Changing Geosciences through Nanotechnology: 20 years of NNI

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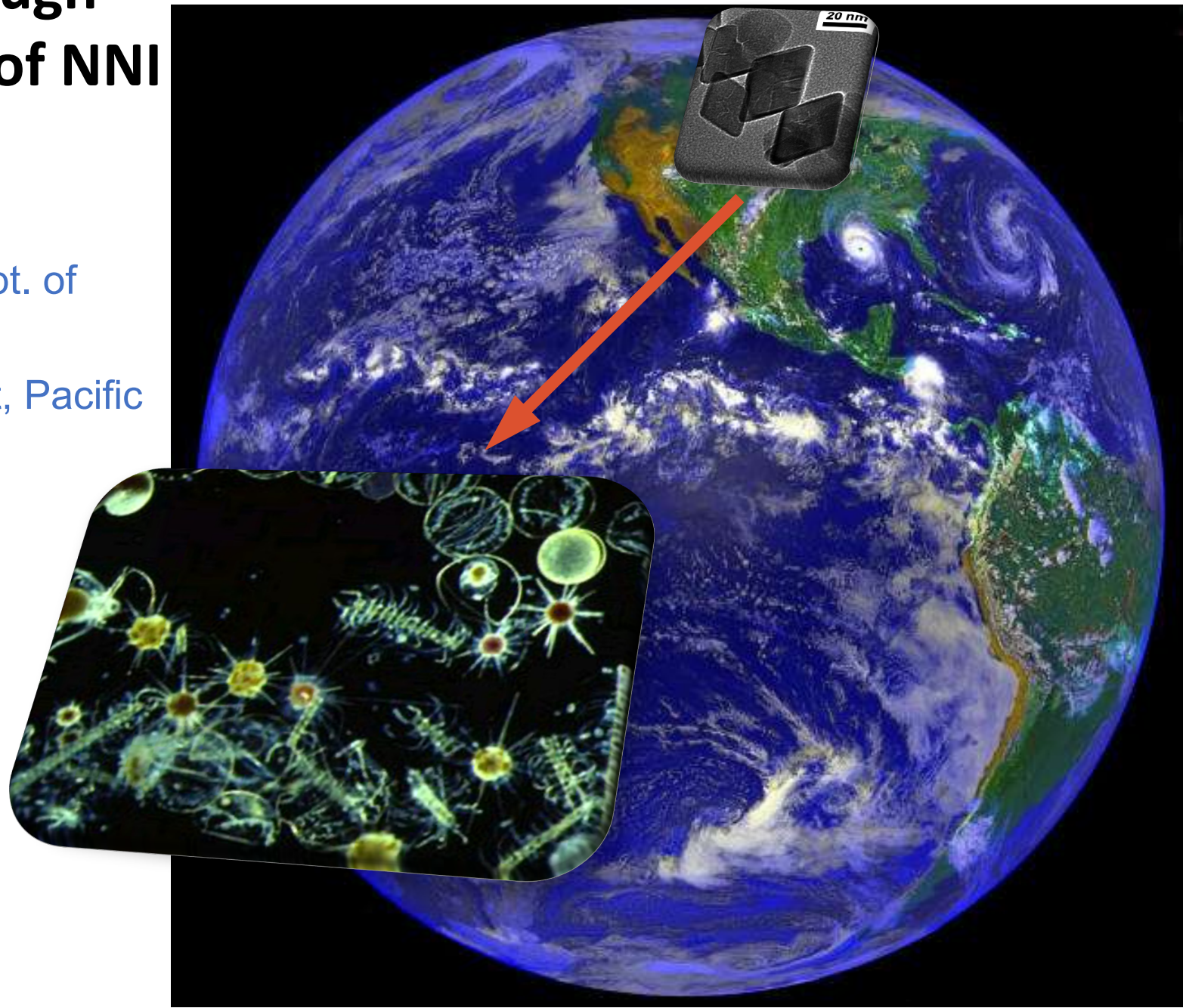
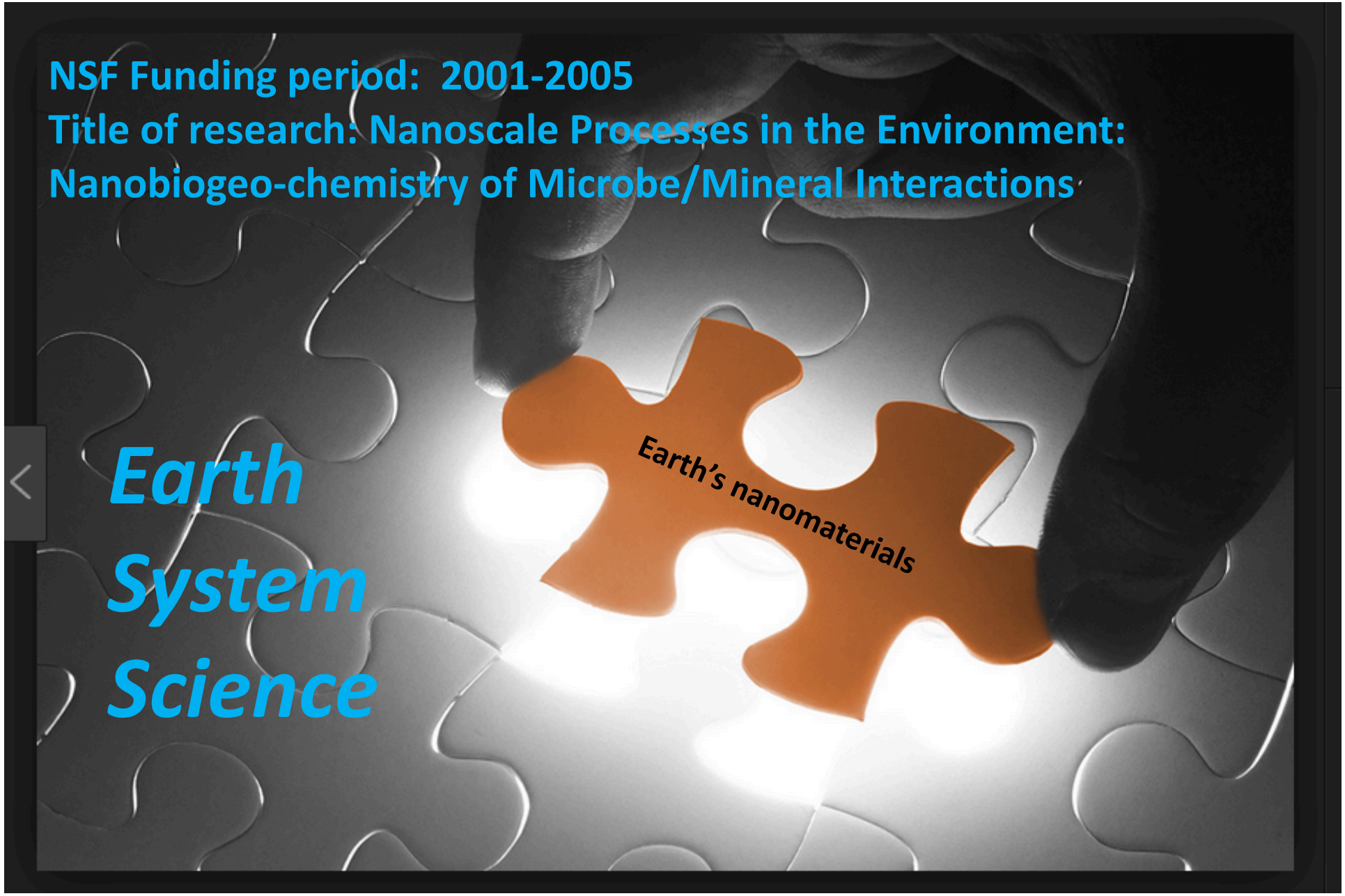
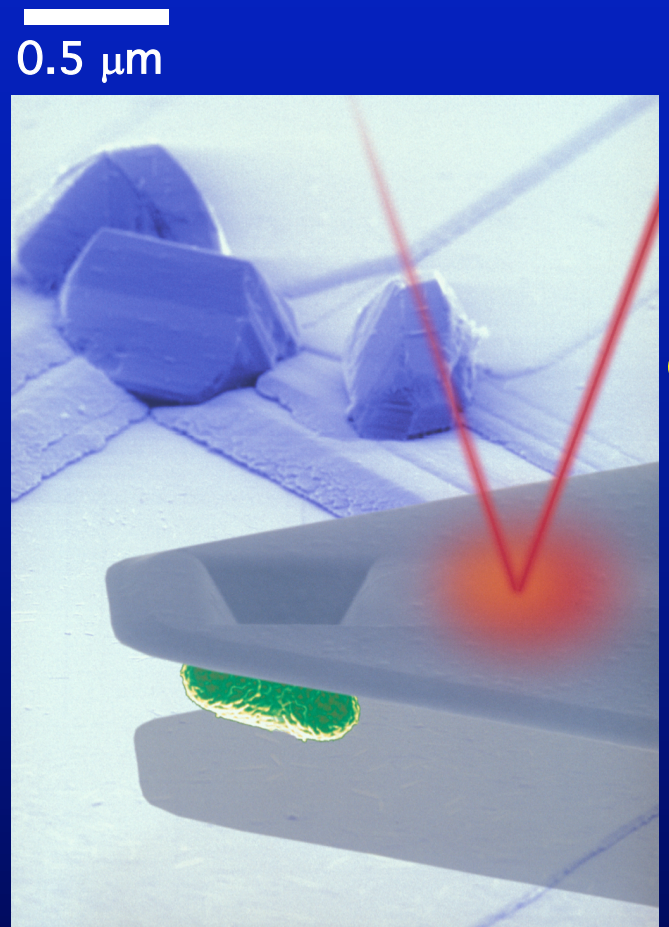
National Nanotechnology Coordinated Infrastructure

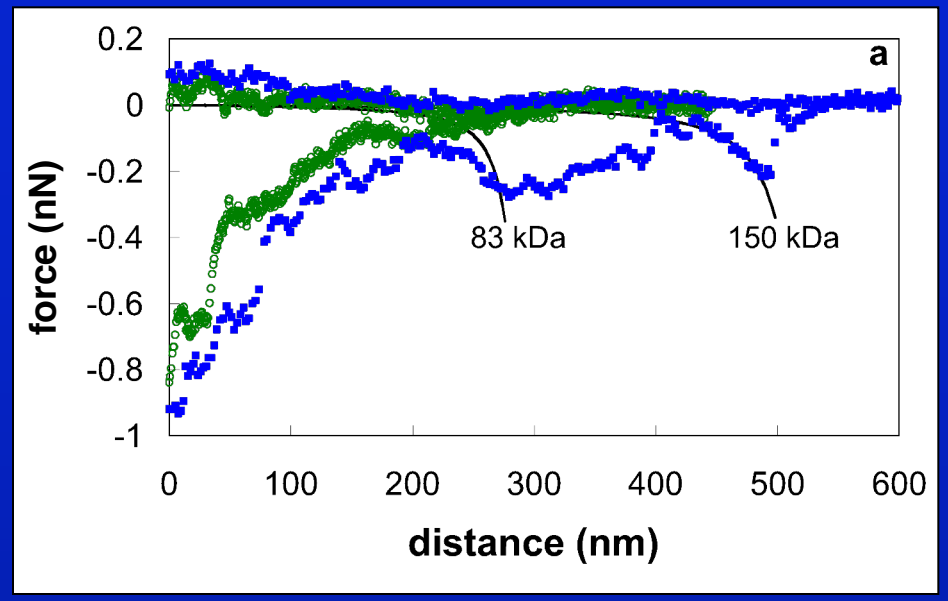
NanoEarth




NSF Funding period: 2001-2005
Title of research: Nanoscale Processes in the Environment:
Nanobiogeo-chemistry of Microbe/Mineral Interactions
Earth
System
Science
Earth's nanomaterials

Nanomechanics

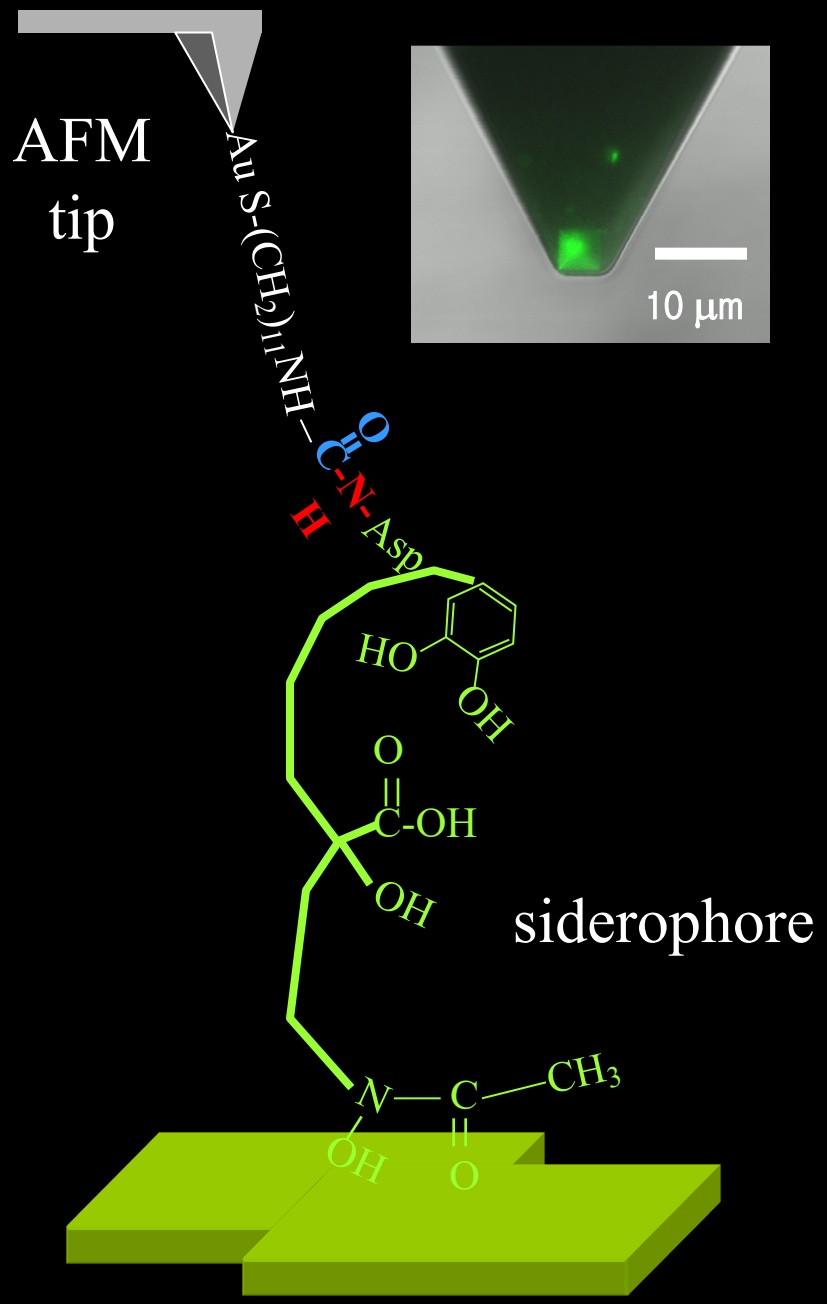




Data from Lower et al. (2001) Science.

Virginia Tech Geological Sciences

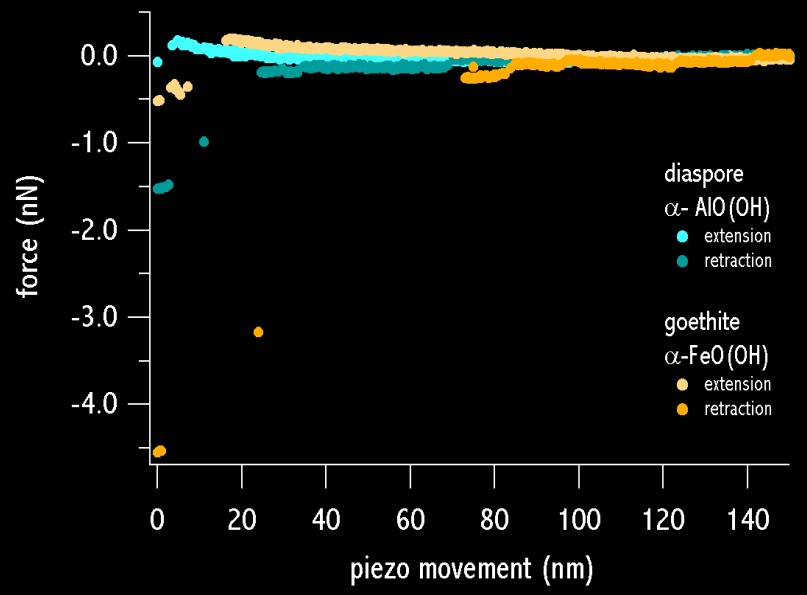
NanoGeoscience and Technology Laboratory



siderophore

Kendall and Hochella (2003) GCA.

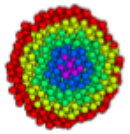
diaspore (AlOOH) 1.4 nN



goethite (FeOOH) 4.5 nN

Introduction of New Generations of Products and Productive Processes (2000-2020)

Timeline for beginning of industrial prototyping and nanotechnology commercialization

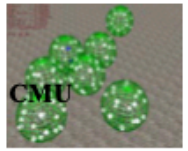


2000

1st: Passive nanostructures (1st generation products)
Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

~ 2005

2nd: Active nanostructures Ex: 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures



~ 2010

3rd: Nanosystems
Ex: guided assembling; 3D networking and new hierarchical architectures, robotics, evolutionary

~ 2015-2020

4th: Molecular nanosystems
Ex: molecular devices 'by design', atomic design, emerging functions

Converging technologies
Ex: nano-bio-info from nanoscale, cognitive technologies; large complex systems from nanoscale

Higher uncertainty & risk

Increase Complexity & Integration

Reference: AIChE Journal, Vol. 50 (5), 2004

Exhibit A: Discovery and ramifications of incidental Magnéli phase generation and release from industrial coal-burning

nature COMMUNICATIONS

Yang et al., 2017

Coal is used to produce approximately 40% of the world's electricity, more than any other energy source, and 70% of the world's steel.

About 18% of coal does not burn, resulting a coal ash.

The US produces 140 million tons annually. In China, 375 million tons.

Fly ash can end up in the atmosphere.

A coal ash impoundment in China

Air pollution has been estimated to lead to 3.3 million premature deaths per year worldwide.

Most Chinese megacities suffer over 100 severely hazy days every year with PM2.5 concentrations two to four times higher than World Health Organization (WHO) guidelines.

After Toxic Ash Spill, Energy Company And Locals Struggle Over Solution

MARCH 18, 2015 3:22 AM ET

DAVE DEWITT

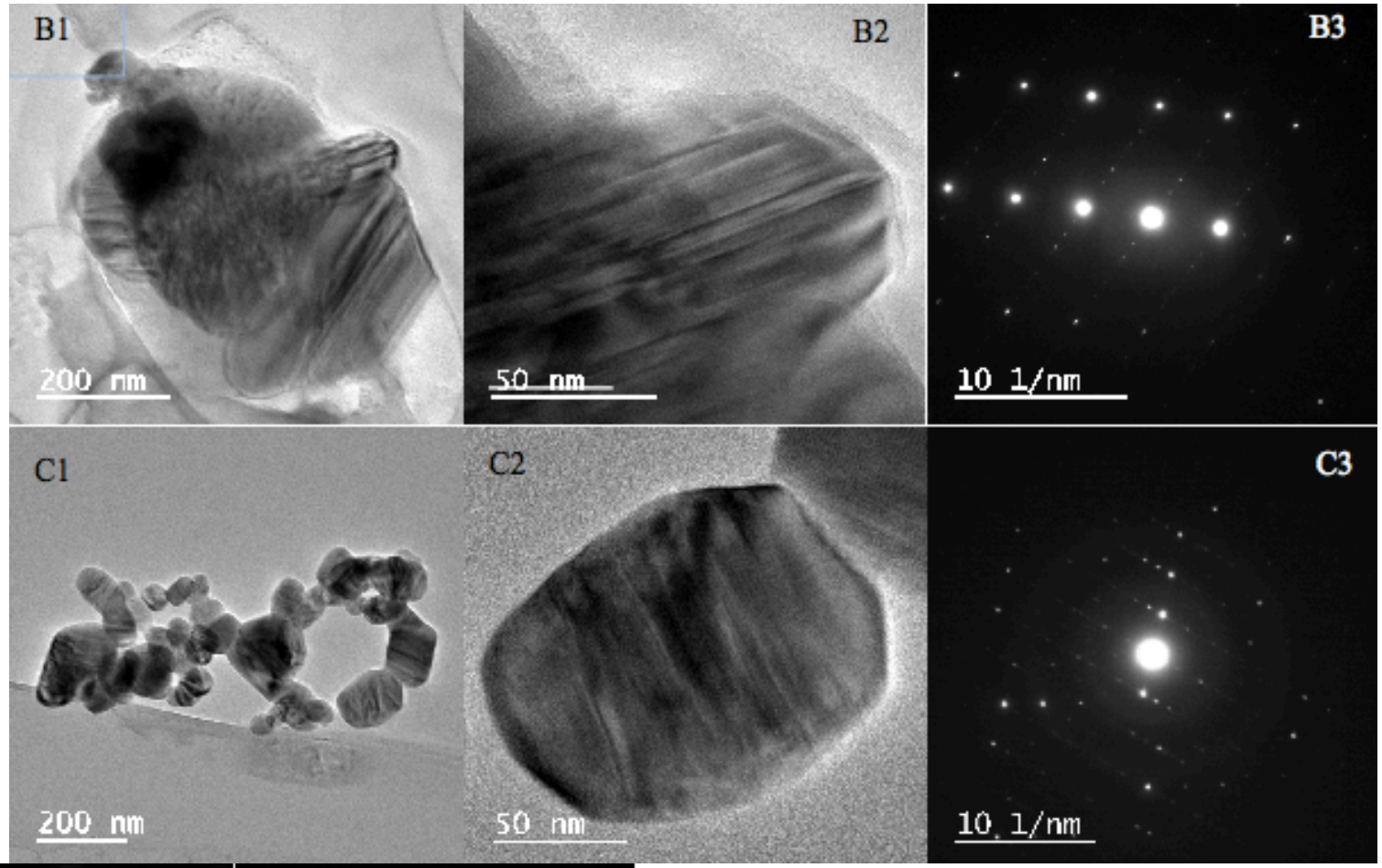
from WUNC 91.5

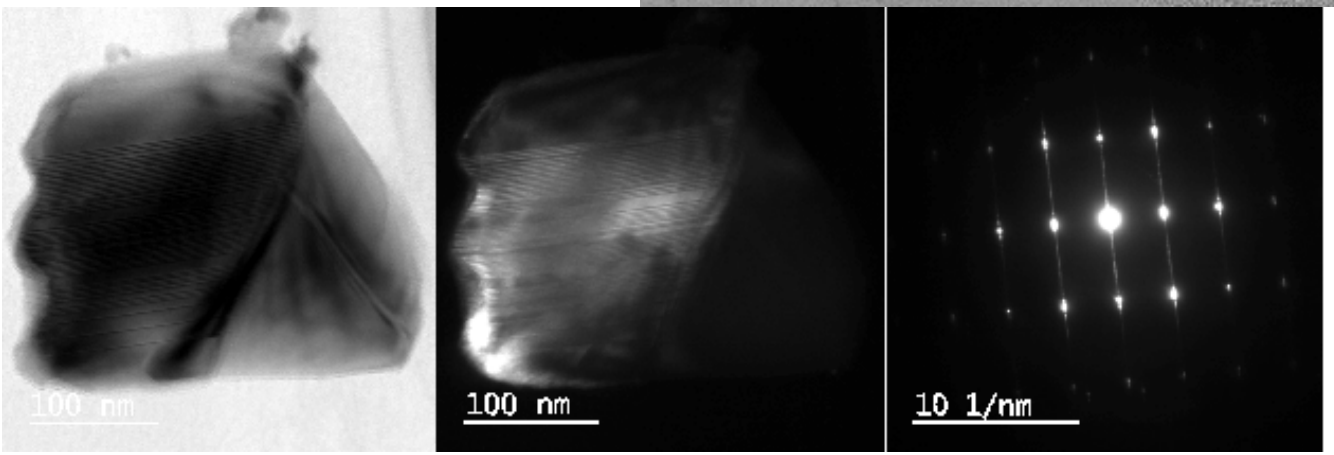
The spill was estimated to contain 27 million gallons of water and 39,000 tons of coal ash flowing into the Dan River from February 2 to 8, 2014, when the leak was finally and successfully capped.

The result . . .

Magnéli phases

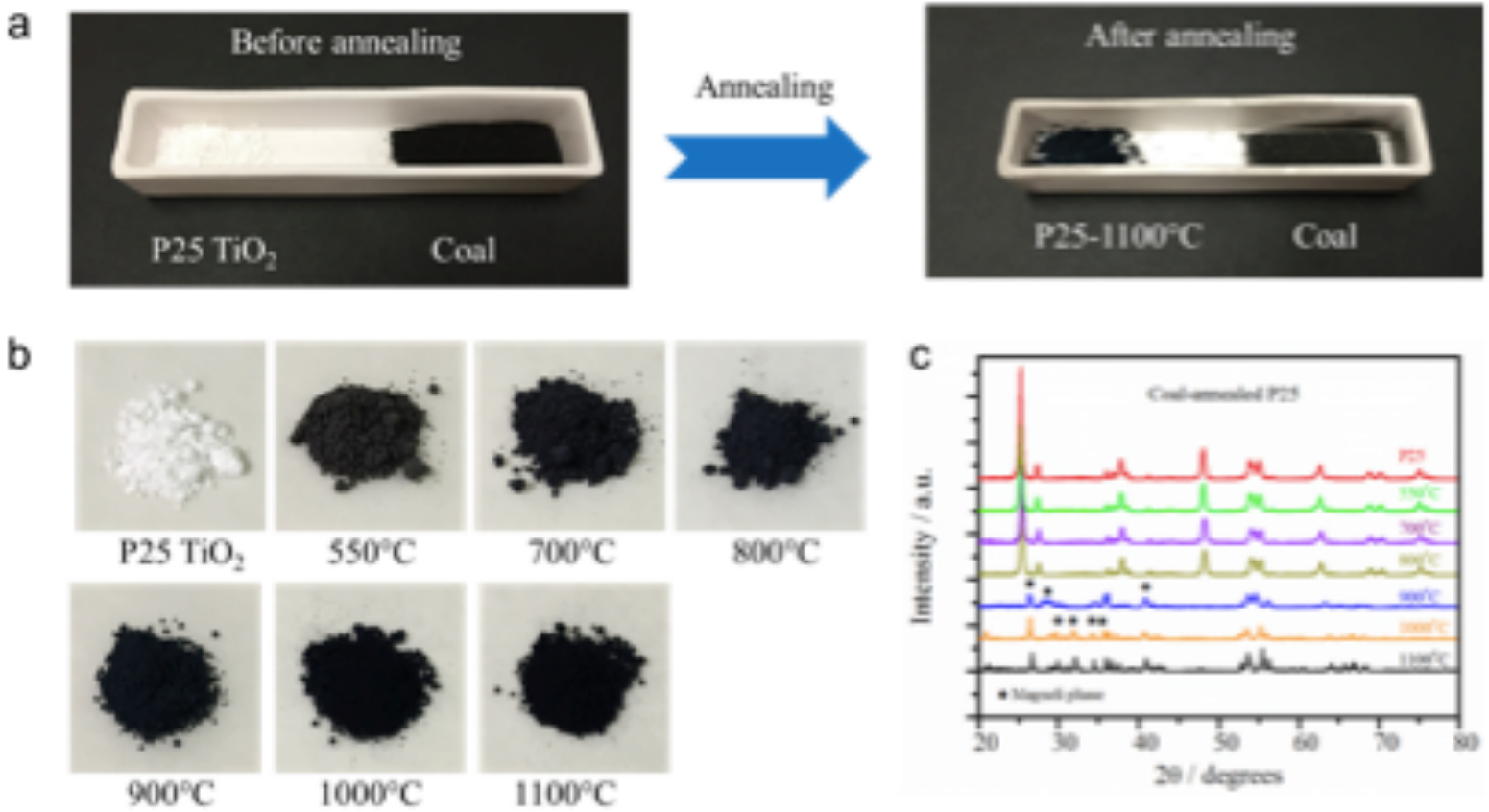
Ti_nO_{2n-1}



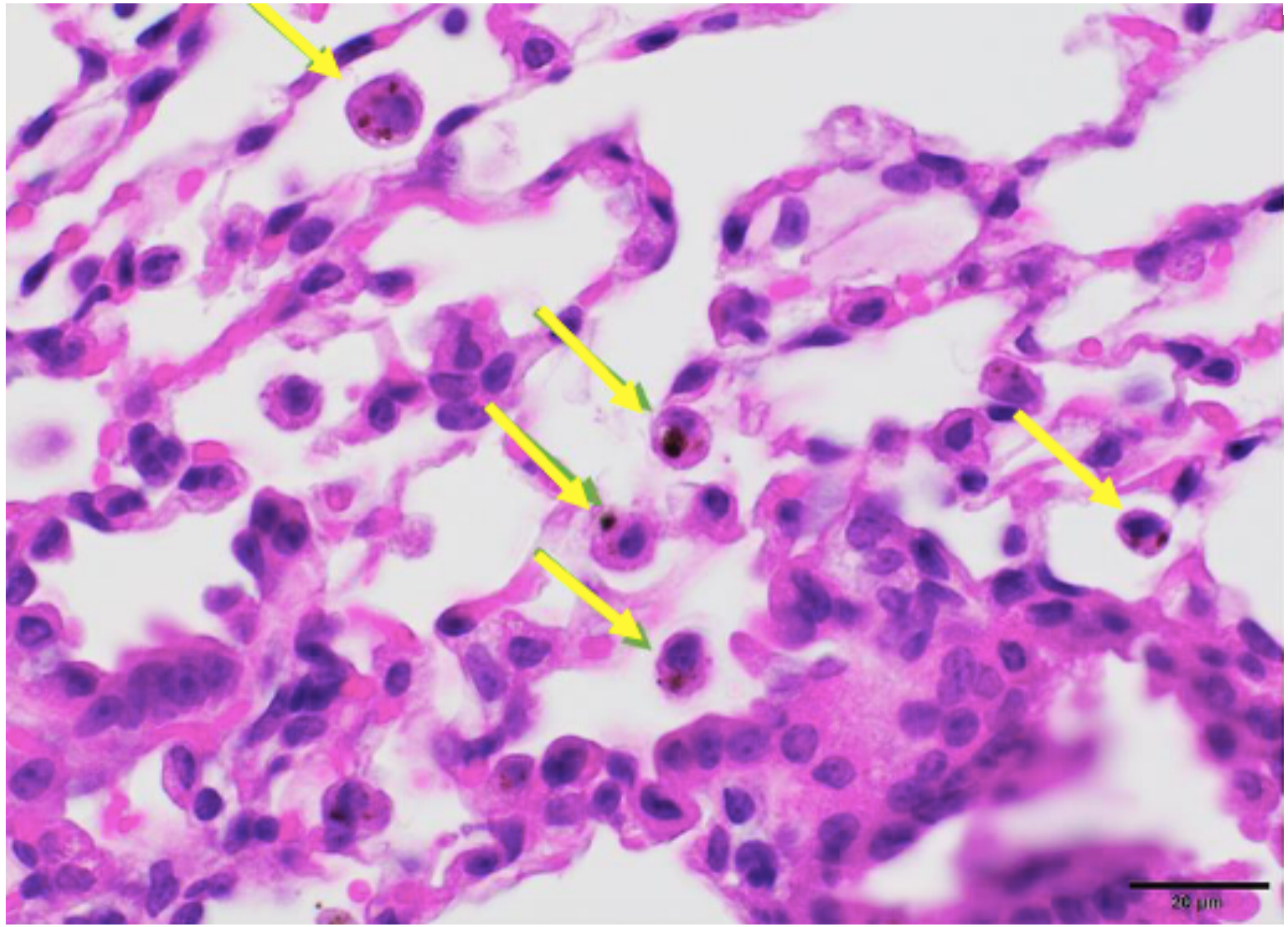


NanoEarth

For biological testing, we learned how to synthesize Magnéli phases most commonly found in coal ash from around the world.



The bad news . . .



Chronic exposure and accumulation of Magnéli phases ultimately results in significantly reduced lung function, impacting airway resistance, compliance, and elastance. Together, these studies demonstrate that Magnéli phases are toxic in the mammalian airway and are likely a significant environmental pollutant.

For Exhibit B, actually good news: Unveiling a natural nano-energy source

PNAS

Check for updates

Photoelectric conversion on Earth's surface via widespread Fe- and Mn-mineral coatings

Anhuai Lu[a,b,c,1,2], Yan Li[a,b,1,3], Hongrui Ding[a,b,1], Xiaoming Xu[a,b], Yanzhang Li[a,b], Guiping Ren[a,b], Jing Liang[d], Yuwei Liu[a,b], Hao Hong[d], Ning Chen[e], Shengqi Chu[f], Feifei Liu[a,b], Yan Li[a,b,4], Haoran Wang[a,b], Cong Ding[a,b], Changqiu Wang[a,b], Yong Lai[a,b], Juan Liu[a,g], Jeffrey Dick[c], Kaihui Liu[d,2], and Michael F. Hochella Jr.[h,i,2]

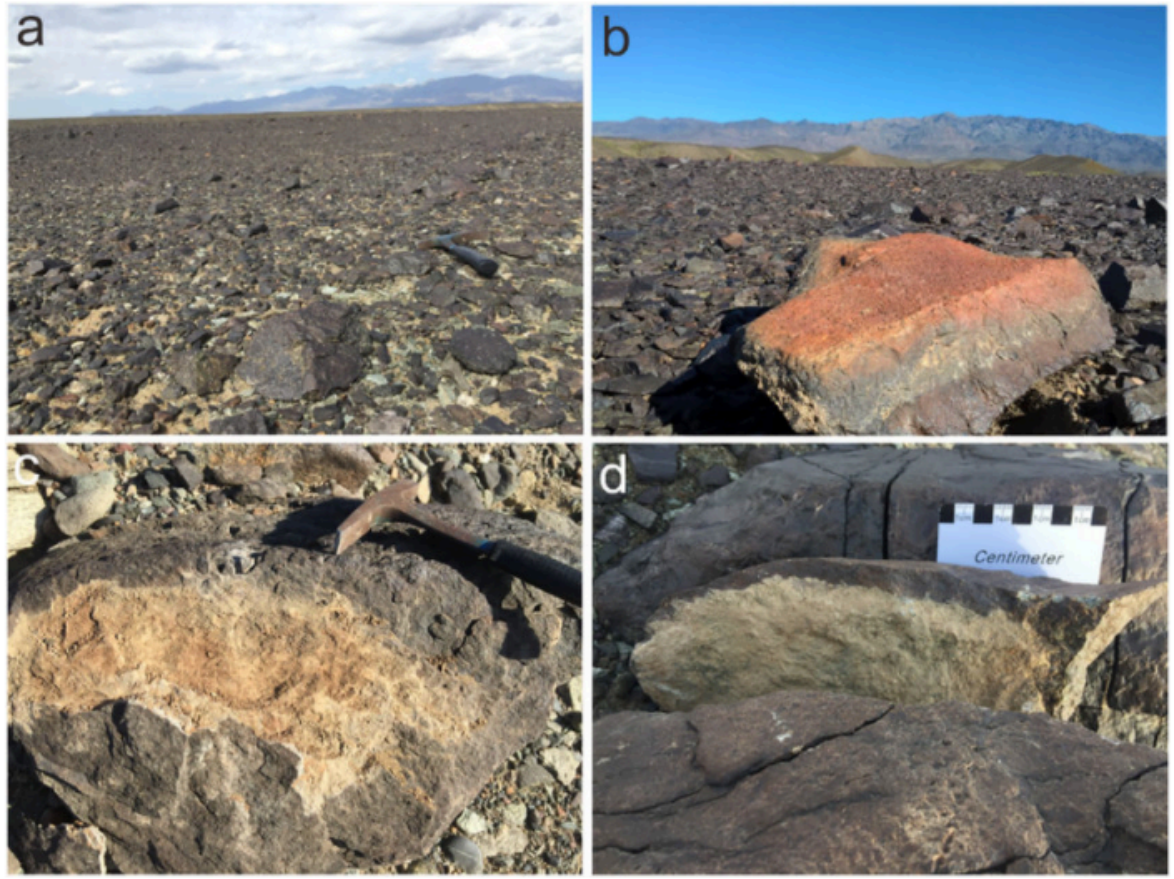
[a]Beijing Key Laboratory of Mineral Environmental Function, School of Earth and Space Sciences, Peking University, 100871 Beijing, People's Republic of China; [b]The Key Laboratory of Orogenic Belts and Crustal Evolution, School of Earth and Space Sciences, Peking University, 100871 Beijing, People's Republic of China; [c]The Key Laboratory of Metallogenic Prediction of Nonferrous Metals and Geological Environment Monitoring, School of Geosciences and Info-Physics, Central South University, 410083 Changsha, People's Republic of China; [d]State Key Laboratory for Mesoscopic Physics, Collaborative Innovation Center of Quantum Matter, School of Physics, Peking University, 100871 Beijing, People's Republic of China; [e]Hard X-ray MicroAnalysis (HXMA) Beamline, Canadian Light Source, Saskatoon, SK S7N 2V3, Canada; [f]Beijing Synchrotron Radiation Facility, Institute of High Energy Physics, Chinese Academy of Sciences, 100039 Beijing, People's Republic of China; [g]School of Environmental Sciences and Engineering, Peking University, 100871 Beijing, People's Republic of China; [h]Department of Geosciences, Virginia Institute of Technology, Blacksburg, VA 24061; and [i]Subsurface Science and Technology Group, Energy and Environment Directorate, Pacific Northwest National Laboratory, Richland, WA 99352

Edited by Susan L. Brantley, Pennsylvania State University, University Park, PA, and approved March 26, 2019 (received for review February 13, 2019)

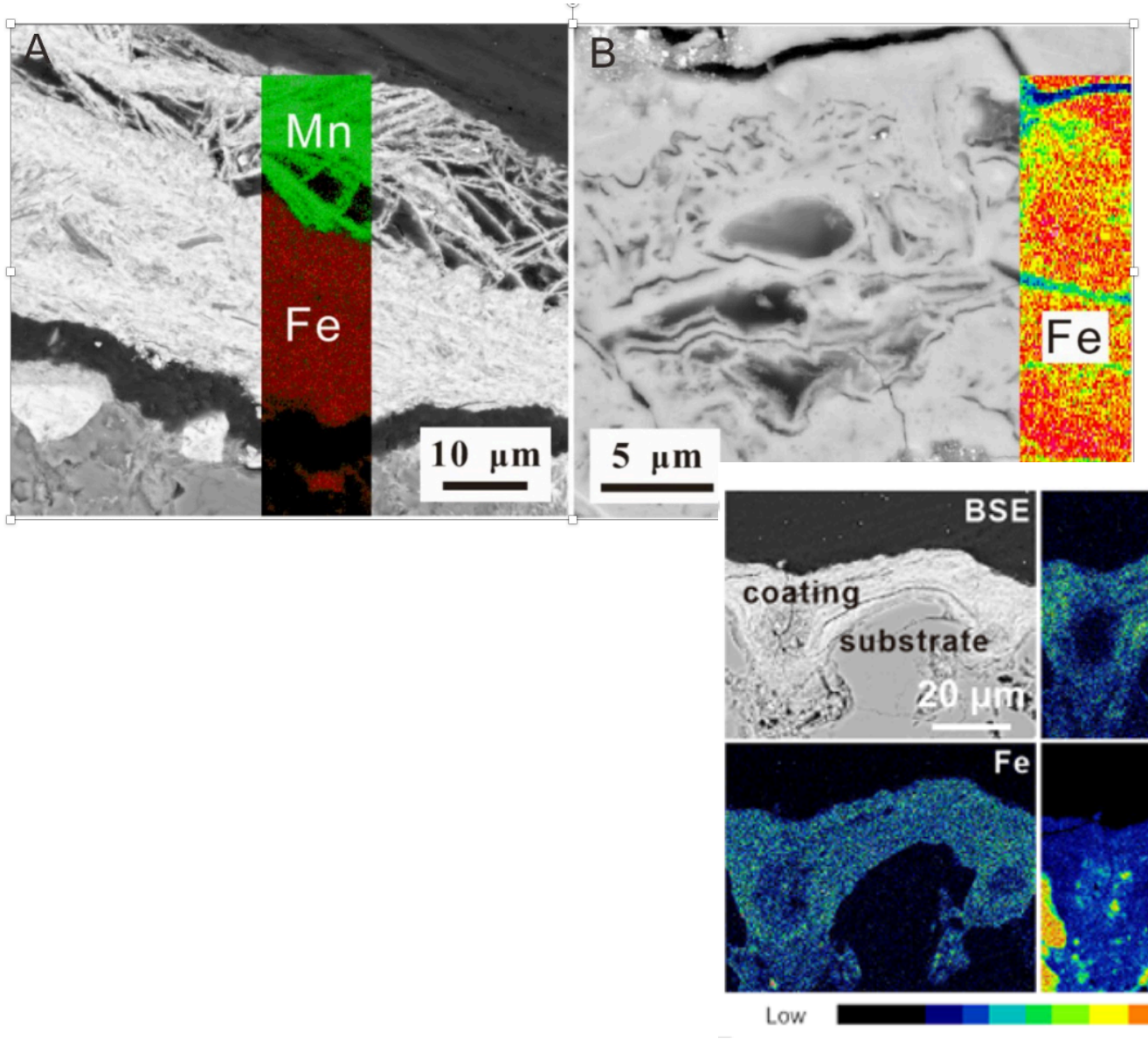
Sunlight drives photosynthesis and associated biological processes, and also influences inorganic processes that shape Earth's climate and geochemistry. Bacterial solar-to-chemical energy conversion on

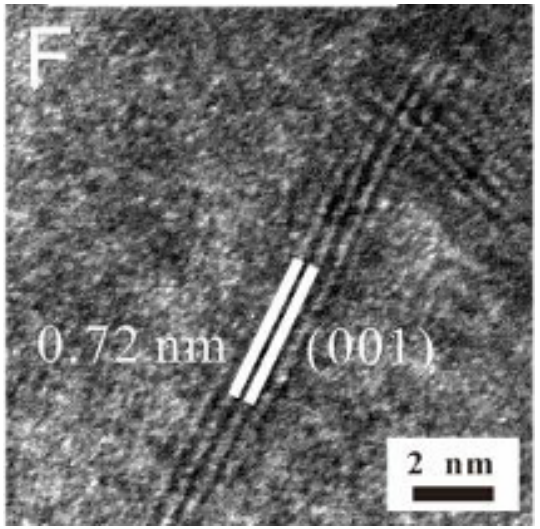
11), no evidence has yet emerged for the widespread existence of a nonbiological component of a light-harvesting system that could be an inherent component of any portion of life on this

Naturally-occurring Fe- and Mn- (oxyhydr)oxide-mineral coatings on rocks. What are their interactions with solar energy input?

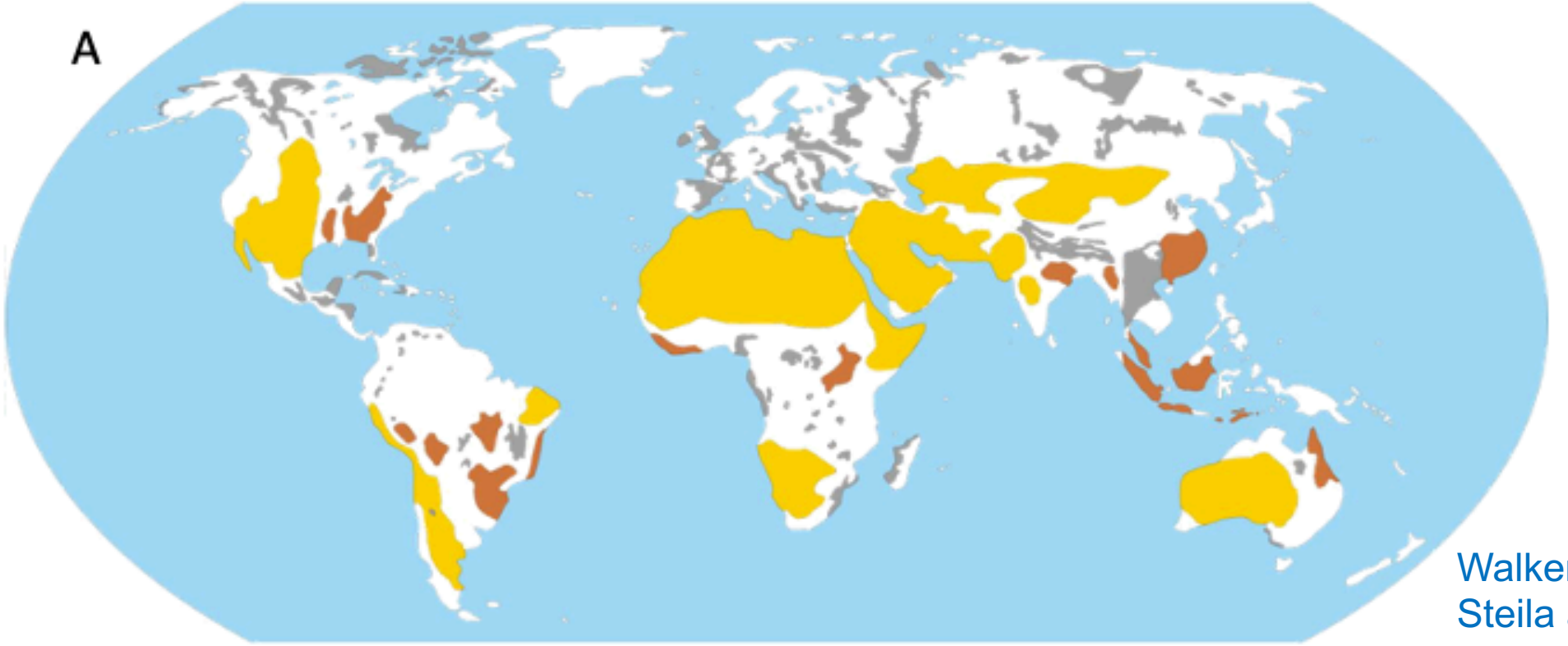


Fe- and Mn- (oxyhydr)oxide- mineral coatings on rocks contain micro and abundant nano photon to electron converters that look like . . .





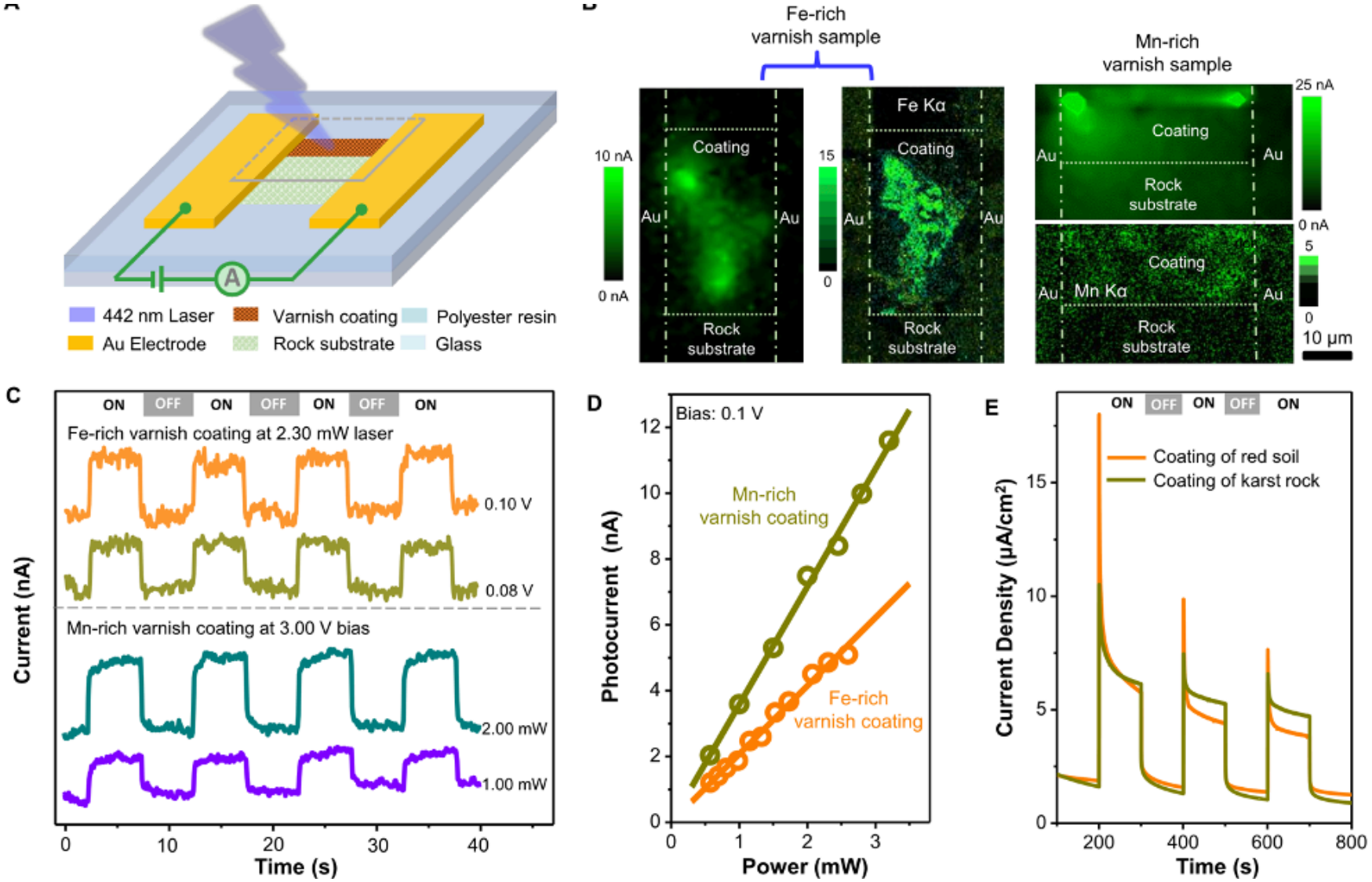
And they are exceptionally widespread on Earth . . .



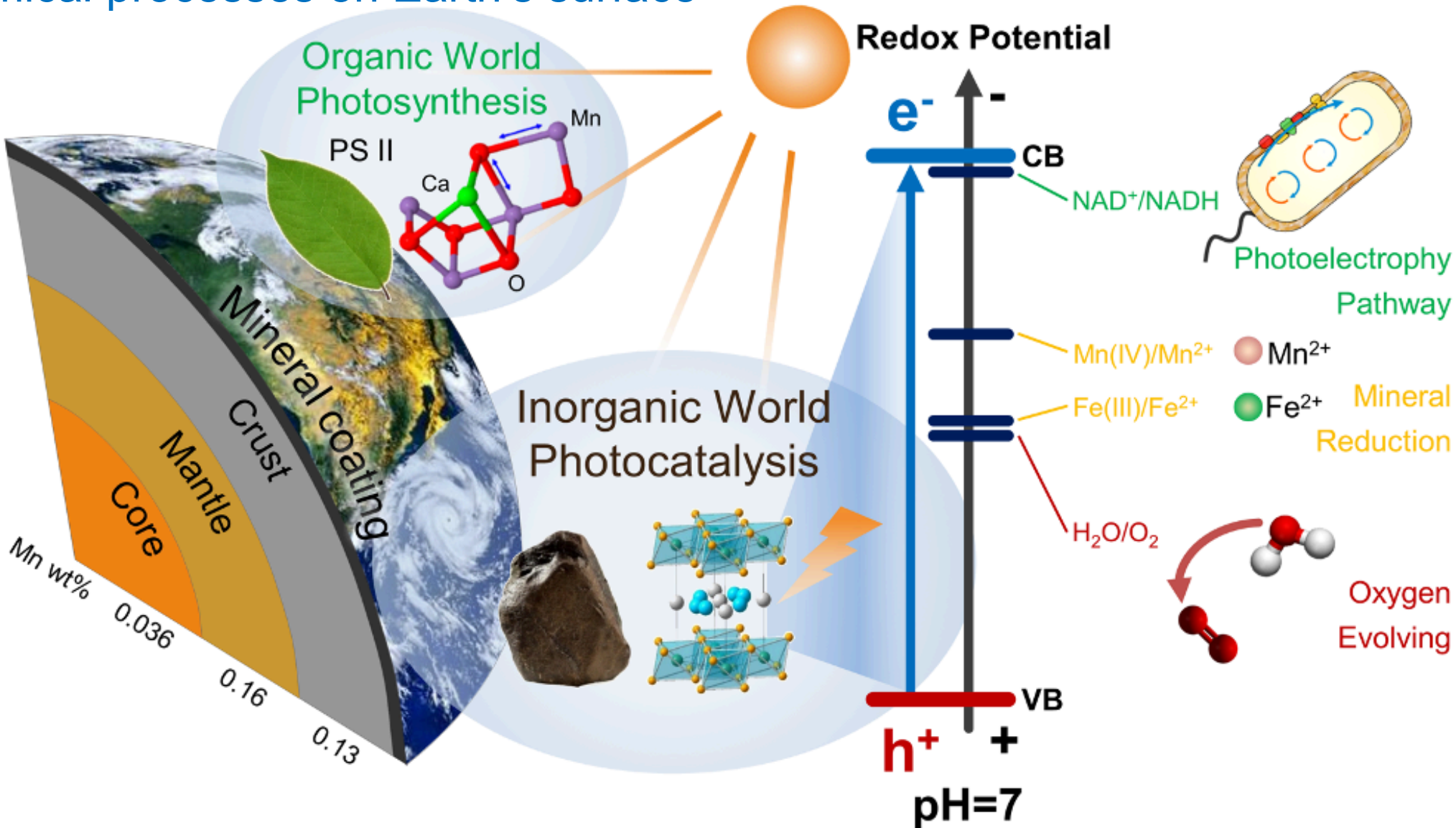
Walker, 1996
Steila and Pond, 1989

Rock varnishes (yellow)
Red soils (rust)
Karst terranes (grey)

When these coatings are exposed to visible light in a controlled setting, they produce photocurrents and current densities that rival perfect synthetic variants.



We conclude that the solar light response and photocurrent production of widespread semiconducting mineral coatings are capable of playing important roles in biogeochemical processes on Earth's surface



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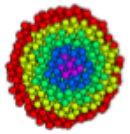

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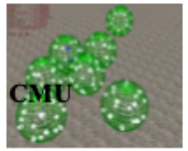

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