GEOTECHNICAL PROPERTY TOOL ON NASA AMES K-10 ROVER.

leag-ilewg-srr

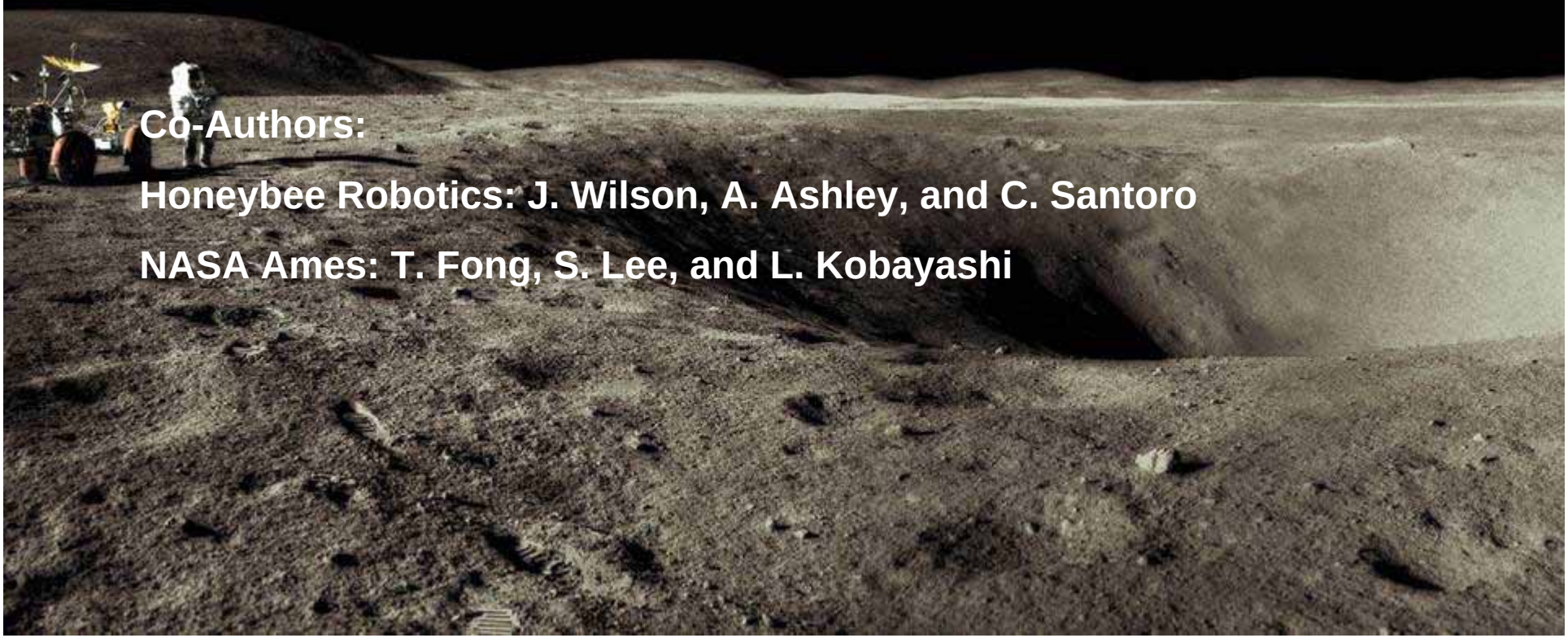
28-31 October '08, The Cape, FL

Kris Zacny, zacny@honeybeerobotics.com

Co-Authors:

Honeybee Robotics: J. Wilson, A. Ashley, and C. Santoro

NASA Ames: T. Fong, S. Lee, and L. Kobayashi



why measure soil mechanical (strength) properties?

When you want to build a house, road etc. you call geotechnical engineer first…

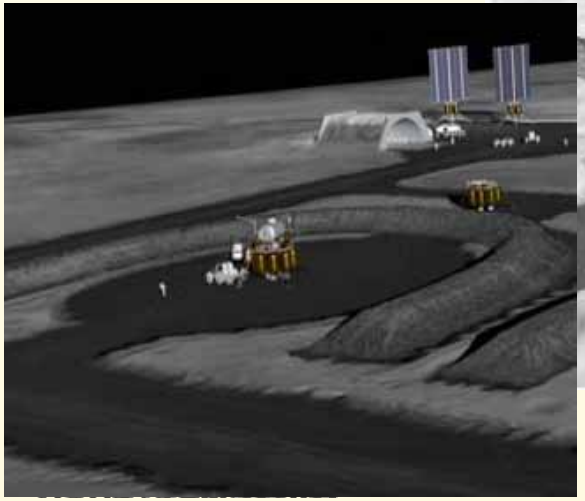
HONEYBEE ROBOTICS

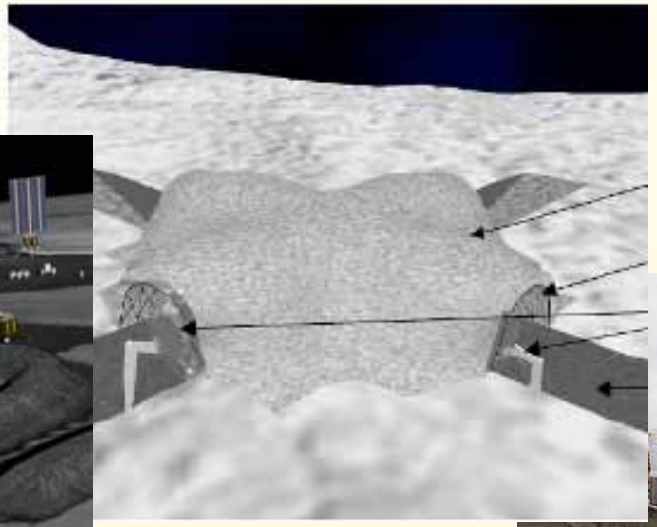
but is it important for the space exploration ?

yes

Surface operations require geotech data

- excavation forces and energy
  - size of an excavator
- traction requirements
  - mass, wheel design
- radiation protection (density)
- road/landing pad conditions





JSC Chariot

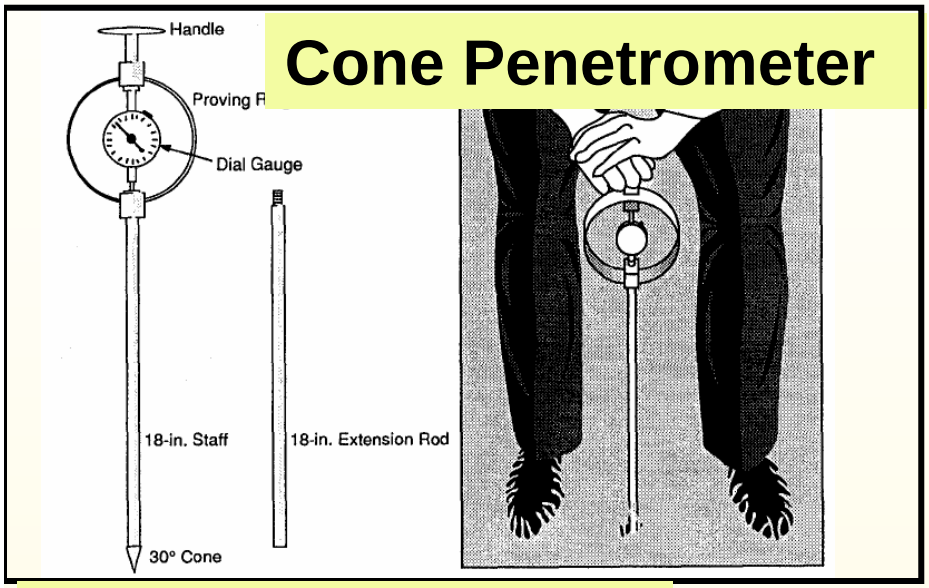
MER Opportunity

what has been done so far

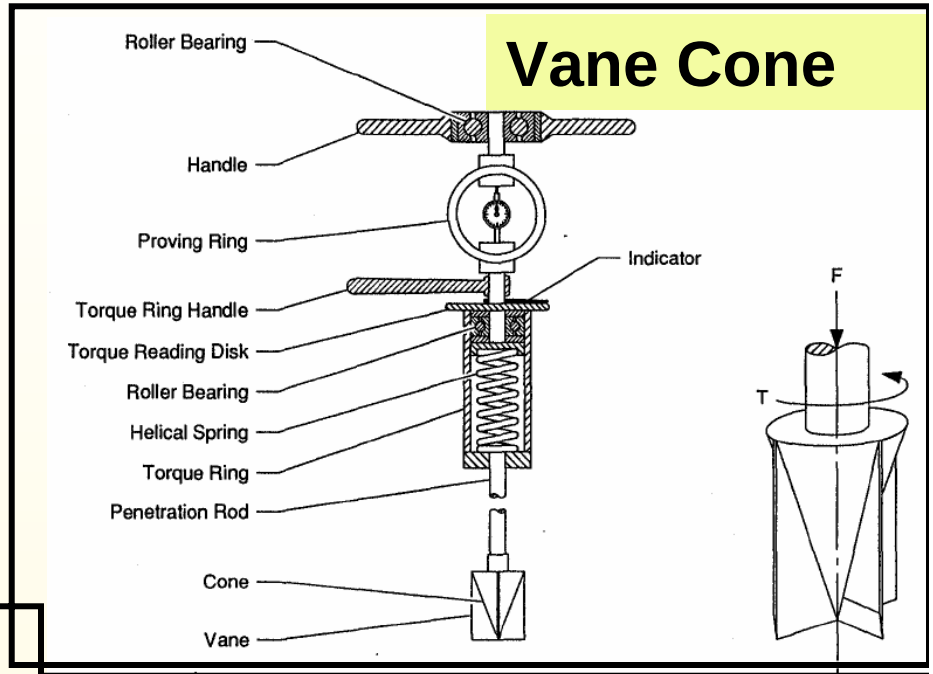
Methods of in-situ soil testing

S. Shoop, 1993

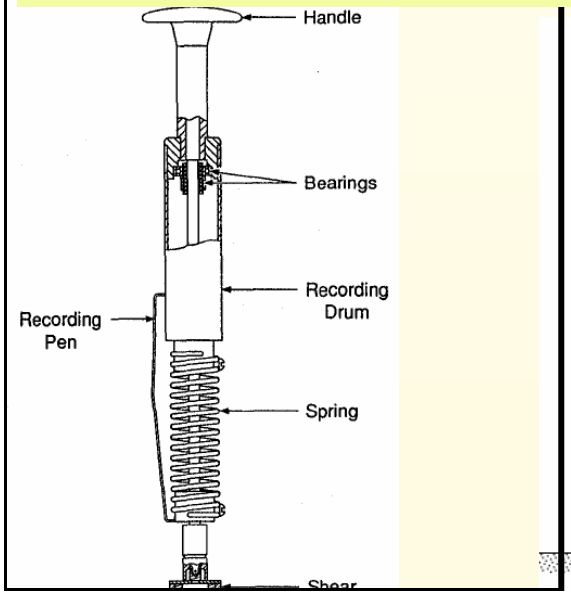
Cone Penetrometer



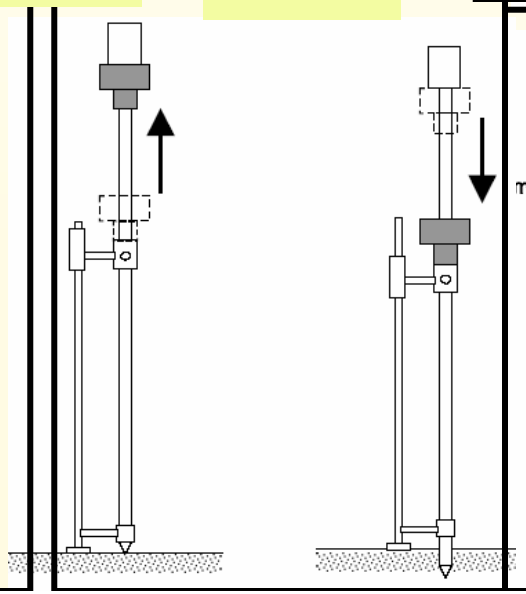
Vane Cone



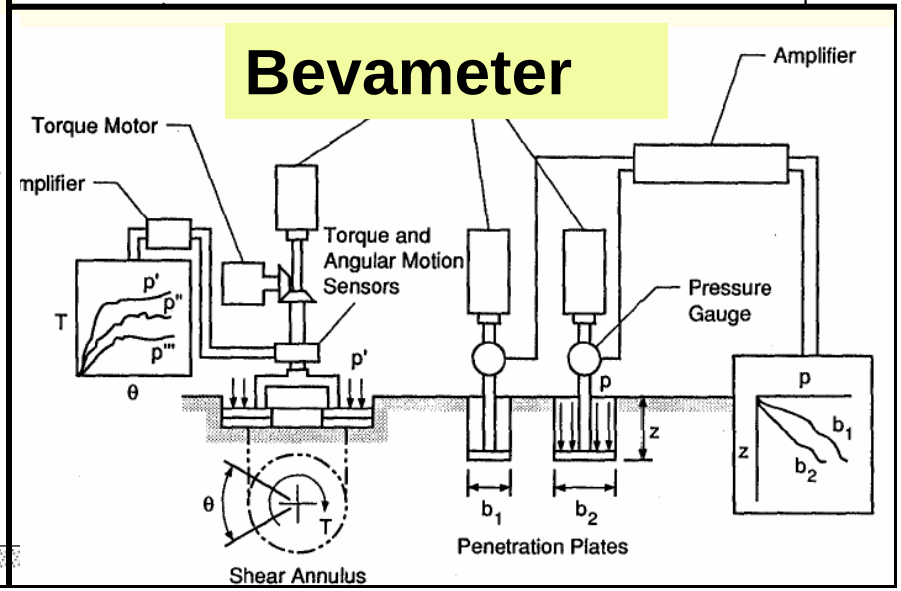
Cohron Sheargraph



DCP



Bevameter

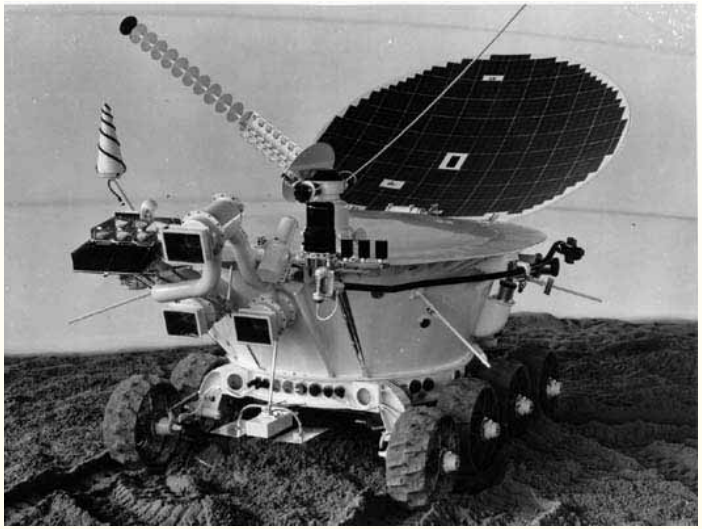


Space Heritage

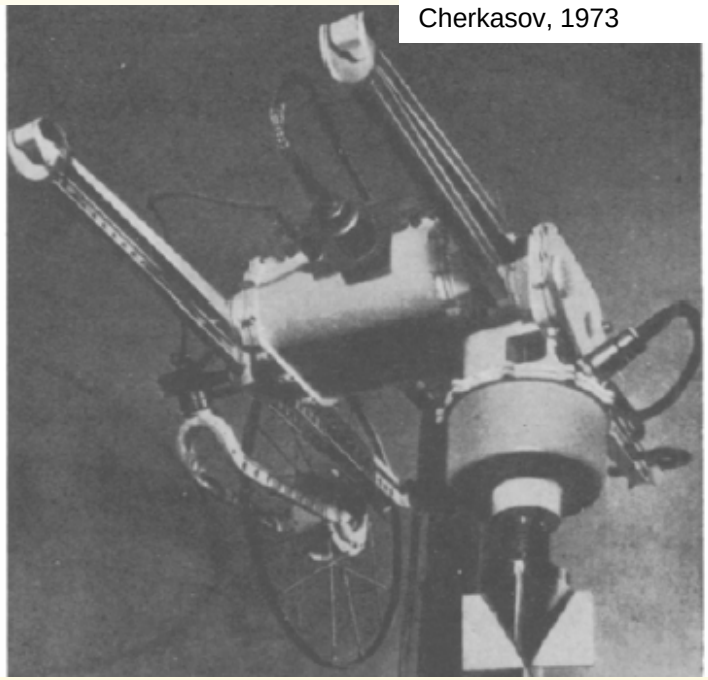
Soviet Lunokhod: Cone-Vane (>100 tests)

- Bearing capacity & Shear resistance
- **Surface measurements only**

- Findings
  - Greatest strength was found in the level areas between craters, the least in the circular embankments around craters.
  - The bearing capacity for the cone ranged from 0.2 to 1.0 kg/cm^2, with a most probable value of 0.34 kg/cm^2.
  - The most probable value of shear strength (according to vane test) is ~- = 0.048 kg/cm^2, with a range from 0.03 to 0.09 kg/cm^2.



Cherkasov, 1973

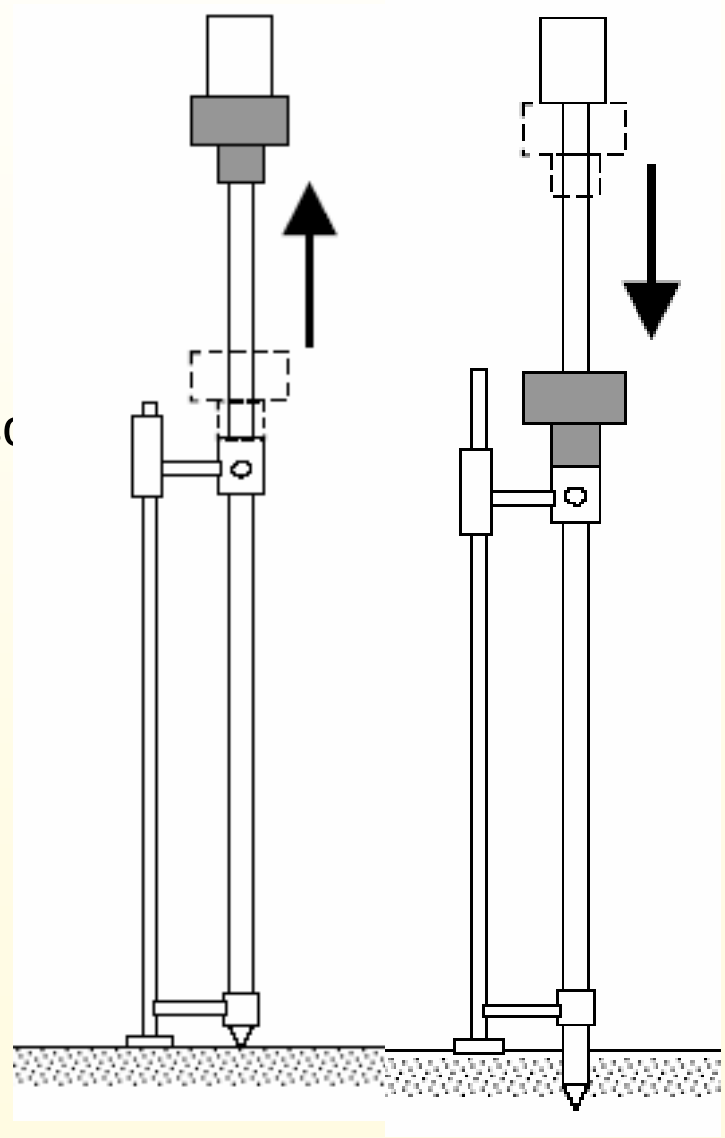


HONEYBEE ROBOTICS

what about greater depths?

Use Dynamic Cone Penetrometer

- Rate of penetration per impact is converted to
  - **California Bearing Ratio (CBR).**
- 1 < CBR < 100
  - CBR=1 (weak soils); CBR=100 (strong so



HONEYBEE ROBOTICS

And we can get other soil properties

- Additional correlations developed over the years
- Example: DCP test (in situ) vs. Tri-axial in lab on same soil (undisturbed)

Geotechnical parameter	What it describes	Relationship to CBR	Source
Bearing Capacity, q	A parameter used in the design of shallow foundations	$q(kPa) = 26.16 * CBR^{0.664}$	Portland Cement Association (PCA)
Dynamic Modulus (E) Resilient Modulus (M_R)	Characterizes soil under a variety of temperatures and stress states that simulate the conditions in a soil subjected to moving wheel loads. Dynamic Modulus: if loading is continuous (e.g. constant traffic) Resilient Modulus: if loading has a rest period (e.g. intermittent traffic)	$E(MPa) = 10.34 * CBR$	Huekelom and Klomp, 1962
		$E(MPa) = 17.58 * CBR^{0.64}$	Powel et al., 1984
The Modulus of Subgrade Reaction, k,	Used during the design and later in evaluation of rigid pavements	$k(M/m^3) = -65.91 - 1.49 * CBR + 35.23 * CBR^{0.5}$ For CBR < 20	Department of Defense Unified Facilities Criteria Manual, 2001
		$k(M/m^3) = -3.05 - 0.59 * CBR + 16.34 * CBR^{0.5}$ For CBR>20	

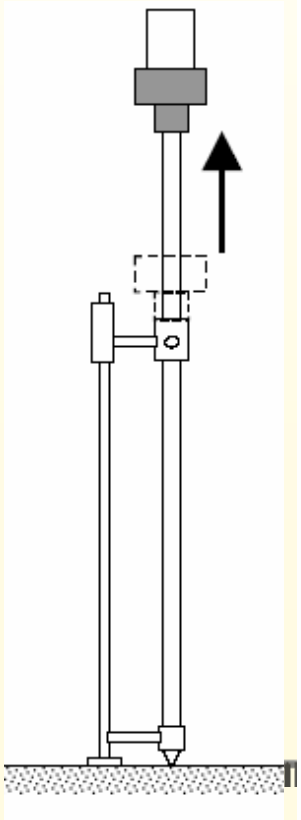
DoD has been using it for over 30 years…

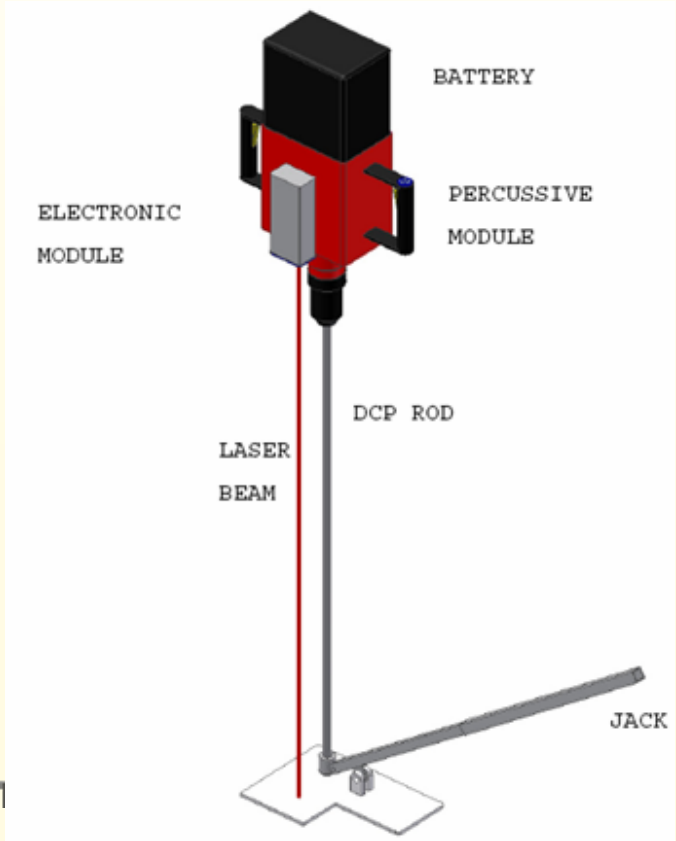
but…

they needed something ‘more’ man portable and easier to use…

Percussive DCP: Concept for DoD

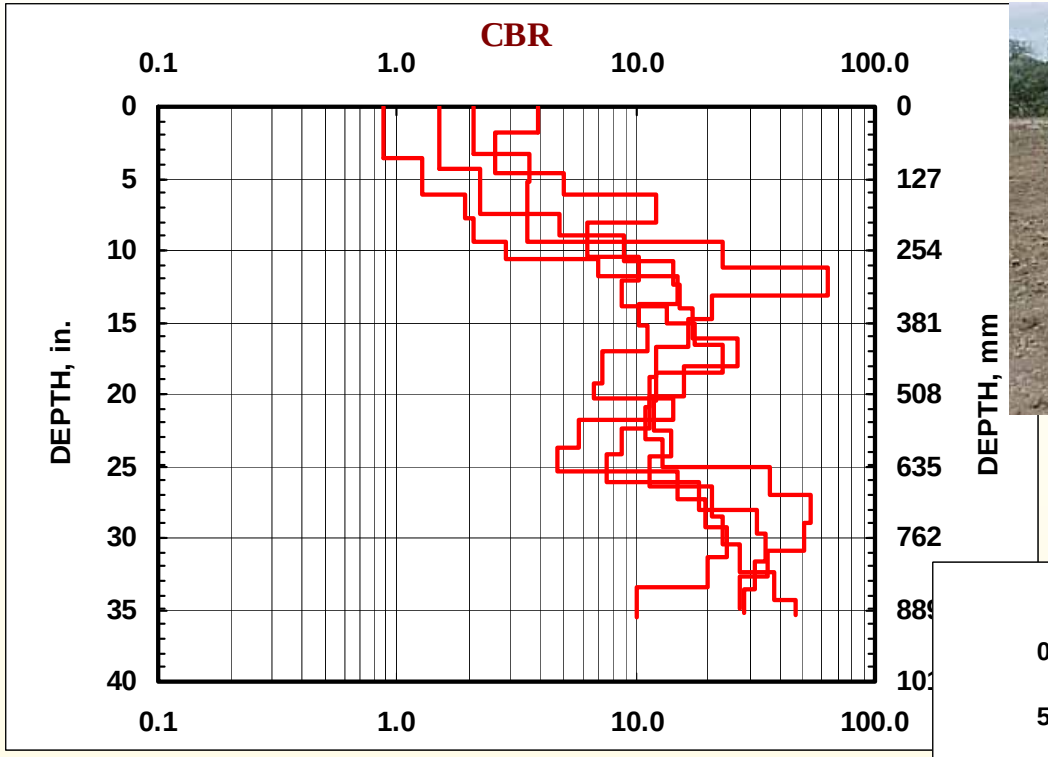
- **Drop hammer -> Percussive hammer**
- **Lighter, 1 operator, more accurate, Less noise**
- **Quick soil assessment for trafficability, airfields construction, etc.**





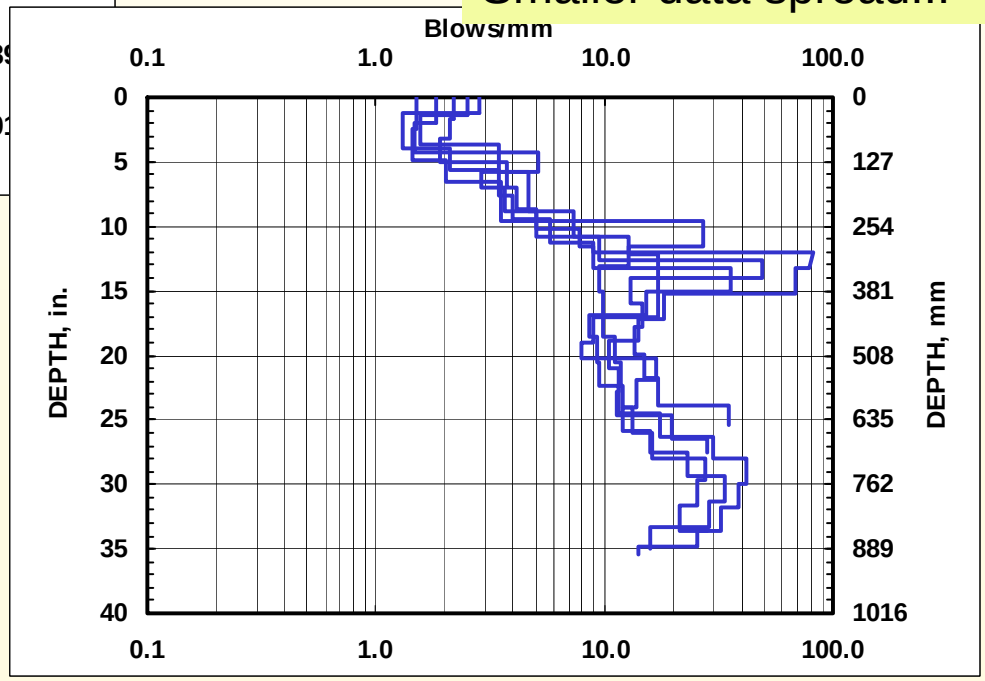
Percussive DCP in operation

Side-By-Side Field Tests



DCP

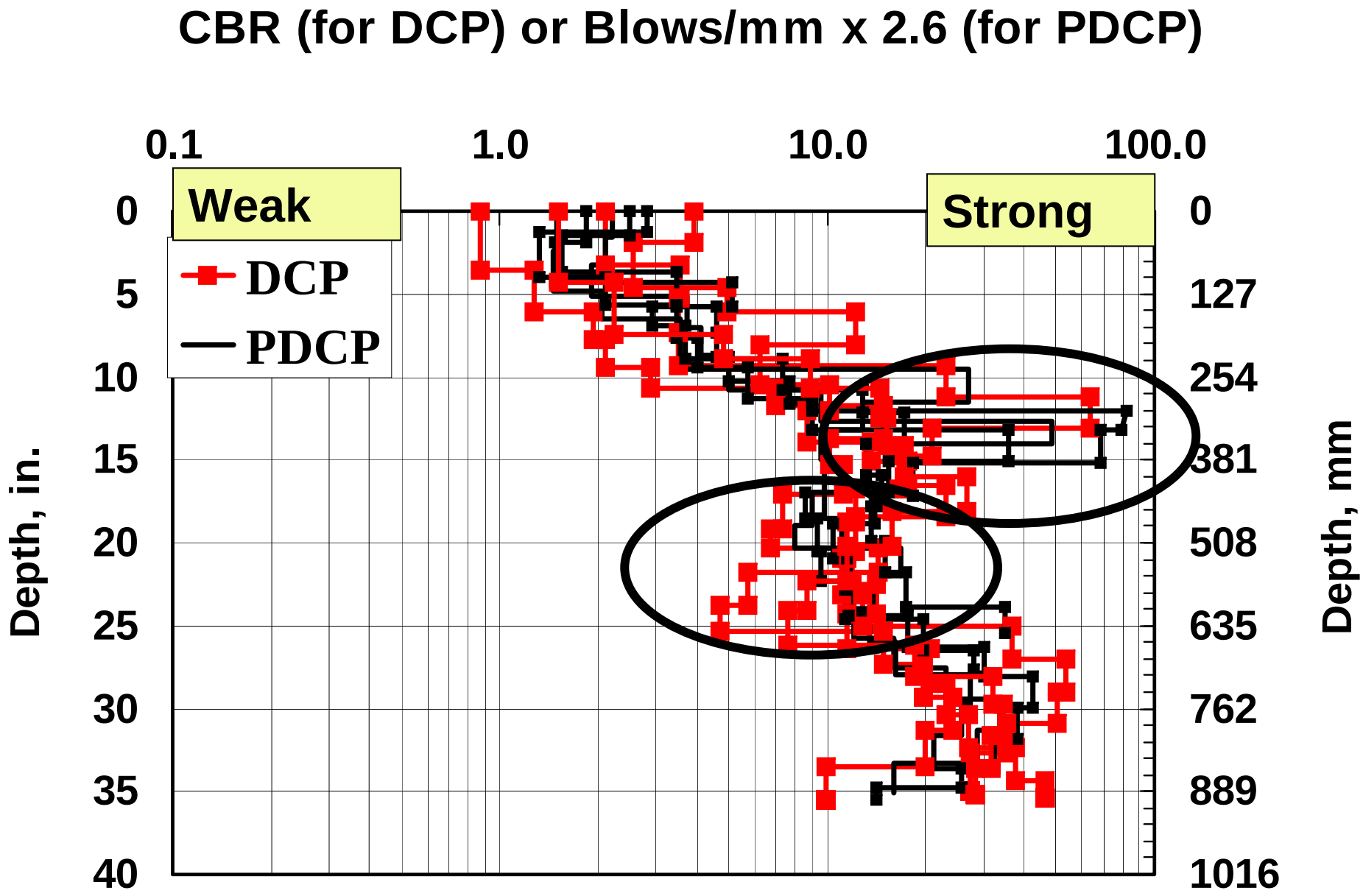
Smaller data spread!!!



PDCP

HONEYBEE ROBOTICS

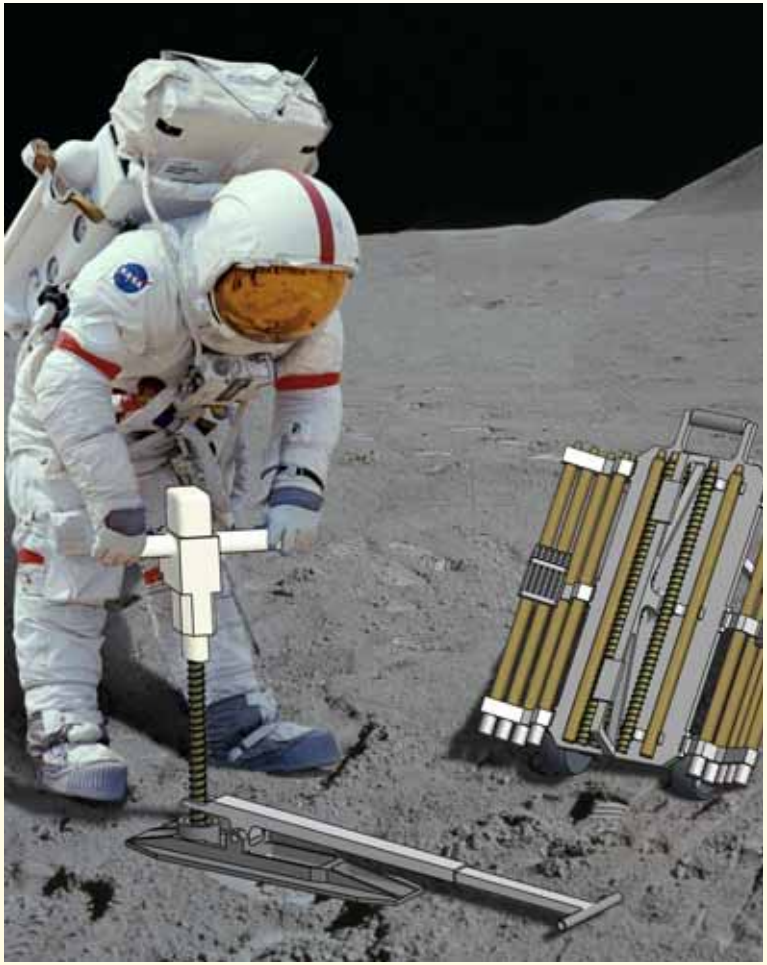
Correlations: PDCP->DCP->CBR



what about space application?

Percussive DCP: Concept for NASA

Change outfit
(and planet)



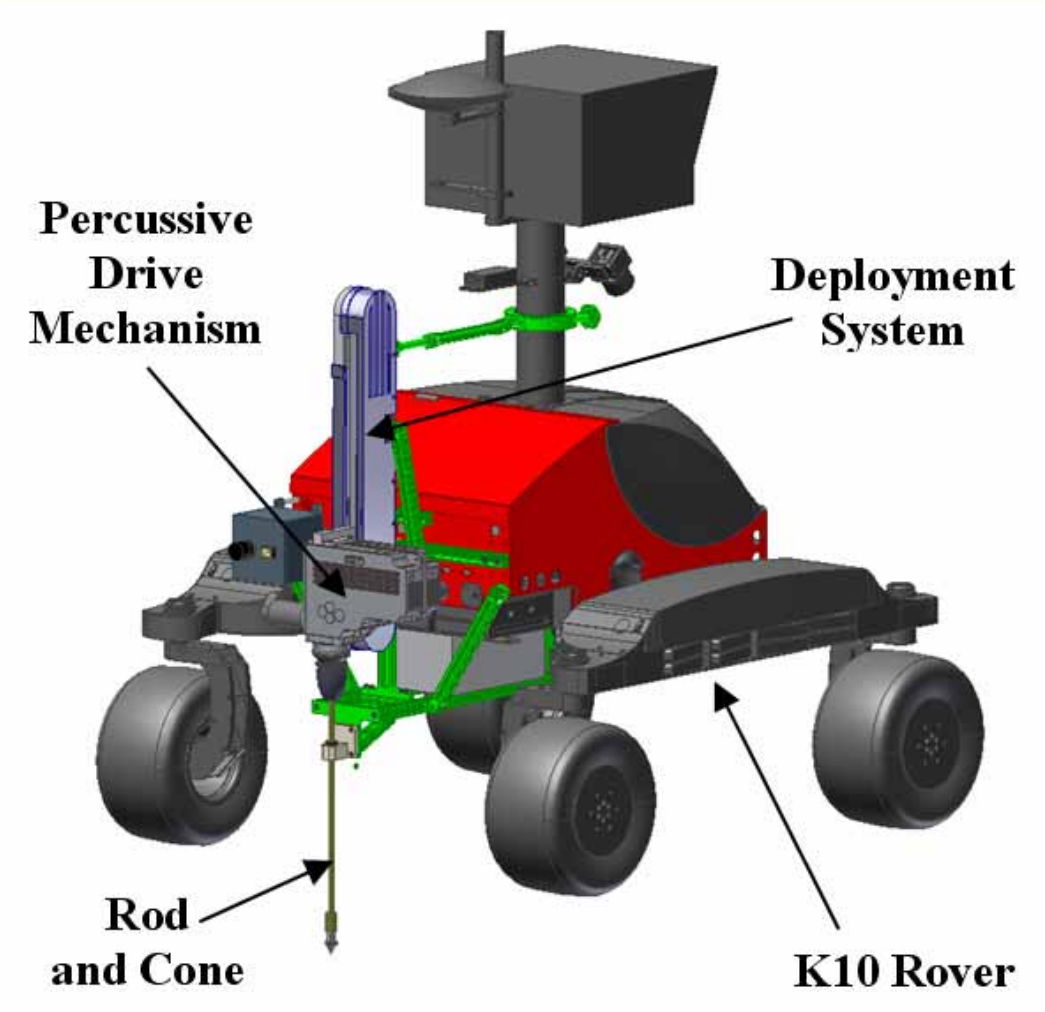
HONEYBEE ROBOTICS

but….

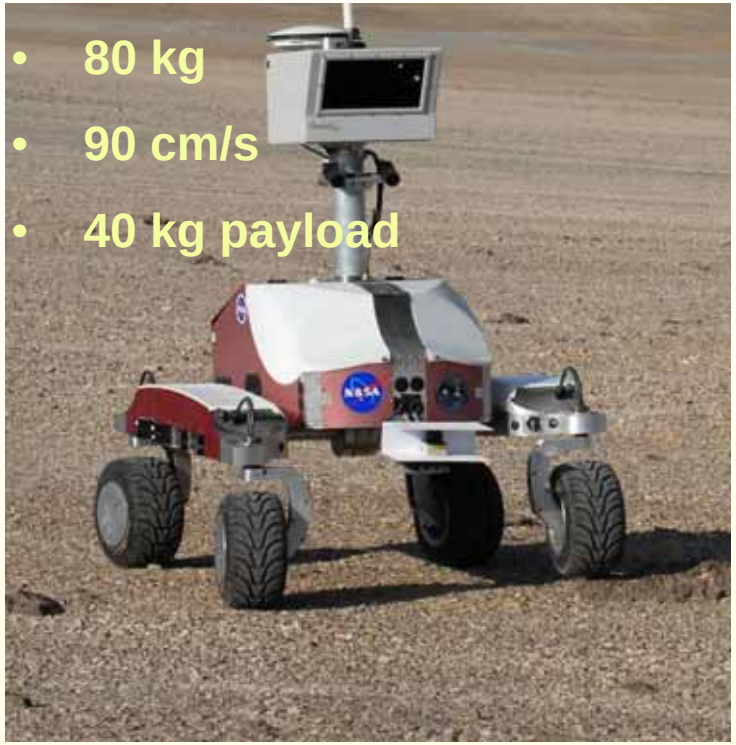
astronauts don't want to drill any more

PDCP Concept for Planetary Rover

Final Concept: Auto operation



NASA Ames K-10 rover



Final Product

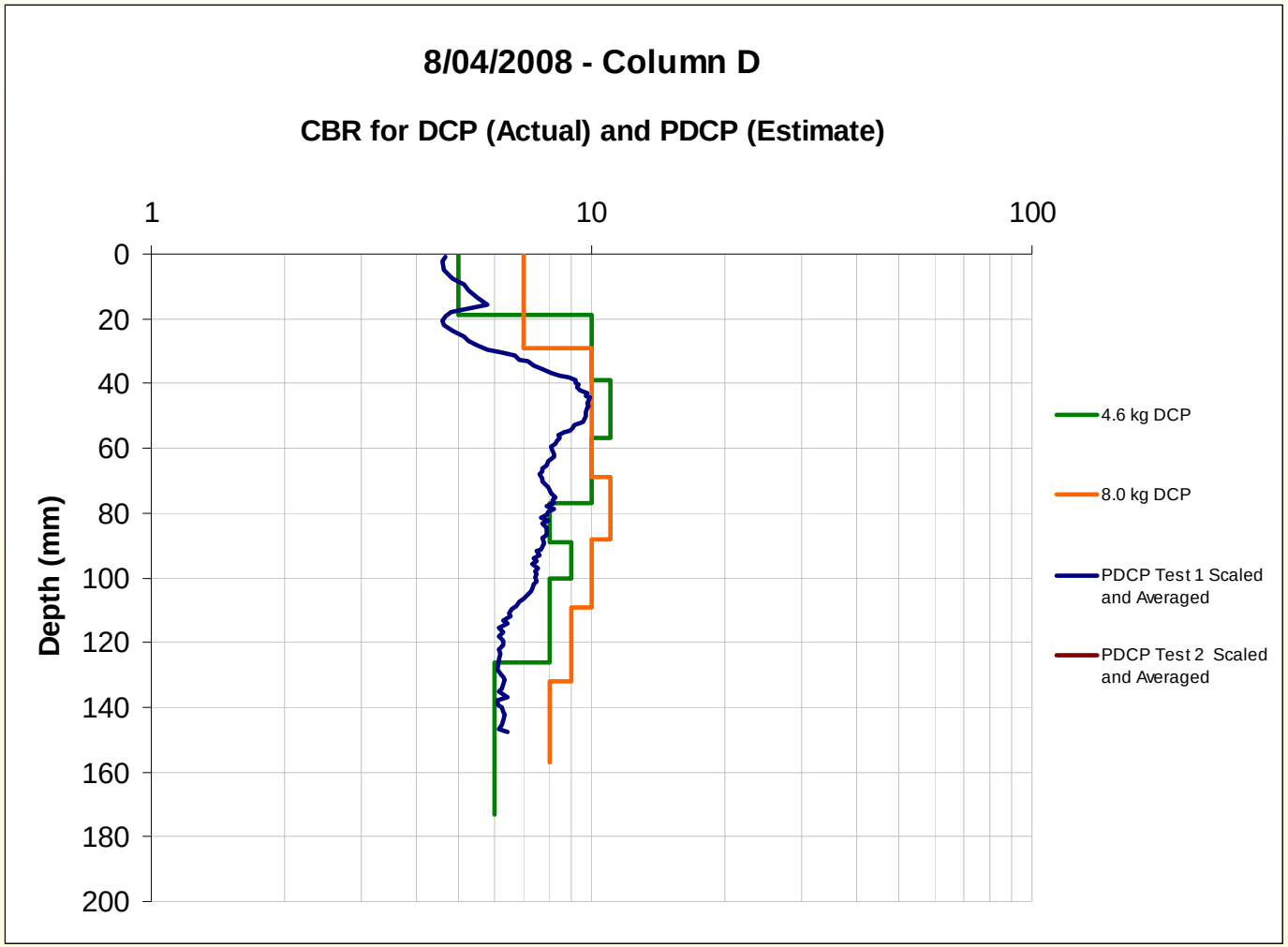
	Mass in kg (lbs)
Percussion System	**3.2 (7.0)**
Deployment System	4.2 (9.2)
Battery & Electronics	**2.7 (6.0)**
Framing & Support	3.0 (6.7)
Total	**13.1 (28.9)**

Lab Data (at Honeybee Facility)

Soil Type

Sandy Clay

~ 20% wt. H20

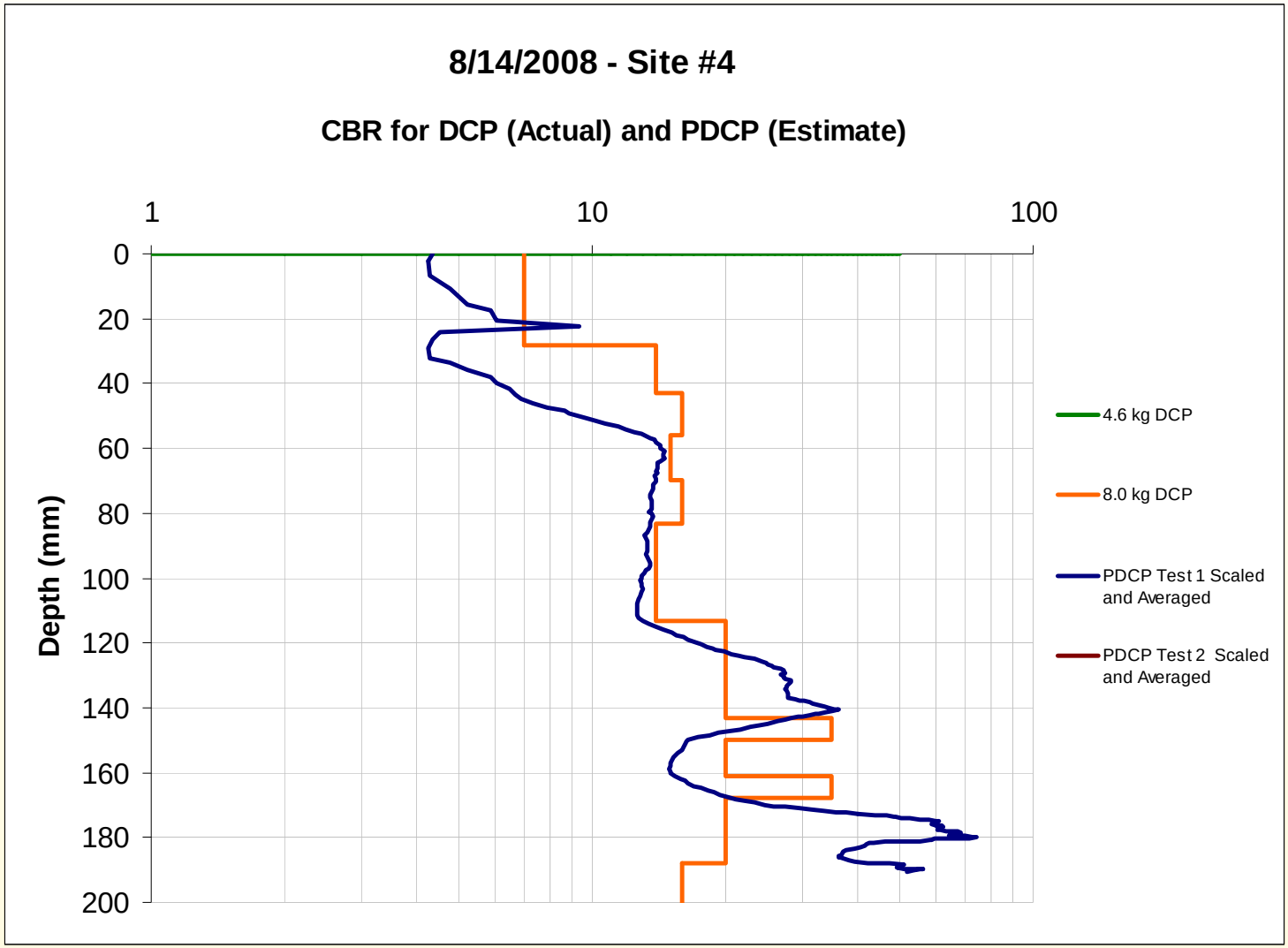


HONEYBEEROBOTICS

Field Data (at NASA Ames "Marscape")

Soil Type

Sandy Gravel

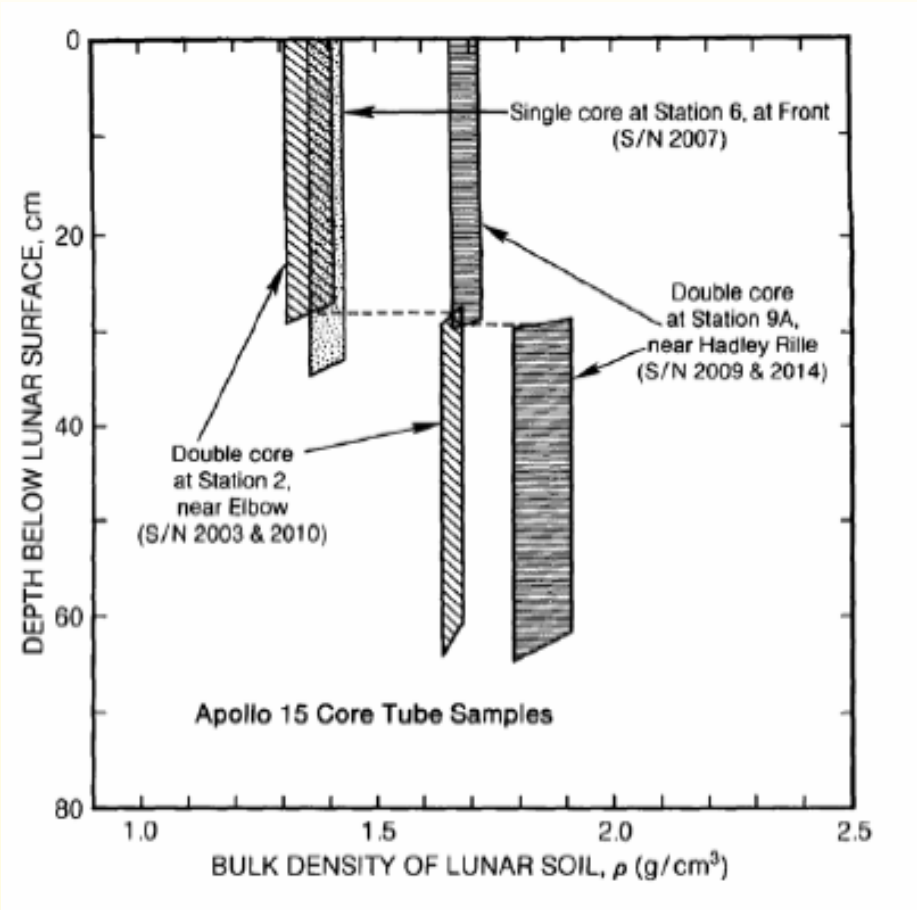


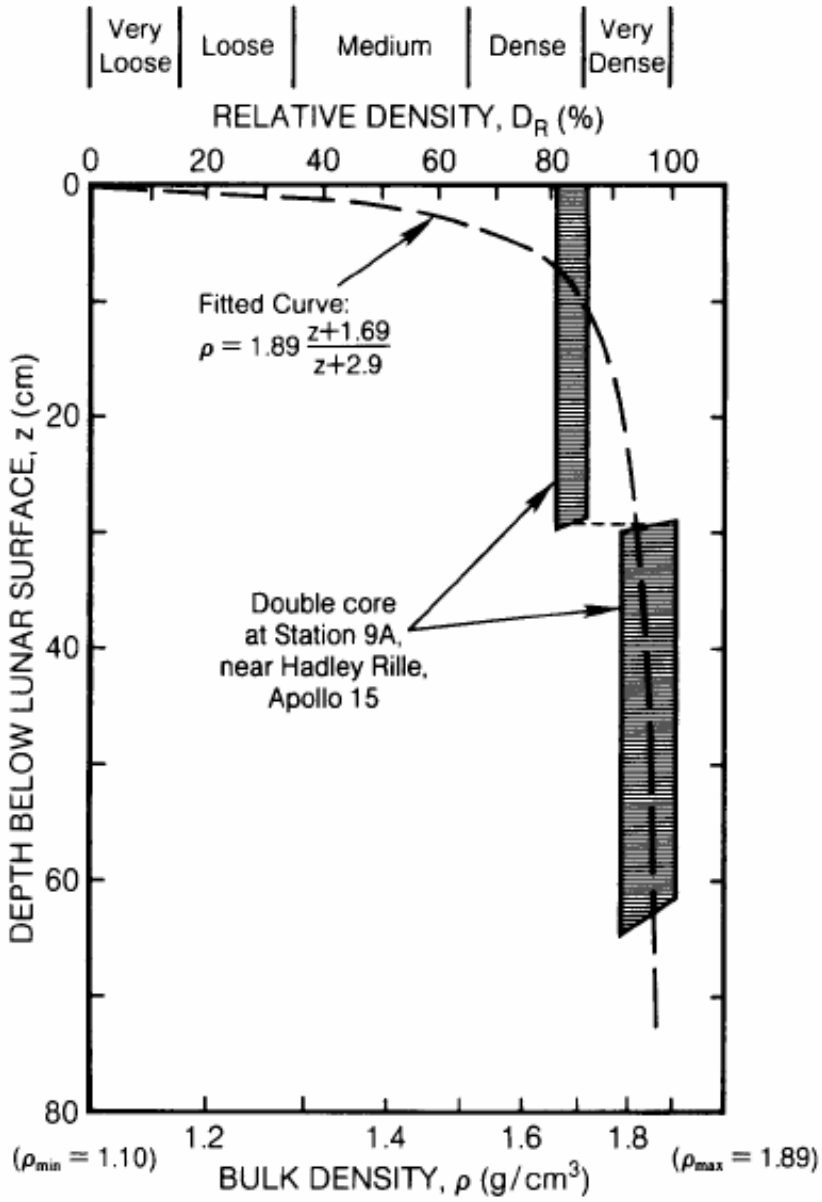
HONEYBEE ROBOTICS

the issue of lunar regolith

Luna regolith

- Regolith becomes very dense very quickly
  - 1.9g/cc
- Relative density >90%





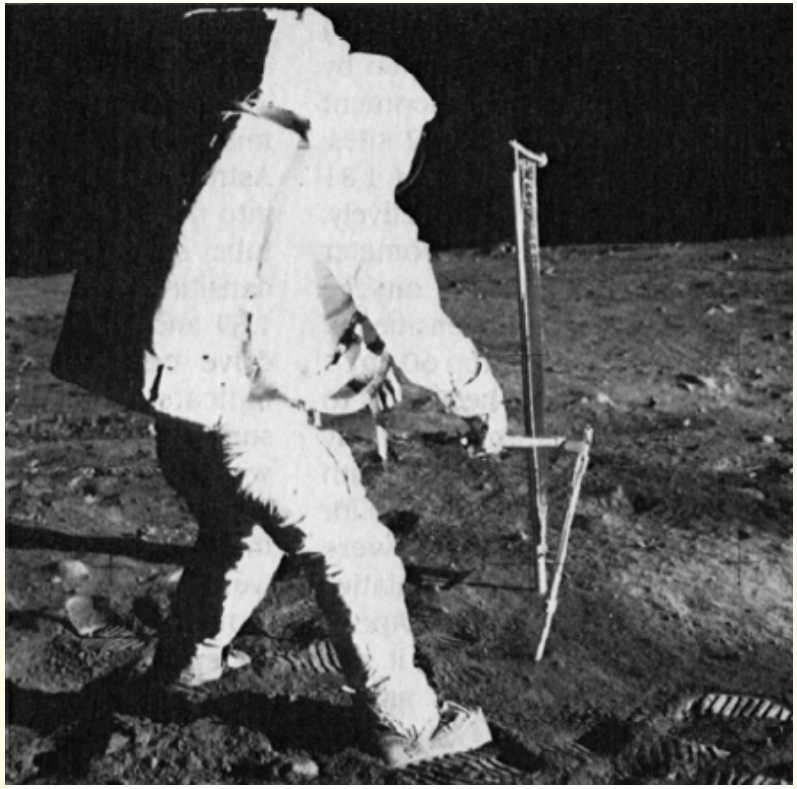
Apollo Core Tubes -> PDCP

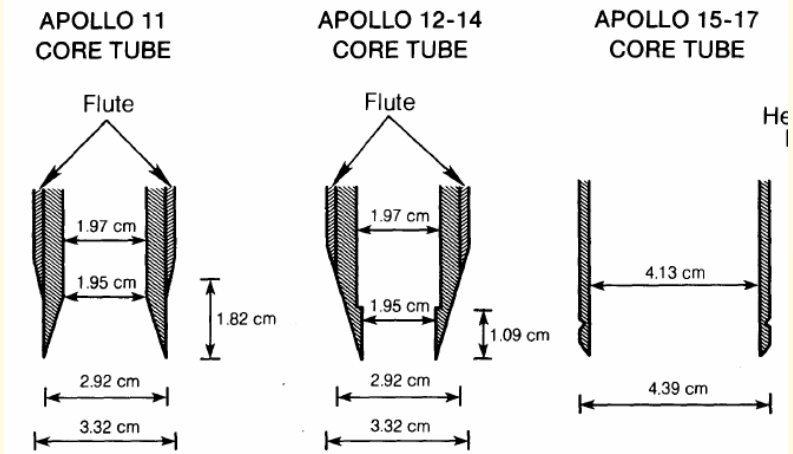
Apollo Experience

- Apollo Astronauts managed to hammer core tubes into the regolith
- It was a tough job, but doable
- A17: core tube to 68 cm in 50 hammer blows
  - (that`s 2 sec with PDCP)

PDCP

- No sleeve friction
- Cone can be smaller diameter
- High energy and frequency percussion
- And, if you can't get any deeper:
  - it's hard enough for construction
  - too hard for excavation

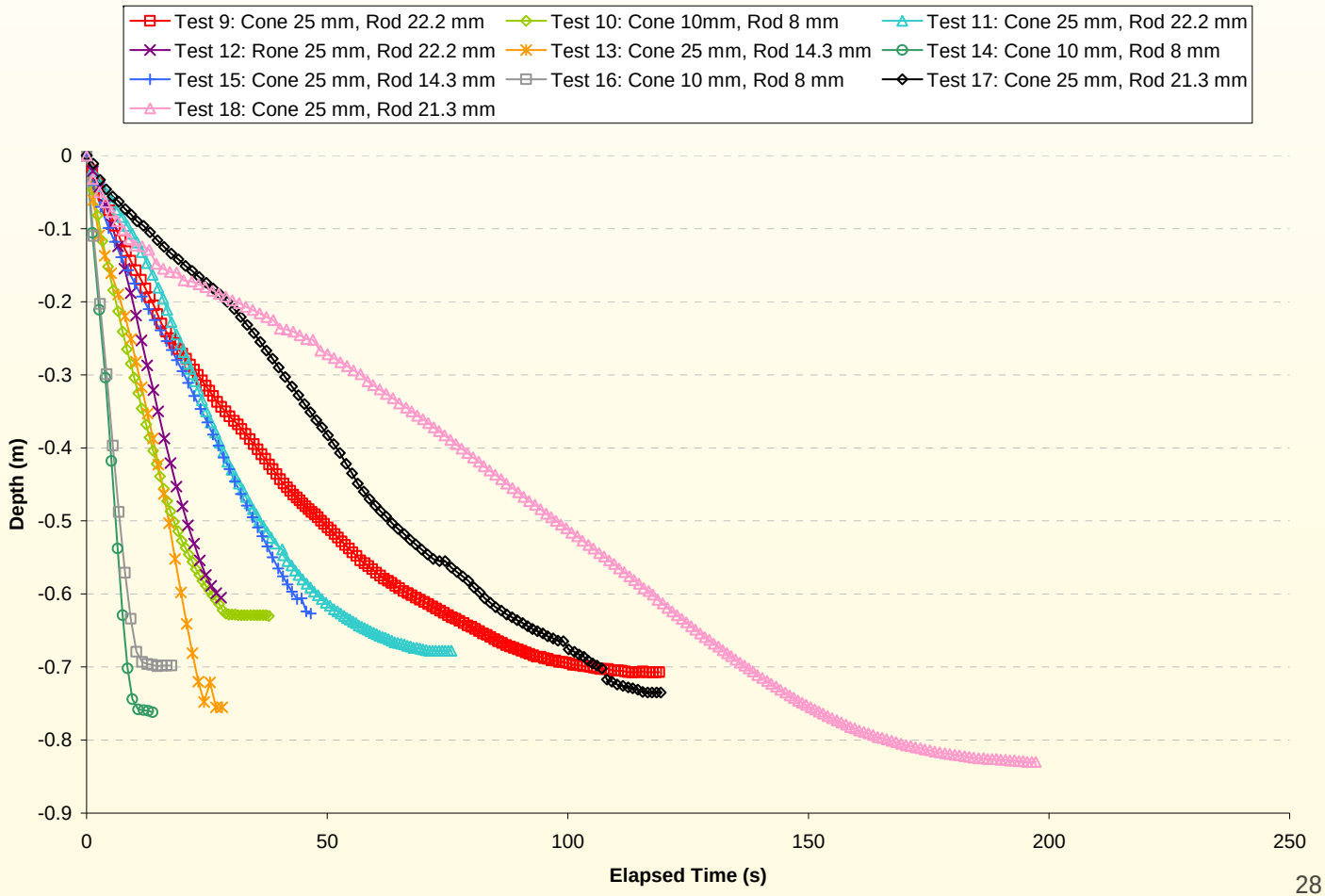




HONEYBEE ROBOTICS

PDCP tests in compacted JSC1a

- Yes, it's not lunar regolith, but we don't have anything better right now (MSFC simulant not available yet)
- Resistance is a function of a cone diameter and rod diameter



Acknowledgements

1. Army: ERDC
2. NASA Ames

HONEYBEE ROBOTICS

PDCP on K10 rover at NASA Ames Marscape

contact: kris zacny, zacny@honeybeerobotics.com

HONEYBEEROBOTICS