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Understanding the Reactivity of Lunar Dust for Future Lunar Missions

W.T. Wallace
Wyle/NASA Johnson Space Center
Houston, TX

A.S. Jeevarajan
NASA Johnson Space Center

L.A. Taylor
University of Tennessee-Knoxville

Words of Wisdom

"I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust."

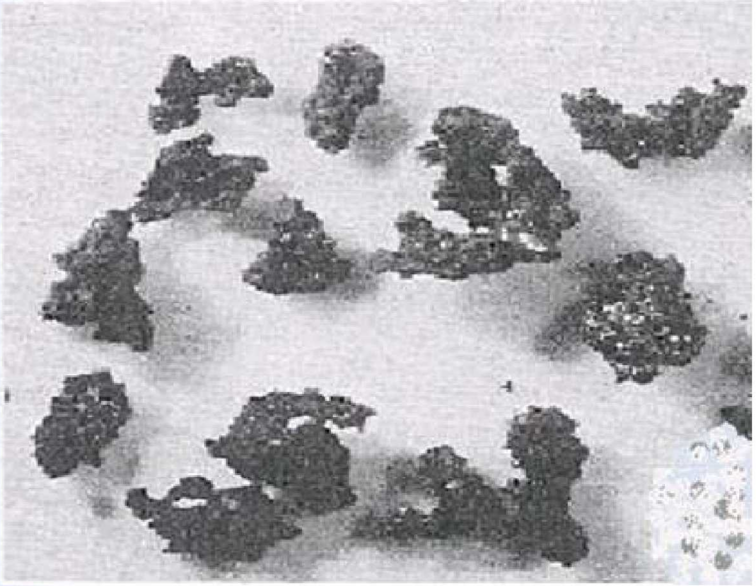
Gene Cernan
Apollo 17 Technical Debrief

Dust clings to Eugene Cernan's suit after a 1972 moonwalk.

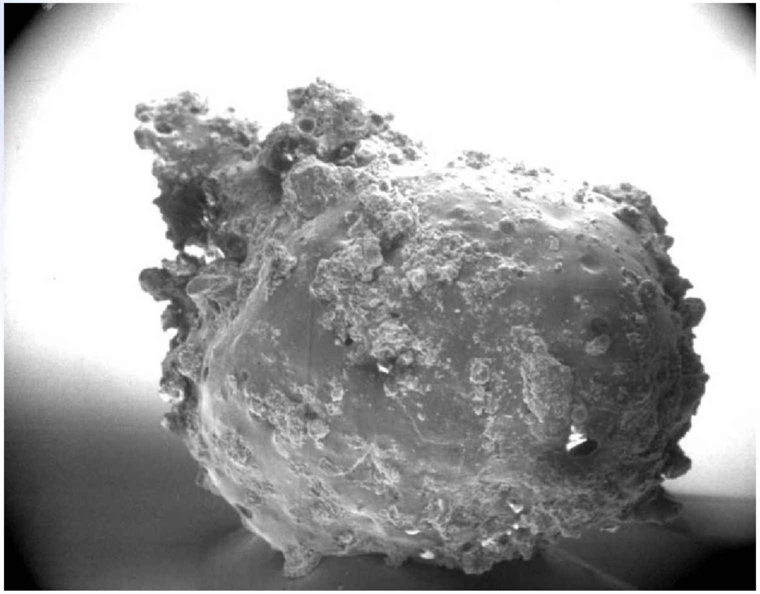
What is lunar dust?

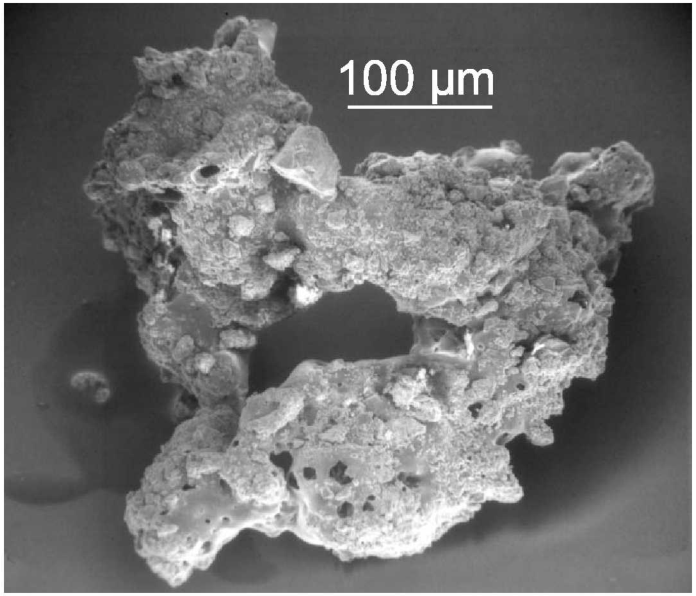
- Lunar soil is defined as the loose fragmental material with a grain size smaller than 1 cm on and near the surface of the moon. It is a subset of the lunar regolith which includes all size fragments including boulders.
- Lunar dust is the finest size fraction of lunar soil. A working definition of lunar dust is that it is all grains smaller than 20 µm.

Lunar Dust



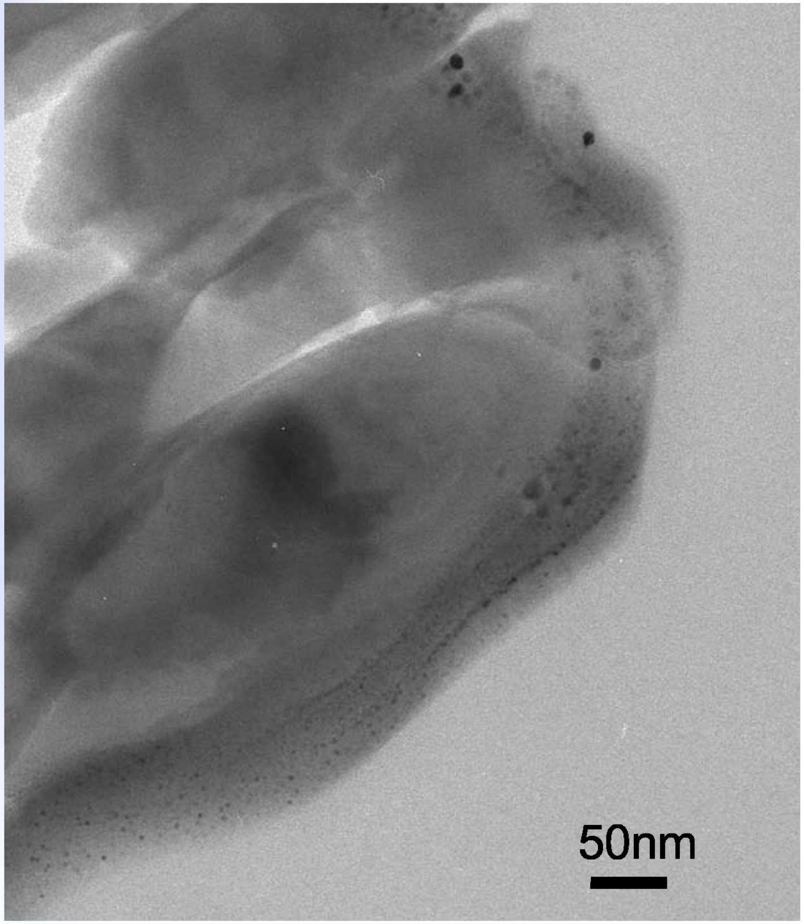
- Contains silicon-based minerals, other oxides, and trace metals
- Magnetic
- Particles are oddly shaped, with jagged edges, and do not pack together well

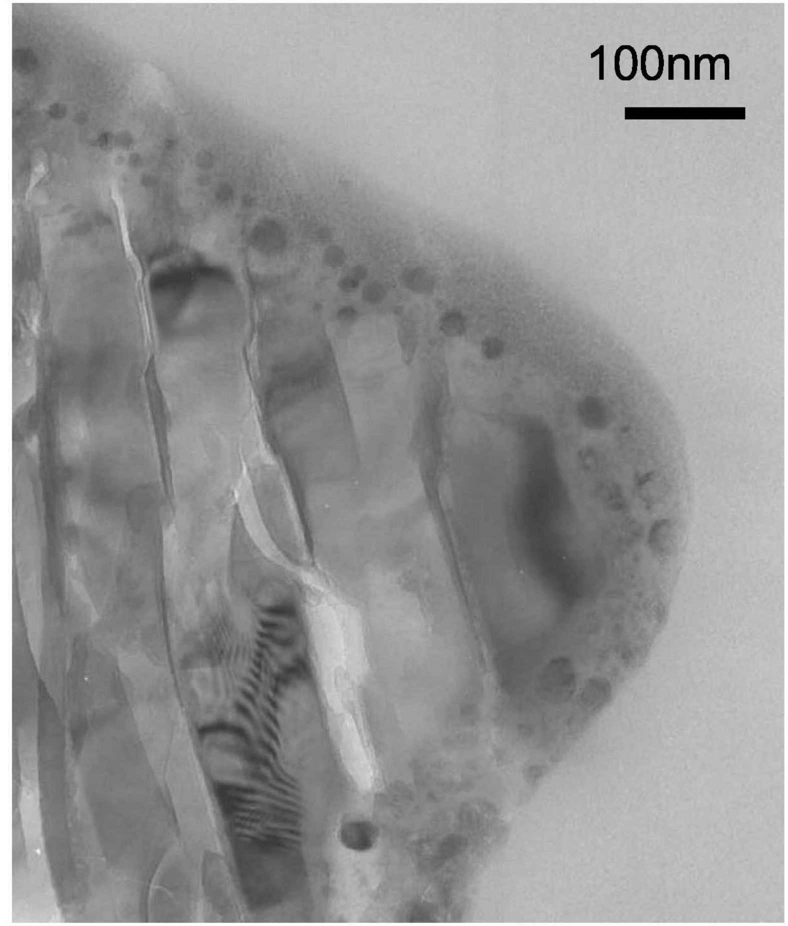




Dave McKay, JSC

Lunar Dust Rims





Glassy rims produced by vapor/sputter deposition. Also contain ~ 10 nm Fe nanoparticles (nanophase iron)

Sarah Noble, MSFC

Lunar Dust Simulant

Only 842 lbs of material returned from the moon!
Simulant material needed for preliminary studies.

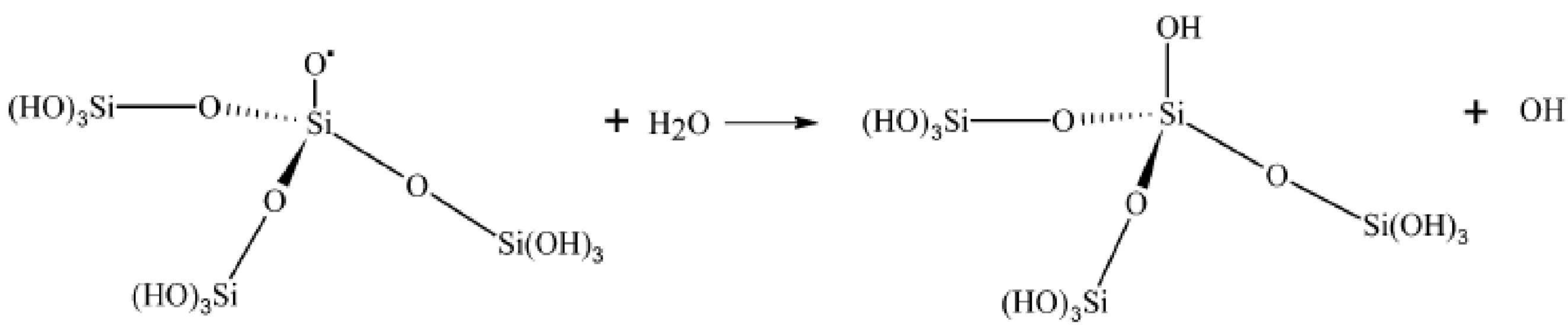
- JSC-1A-vf
- Made from volcanic ash
- 50% silicon-containing minerals
- 42-45% other oxides (Al_2O_3, FeO, MgO, CaO)
- No trace metals
- Size distribution of particles similar to samples of lunar dust
- 90% smaller than 13 µm diameter

Lunar Dust Activation

- Constant activation of lunar dust by meteorites, UV radiation, and elements of solar wind
- No passivating atmosphere
- Active dust could produce reactive species in the lungs
  - Freshly fractured quartz
- Must determine methods of deactivation before new lunar missions
- First, must understand how to *reactivate* dust on Earth

What Does "Activated" Mean?

- Presence of reactive sites on surface
  - Free radicals
- Ability to produce reactive species in solution



Reaction 5

J. Narayanasamy and J.D. Kubicki, *J. Phys. Chem. B* **109** (2005) 21796-21807

How Should We Monitor ·OH?

- Electron Spin Resonance
  - Provides quantitative measure of radical production
  - Equipment is costly and bulky
- Fluorescence Spectroscopy
  - Can also provide quantitative analysis
  - Large number of chemical sensors already in use for other systems
  - Need to determine correct probe

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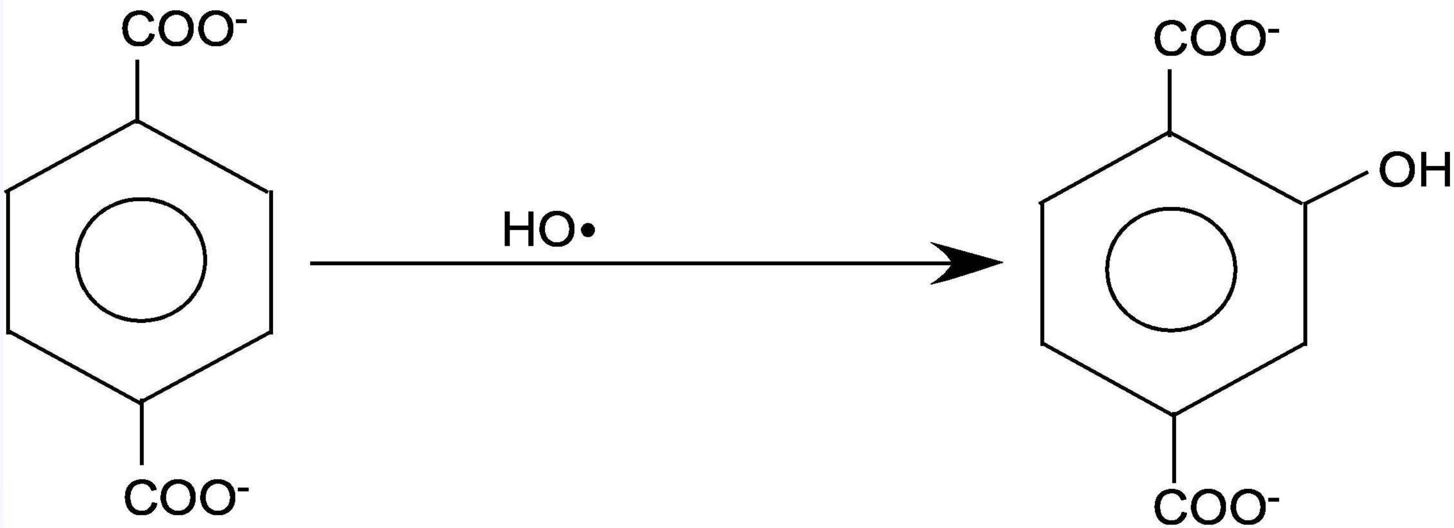
Hydroxyterephthalate as a Probe of Hydroxyl Radical Generation



Terephthalate (non-fluorescent)

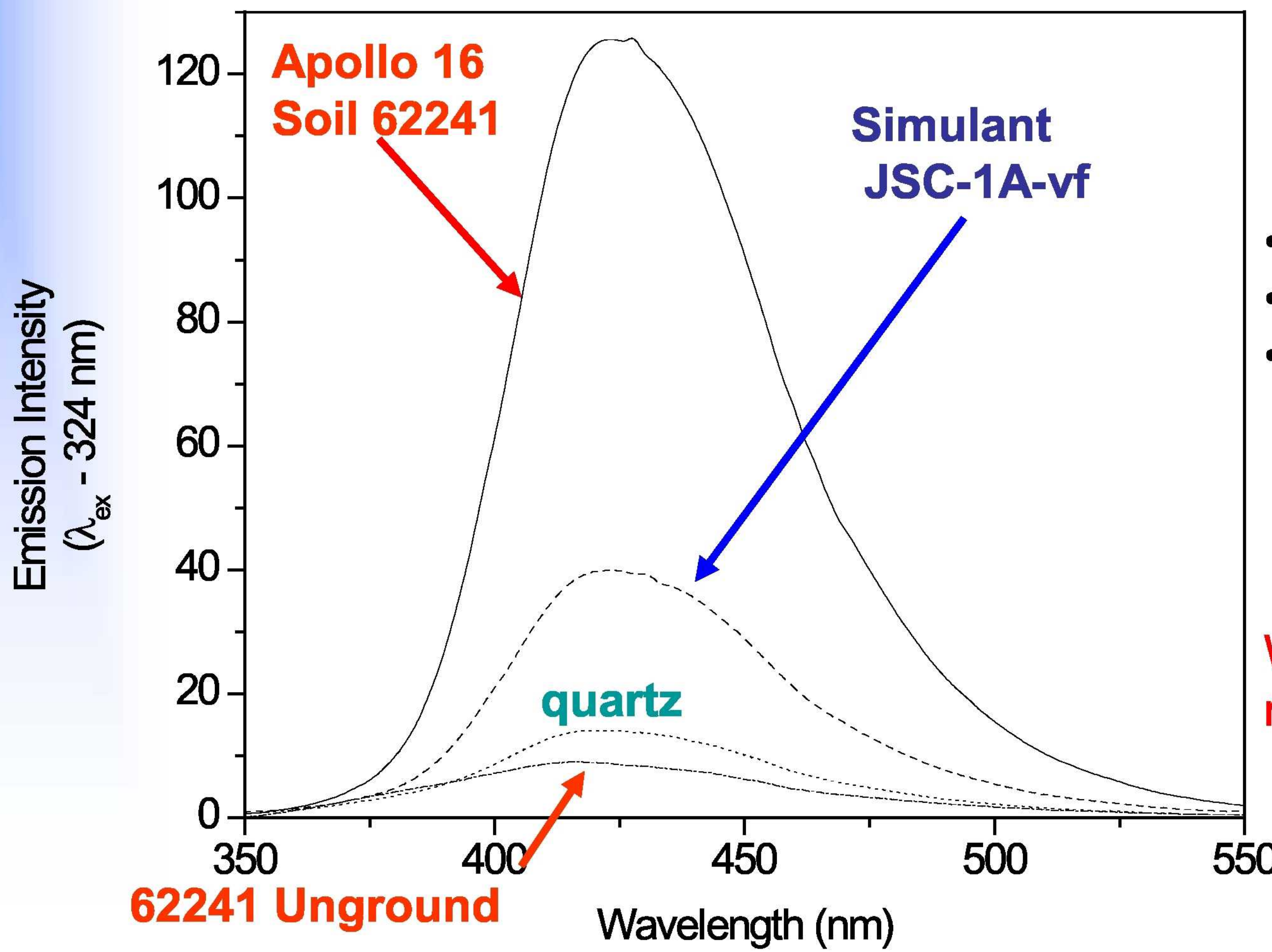
2-Hydroxyterephthalate (fluorescent)

Materials Used

Sample	SiO_2	Al_2O_3	TiO_2	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
JSC-1A-vf, % oxides	48.77	15.65	1.49	8.88 (+ 1.71% Fe_2O_3)	0.19	8.48	10.44	2.93	0.81	0.66
Apollo 16 Soil (62241), % oxides	44.65	27	0.56	5.49	0.7	5.84	15.95	0.44	0.13	0.1
Min-U-Sil Quartz, %	99.0-99.9	< 0.8	< 0.1	< 0.1 (Fe_2O_3)	0	0	0	0	0	0

D.S. McKay, *et al.*, *LPSC XXIV* (1993) 963-964.
H.J. Rose, Jr., *et al.*, *Proc. 4th LSC* **2** (1973) 1149-1158.

Activity Comparison of Ground Lunar Soil, Lunar Simulant, and Quartz

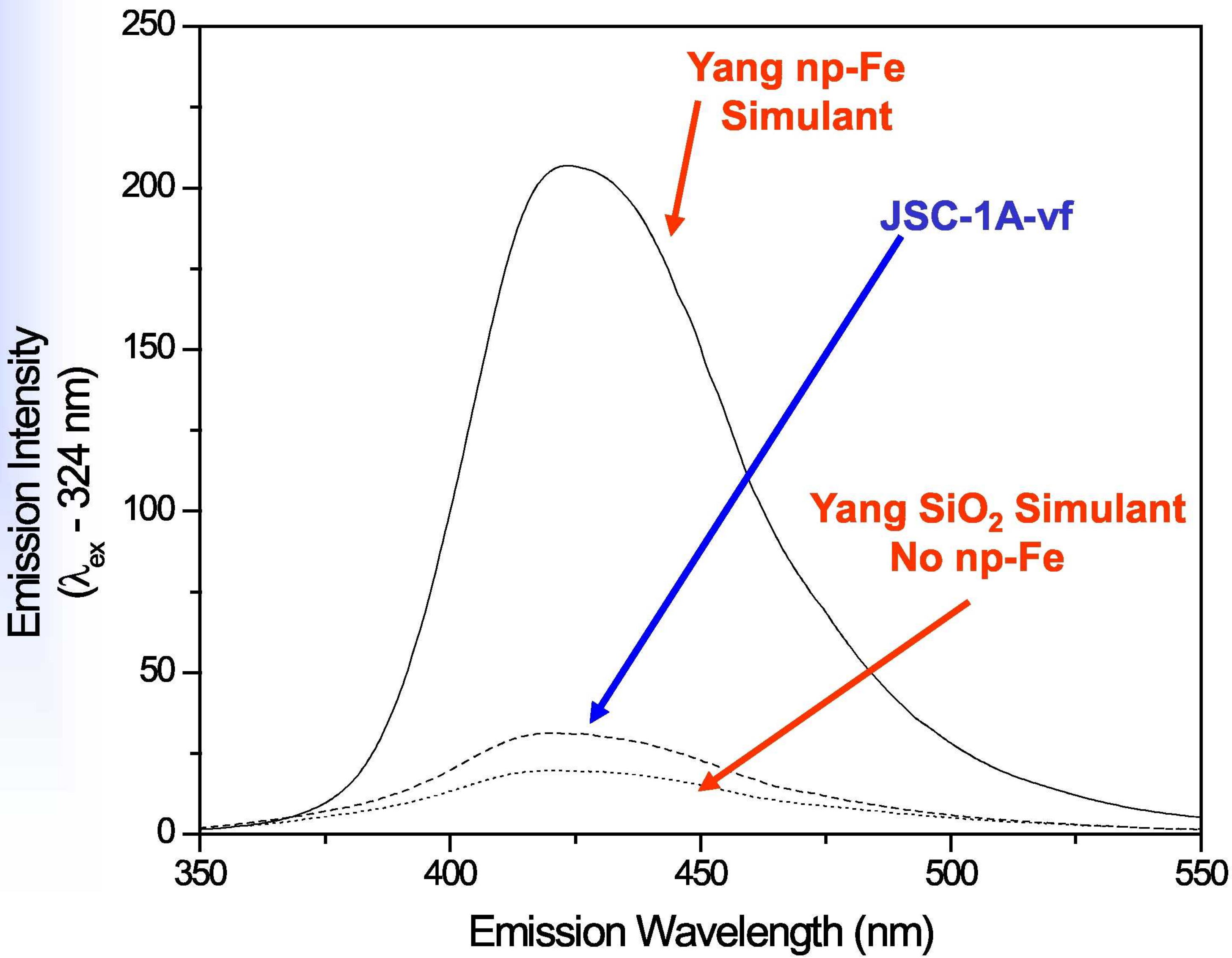


- 10 minute grinding
- 4 mg/mL
- 10 mM Terephthalate

What causes the reactivity increase?

W.T. Wallace *et al.*, *Meteor. Planet. Sci.* 44 (2009) 961-970.

Effects of Nanophase Iron

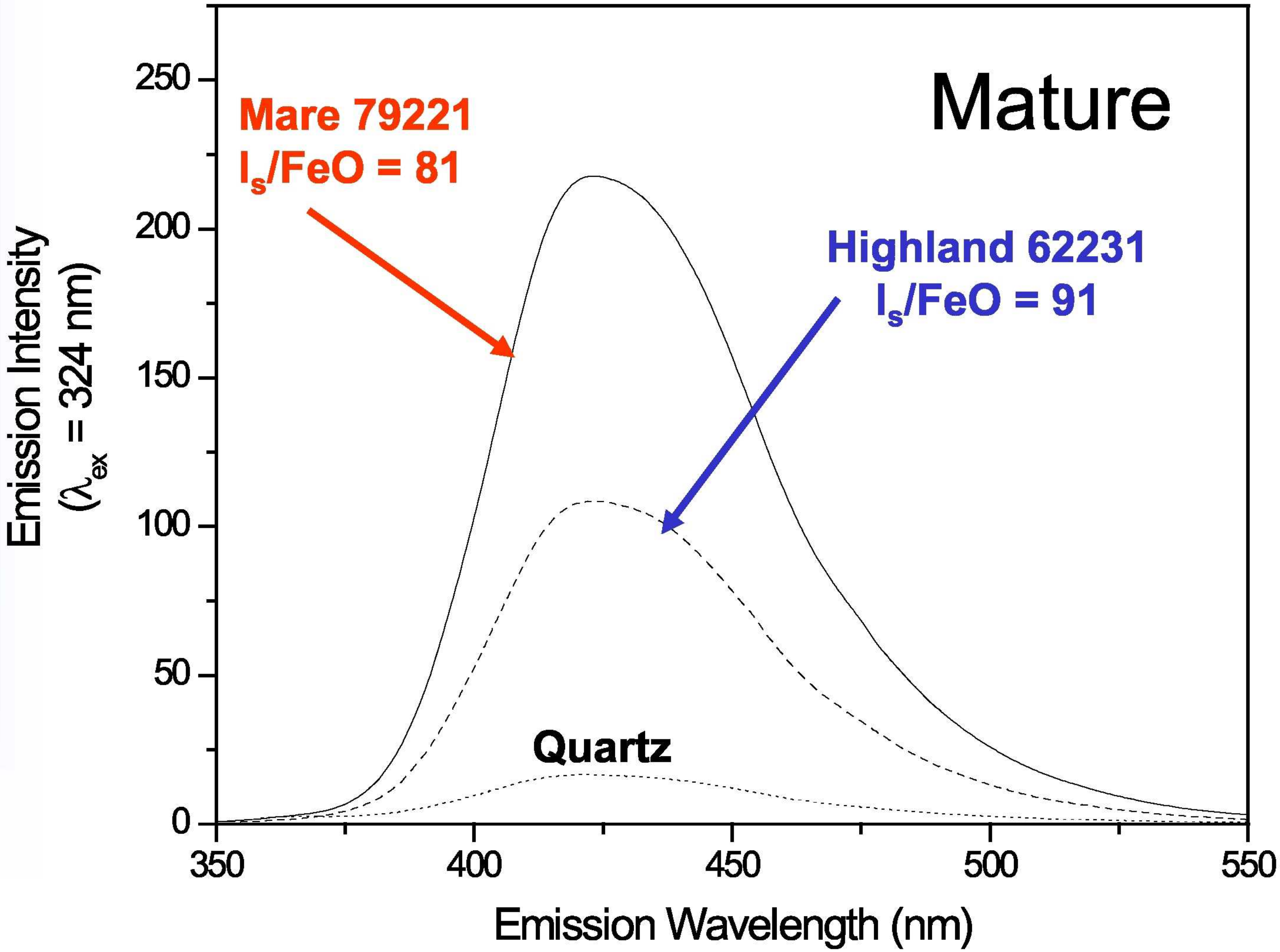


W.T. Wallace *et al*., *Earth Planet. Sci. Lett.* (2009) submitted.

Soil Chemistry and Maturity

	Lo-Ti Mare		Hi-Ti Mare		Highlands				
Sample	15071	15041	71061	79221	67461	67481	61141	62231	62241
I_s/FeO	52	94	14	81	25	31	56	91	100
SiO_2	45.9	46.4	39.8	41.7	44.6	44.6	45.0	45.0	44.65
TiO_2	1.81	1.83	8.76	6.39	0.35	0.44	0.59	0.60	0.56
Al_2O_3	13.1	13.5	10.5	13.5	28.4	28.1	26.3	26.3	27
Cr_2O_3	0.41	0.41	0.48	0.37	0.08	0.10	0.12	0.11	-
MgO	11.3	10.8	10.5	10.3	4.46	4.91	6.39	6.20	5.84
CaO	10.3	10.3	9.90	10.8	16.5	16.2	15.3	15.4	15.95
MnO	0.19	0.20	0.24	0.21	0.06	0.06	0.07	0.09	0.7
FeO	**14.9**	**14.2**	**17.5**	**14.0**	**4.24**	**4.38**	**4.80**	**4.87**	**5.49**
Na_2O	0.37	0.41	0.41	0.41	0.40	0.43	0.43	0.43	0.44
K_2O	0.13	0.19	0.09	0.09	0.06	0.06	0.11	0.12	0.13
P_2O_5	0.18	0.21	0.06	0.07	0.04	0.04	0.06	0.07	0.1
SO_2	0.12	0.13	0.15	0.19	0.06	0.04	0.09	0.09	-

Effects of Dust Source (Highland vs Mare)



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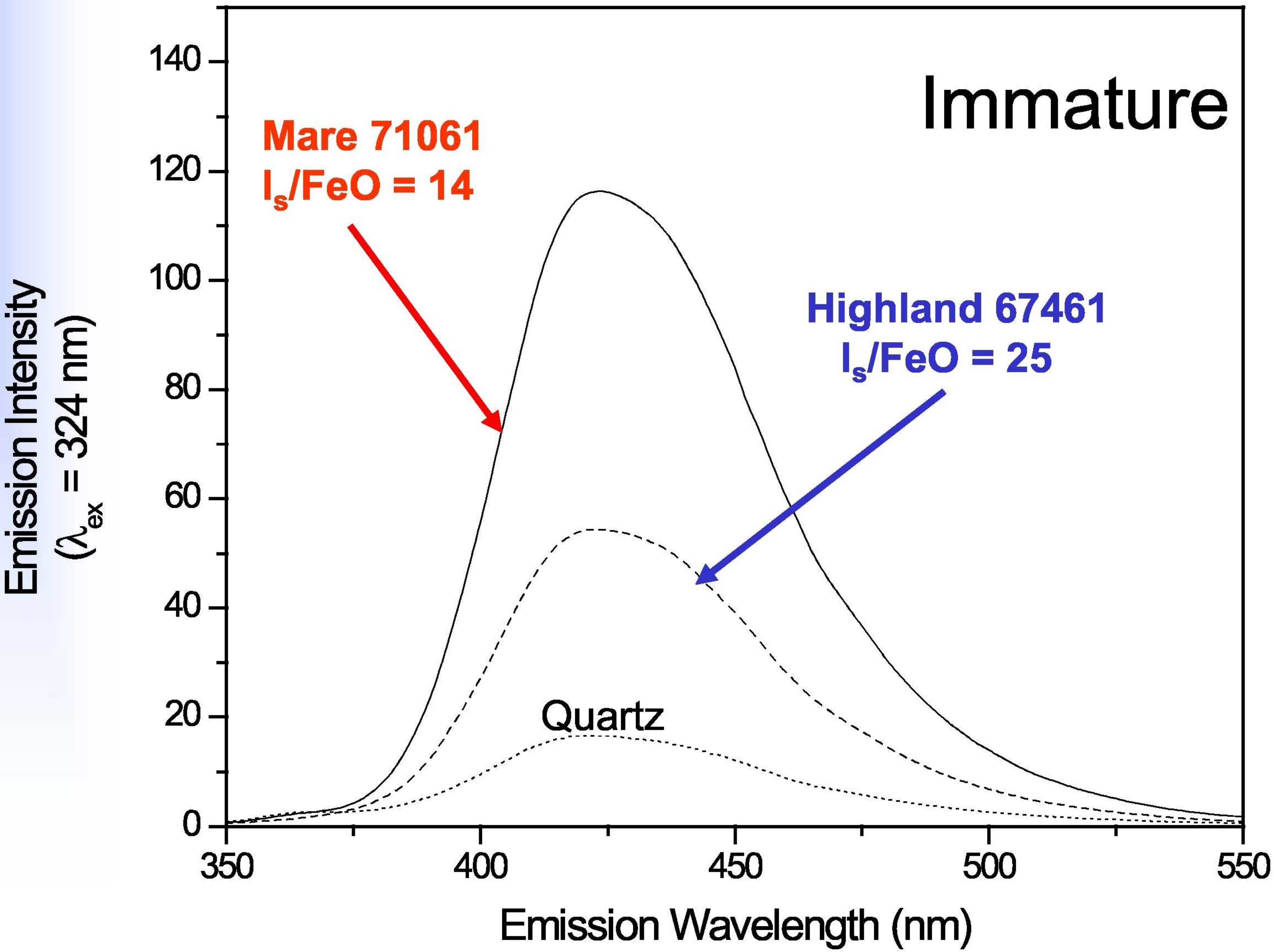
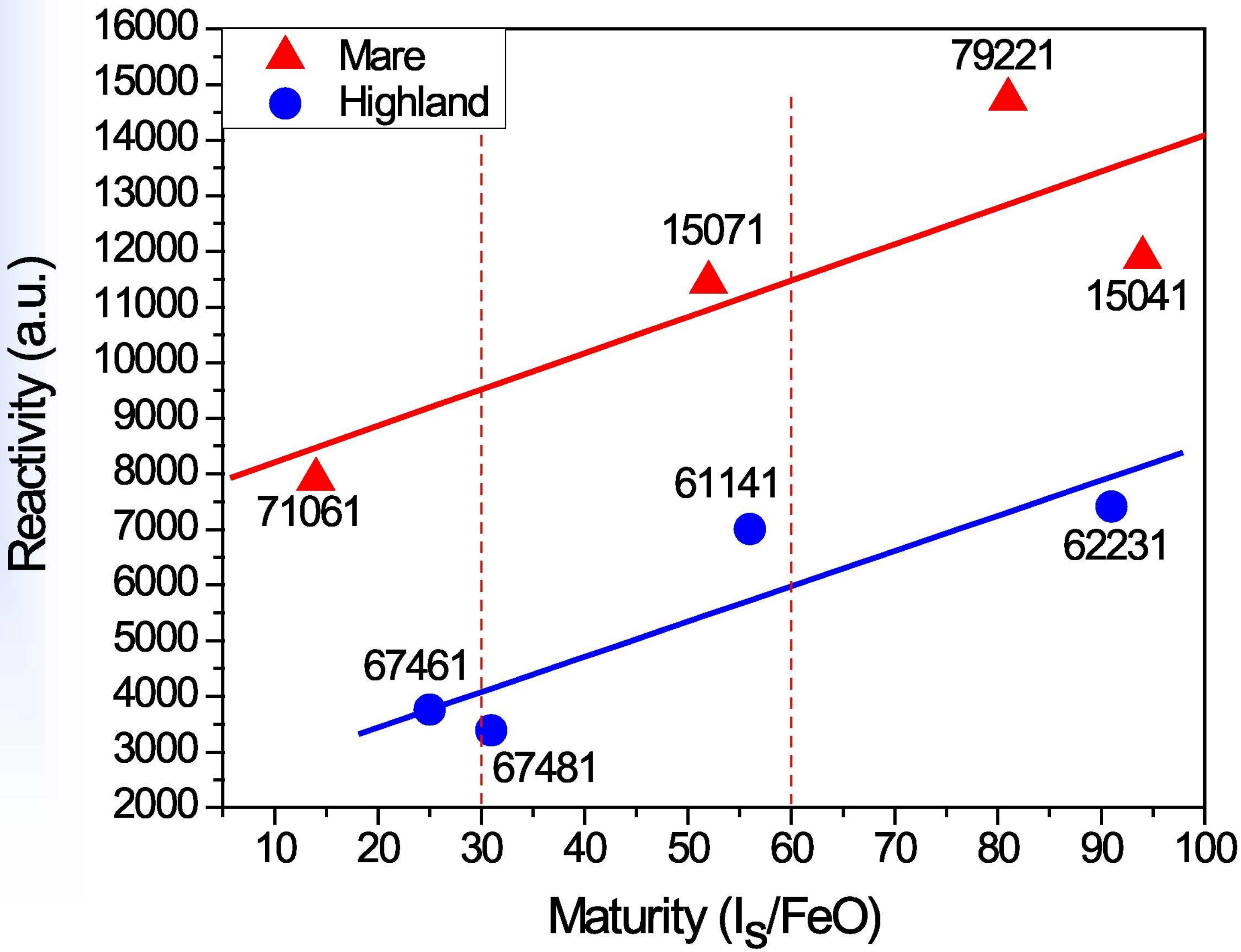


W.T. Wallace *et al.*, *Earth Planet. Sci. Lett.* (2009) submitted.

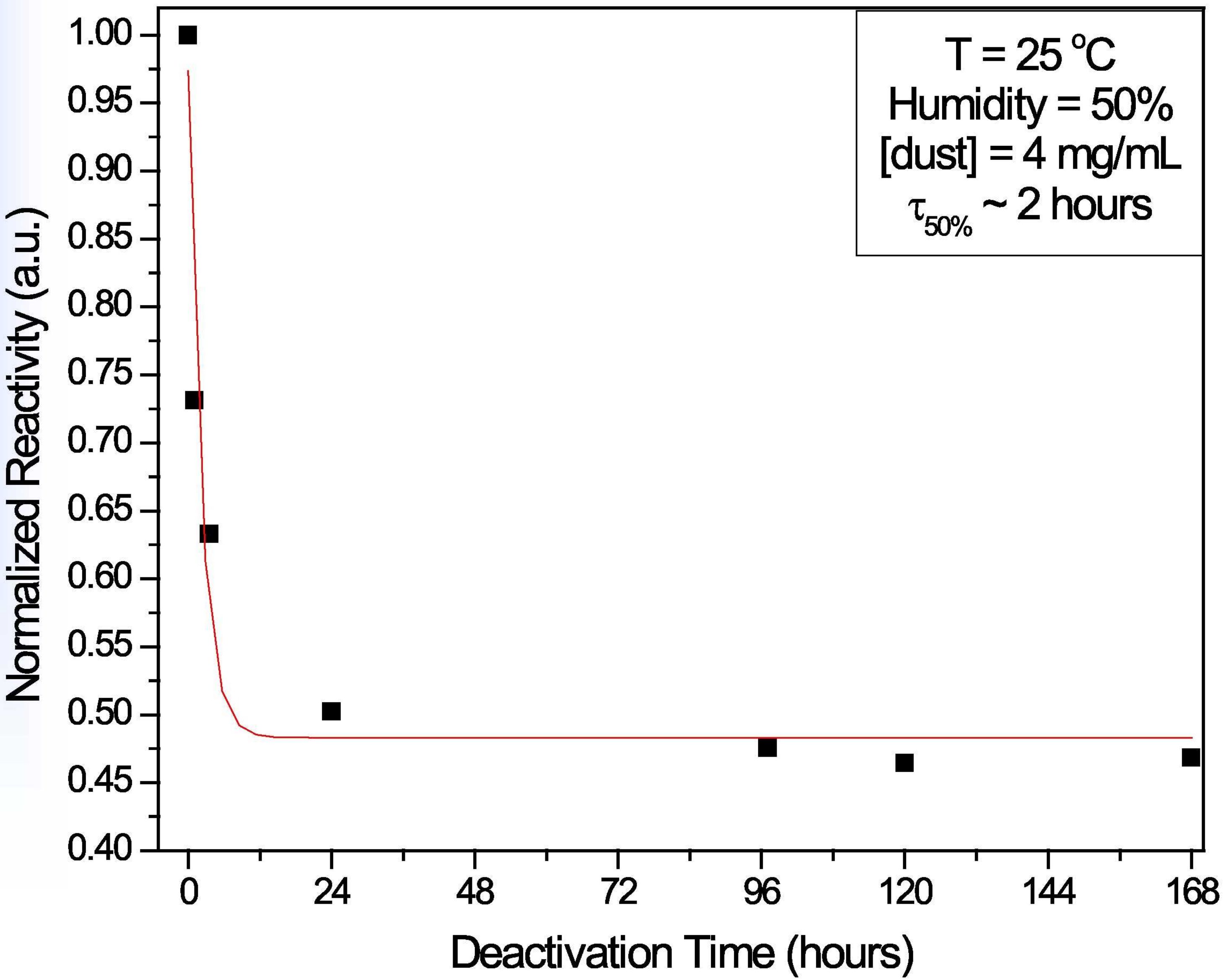
Effects of Maturity on Reactivity



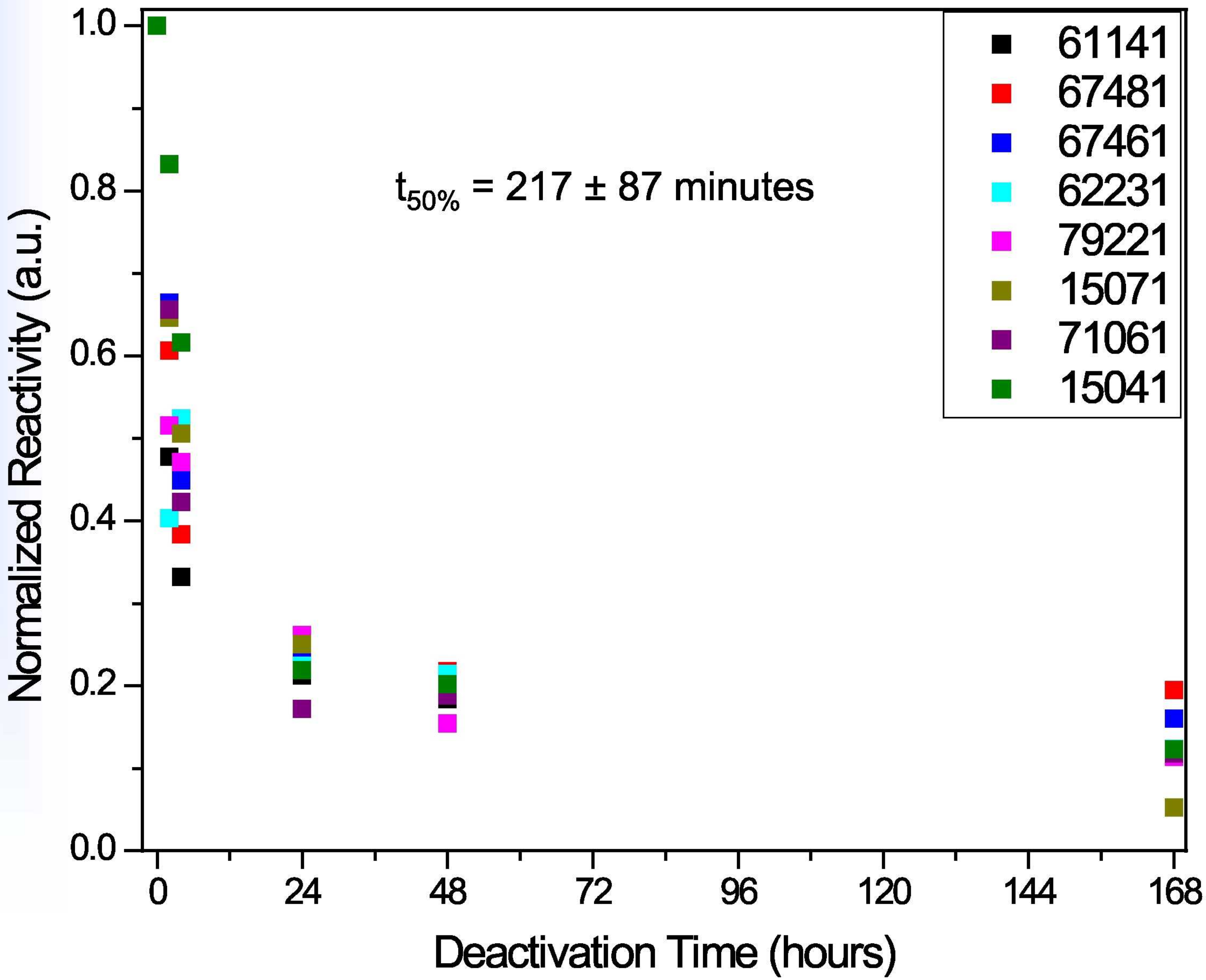
W.T. Wallace *et al.*, *Earth Planet. Sci. Lett.* (2009) submitted.

Deactivation after Grinding

Deactivation of JSC-1A-vf



Deactivation of Lunar Soils



Summary

- Fluorescence and EPR can be used to measure the reactivity of lunar soil

- Lunar soil is highly activated by grinding
    - Reactivity is dependent upon soil maturity and locale

- Maturity is based on the amount of nanophase iron (np-Fe) in a soil relative to the total iron (FeO)

- LUNAR SOIL ACTIVITY IS A DIRECT FUNCTION OF THE AMOUNT OF Np-Fe PRESENT

- Reactive soil can be “deactivated” by humid atmosphere

Acknowledgements

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