Some Expected Mechanical Characteristics of Lunar Dust: A Geological View

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Lunar Geologic History

Initial lunar rock ~ norite.

Subsequent basaltic volcanic (& other)flows.

Hypervelocity impacts largely destroyed original rock.

Resulting broken material covering surface = Regolith.

Except for some outcrops in or around the mare,
all interactions (people, equipment, etc.)
will be with regolith!

Subsequent Geologic Processing

Particle Size -

Net result of continuing meteor bombardment.

Surface of Moon is ground mixture of fragments.
Size range: nanoscopic to large blocks of rock.

Mixture believed to be meters deep everywhere.

For Apollo mission samples
typical average particle sizes from ~ 30 to 100 um.

Subsequent Geologic Processing

Sorting -

All Terrestrial particles are sorted.
Based on size, shape and composition.

No Terrestrial segregation processes operate in a vacuum.

Energy input lunar surface sufficient to cause particle motion.
Can mix but not sort.

What designers can expect:
for any reasonable sized sample
from top few meters
it is possible, and even probable to have:
Particles of all size ranges and
Any lunar component in the sample.

Subsequent Geologic Processing

Particle Composition -

Lunar dust fraction (material < 20μm):
- currently not well characterized.

Some aspects may or may not be important:
- presence of nanoscopic Fe.
- vapor deposited rims.

Regolith (macroscopically) is minerals and silicate glass.

Mineral is:
- naturally occurring substance.
- characteristic, limited chemical composition.
- highly ordered atomic structure.

Therefore the range of each mineral's properties is:
- limited.
- properties basically source independent (lunar or terrestrial).

Rock Names

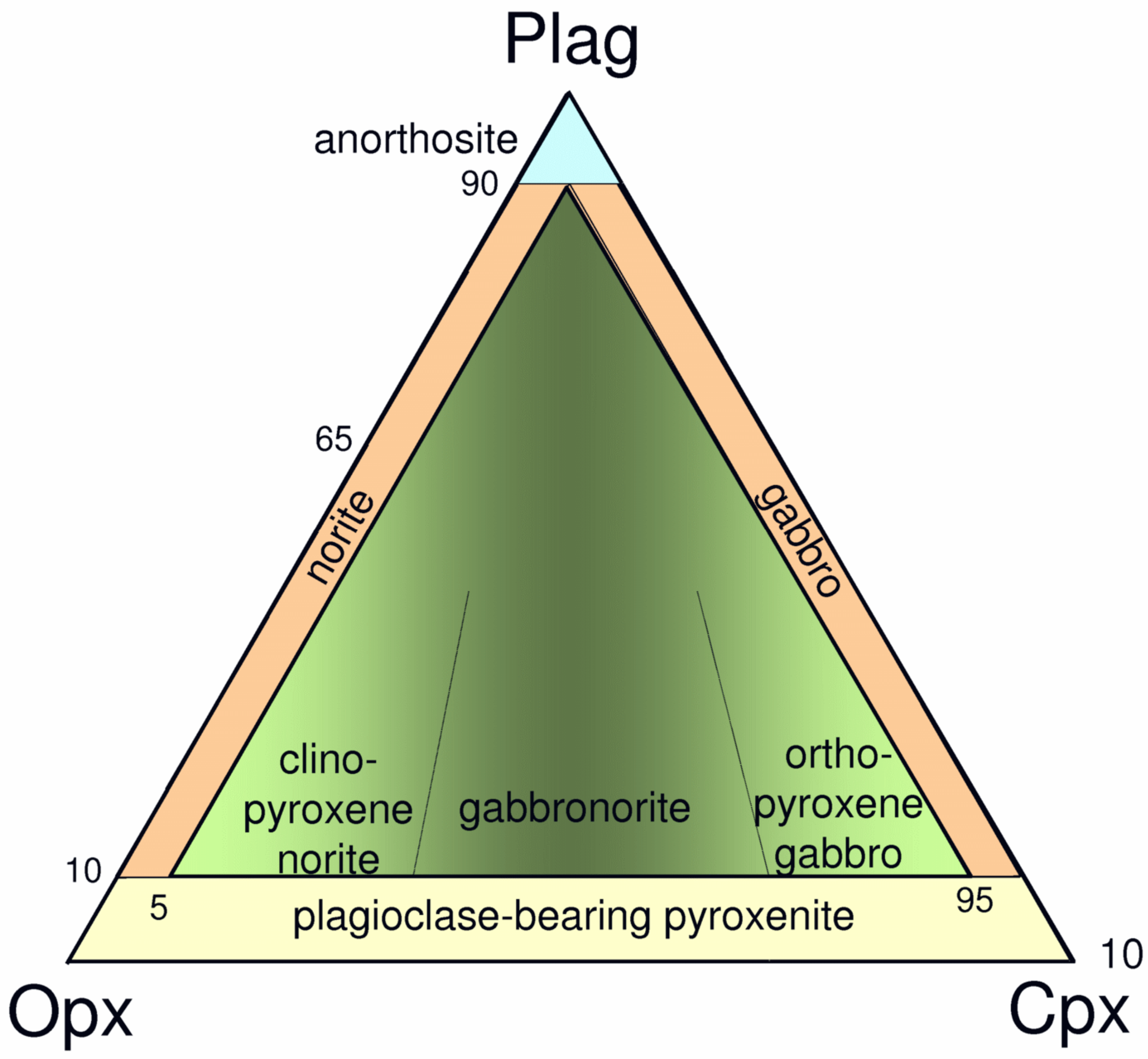

Plag
anorthosite
90
65
norite
gabbro
clino-
pyroxene
norite
gabbronorite
ortho-
pyroxene
gabbro
10
5
plagioclase-bearing pyroxenite
95
10
Opx
Cpx

TABLE 1. Significant Lunar Minerals..

	Mineral	Dana #	Mohs	Spec Gravity	Chemical Composition
Plagioclase	Anorthite	76.1.3.6	6	2.75	$CaAl_2Si_2O_8$
	Bytownite	76.1.3.5	6.0-6.5	2.73	$(Ca,Na)(Si,Al)_4O_8$
	Labradorite	76.1.3.4	7	2.71	$(Ca,Na)(Si,Al)_4O_8$
Olivine	Fayalite	51.3.1.1	6.5-7.0	4.39	Fe_2SiO_4
	Forsterite	51.3.1.2	6.5-7.0	3.24	Mg_2SiO_4
Pyroxene	Clinoenstatite	65.1.1.1	5.0-6.0	3.4	$Mg_2\,[Si_2O_6]$
	Pigeonite	65.1.1.4	6	3.3	$(Mg,Fe^{+2},Ca)_2[Si_2O_6]$
	Hedenbergite	65.1.3a.2	6	3.5	$CaFe^{+2}[Si_2O_6]$
	Augite	65.1.3a.3	5.5-6.0	3.3	$(Ca,Na)(Mg,Fe,Al,Ti)[(Si,Al)_2O_6]$
	Enstatite	65.1.2.1	5.0-6.0	3.4	$Mg_2[Si_2O_6]$
Spinel	Spinel	7.2.1.1	7.5-8.0	3.56	$MgAl_2O_4$
	Hercynite	7.2.1.3	7.5-8	3.93	$Fe^{+2}Al_2O_4$
	Ulvospinel	7.2.5.2	5.5-6.0	4.7	$TiFe^{+2}{}_2O_4$
	Chromite	7.2.3.3	5.5	4.7	$Fe^{+2}Cr_2O_4$
	Troilite	2.8.9.1	4	4.75	FeS
PO4	Whitlockite	38.3.4.1	5	3.12	$Ca_9(Mg,Fe^{+2})(PO_4)_6(PO_3OH)$
	Apatite	41.8.1.0	5	3.19	$Ca_5(PO_4)_3(OH,F,Cl)$
	Ilmenite	4.3.5.1	5.5	4.72	$Fe^{+2}TiO_3$
	Native Iron	2.9.1.1	4.5	7.87	Fe

TABLE 1. Significant Lunar Minerals. %: A-abundant, M-major, m-minor, t-trace.

	Mineral	Mohs	Mode: Cleavage	Mode: Fracture	%
Plagioclase	Anorthite	6	{001} p, {010} g	Conchoidal to uneven; brittle	A
	Bytownite	6.0-6.5	{001} p, {010} g	Conchoidal to uneven; brittle	M
	Labradorite	7	{001} p, {010} g	Conchoidal to uneven; brittle	M
Olivine	Fayalite	6.5-7.0	{010} moderate, {100} weak	Conchoidal	-
	Forsterite	6.5-7.0	{100}, {010} i - g; {001} po -f	Conchoidal	-
Pyroxene	Clinoenstatite	5.0-6.0	{110} g - p	Brittle	M
	Pigeonite	6	{110} p	Conchoidal to uneven; brittle	M
	Hedenbergite	6	{110} g	Conchoidal to uneven	M
	Augite	5.5-6.0	{110} g	Uneven	M
	Enstatite	5.0-6.0	{210} g - p	Conchoidal	A
Spinel	Spinel	7.5-8.0	No cleavage	Conchoidal	m
	Hercynite	7.5-8	No cleavage	Uneven	m
	Ulvospinel	5.5-6.0	No cleavage	Uneven	m
	Chromite	5.5	No cleavage	Uneven	m
	Troilite	4	No cleavage	Uneven	t
PO4	Whitlockite	5	No cleavage	Uneven to sub-conchoidal	t
	Apatite	5	No cleavage	Uneven to conchoidal	t
	Ilmenite	5.5	No cleavage	Conchoidal	m
	Native Iron	4.5	{001} i - f	Hackly	t

p = perfect; g = good; f = fair; I = indistinct; po = poor

Material Testing Methods

- Indentation: Hardness
  - Brinell, Knoop, Rockwell, Vickers, **.....**

    (plasticity)

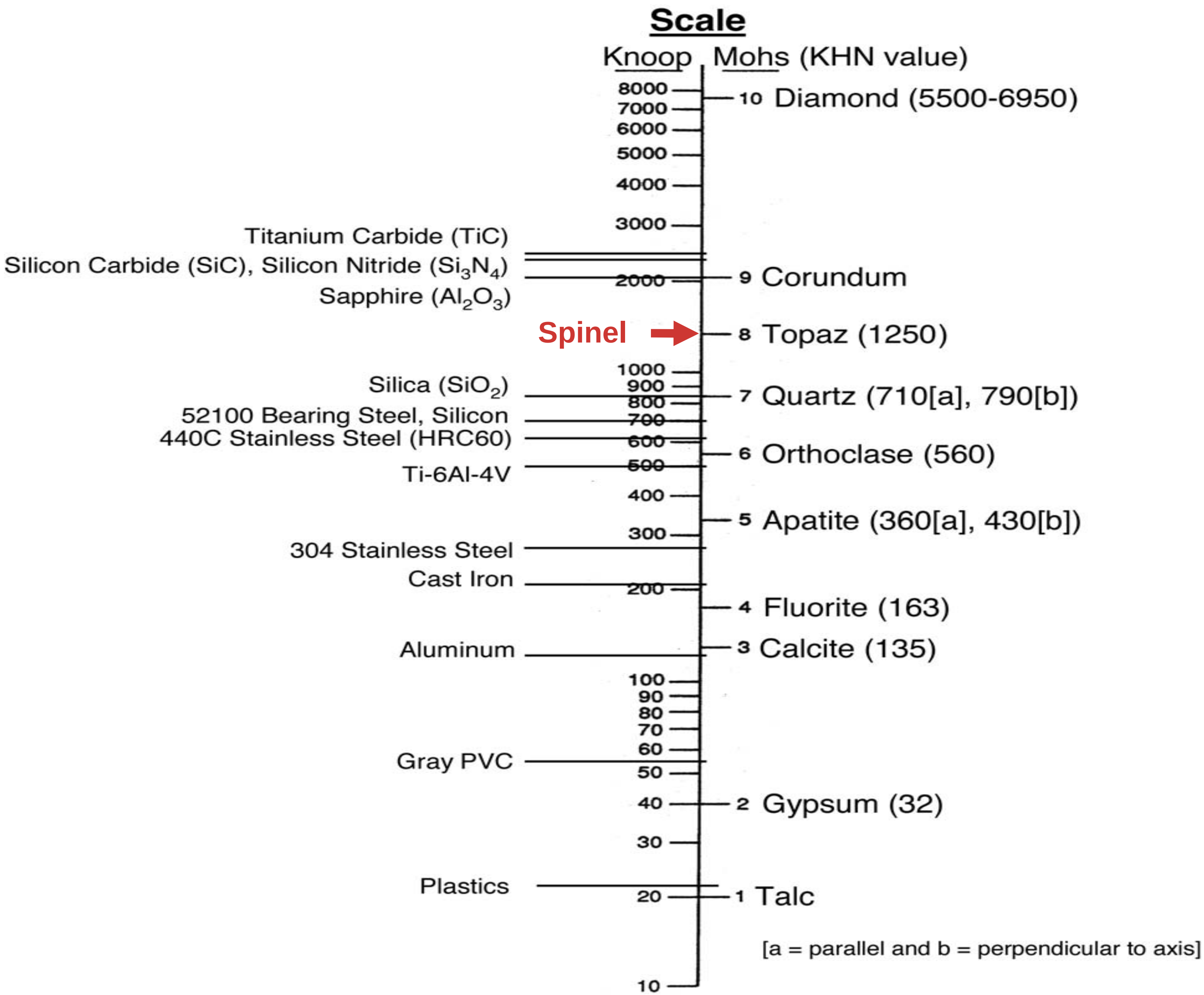
- Impaction: Brittleness
  - Falling Weight, Incline Impact, **....**

    (toughness)

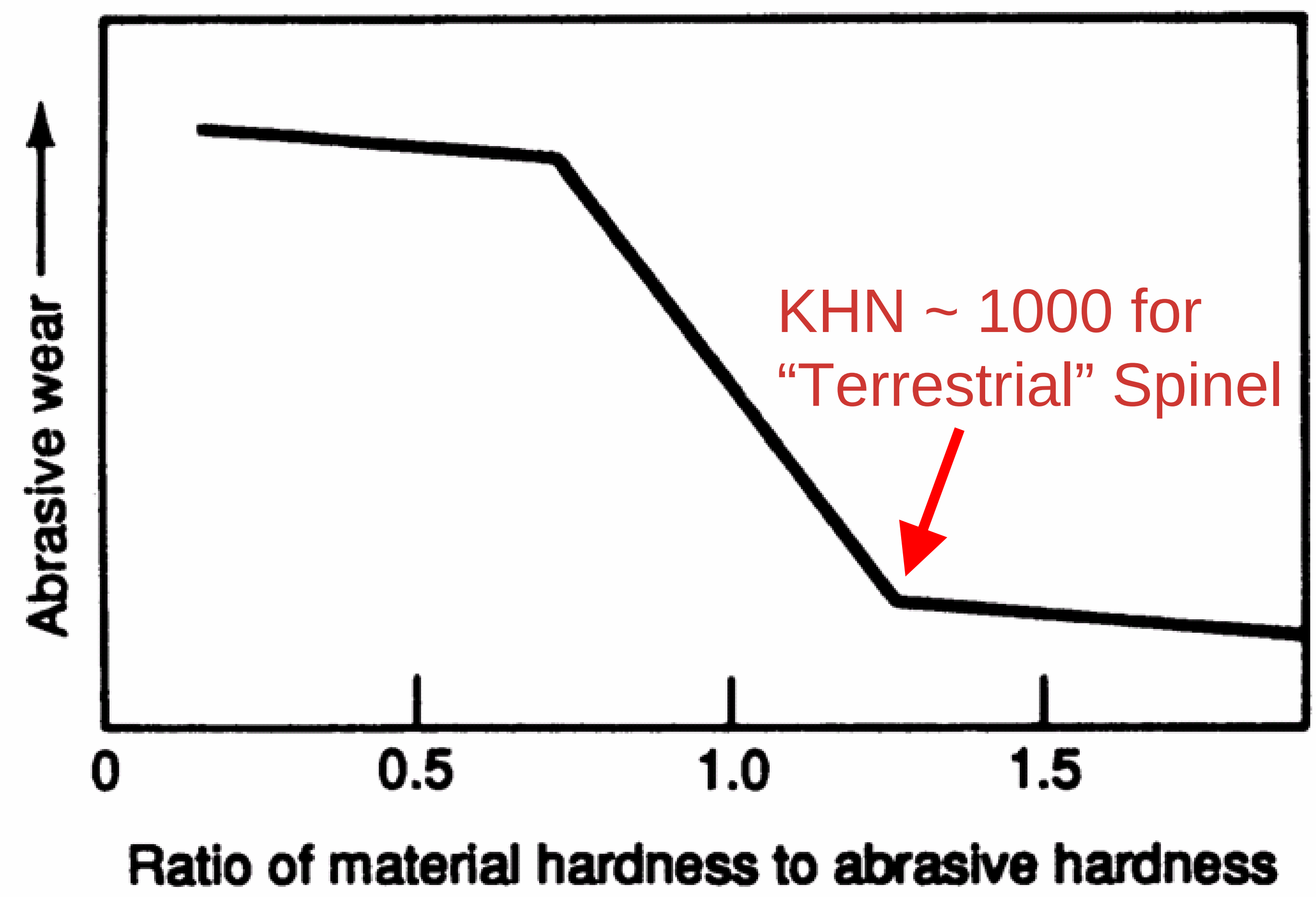
- Scratch
  - Mohs, Diamond Stylus, **....**

    (abrasion – A key issue in Lunar exploration!)

Relating Hardness Scales:
Mineral (scratch) vs. Metal (indentation)

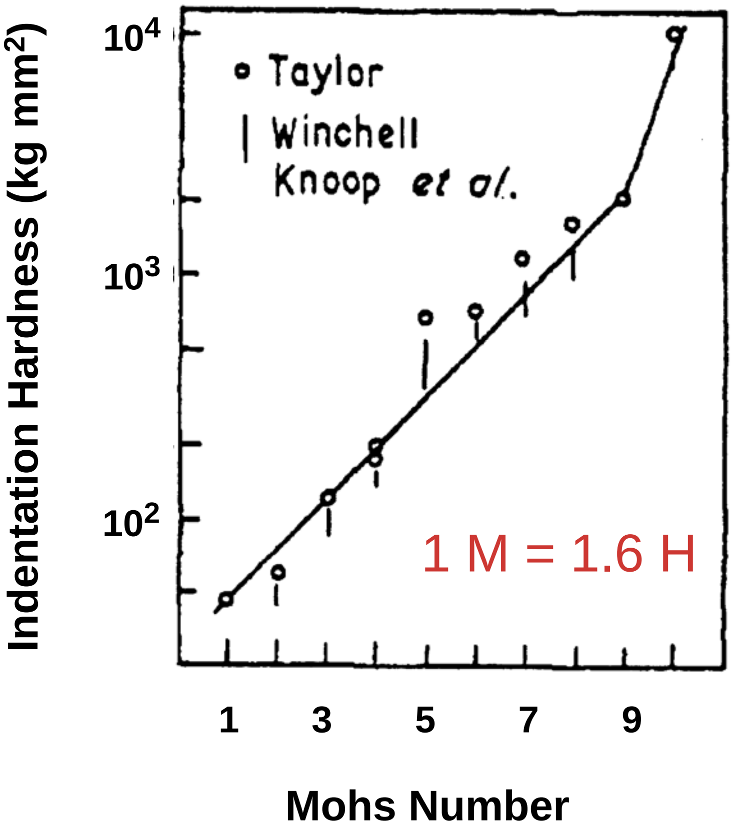


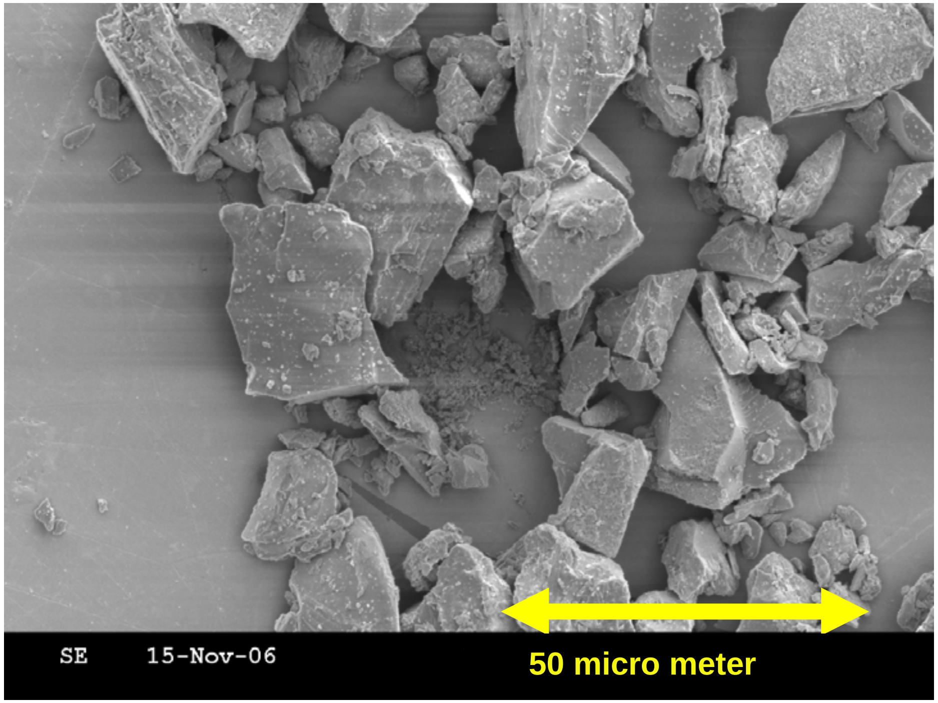
Effect of Hardness on Abrasiveness



The microhardness of synthetic corundum is significantly lowered by water adsorbed from the air. Such softening is commonly experienced by a wide variety of nonmetallic materials (although not by metallic substances). **On the moon things will be worse!!!**

Hardness and Geometry

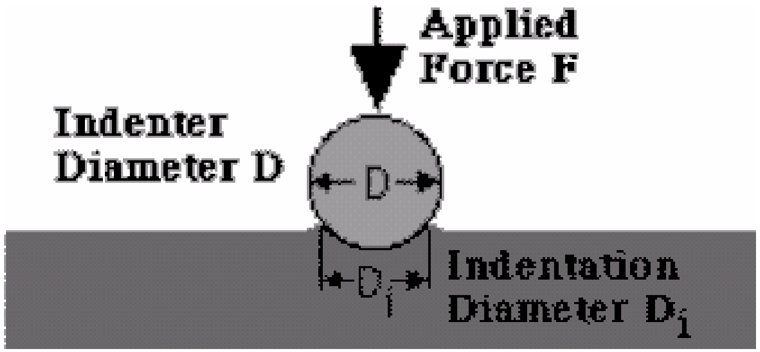




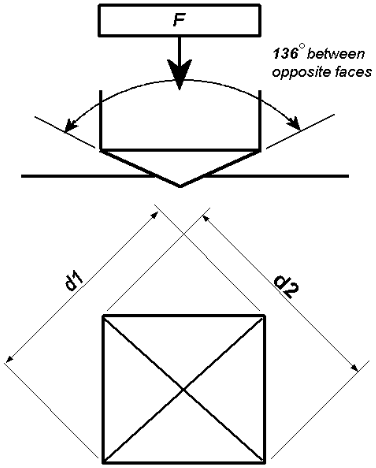
SEM of JSC-1a

Hardness Measurements

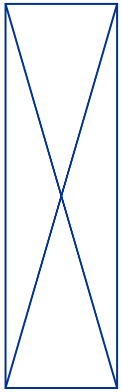
Brinell Hardness



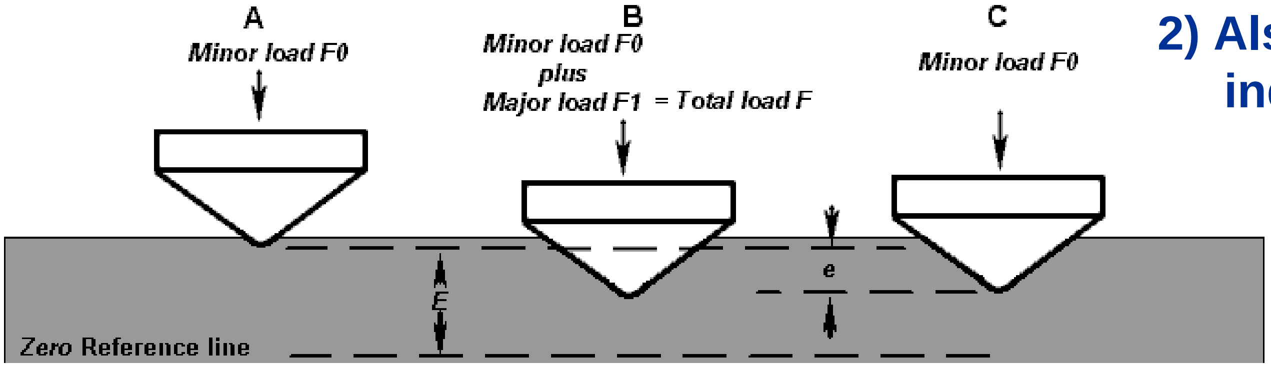
Vickers Hardness



Knoop Hardness



Rockwell Hardness



1) Incremental indent

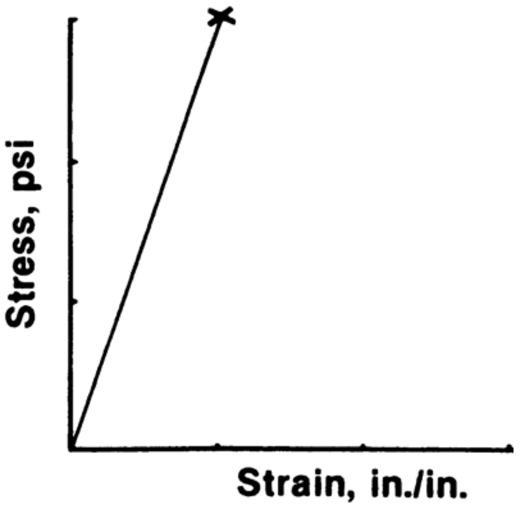
2) Also uses spherical indenter

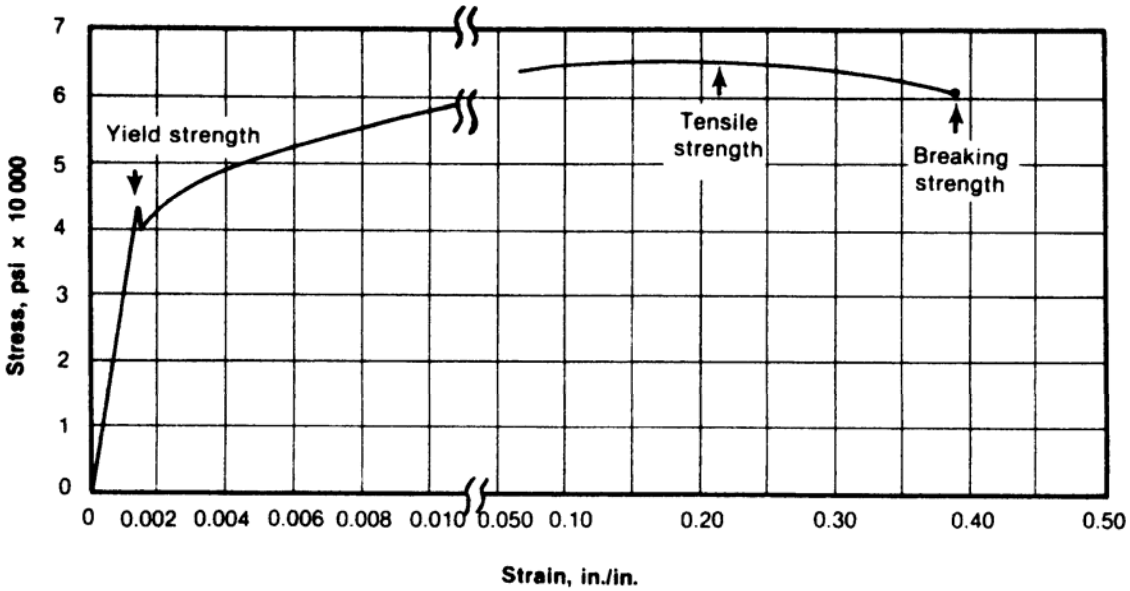
Table 2. Approximate Correlation Between Hardness Scales.

Hardness Values (load)						
HV (10 kg)	**HB** (500g)	**HB** (3 kg)	**HRB**	**HRC**	**KHN** (10 g)	**KHN** (1 kg)
1865	-	-	-	80	-	-
832	-	739	-	65	-	-
595	-	560	120	55	840	605
254	201	240	100	23	376	250
156	133	153	81	0	223	145
70	53	-	0	-	-	60

Note: ASTM Tables available for more exact conversion

Hardness vs. Toughness





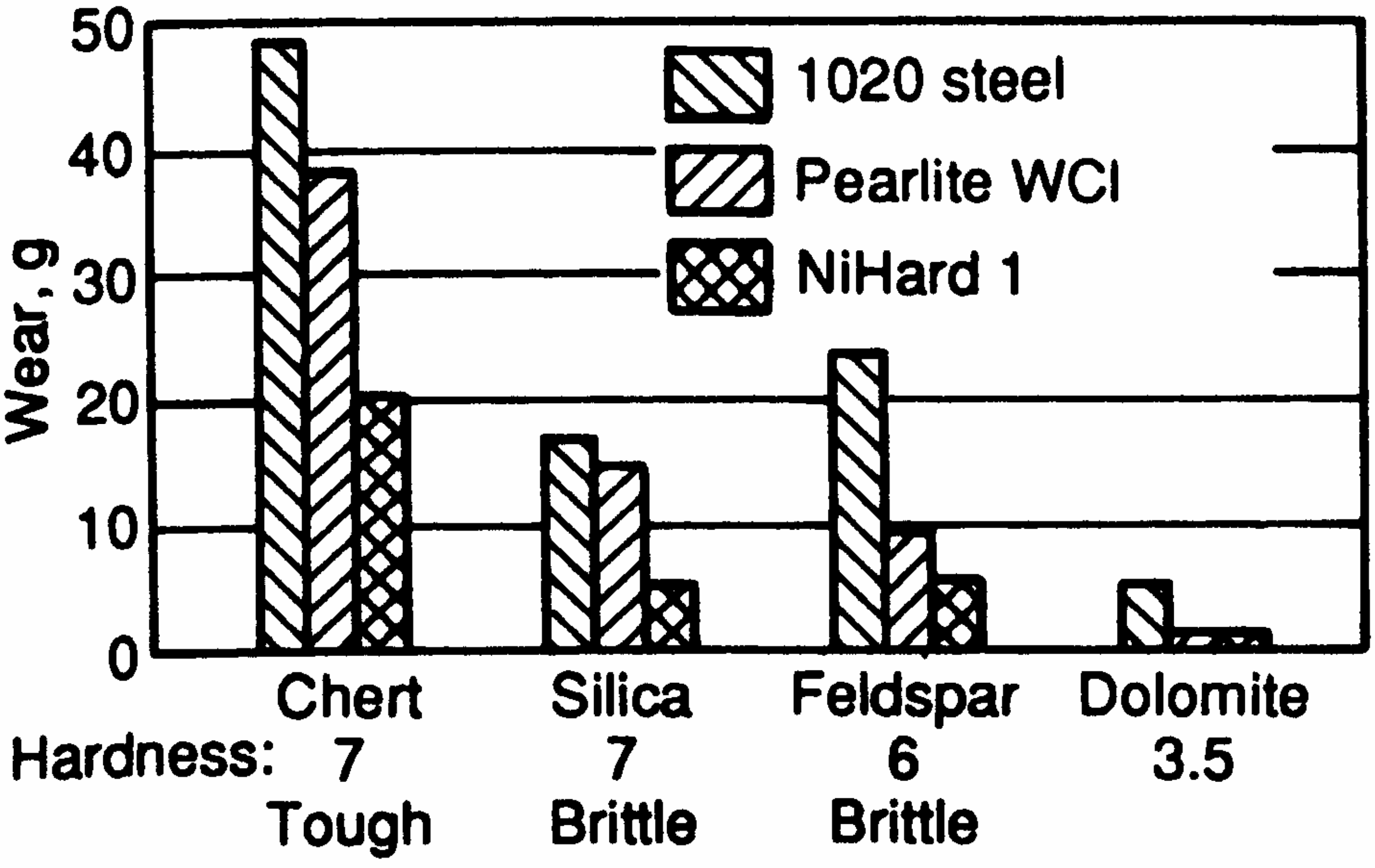
Brittle: **Ceramics, Minerals**

Tough (Ductile): **Metals (Carbon Steel)**

Hardness ≠ Toughness

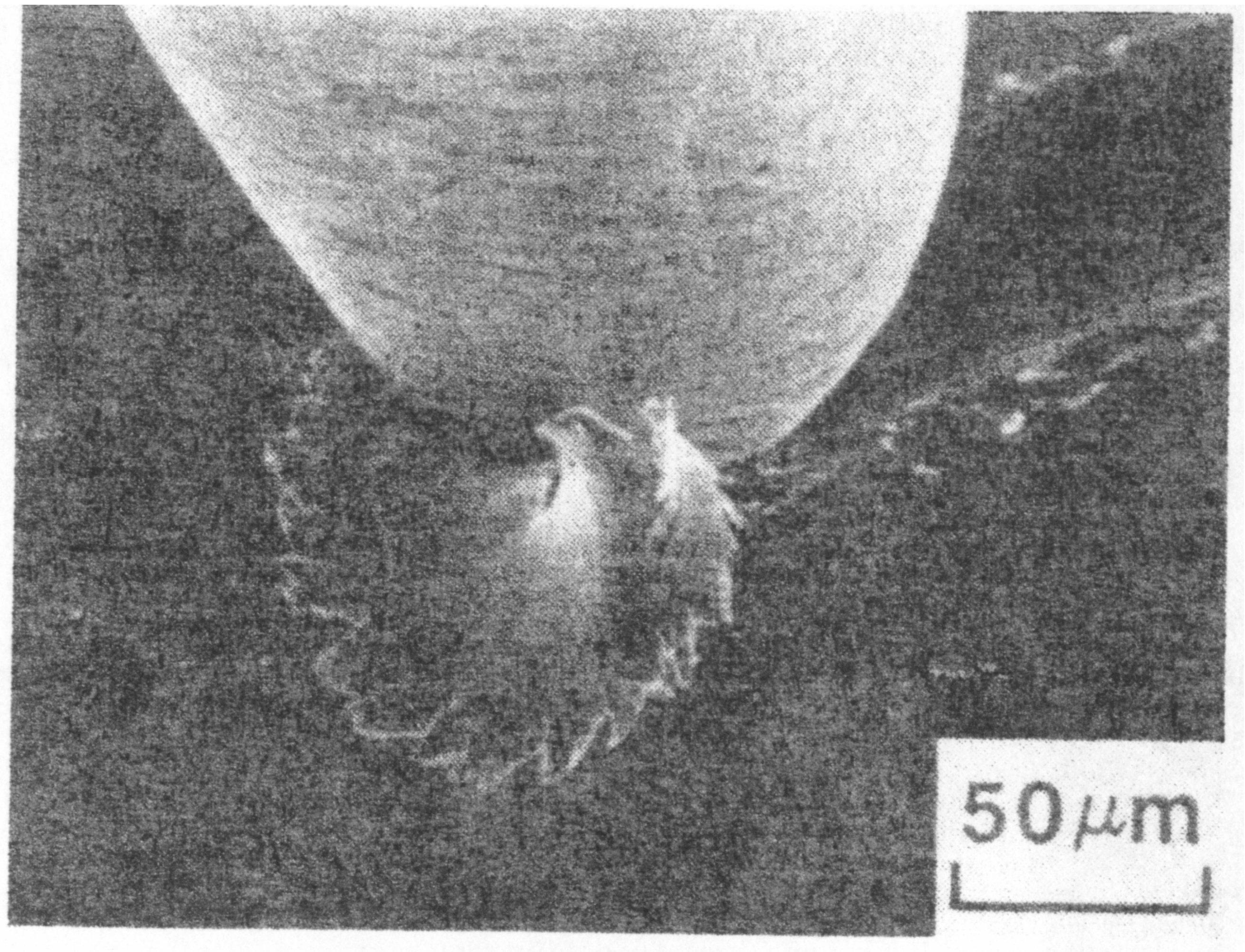
Toughness = Area under Stress-Strain curve

Toughness vs. Hardness (For Minerals)



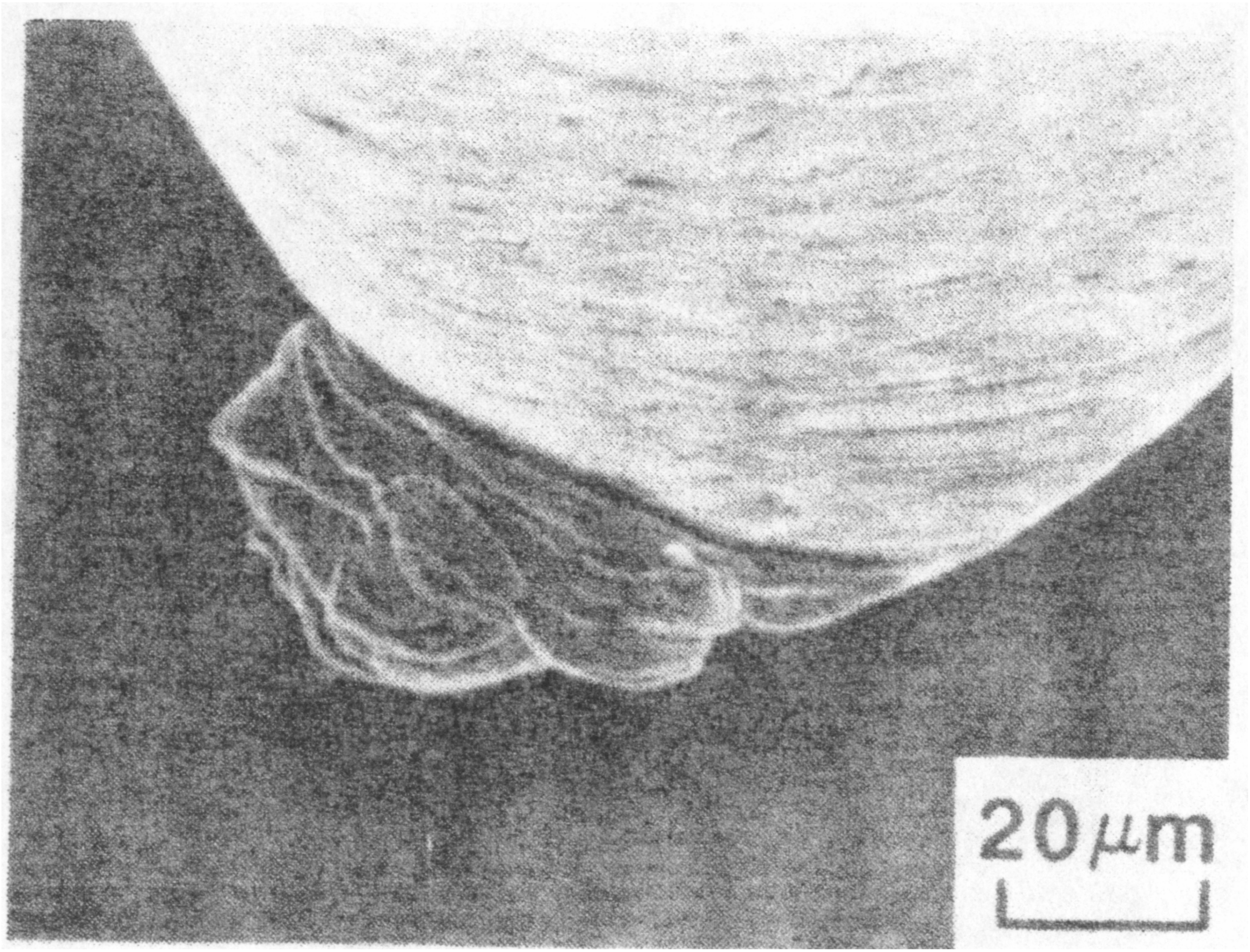
The third part of the answer is geometry!

Plastic Deformation - Cutting

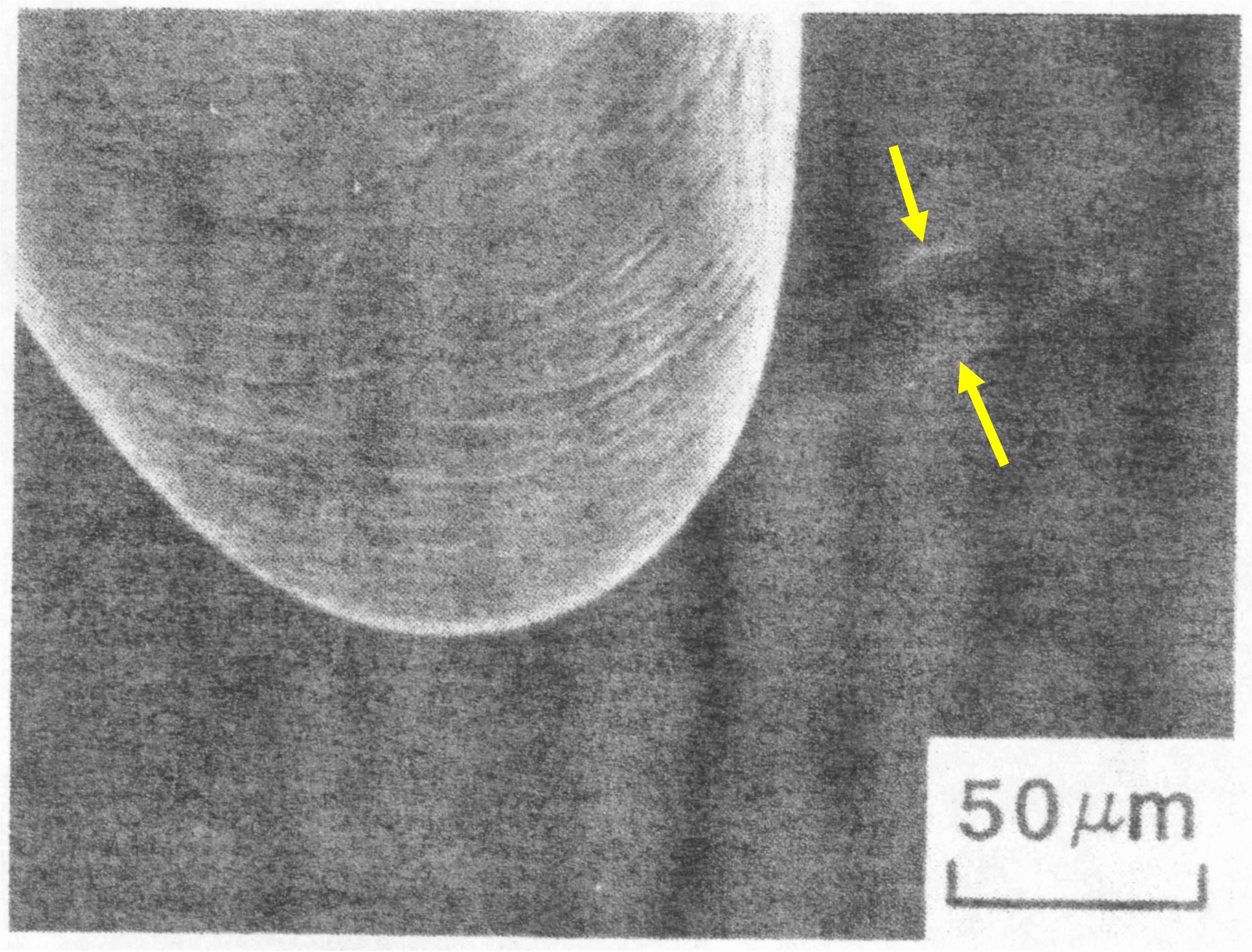


Note: Elasticity (polymers) vs. Plasticity (metals)

Plastic Deformation - Wedge



Plastic Deformation - Plowing



Major Omissions !!!

- **Polymers (elastic)**
- **Surface coatings, treatments and substrate effects**

Conclusions:

- Engineering is constrained by Regolith properties
- Preliminary geologic data can be useful in engineering design
- A comparison of geologic properties to engineering material is presented
- Some Lunar minerals are hard, tough and sharp (abrasive)
- Some processes may concentrate trace components

Acknowledgement: J.R. Skok & Ashley Boudreaux for compiling and developing literature data on mineral properties and lunar mineral abundances.