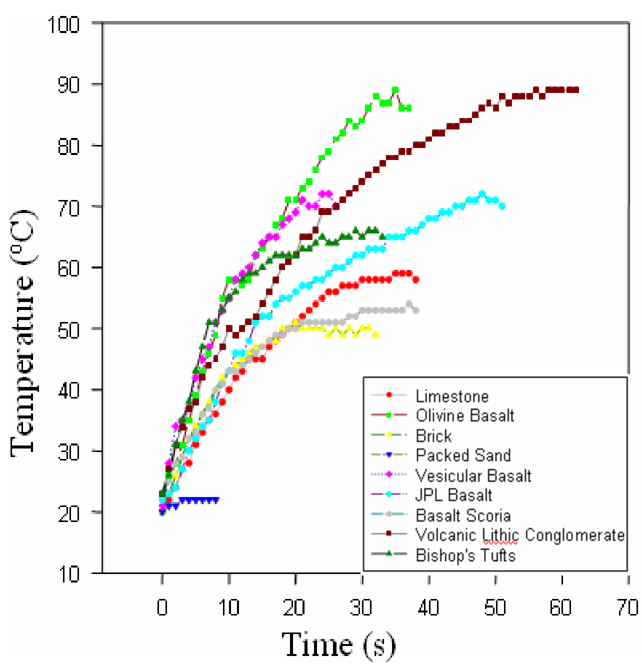
The Ultrasonic/Sonic Driller/Corer (USDC) as a probing, sampling and sensing system

- The USDC was demonstrated to core samples from rocks that range in hardness from soft to very hard using very low axial force and with no need for bit sharpening.
- Effective sampling of cores, gases and powdered cuttings is being developed.
- The capability to probe the sampled medium and the ability to equipped it with sensors are being established.



Bit Temperature measurements

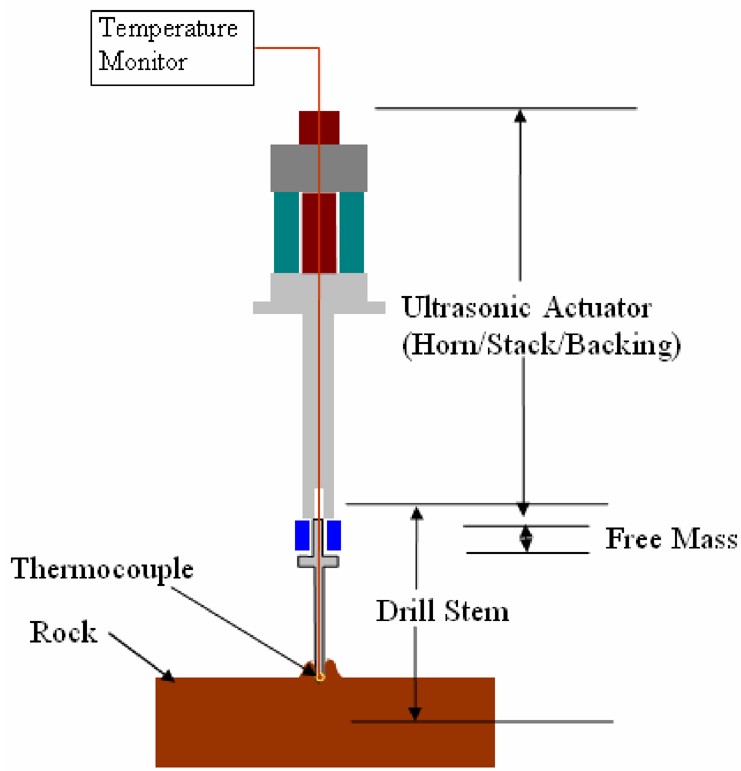
A thermocouple was integrated into the USDC bit to allow real time monitoring the temperature during drilling.



Temperature rate of rise and maxima as a function of time for drilling variety of media

Power < 40 watts

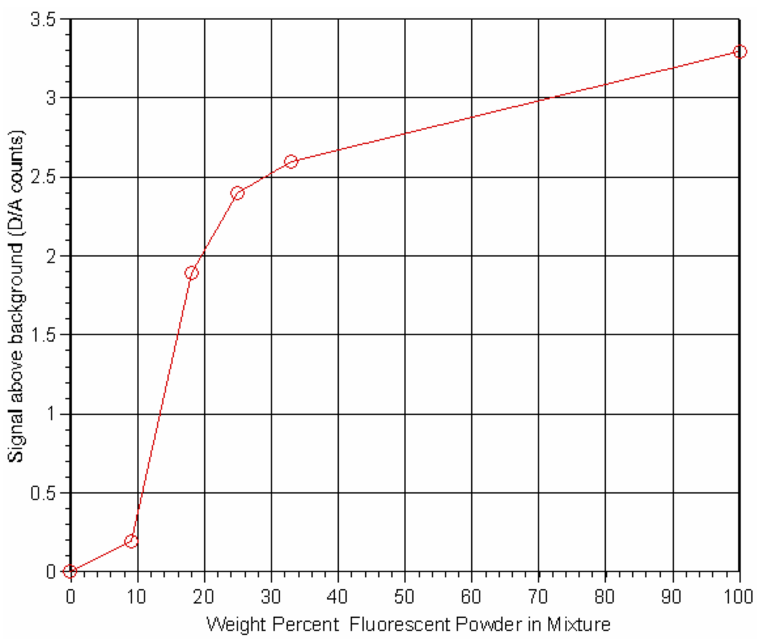
Bit diameter = 3.6 mm



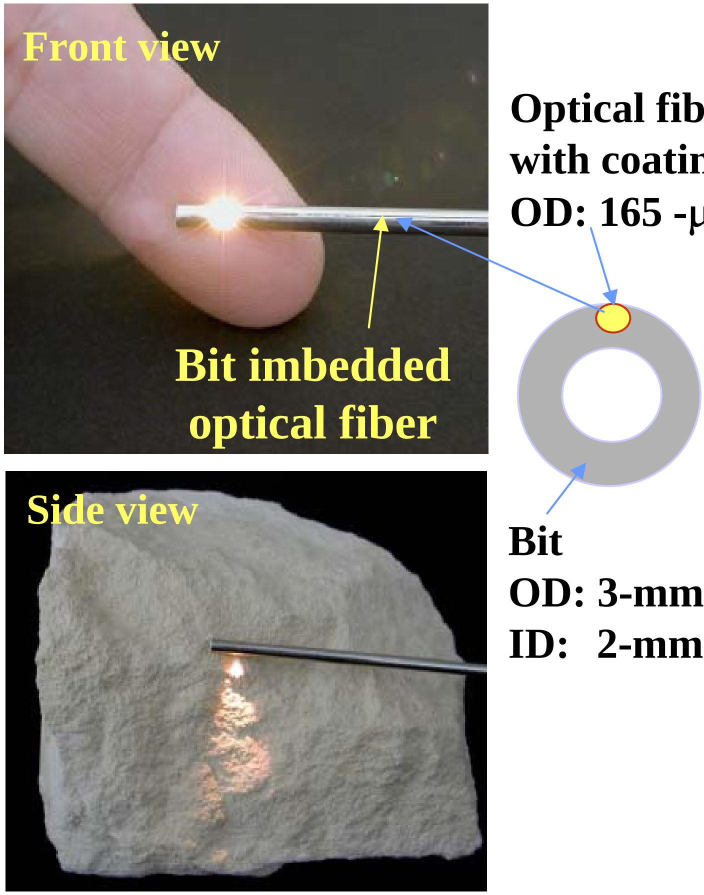
Experimental Setup

Integrated fiberoptics and measured reflectivity

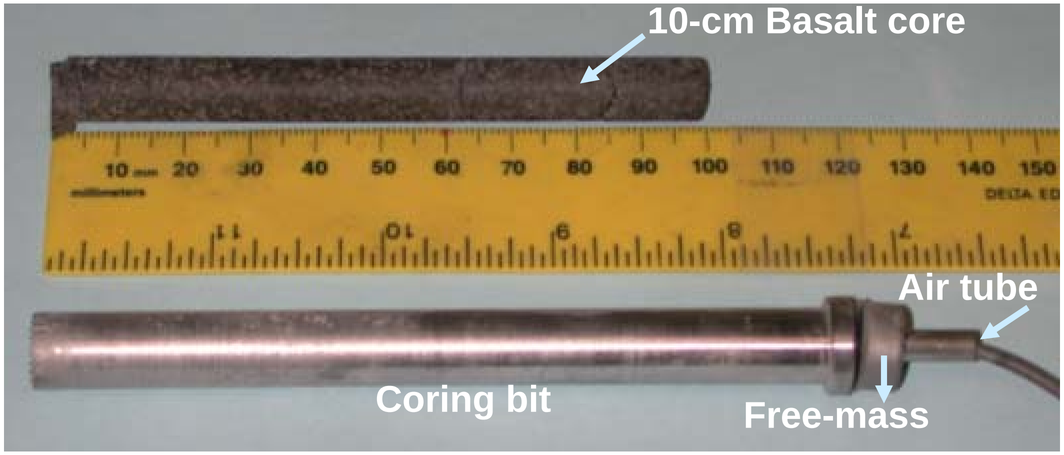
Preliminary study jointly with Research International, Inc

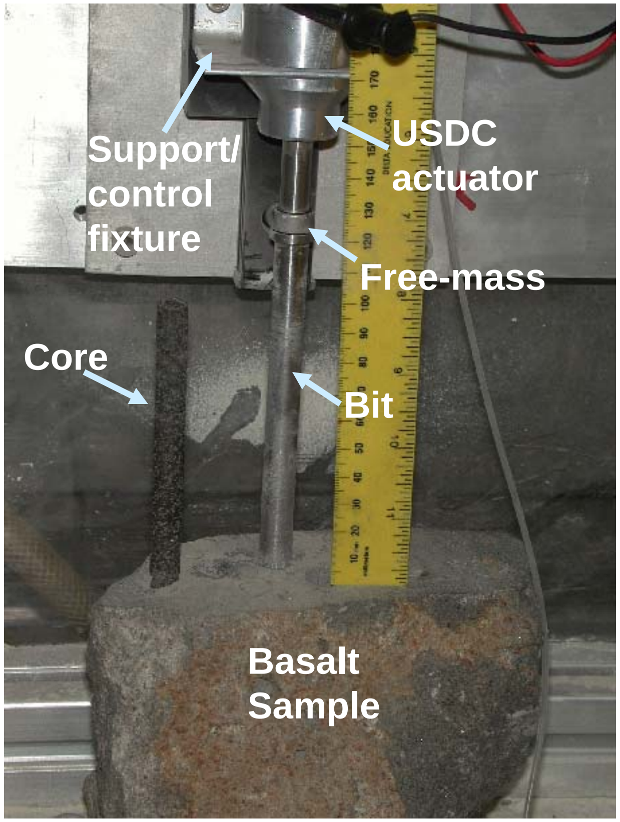


Differential response in the range of 545nm and 700nm



Coring basalt via the USDC

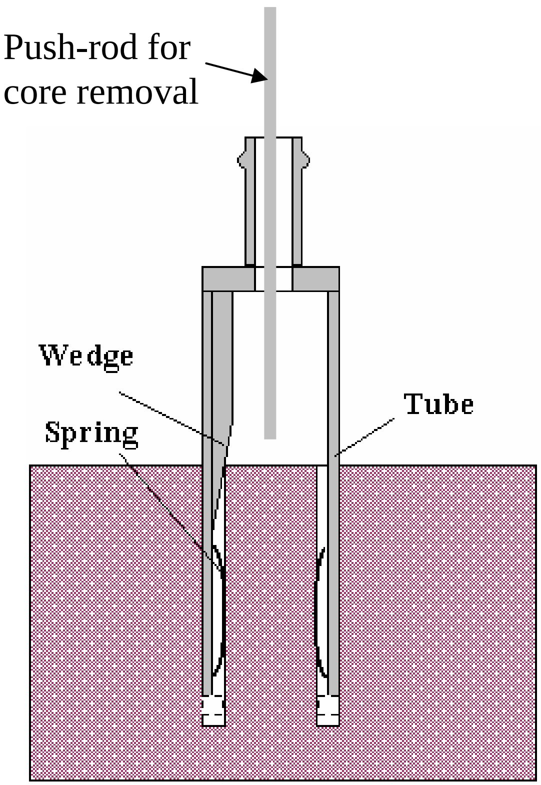




Coring set-up

USDC Core Breaking/Holding/Extracting

All-in-one bit using an internal wedge and side springs



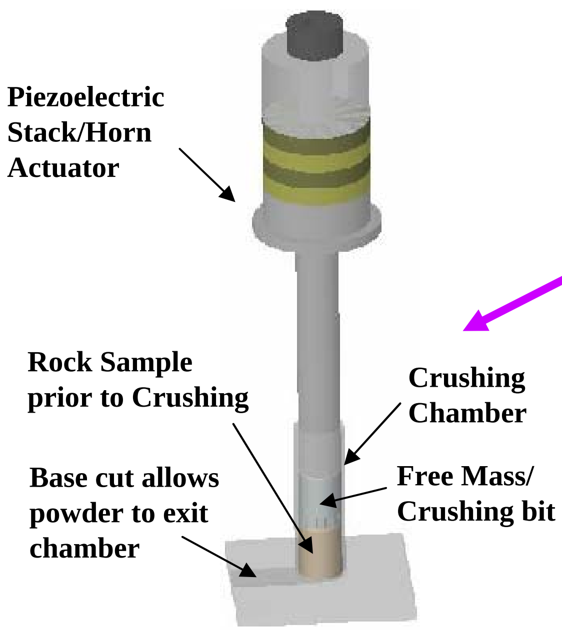
Retaining spring and a grabbed core

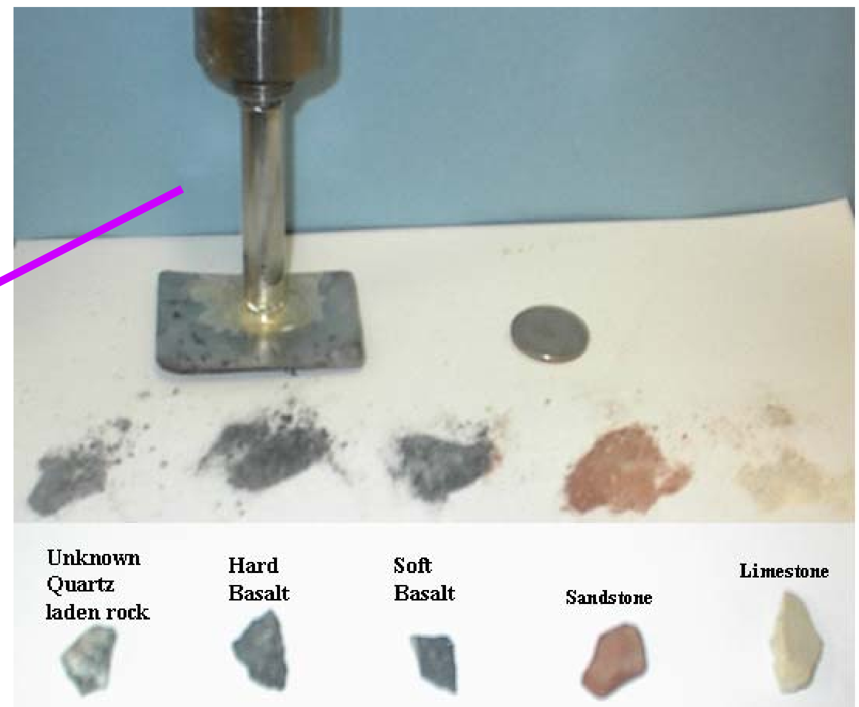
Two created cores (out of two attempts)

Powdered Cuttings

USDC crusher

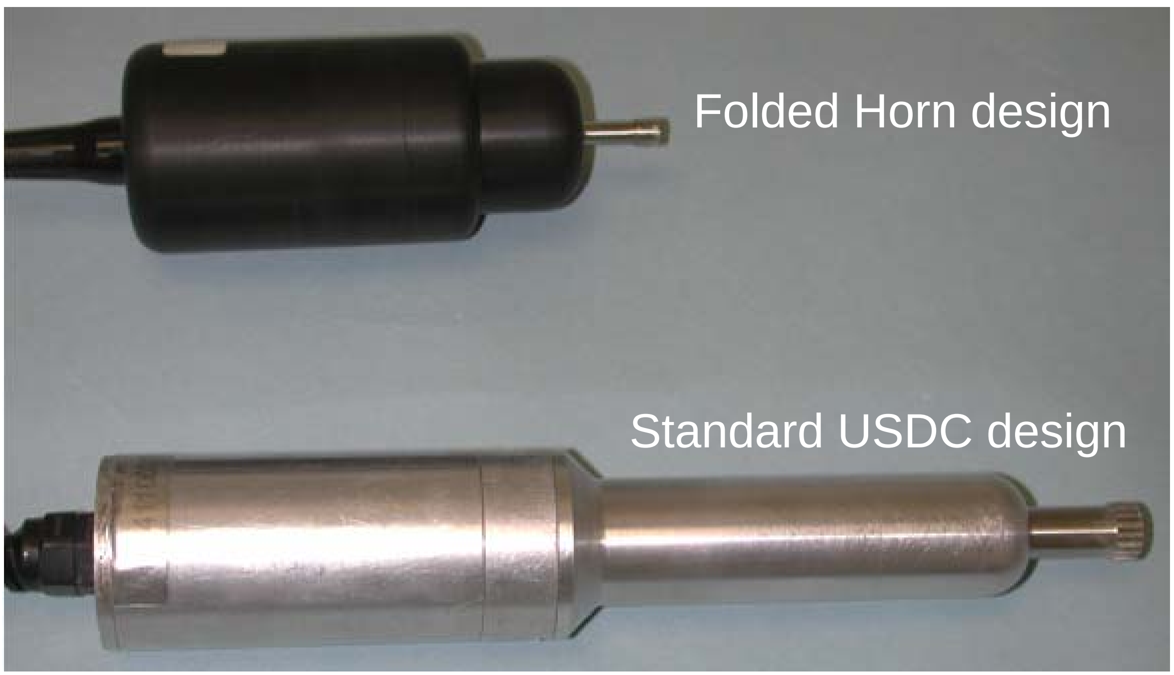
- The USDC is used as a rock crushing, milling, and powdering device.
- Its actuator harmonic motion creates a series of low frequency impacts that grind the sample into powder within a short time period.
- A crushing chamber confines the free-mass to movement in one direction only leading to a very efficient milling.
- The grinding effect can be enhanced by making a free-mass with teeth on its interface with the sample.

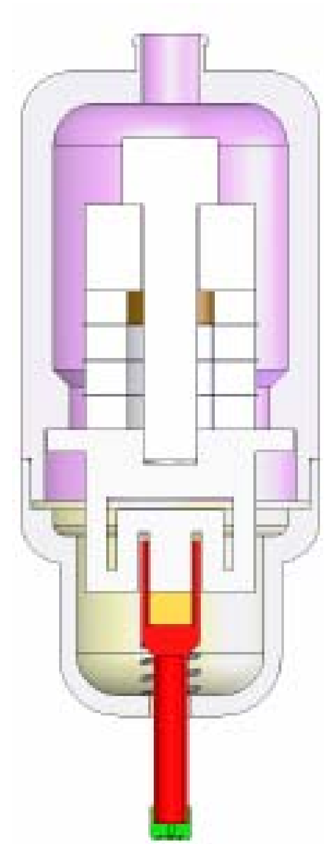




Dimensions reduction

- Using a folded horn the length of the powdered cuttings sampler was significantly reduced.





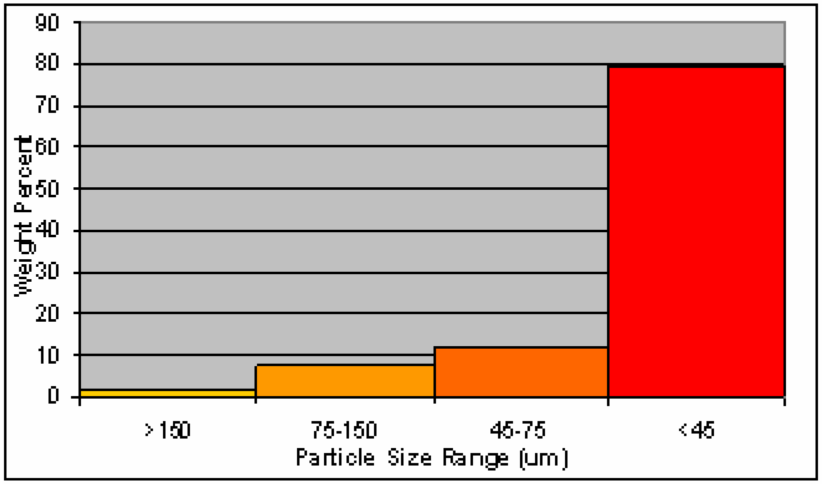
Powdered Cuttings Sampler

A view of the bit cutting edge

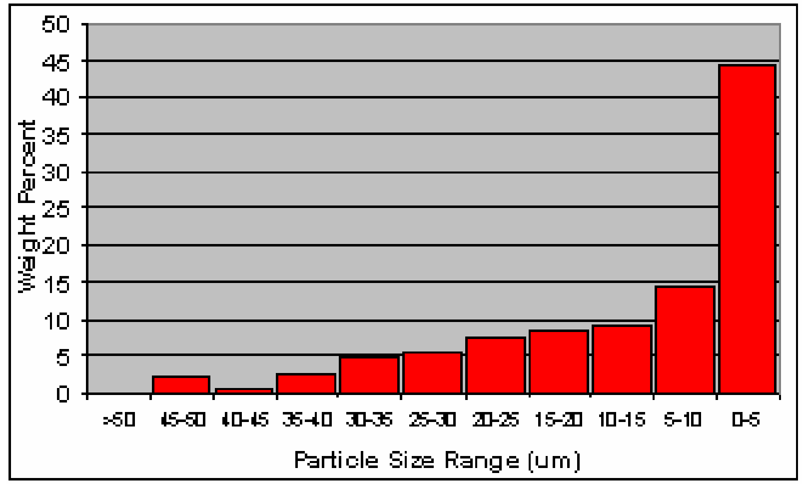
Sampled powder

The sampler in action drilling limestone and accumulating powdered cuttings inside the bit

CHEMIN Sample #1 – Chinle Sandstone



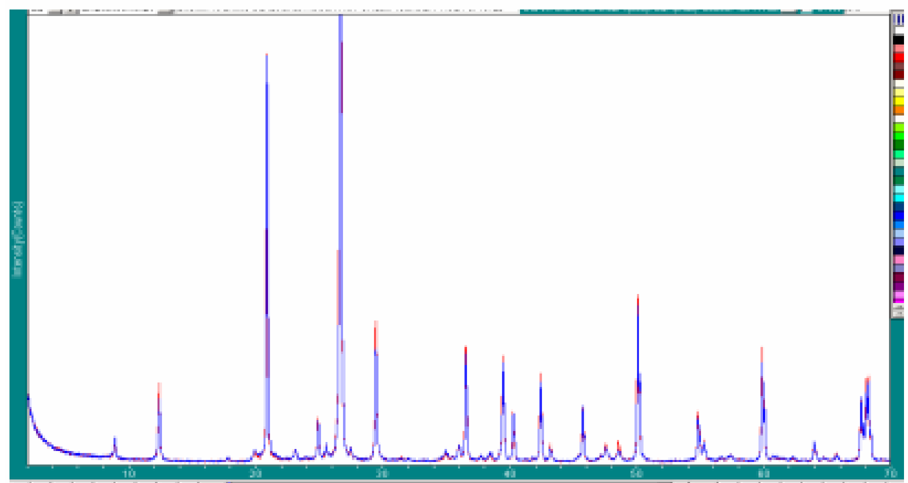
Size fractions obtained during wet sieving



Particle size distribution of the <45μm powder obtained using a Horiba CAPA-500 particle size distribution analyzer.

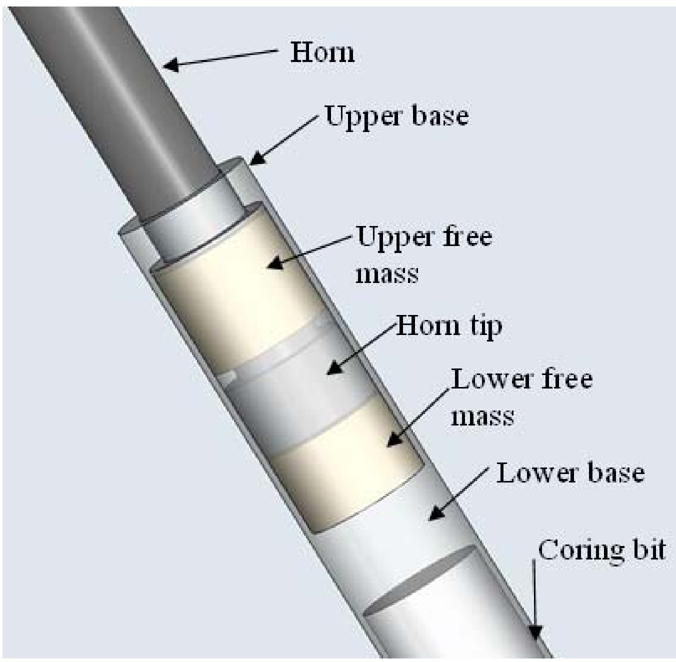
LANL's Lab XRD patterns of the <45 μ m USDC powder (blue) compared to the Retsch milled <5 μ m powder (red).

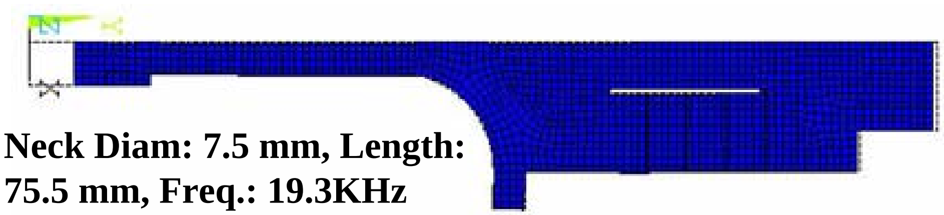
Note: The patterns compared extremely well.



Dog-bone horn

The dog-bone horn offers in addition to the performance enhancement also design benefits as a mounting fixture.



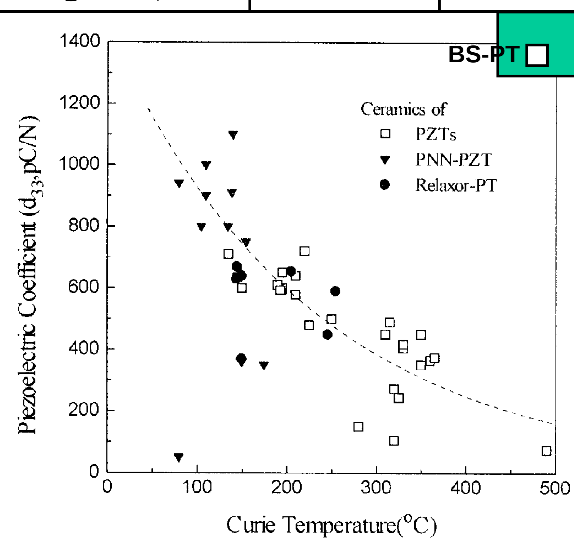


Neck Diam: 7.5 mm, Length: 75.5 mm, Freq.: 19.3KHz

Operation in extreme environments

Comparison of various Piezoceramics with $BiScO_3$–$PbTiO_3$

Material	Structure	T_c (˚C) (C/cm^2)	P_r	E_c kV/cm	d_{33} pC/N
PZT-5A (soft)	Perovskite (MPB)	330	36	~ 10–12	~ 400
PZT-8 (hard)	Perovskite (MPB)	330	25	> 15	~ 225
$PbNb_2O_6$ (modified)	Tungsten Bronze	~ 500	—	—	~ 85
$Na_{0.5}Bi_{4.5}Ti_4O_{15}$	Bismuth Layered	~ 600	—	—	18
$BiScO_3$– x$PbTiO_3$ x=62	Perovskite (rhombohedral)	420	28	17	290
$BiScO_3$– x$PbTiO_3$ x=64	**Perovskite (MPB)**	**450**	**32**	**21**	**465**
$BiScO_3$– x$PbTiO_3$ x=66	Perovskite (tetragonal)	460	23	25	260



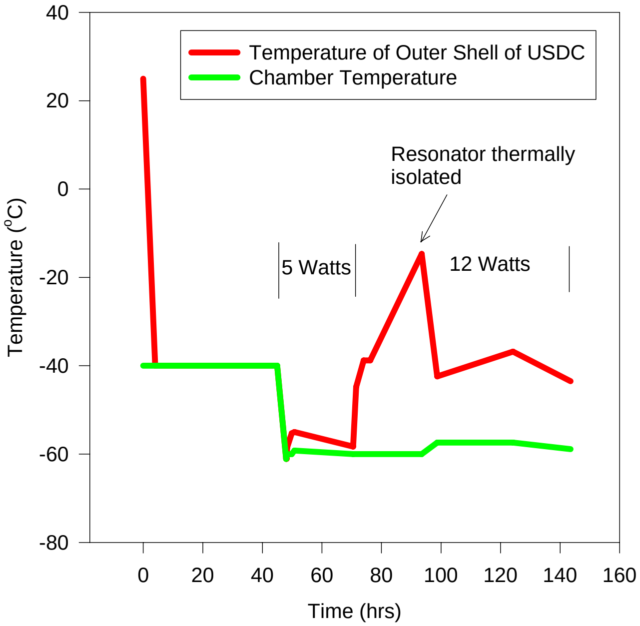
Ref: T. Shrout, Penn State U.

Preliminary tests of USDC at Low temperatures

Demonstrated drilling cold ice including: -40ºC crashed ice, crashed ice with water and solid ice as well as -140ºC in crashed ice and solid ice.

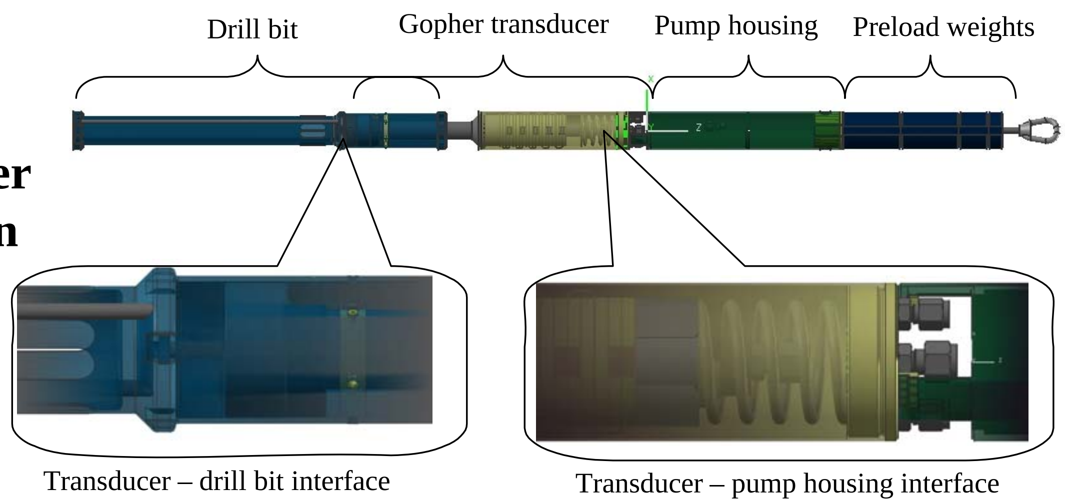
- **Crashed ice at -40ºC and 140ºC -** At both -40ºC and 140ºC no problem drilling and the speed was too fast to measure.
- **-40ºC slush ice with water** - Drilled 7mm deep using 6-mm diameter drill in 1-minute.
- **-40ºC solid ice -** About 1-cm in about 30-sec.
- **-140ºC solid ice -** Cored about 3-mm deep using a 10-mm diameter
- **-40ºC and -60ºC** - Environmental testing for 160 hours

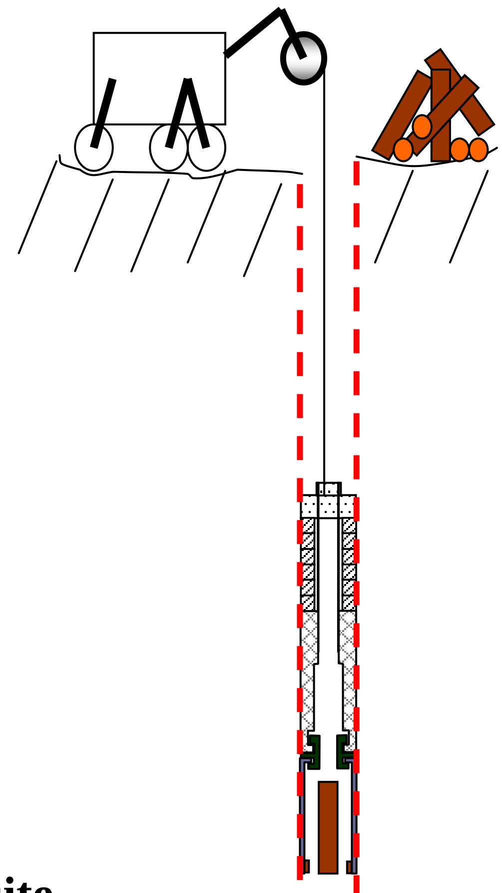
Tests were done at the JPL's Extraterrestrial Materials Simulation Laboratory.



Gopher

Gopher design





Mt. Hood test site

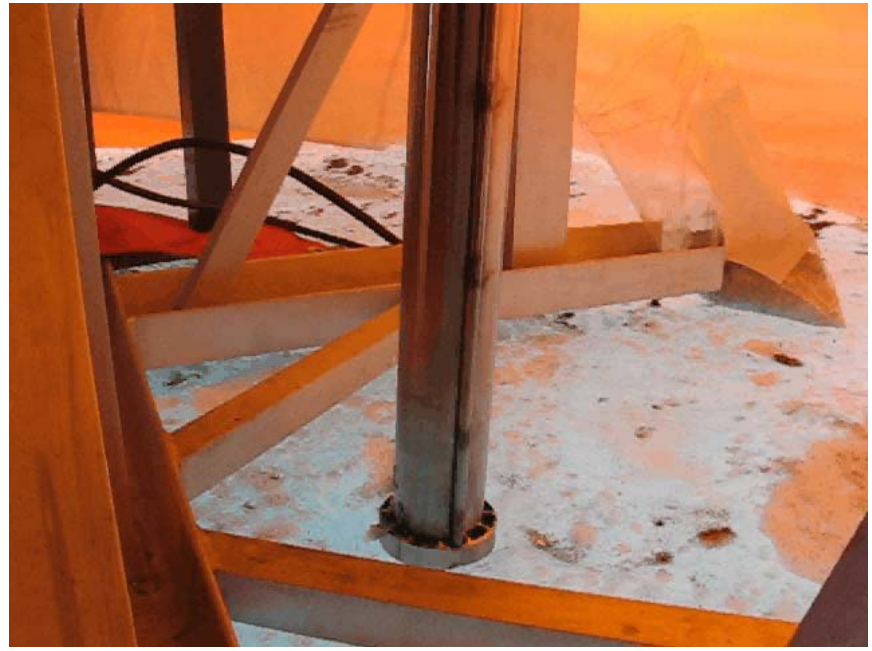
Close up view of the drill site

A total of 1.25-m was accomplished in a total drilling of 5 hours with an average drilling of 0.25 m/hr.

Field test in Lake Vida, Antarctica

A total depth of 176cm was reached

Lake Vida test site.



Inside the drilling tent.

The gopher in the drilled hole

SUMMARY

The USDC has been studied as a probing device that can sample cores, powdered cuttings as well as operate as a platform for sensors

Noninvasive probing

- The reflection and transmission of imparted elastic waves (bulk and surface) were measured to establish means of rocks characterization. Also, the effect of loading the actuator by the sample were monitored by measuring the change in impedance and resonance frequency.
- Surface wave velocity measurements were the only reliable quantitative data that was obtained.

Sampling techniques

– Methods of operating the bit as an all-in-one unit for extraction of cored rocks (including basalt) with maximum integrity were developed.
- Devices for the acquisition of powdered cutting and cores of various materials were developed and being studied including powder sampler, gopher and many others.

Integrated sensors

– An integrated thermocouple showed great potential in determining the hardness of drilled rocks using the heating rate and maximum temperature rise. Assuming relatively similar heat transfer to rocks, this should provide an effective sensing technique. It can also help protecting cored samples from thermal damage.
– We demonstrated the integration of an optical-fiber into a bit and the the measurement of reflectance and fluorescence levels in the wavelength range of 400 – 1150 nm.