STRENGTH OF SOIL DEPOSITS ALONG MER TRAVERSES

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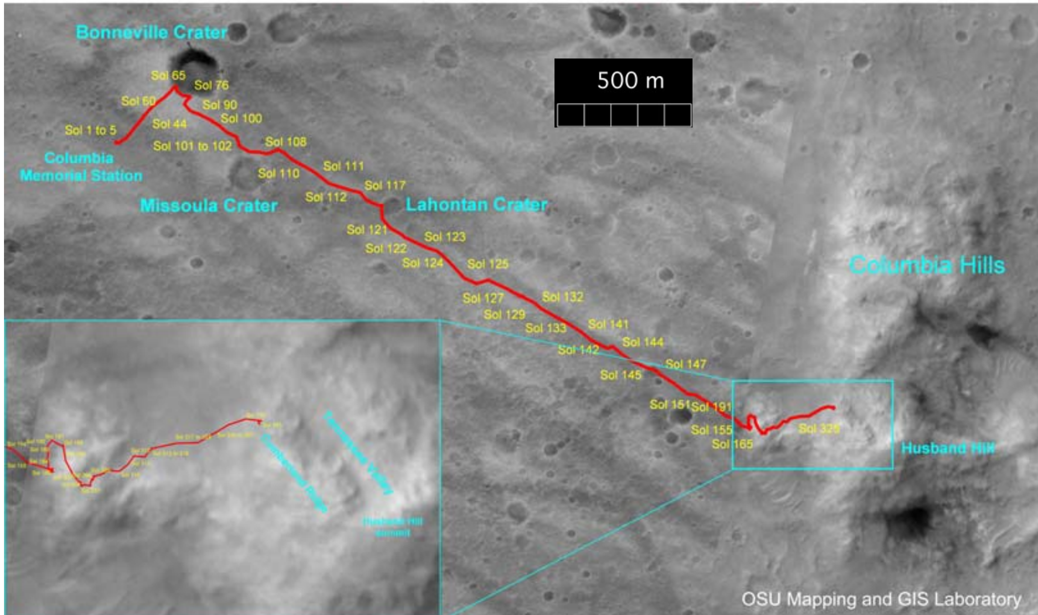
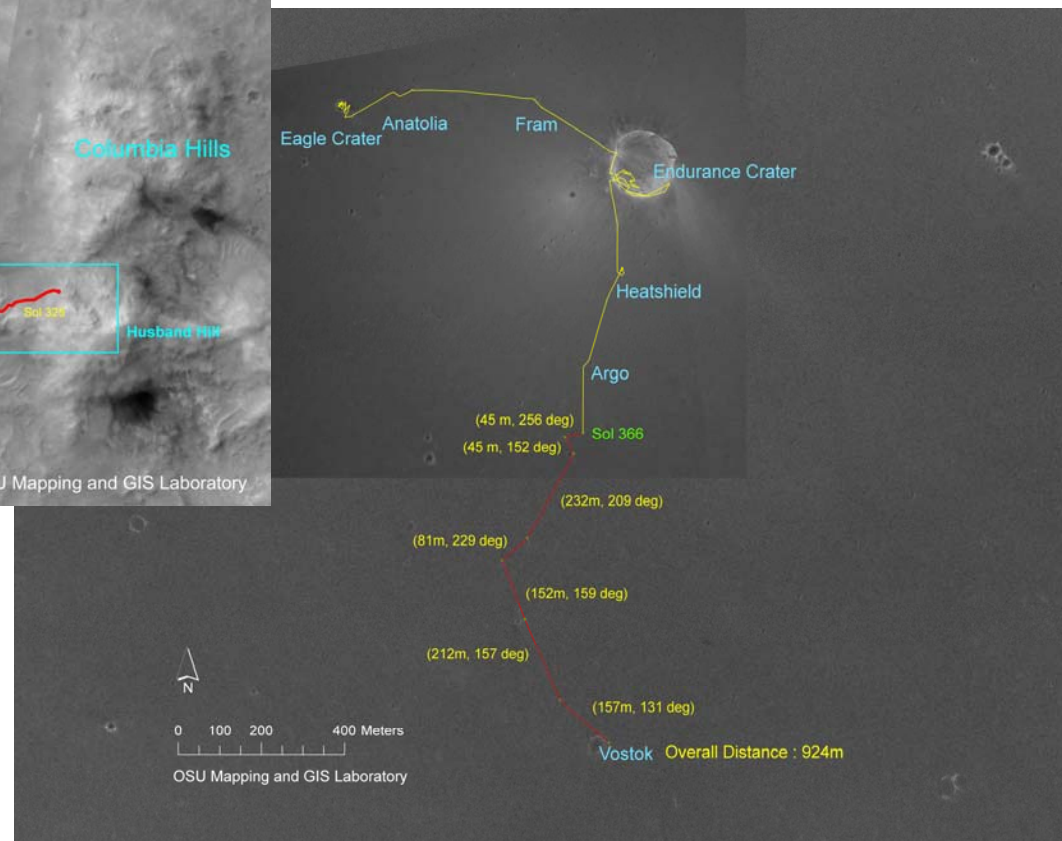
Two traverses on Mars

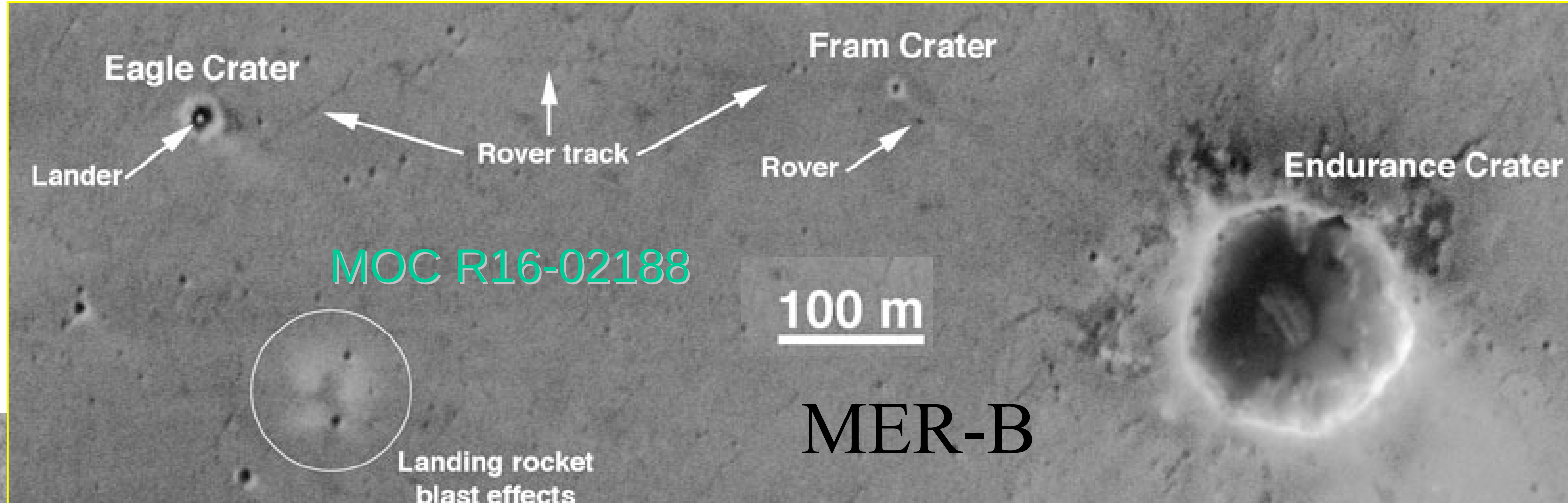
Mars Exploration Rover

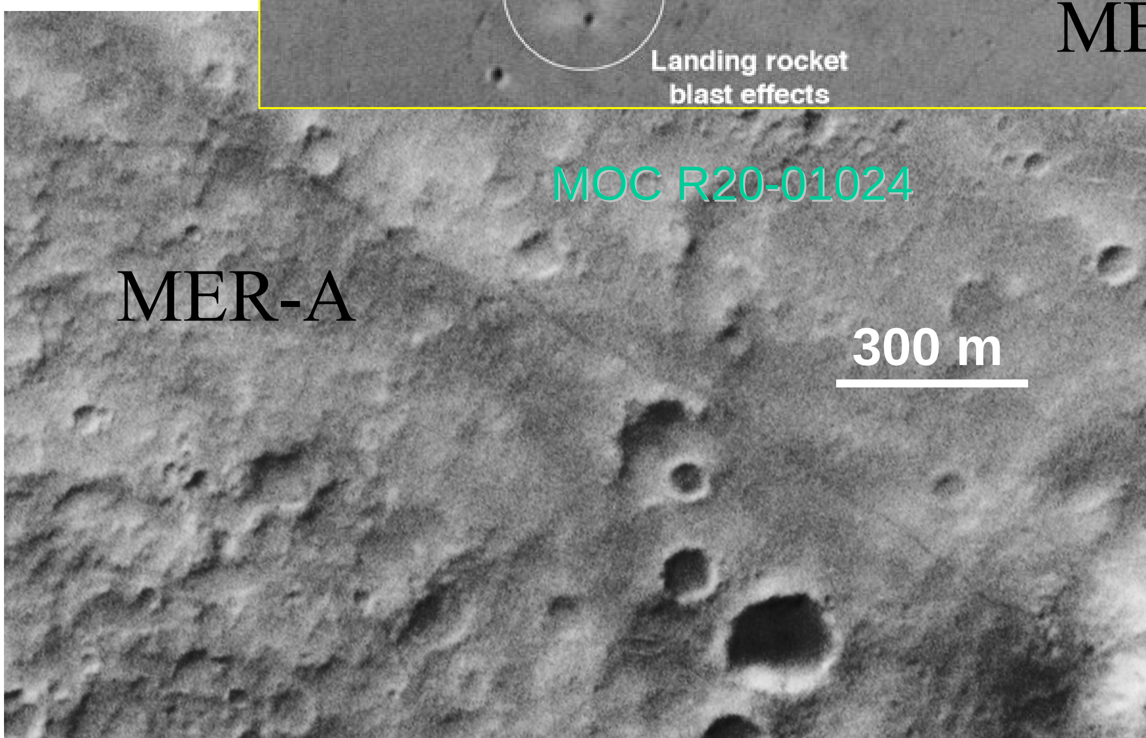
Spirit Rover Traverse Map (Sol 343)





Wheel tracks from orbit





MER physical properties studies

- **Relevance of physical properties: knowledge of strengths of soils and rocks, and observation of physical processes, to:**
  - **identify different materials from their strengths**
  - **compare physical and compositional properties**
  - **correlate materials with geologic units**
  - **identify stratigraphic relationships**
  - **identify modification and transport processes**
- **No dedicated instruments -> works across multiple disciplines and payload elements**
- **Reported here: soil strength and other properties from wheel sinkage**

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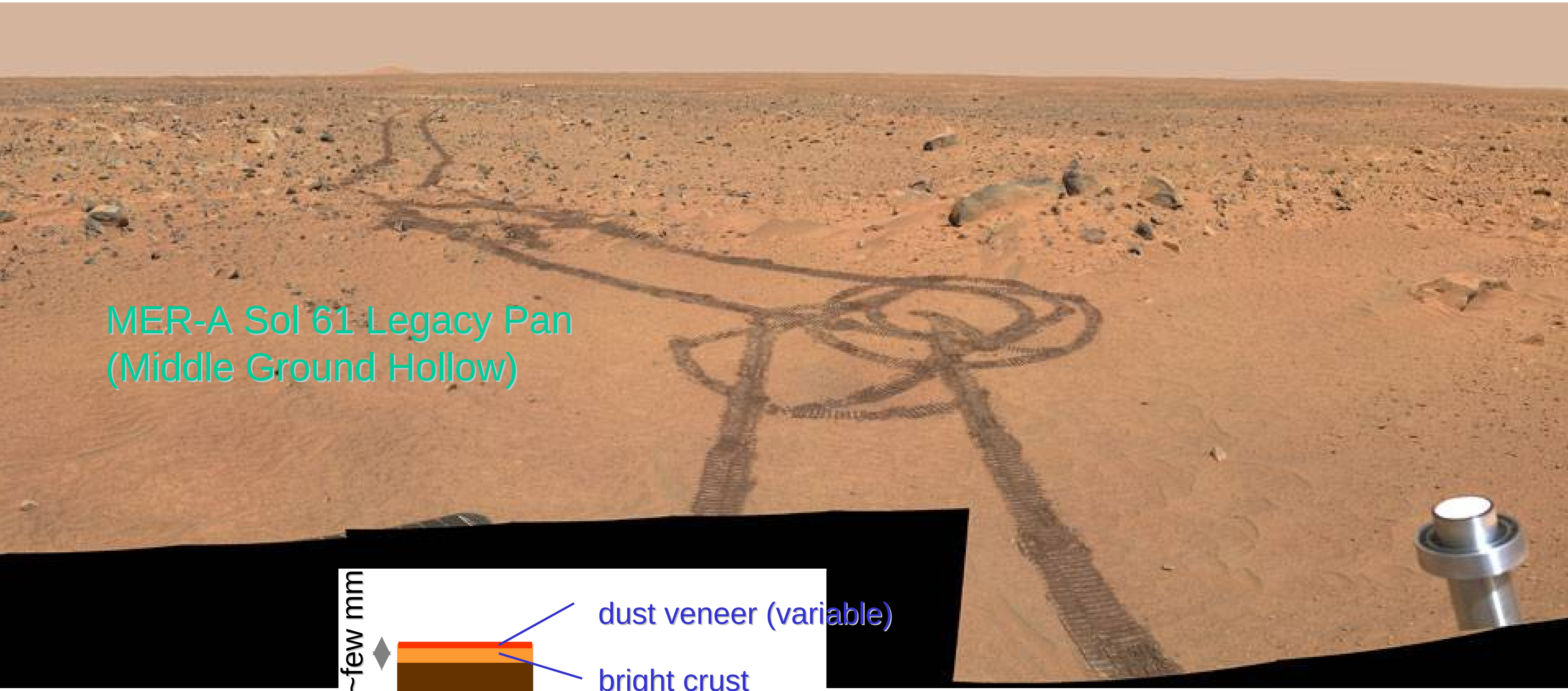
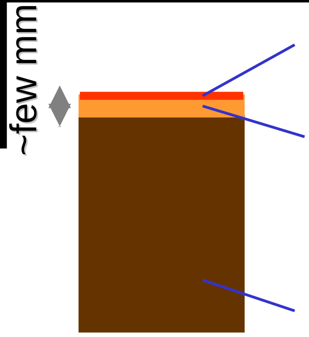
‚Spirit‘ wheel tracks





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Soil crusts evidence

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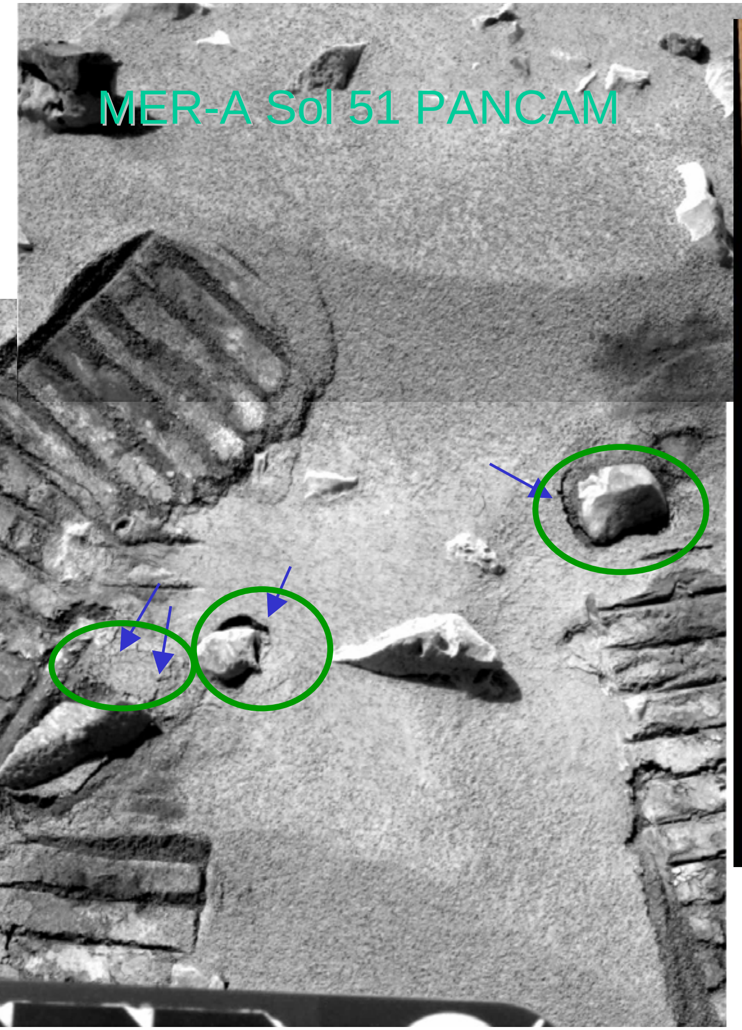

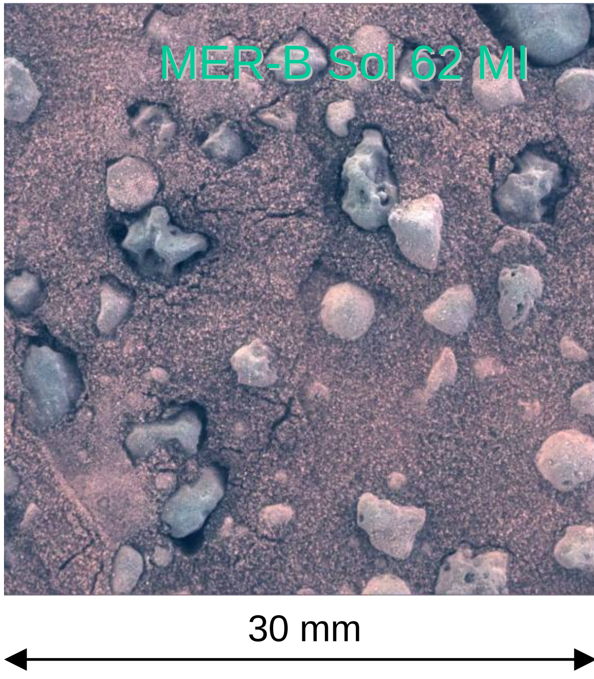

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‚Opportunity‘ wheel tracks

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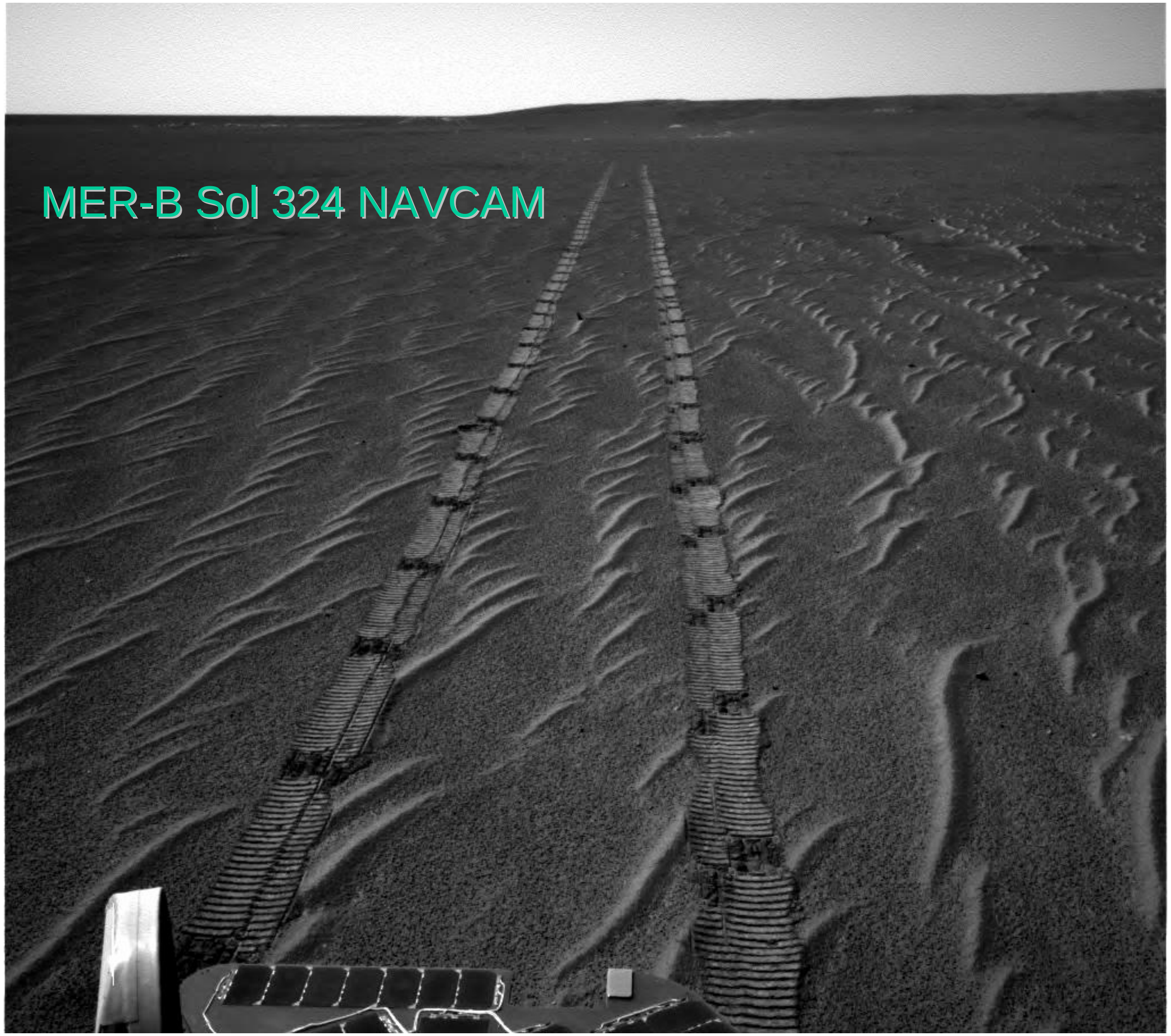

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Tracks PANCAM observations

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Tracks MI observations

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30 mm

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Soil strength from wheel sinkage

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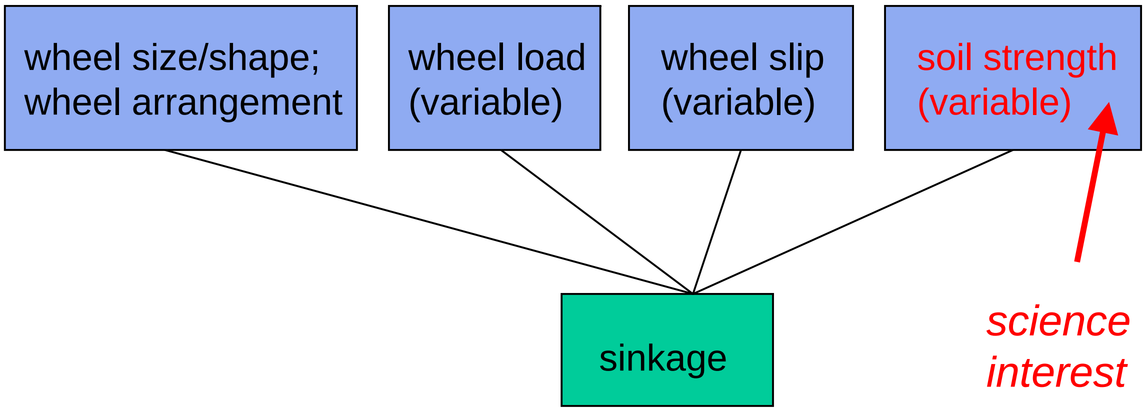
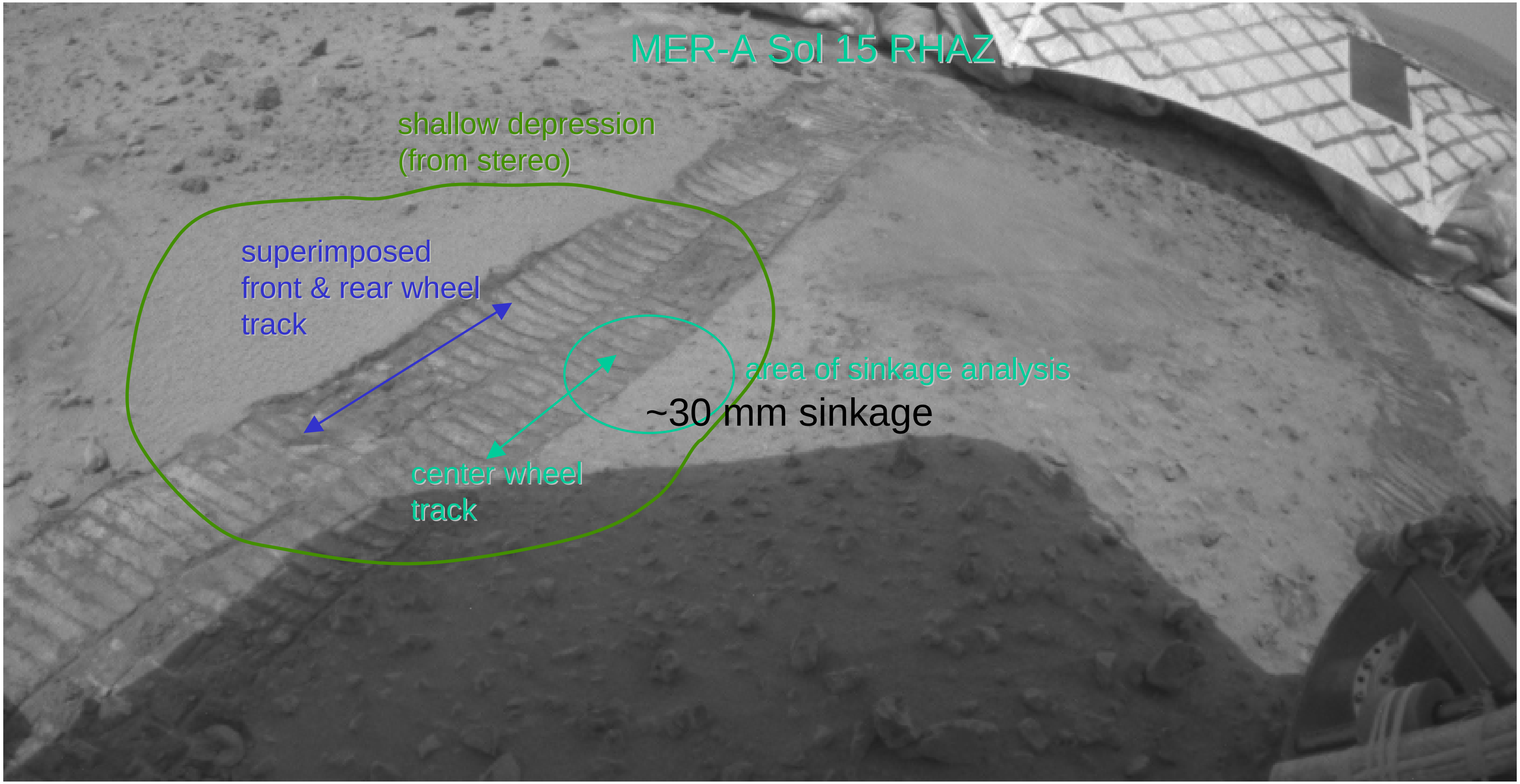


- **Measure wheel rut depth in stereo images (< 1 mm error in near-field)**
- **Wheel-soil theory calibrated for MER wheel: obtain soil strength parameters for vertical loading**
- **Compare with known soils: estimation of soil strength parameters for shear loading**
- **Results applicable to upper 20-30 cm of soil (stress dissipation for wheel width)**
- **Soil strength -> correlated with bulk density -> correlated with thermal inertia and dielectric properties -> comparison with datasets from orbital missions/remote sensing**

Soil strength from wheel sinkage



Systematic rut depth results

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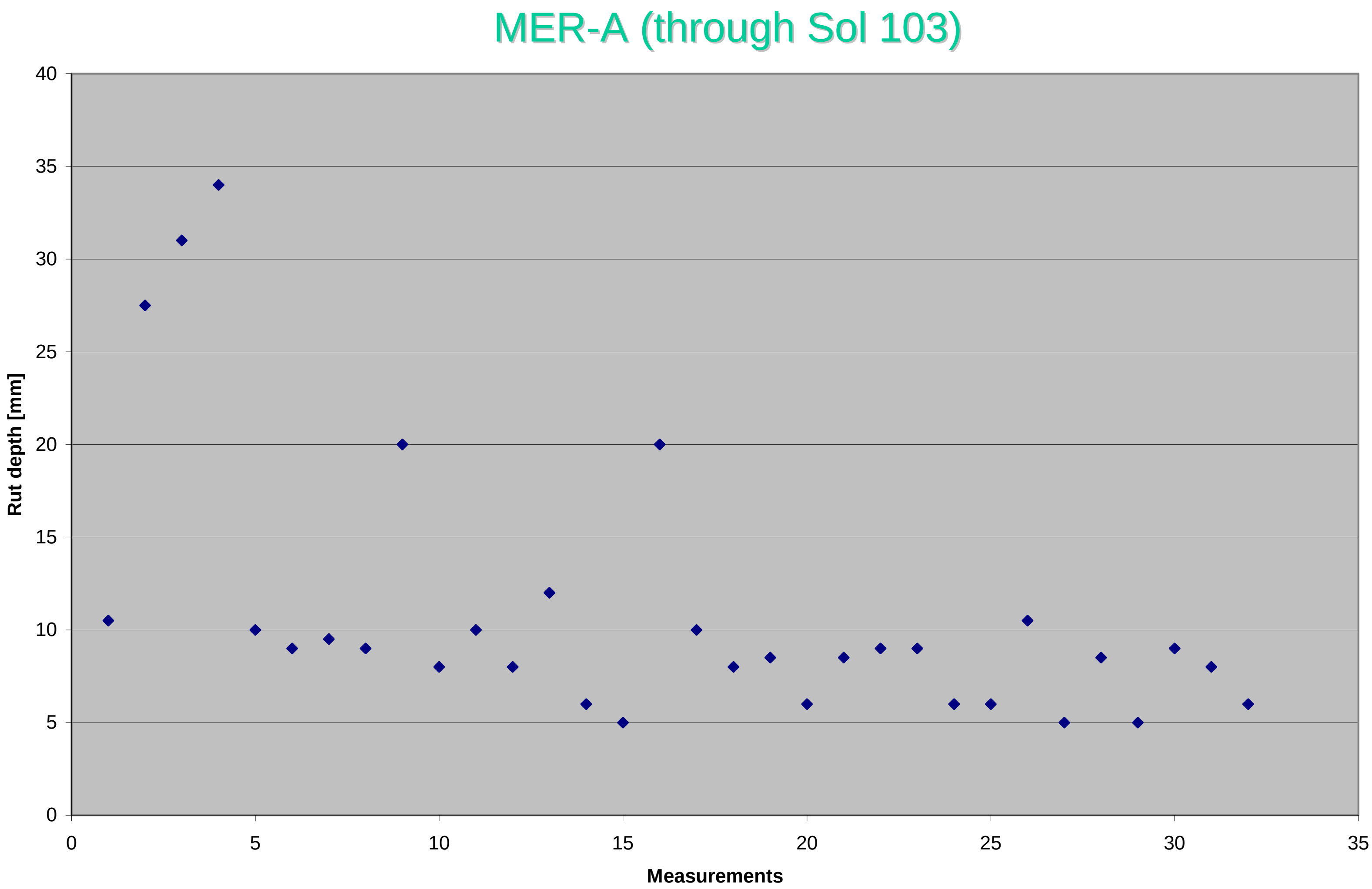

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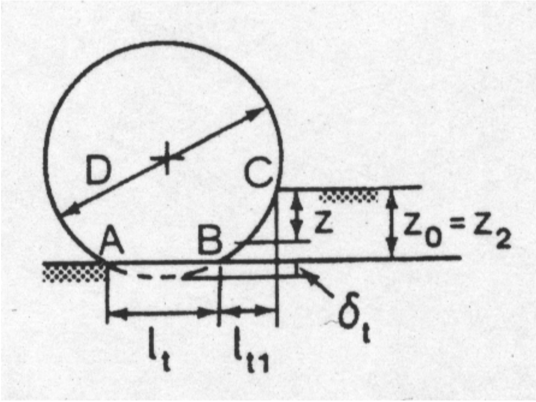
Soil strength from wheel sinkage

- **Wheel slip estimate from traverse reconstructions (absolute localization vs. wheel turns) -> account for wheel slip-sinkage**
- **Relation between wheel dimensions (*D*,*b*), wheel load (*W*), soil parameters for vertical loading (k_c, k_ϕ, *n*) and load-sinkage z_0:**

$$W = -b \cdot k^* \cdot \int_0^{z_0} z^n \frac{2(z_0 - z) - D}{2\sqrt{D(z_0 - z) - (z_0 - z)^2}} \mathrm{dz}$$

$$k^* = \frac{k_c}{b} + k_\phi$$



- **Caveat: no unique solution for *k****
- **Ways out:**
  - **Additional loading surface in same soil unit (Mössbauer contact plate) OR**
  - **Comparison with known soils -> also gives values for shear strength parameters by analogy**

MB ‚noseprint‘

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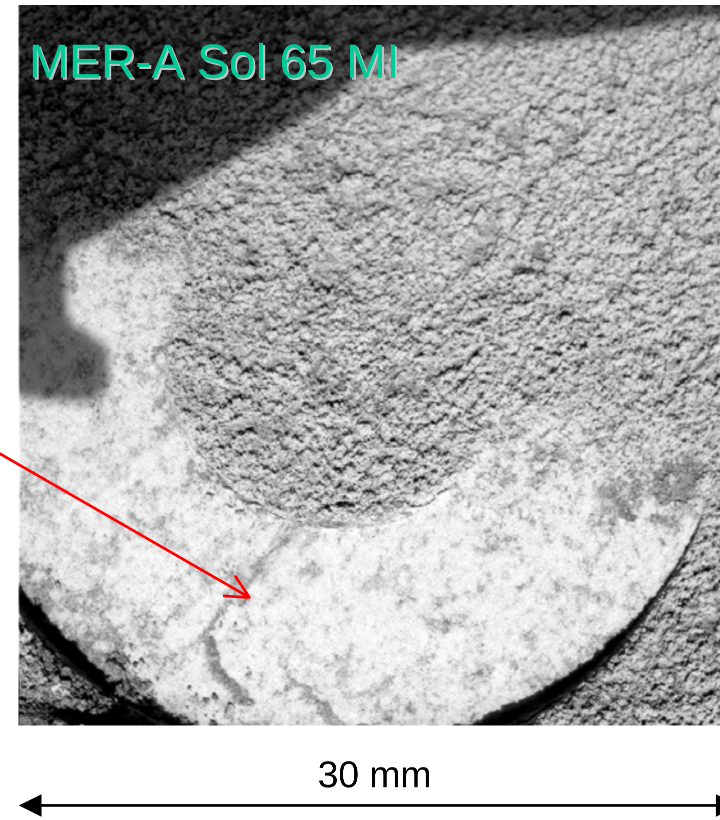

Example: MER-A egress soil

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- **Solving for *k** for different values of *n* (exponent of soil deformation for vertical loading):**

n	1.0	0.8	0.5	0.3
k*	2.375E+06	8.786E+05	1.947E+05	7.031E+04

Comparative database:

Soil	n	k_c [N/m^{n+1}]	k_phi [N/m^{n+2}]	k* [N/m^{n+2}] (for b=160 mm)	phi [°]	c [kPa]
Dry sand (Land Locomotion Laboratory)	1.1	9.90E+02	1.53E+06	1.53E+06	28	1.04
Sandy loam (Land Locomotion Laboratory)	0.7	5.27E+03	1.52E+06	1.55E+06	29	1.72
Sandy loam Michigan (Strong, Buchele)	0.9	5.25E+04	1.13E+06	1.46E+06	20	4.83
LETE sand (Wong)	0.79	1.02E+05	5.30E+06	5.94E+06	31.1	1.30
DLR mechanical Mars soil simulant	0.8	5.79E+03	1.80E+05	2.16E+05	17.8	0.30
Lunar nominal soil	1	1.40E+03	8.20E+05	8.29E+05	35	0.17
Sandy loam (Land Locomotion Laboratory)	0.2	2.56E+03	4.31E+04	5.91E+04	38	1.38
Sandy loam (Hanamoto)	0.3	2.79E+03	1.41E+05	1.59E+05	22	13.79
Clayey soil (Thailand)	0.5	1.32E+04	6.92E+05	7.75E+05	13	4.14
Heavy clay (WES)	0.11	1.84E+03	1.03E+05	1.15E+05	6	20.69

best match → Sandy loam (Hanamoto)

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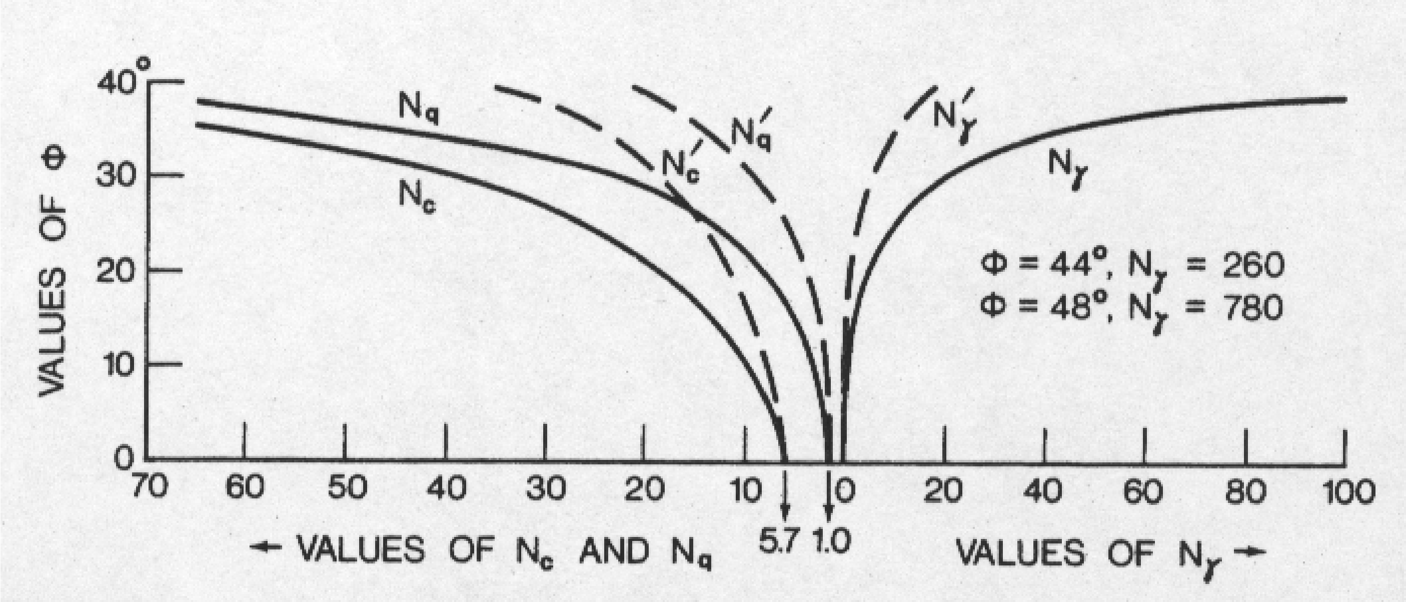
Example: MER-A egress soil

- **Apply bearing capacity theory to derive bearing strength**

$$W'_c = 2\gamma_s l \cdot b^2 N'_\gamma + 2l \cdot b \cdot qN'_q + \frac{4}{3} l \cdot b \cdot cN'_c$$



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Some results and comparisons

	Bearing strength	Cohesion	Internal friction angle	Bulk density (soil)	Thermal inertia (soil)
Gusev loose soils	5 kPa	1 kPa	20°	1230 kg/m^3 *)	134 $J\ m^{-2}\ s^{-1/2}\ K^{-1}$ **)
Gusev dense soils	200 kPa	15 kPa	25°	1483 kg/m^3 *)	153 $J\ m^{-2}\ s^{-1/2}\ K^{-1}$ **)
Meridiani Eagle crater floor & M. plains	80 kPa	5 kPa	20°	1333 kg/m^3 *)	142 $J\ m^{-2}\ s^{-1/2}\ K^{-1}$ **)
Meridiani Eagle crater wall (loose soil)	8 kPa	0.5 kPa	20°	1186 kg/m^3 *)	130 $J\ m^{-2}\ s^{-1/2}\ K^{-1}$ **)
VL-1 ‚drift'		1.6±1.2 kPa	18±2.4°	1150±150 kg/m^3	
VL-1 ‚blocky'		5.5±2.7 kPa	30.8±2.4°	1600±400 kg/m^3	
MPF ‚cloddy'		0.17±0.18 kPa	37.0±2.6°	1530±110 kg/m^3	
Lunar soil (inter-crater areas) (Kemurdjian et al., 1978)	36-55 kPa	2.7-3.4 kPa	22-27°		
Coarse sand (Earth)	150-300 kPa	0.1-2.0 kPa	30-39°		

*) assuming behavior like lunar regolith: $\tan\phi$=0.725*1/E, c=0.720*E**(-5.664)

**) assuming κ=0.01 $W\ m^{-1}\ K^{-1}$+[6.4*10^{-6} $m^4\ s^{-3}\ K^{-1}$]ρ, and c_p=820 $J\ kg^{-1}\ K^{-1}$

Wheel trenching

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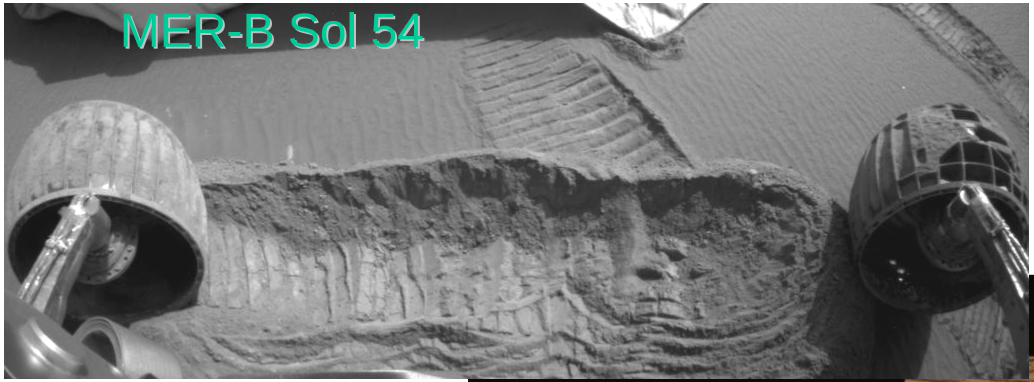

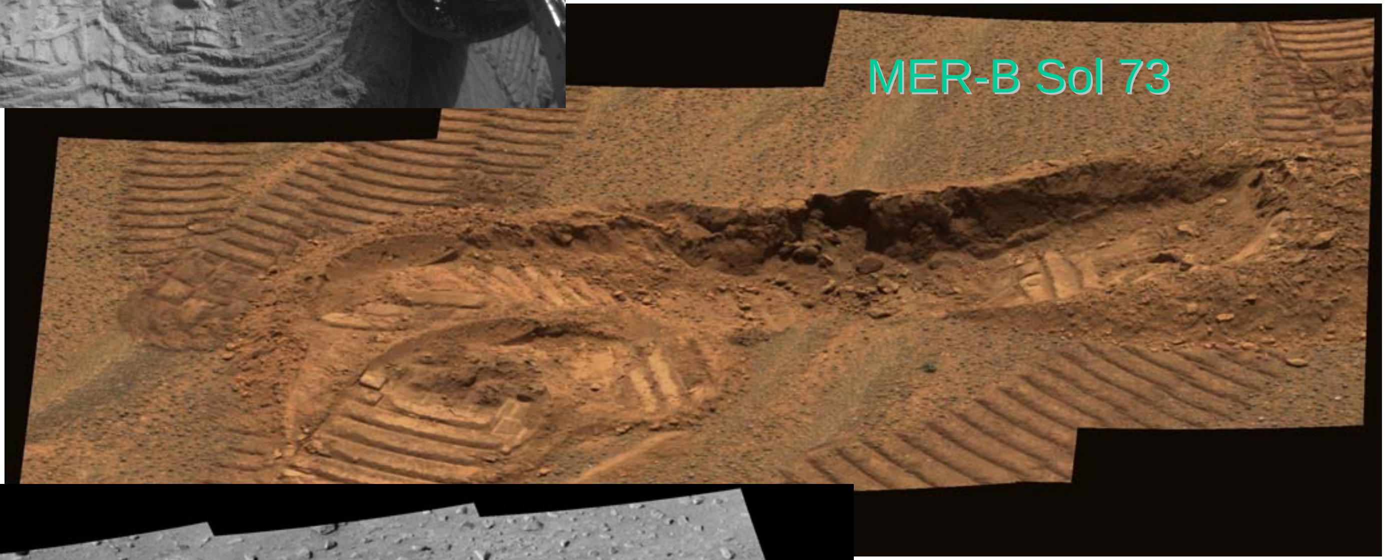

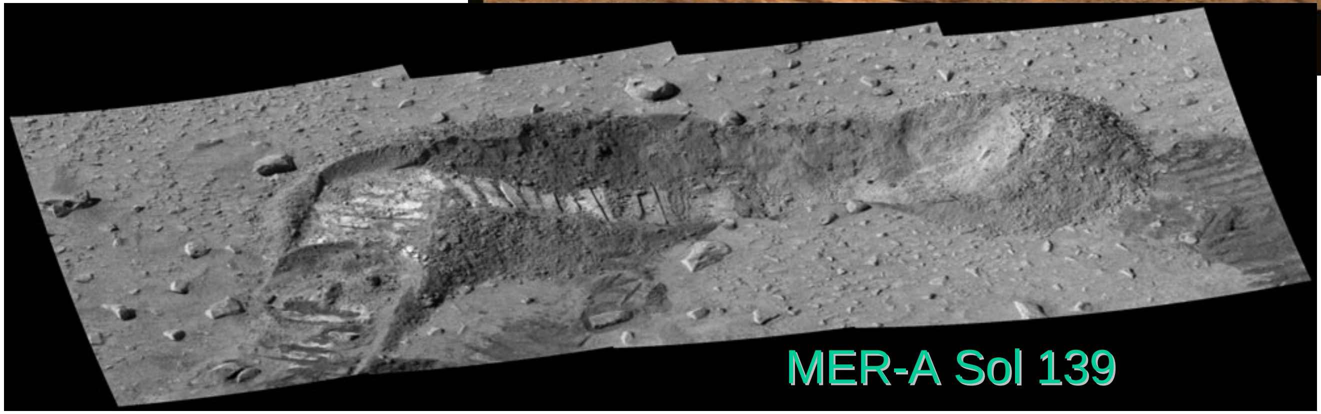

MER-B Sol 73 trench

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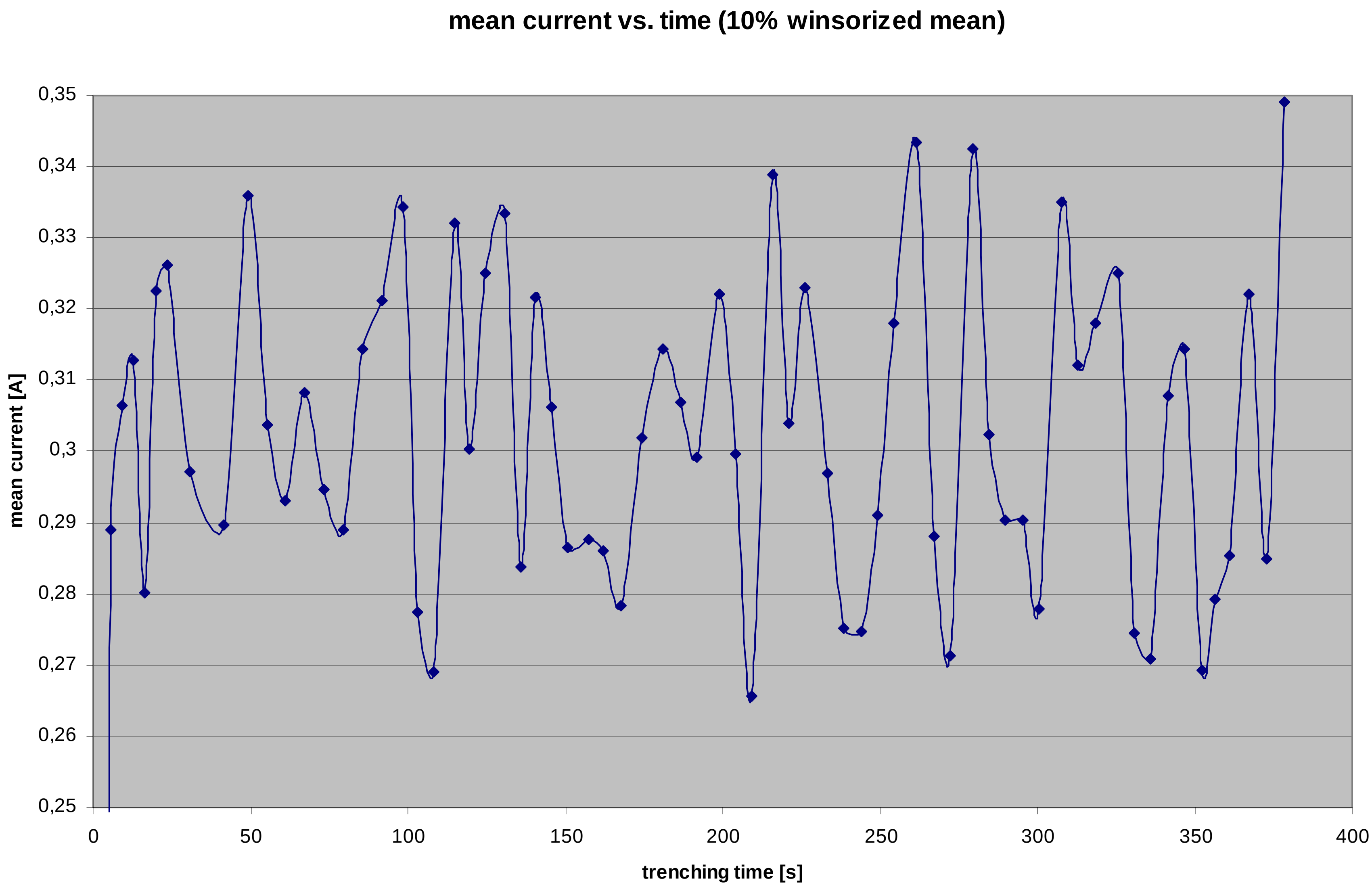
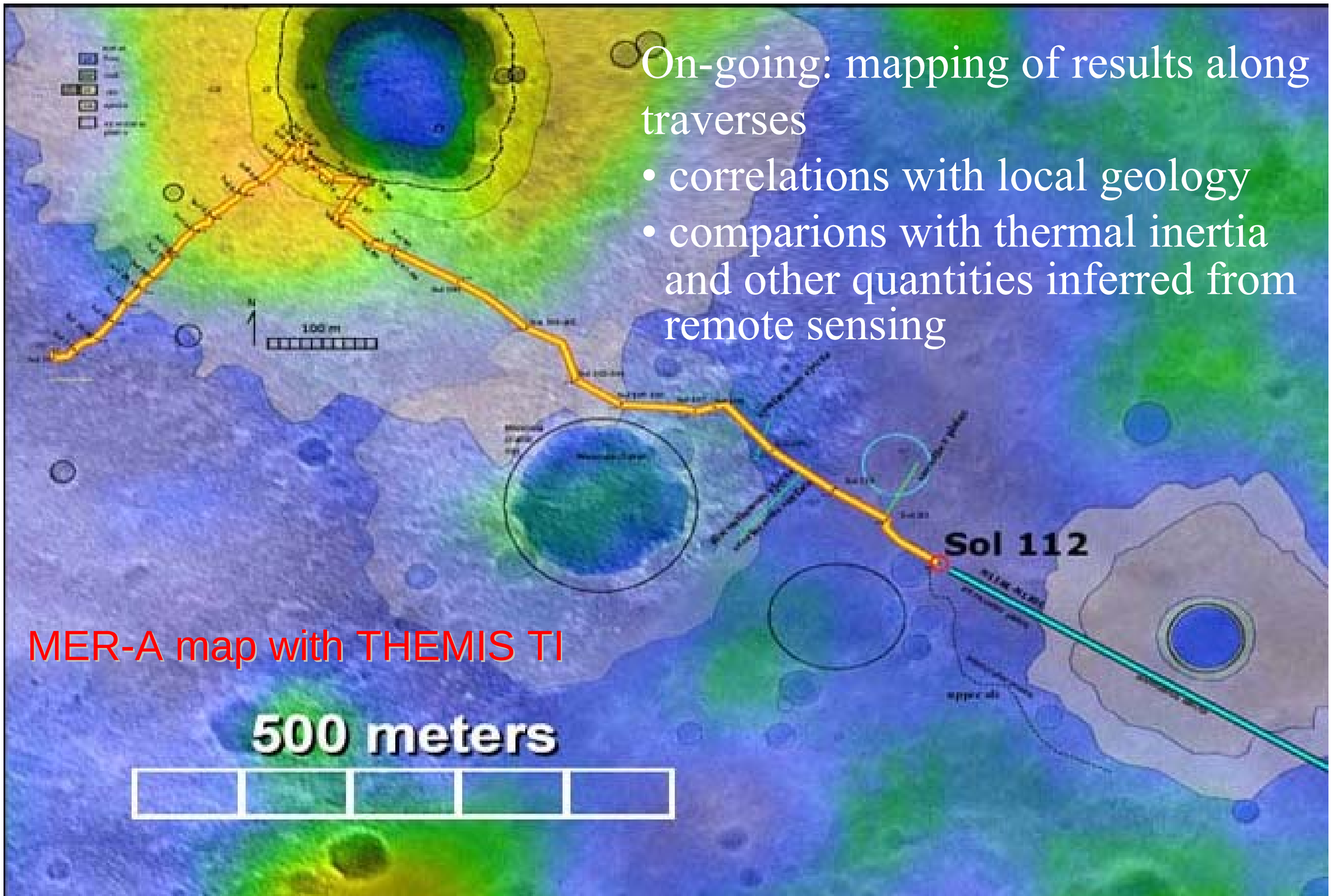


-> being used to infer soil shear strength vs. depth

Geologic context



On-going: mapping of results along traverses

- correlations with local geology
- comparions with thermal inertia and other quantities inferred from remote sensing

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Implications

- **Soil deposits with distinct mechanical properties**
- **Cohesion inferred for all soil types observed with the described methods**
- **Soil thermal inertia retrievals: slightly lower than fine-component TI from orbital measurements? (comparisons in progress, also with Mini-TES derived TI)**
- **Soil crusts formation as recent or modern process (action of moisture & salts?)**