COMPARISON OF GEOTECHNICAL PARAMETERS ON THE MOON AND MARS. Jørgen Natvig Løvseth[1,2], Akos Kereszturi[3], [1]Eotvos Lorand University of Sciences, Budapest, Hungary. [2]Norwegian University of Science and Technology, Norway. [3]Konkoly Observatory, RCAES, Hungary. (email: kereszturi.akos@csfk.org)

Introduction: For the effective realization of future in-situ activity on the lunar surface evaluation of geotechnical parameters is important. In this work we summarize and review these parameters together with Martian values in order to see how the knowledge supporting mission planning could be improved. The literature based survey is summarized in Table 1.

Table 1. Summary of published geotechnical parameters

Parameter	Mars	Moon
Bulk density (kg/m^3)	**1230** (Gusev loose soils) [12] **1483** (Gusev dense soils)[12] **1333** (Meridani Eagle crater floor and m. plains) [12] **1186** (Meridani Eagle crater wall (loose soils)) [12] **1150** (Viking Lander 1, drift)[12] **1600** (Viking lander 1, blocky) [12] **1530** (Mars Pathfinder, cloddy)[12] **1300** (Viking lander 1, sandy flats, soil)[10] **1400** (Viking lander 1, rocky flats soil)[10] **2900** (Viking lander 1, rocky flats rock)[10] **1290** (Viking lander 2, soil)[10] **2600** (Viking lander 2, rocks)[10] **2100** (MPF soujourer, cloddy)[4] **1168** (MPF soujourer, drift)[4]	**1300** (Surface, Apollo core samples)[1] **1520** (10 cm depth, Apollo core samples)[1] **1830** (1 m depth, Apollo core samples)[1] **1920** (value bulk density is approaching in large depths, average Apollo core samples)[1] **1500** (Surveyor 1) [5] **800** (Luna 13) [5] **1500** (Surveyor 1, 3 and 7) [5] **1100** (Surveyor surface) [5] **1600** (Surveyor 5 cm depth) [5] **1600** (Lunkhod 1 / Luna 16) [5] **1700** (Surveyor 3) [5] **1500** (Lunkhod 1 and 2 / Luna 16 and 20) [5] **1645** (Apollo 11) [5] **1800** (Apollo 12) [5] **1200** (Luna 16) [5] **1525** (Apollo 14) [5] **1605** (Apollo 15 core tubes) [5] **1775** (Apollo 15 drill cores) [5] **1450** (Luna 20) [5] **1600** (Apollo 16 core tubes) [5] **1900** (Apollo 17 drill cores and core tubes) [5] **1850** (Luna 24) [5]
Internal friction angle (degrees)	**20** (Gusev loose soils) [12] **25** (Gusev dense soils) [12] **20** (Meridani Eagle crater floor and m. plains) [12] **20** (Meridani Eagle crater walls (loose soils) [12] **18** (Viking Lander 1, drift) [12] **30** (Viking lander 1, blocky) [12] **37** (MPF, cloddy) [12] **25** (Intercrater areas) [12] **38** (Viking lander 1, Viking lander 2)[10] **38** (Gusev crater, mesa, mixed course and fine)[11] **13** (Gusev crater, mesa, active dust deposit) [11] **18** (Gusev crater, crater rim, indurated surface) [11] **15** (Gusev crater, crater rim, active dust deposit) [11] **30** (Hematite area, crater rim, indurated surface) [11] **20** (Hematite area, crater rim, active dust deposit) [11] **28** (Hematiete area, crater rim, indurated surface) [11] **30** (Hematite area, crater rim, indurated surface) [11]	**33** (Inferred boulder tracks) [5] **20** (Inferred boulder tracks) [5] **39** (Inferred boulder tracks) [5] **37** (Apollo 17, N, E and S Massifs) [5] **36** (Surveyor Soil Mechanics Surface Sampler) [5] **41** (Apollo 11, core tube flagpole, SWC shaft penetration) [5] **41** (Apollo 12, core tube, SWC shaft penetration) [5] **38** (Lunokhod I, vane shear) [5] **35**(Lunokhod, cone penetrometer) [5] **40** (Apollo 14, soil mechanics trench) [5] **42** (Apollo 14, MET tracks) [5] **50** (Apollo 15, SRP data simulation studies) [5] **50** (Apollo 15, SRP data and soil mechanics trench) [5] **47** (Apollo 16 SRP station 4, 10-20 cm depth) [5] **50** (Apollo 16, SRP station 10) [5] **47** (Apollo 16 drill core open hole) [5] **40** (Apollo 17 drill core open hole) [5] **35** (Apollo 17, LRV) [5] **40** (Lunokhod 1 and 2 average) [5] **40** (Apollo 11 penetrometer returned samples) [5] **32** (Apollo 12, vacuum direct shear returned sample) [5] **35** (Apollo 12, direct shear returned sample) [5] **55** (Apollo 12, triaxial shear returned sample) [5] **23** (Luna 16 and 20 direct shear and Colomb device, returned sample) [5]
Bearing strength (kPa)	**5** (Gusev loose soils) [12] **200** (Gusev dense soils) [12] **80** (Meridani Eagle crater floor and m. plains) [12] **8** (Meridani Eagle crater wall (loose soils)) [12]	**0.3** (Surveyor 3, at bulk density of 1150 kg/m^3) [7] **650** (Surveyor 3, at bulk density of 1900 kg/m^3) [7]
Porosity (%)	**40** (rough estimate based on data from Viking landings) [9]	**45** (Lunar average) [1] **52** (Lunar average 0-15 cm depth) [5] **46** (Lunar average 0-60 cm depth) [5] **44** (Lunar average 30-60 cm depth) [5]

Discussion: Mars seems to show larger variations than the Moon in general (however consequences of difference in gravity should be further explored). This is in partly due to the atmosphere with active weather systems, eroding and transporting sediments, seasonal freezing and sublimation - while on the Moon only impact and solar wind effects influence the regolith. Many of the measurements were carried out in an indirect way, for example by measuring engine current instead of force. While the Moon is moderately homogeneous and fairly uniform according to [5], showing more variation within a study area than between study areas, Mars is much more diverse, with aeolian drift and dunes but less knowledge for regolith in general. Many of the results are not directly comparable in the Moon vs Mars sense, as collected using different methods.

Table 1. continuation.

Parameter	Mars	Moon
Cohesion (kPa)	**1** (Gusev loose soils) [12] **15** (Gusev dense soils) [12] **5** (Meridani Eagle crater floor and m. plains) [12] **0.5** (Meridani Eagle crater wall (loose soils)) [12] **1.6** (Viking Lander 1, drift) [12] **5.5** (Viking lander 1, blocky) [12] **0.17** (Mars Pathfinder, cloddy) [12]	**0.35** (Inferred boulder tracks) [5] **0.1** (Inferred boulder tracks) [5] **0.5** (Inferred boulder tracks) [5] **1** (Apollo 17, N, E and S Massifs) [5] **0.65** (Apollo 12, core tube, SWC shaft penetration) [5] **<0.1** (Apollo 14, soil mechanics trench) **1** (Apollo 15, SRP data, soil mechanics trench) [5] **0.6** (Apollo 16 SRP station 4, 10-20 cm depth) [5] **0.37** (Apollo 16, SRP station 10) [5] **1.3** (Apollo 16 drill core open hole) [5] **1.5** (Apollo 17 drill core open hole) [5] **0.17** (Apollo 17, LRV) [5] **0.4** (Lunokhod 1 and 2 average) [5] **0.55** (Apollo 11 penetrometer) [5] **0.35** (Apollo 12, vacuum direct shear) [5] **0.5** (Apollo 12, triaxial shear) [5] **4.9** (Luna 16, 20 direct shear, Colomb device) [5]
Cumulative grain size distribution D90-D10 (µm) NB: All Martian values are from wind ripple areas and not represen-tative for general Martian conditions	**497.5-239** Barby [3] **277.3-102.1** Kibnas [3] **929.8-337.9** Enchanted Isl.[3] **395.7-114.2** T. Little Toes [3] **330.4-114.6** Ripogenus [3] **264.7-113** Shin Brook [3] **656-211.3** Traquair [3] **312.3-129** Ratharsair [3] **287.6-91.73** Flume Ridge [3] **341.4-106.2** The Forks [3] **270.7-69.99** Avery Peak [3] **276.5-105.2** Flanders Bay [3] **412.2-158.9** The Shivers [3] **715.3-231.7** Trumpet [3] **214.4-98.03** Gobabeb A [3] **469.1-188.5** Gobabeb B [3] **196.7-91.95** Otavi [3] **494.8-196.2** Warsaw [3]	**1800-75** (Various Apollo missions, values collected from middle curve in graph presented in Carrier (2005)) [1]
Sorting (φ) NB: All Martian values are from wind ripple areas and are probably not the most representative. The average regolite is likely to be much more well graded	**0.414** Barby [3] **0.556** Kibnas [3] **0.543** Enchanted Island [3] **0.694** T. Little Toes [3] **0.582** Ripogenus [3] **0.466** Shin Brook [3] **0.611** Traquair [3] **0.493** Ratharsair [3] **0.666** Flume Ridge [3] **0.662** The Forks [3] **0.565** Avery Peak [3] **0.541** Flanders Bay [3] **0.535** The Shivers [3] **0.621** Trumpet [3] **0.434** Gobabeb A [3] **0.527** Gobabeb B [3] **0.426** Otavi [3] **0.538** Warsaw [3]	**2.88** (Median of average lunar soils) [5] **1.69** (Dark mantle deposits apollo 17 and 19) [5] All inputs visually obtained from the middle curve in the graph presented in Carrier (2005). Value calculated based on the provided formula given in https://www.geological-digressions.com/tag/folk-and-ward-scales/ **1.35** (D84-D16/4)+(D95-D05/6,6)
Gravitational acceleration m/s^2	**3.72** (Martian average) [6]	**1.62** (Lunar average)[5]
Relative density (%)		**65** (Lunar average 0-15 cm depth) [5] **90<** (Lunar average depth >30 cm) [5] **84** (Apollo 15, Hadley Rille 0-30 cm depth) **97** (Apollo 15, Hadley Rille 30-65 cm depth)
Permeability (m^2)		**4*10^-12** (Surveyor V) [2]
Specific area (m^2/kg)		**500** (Lunar soil average, about 8 times more than spheres of similar grain size would produce) [1]

Conclusions: Although there are several sources on the measured geotechnical parameters for the most often visited bodies like Moon and Mars, these are heterogeneous and several important items are missing from them. To date no soil samples have been returned from Mars. The data on grain size distribution on Mars is very limited except for wind transported grains. Many of the available data sets, both on the Moon and Mars consists of very wide intervals and large uncertainties. More precise data are necessary to improve the usability of the data. The influence of gravity on the geotechnical parameters, particularly internal friction angle needs clarification in future works. There is a need to unify measurements and methods to gain comparable data, what should be linked to the already started quality assurance methods for lunar drills, in-situ resource utilization and next surface bases.

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