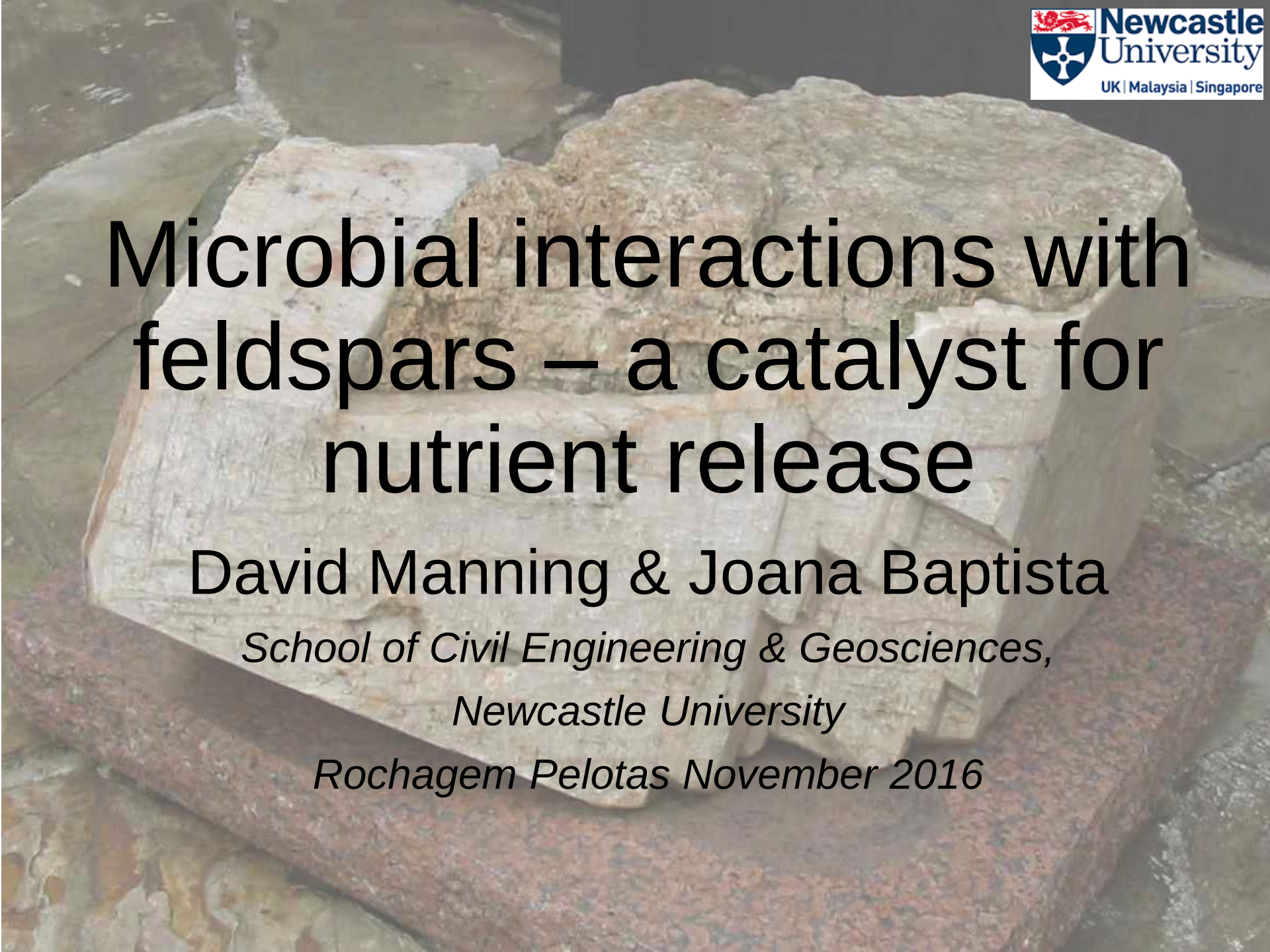


Microbial interactions with feldspars – a catalyst for nutrient release

David Manning & Joana Baptista

School of Civil Engineering & Geosciences,

Newcastle University

Rochagem Pelotas November 2016

Thanks to:

Rochagem III for enabling me to attend

Project partners:

Terrativa SA

Massachussetts Institute of Technology

EMBRAPA

Inspiration and history

The family organic farm: 'you're a geologist, find me some potash': 1996

Mineral Solutions Ltd

Developed and sold ‘MSL-K’

- a zeolitised tuff from the Eifel, Germany
- then a phonolite from Scotland
- 1996-2006

Mineral Solutions

http://www.mineralsolutions.co.uk - legacy website

Rochagem I, Brasilia

An introduction to the wonderful world of Rochagem

- *Leading to partnerships and friendships which continue today*

Mineral Solutions to Global Problems

David Manning FGS CSci CGeol EurGeol

Professor of Soil Science

Newcastle University

Mineral Solutions to Global Problems

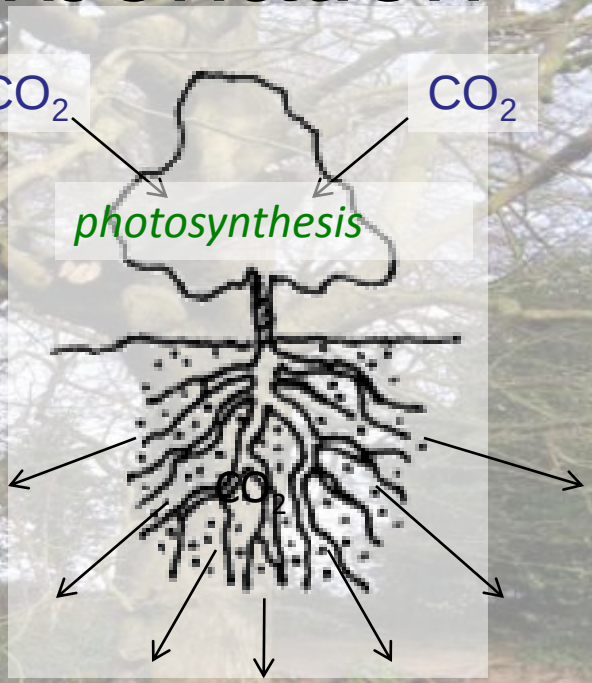
How minerals can save the world!

David Manning FGS CSci CGeol EurGeol

Professor of Soil Science

Newcastle University

Mineral carbonation



Plants are a CO_2 pump

Organic acids

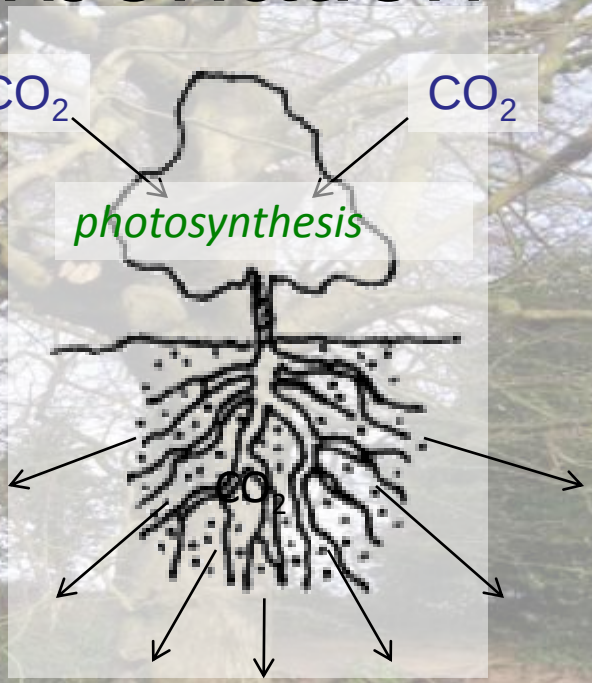
I

$CO_2 + H_2O = H_2CO_3$

I

H_2CO_3 + '$CaSiO_3$' + $H_2O = CaCO_3 + H_4SiO_4$

Mineral carbonation



Plants are a CO_2 pump

This is a one-way street for organic carbon

We have measured $CaCO_3$ 'growth' equivalent to removing 85T CO_2/ha annually

Carbon isotopes and ^{14}C prove the process

How will minerals feed the world in 2050?

David Manning FGS CSci CGeol EurGeol

Professor of Soil Science

Newcastle University

Rochagem

Crops need K (and Si)

- Why consider these two together?
- Both are significant parts of the dry mass of a plant
- Both occur in the same silicate minerals
- Their behaviour contrasts, geochemically

Rice and sugar cane

- Approx 1% K
- Sugar cane: 1% Si
- Rice (overall average) 10% Si

Si can only come from silicates

- Approx 1% K
- Sugar cane: 1% Si
- Rice (overall average) 10% Si

Mineral sources of K

Mineral	Formula	% K_2O
K salts		
Sylvite	KCl	63
Carnallite	$MgCl_2.KCl.6H_2O$	17
Polyhalite	$K_2SO_4 2CaSO_4 MgSO_4 2H_2O$	16
K silicates		
K-feldspar	$KAlSi_3O_8$	17
Leucite	$KAlSi_2O_6$	21
Nepheline	$(Na,K)AlSiO_4$	15
Micas (eg muscovite)	$KAl_3Si_3O_{10}(OH)_2$	11

Feldspars

- One of the most common minerals in the Earth's crust
- 3 major end-members:
  - Orthoclase/microcline (K-feldspar) $KAlSi_3O_8$
  - Albite (Na-plagioclase) $NaAlSi_3O_8$
  - Anorthite (Ca-plagioclase) $CaAl_2Si_2O_8$

Feldspars

- K-feldspar is a source of K (and Si) for plant nutrition
- Ca-plagioclase is a source of Ca for carbon capture

Feldspars

- K-feldspar contains up to 17% K_2O

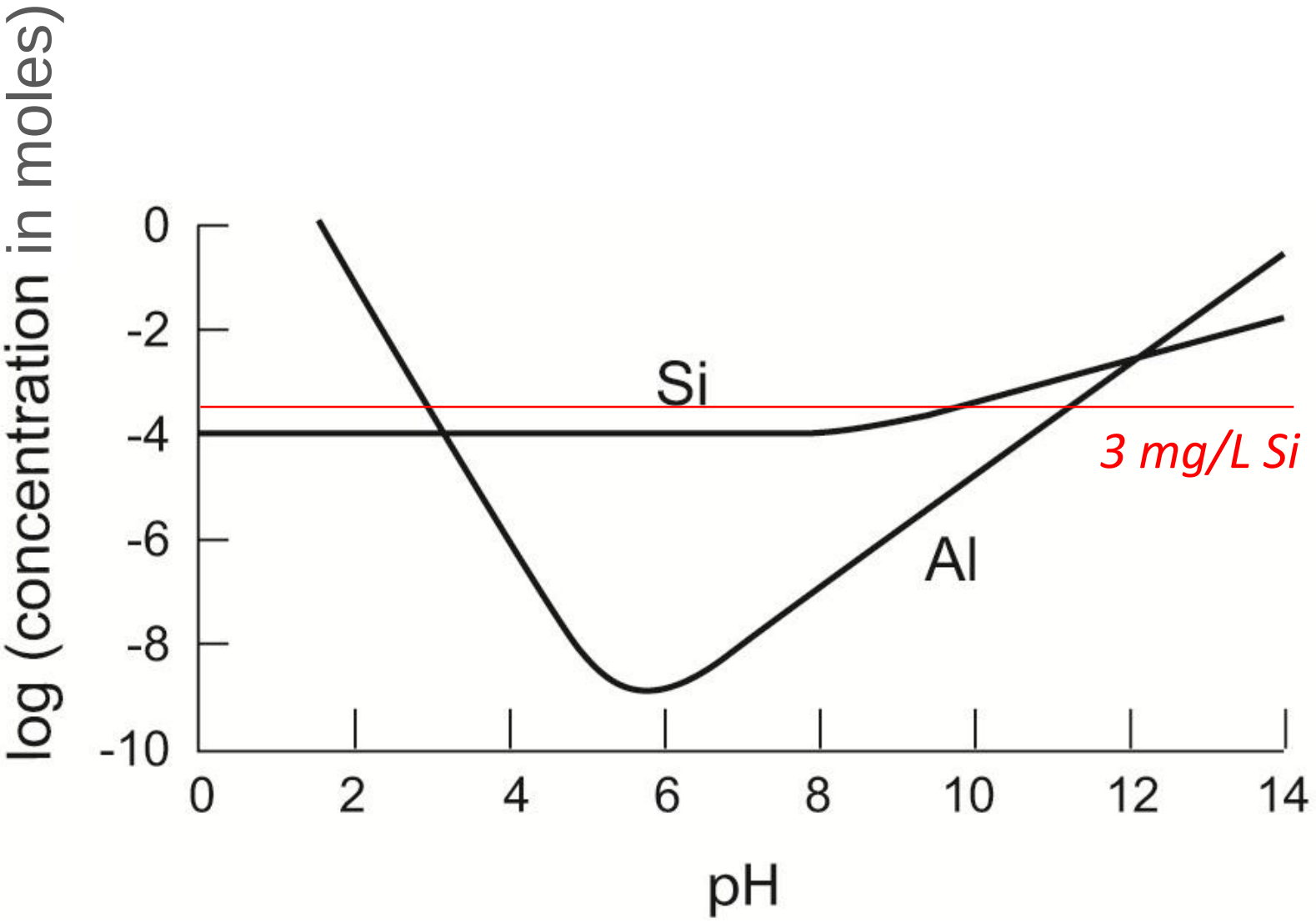
The problem with feldspars

- Is that they dissolve very slowly

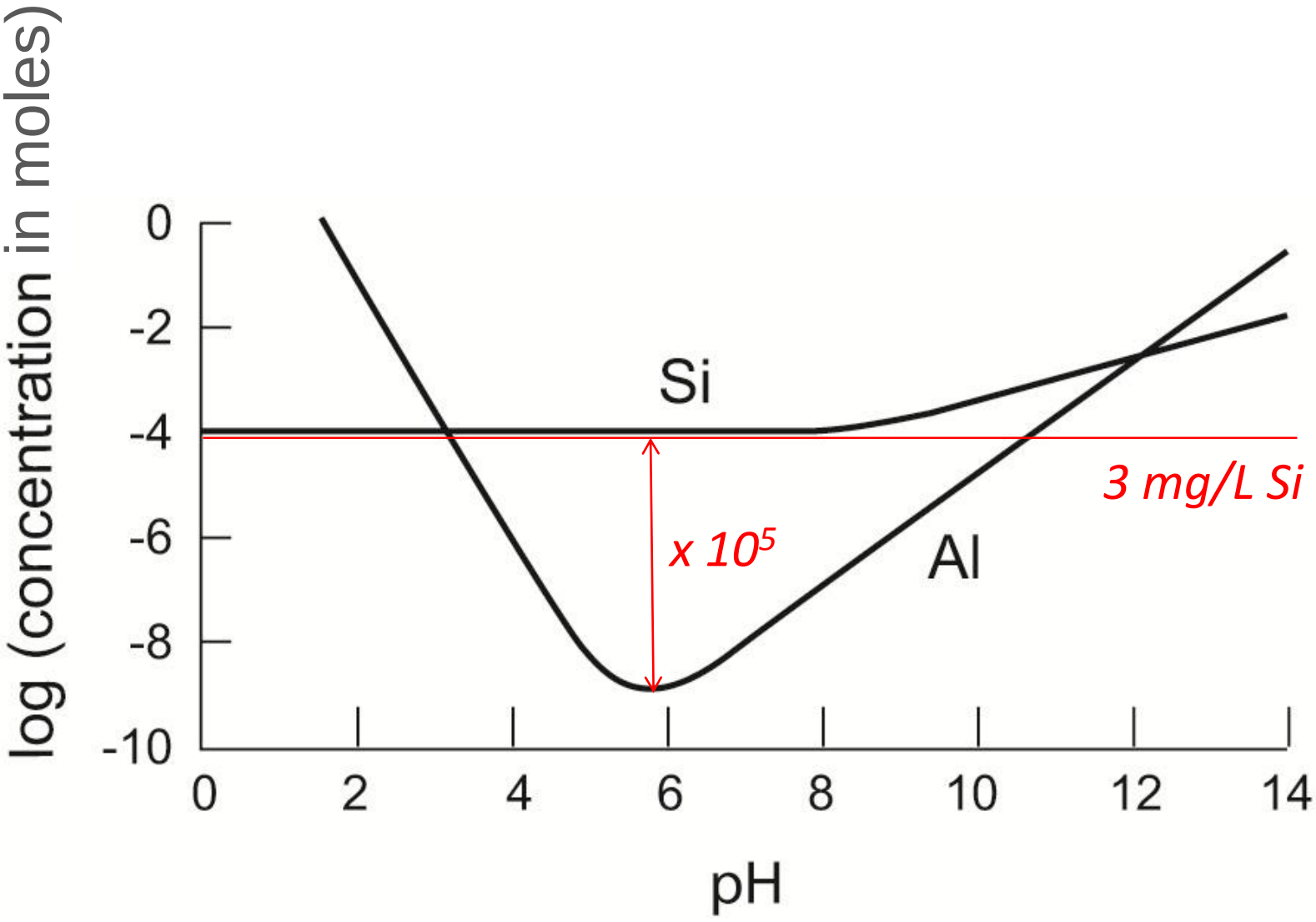
Feldspar dissolution

- Weathering reactions involve dissolution that liberates K and Si
- *But what about Al?*

Al and Si solubility contrast



Al and Si solubility contrast

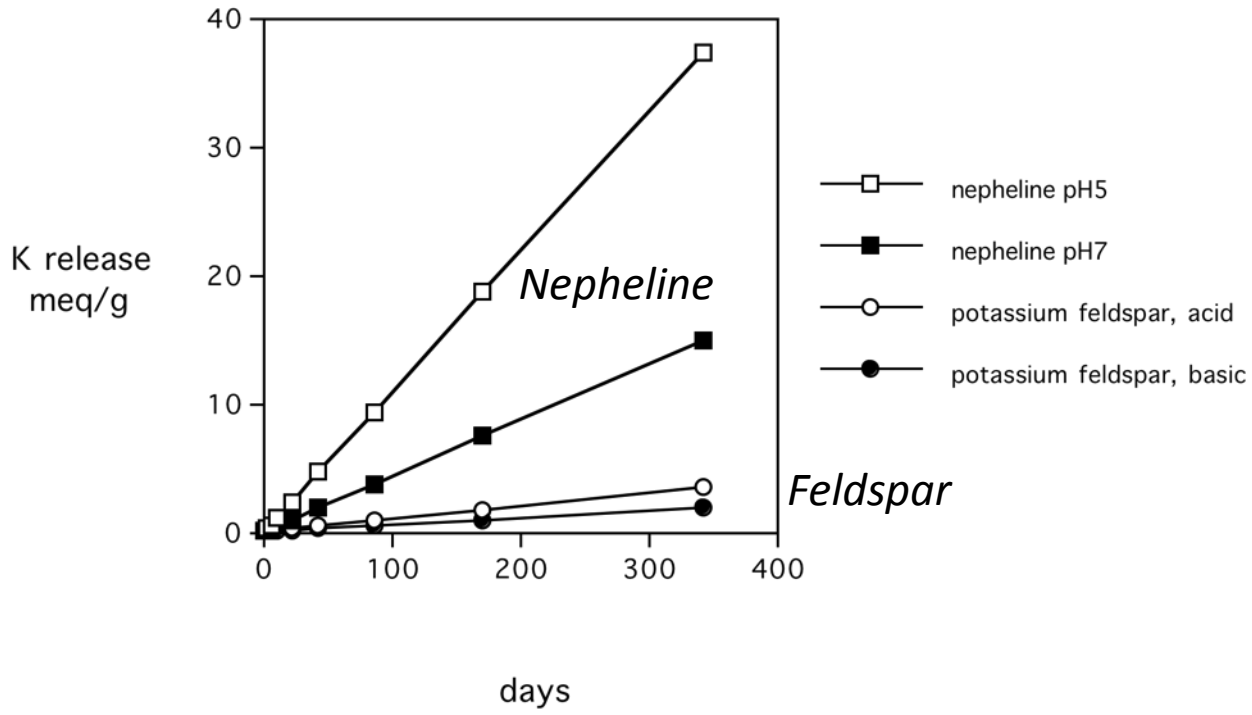


Feldspar dissolution

- Rates measured in the lab are very slow

How effective are rocks as sources of K?

It is the dissolution rate of silicate minerals, not the K content, that has greatest effect on K availability:



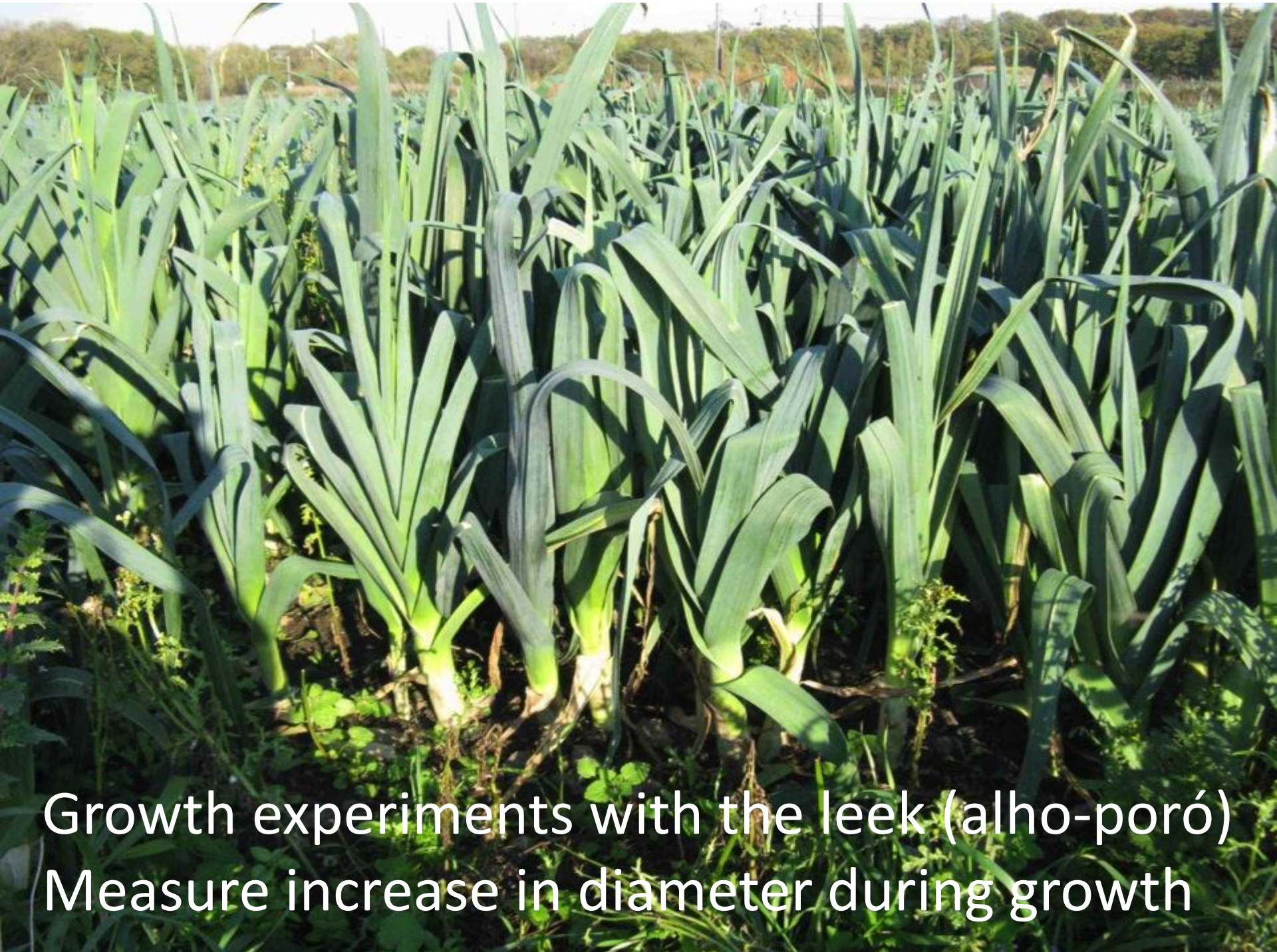
Dissolution rate matters

Mineral	Formula	Weight % K	Dissolution rate, log mol m^{-2} s^{-1}	Relative dissolution rate
Potassium feldspar	$KAlSi_3O_8$	14.0	-10.06	1
Leucite	$KAlSi_2O_6$	17.9	-6.00	10,000
Nepheline	$(Na,K)AlSiO_4$	8.3	-2.73	20,000,000
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	9.0	-11.85	0.01
Biotite	$K_2Fe_6Si_6Al_2O_{20}(OH)_4$	7.6	-9.84	1

Feldspar family Feldspathoid family Mica family: cation exchange

Feldspar corrosion

- A 1 mm diameter grain will last 1,000,000 years, according to lab-derived dissolution rates (which are faster than field).



Growth experiments with the leek (alho-poró)
Measure increase in diameter during growth

Geoff Moscrop with his leeks which broke the world record at the CIU Show at Cramlington WM Club – Northumberland Gazette, 20 Sept 2013

Trials with leeks in artificial soil

- Great care taken to make sure no K-bearing minerals in the soil
- Used a very pure silica sand, with trace of peat compost

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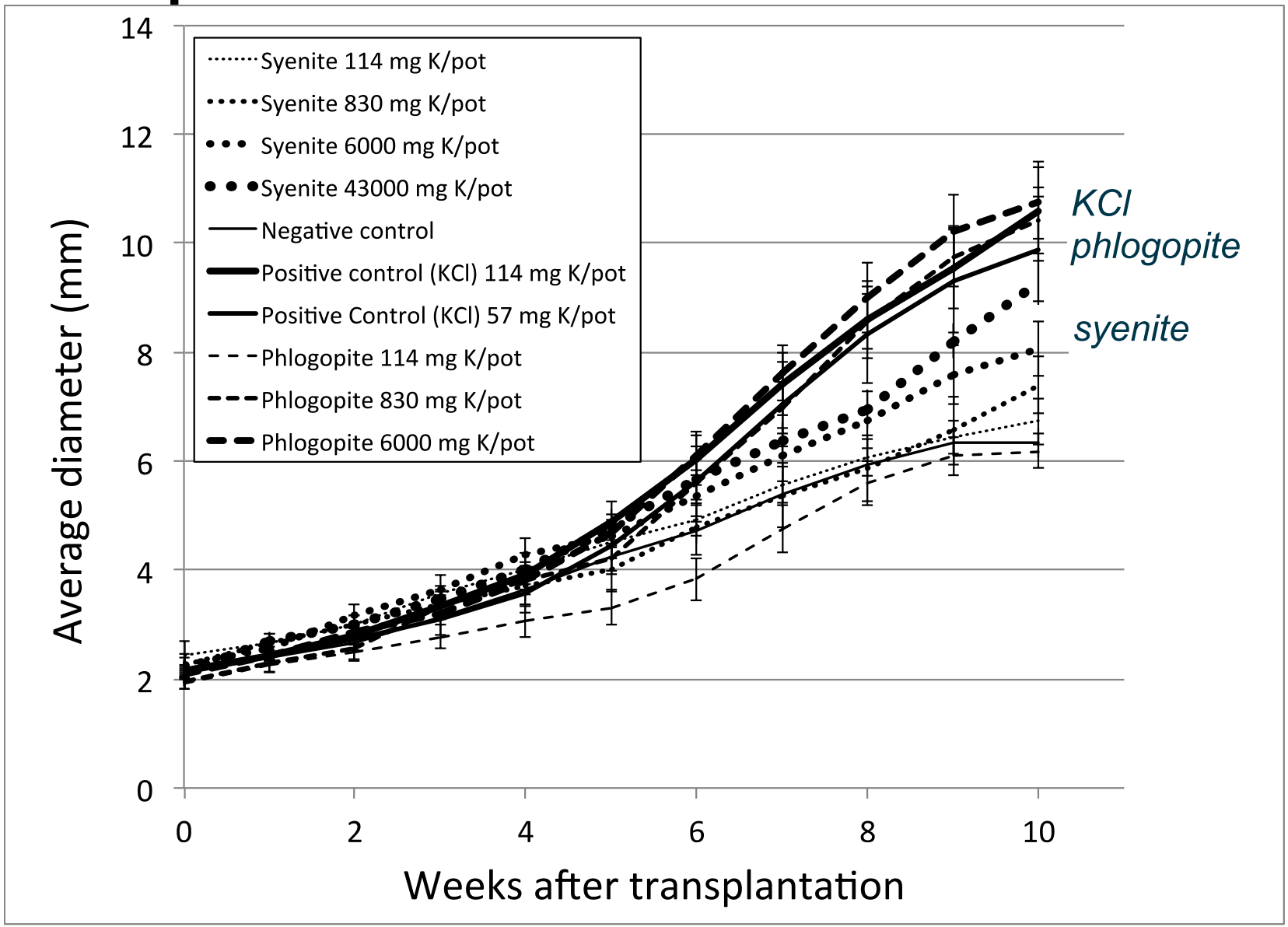
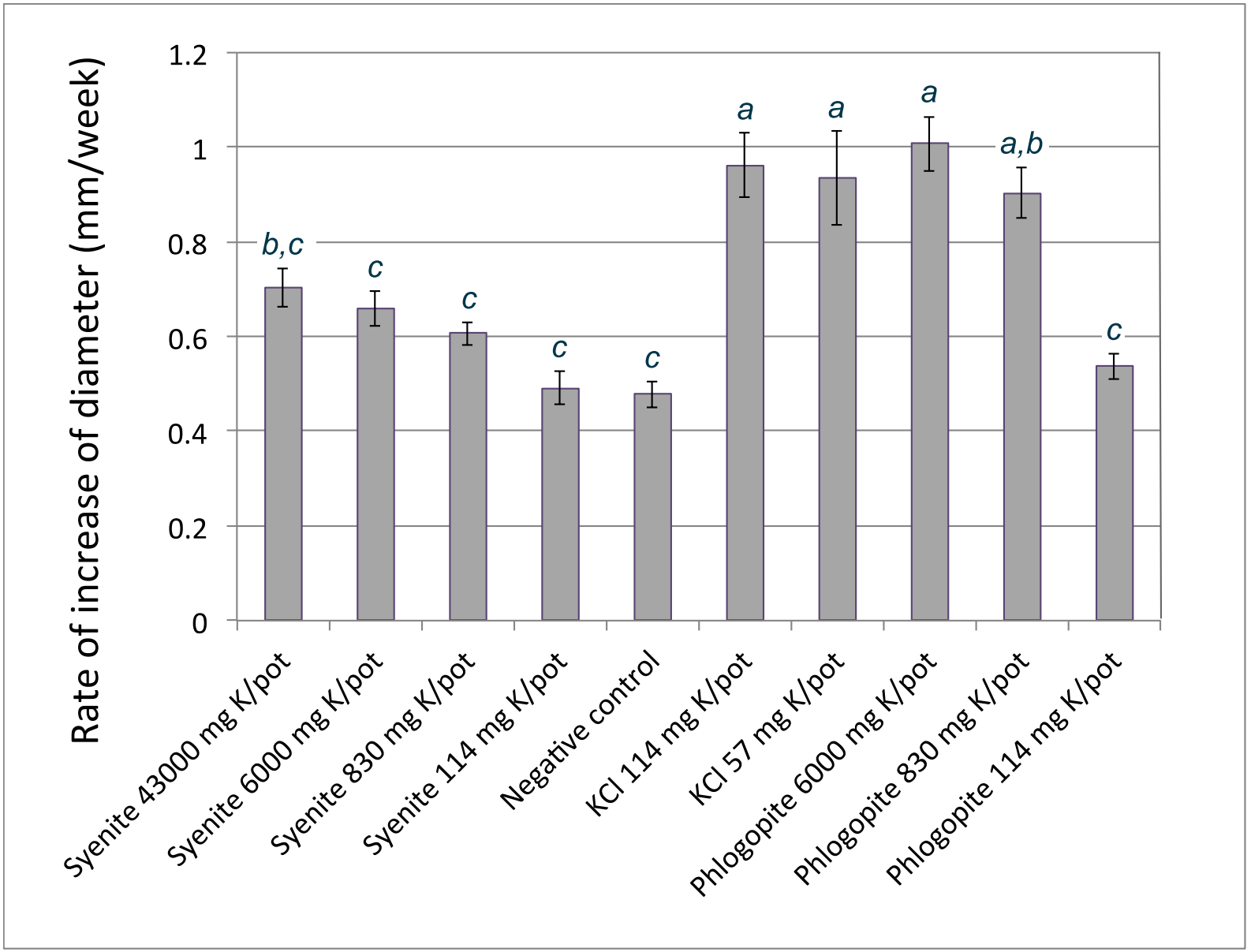
Testing the ability of plants to access potassium from framework silicate minerals

David A.C. Manning [a,*], Joana Baptista [a], Mallely Sanchez Limon [b], Kirsten Brandt [c]

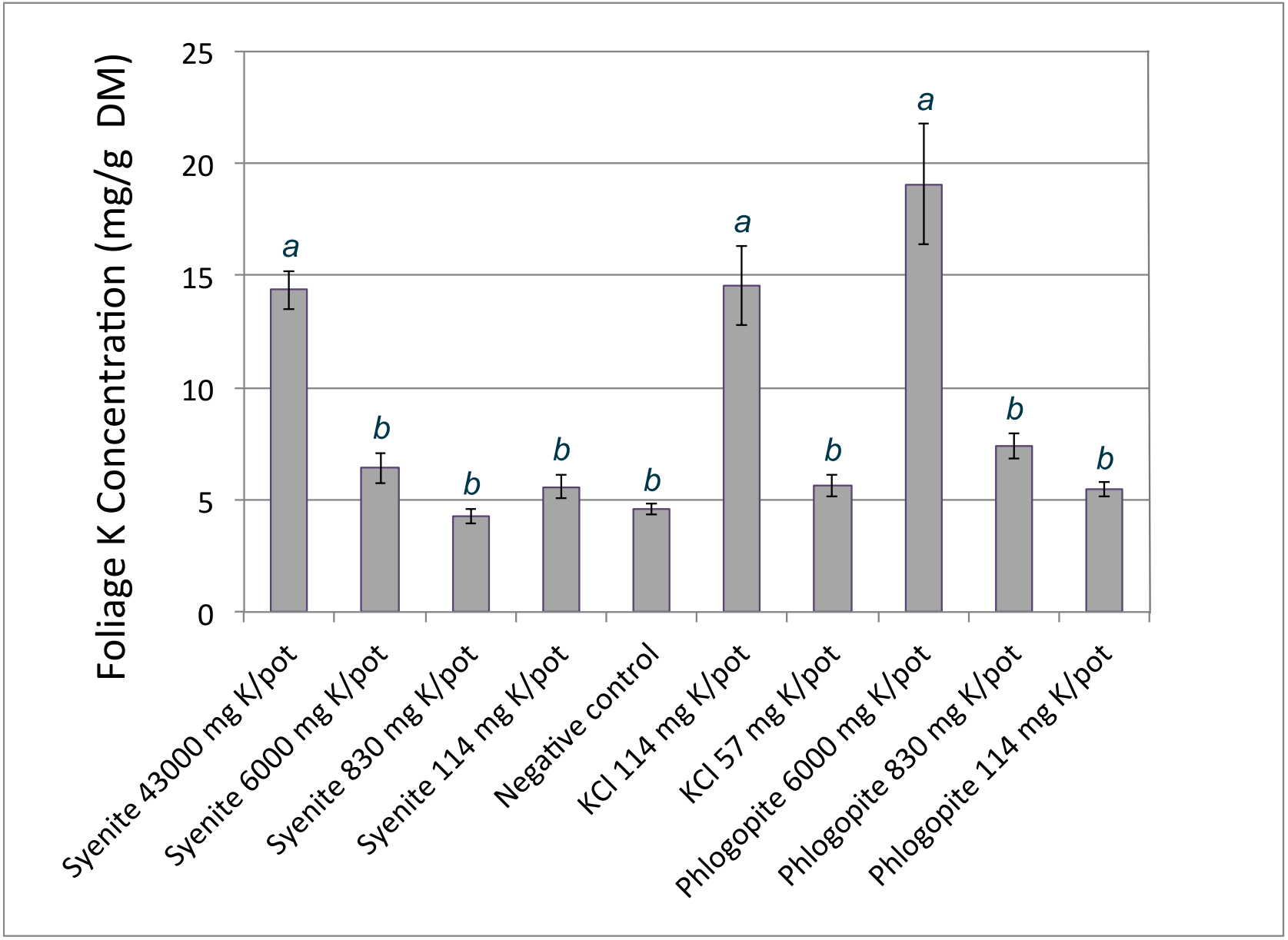
Response to treatment



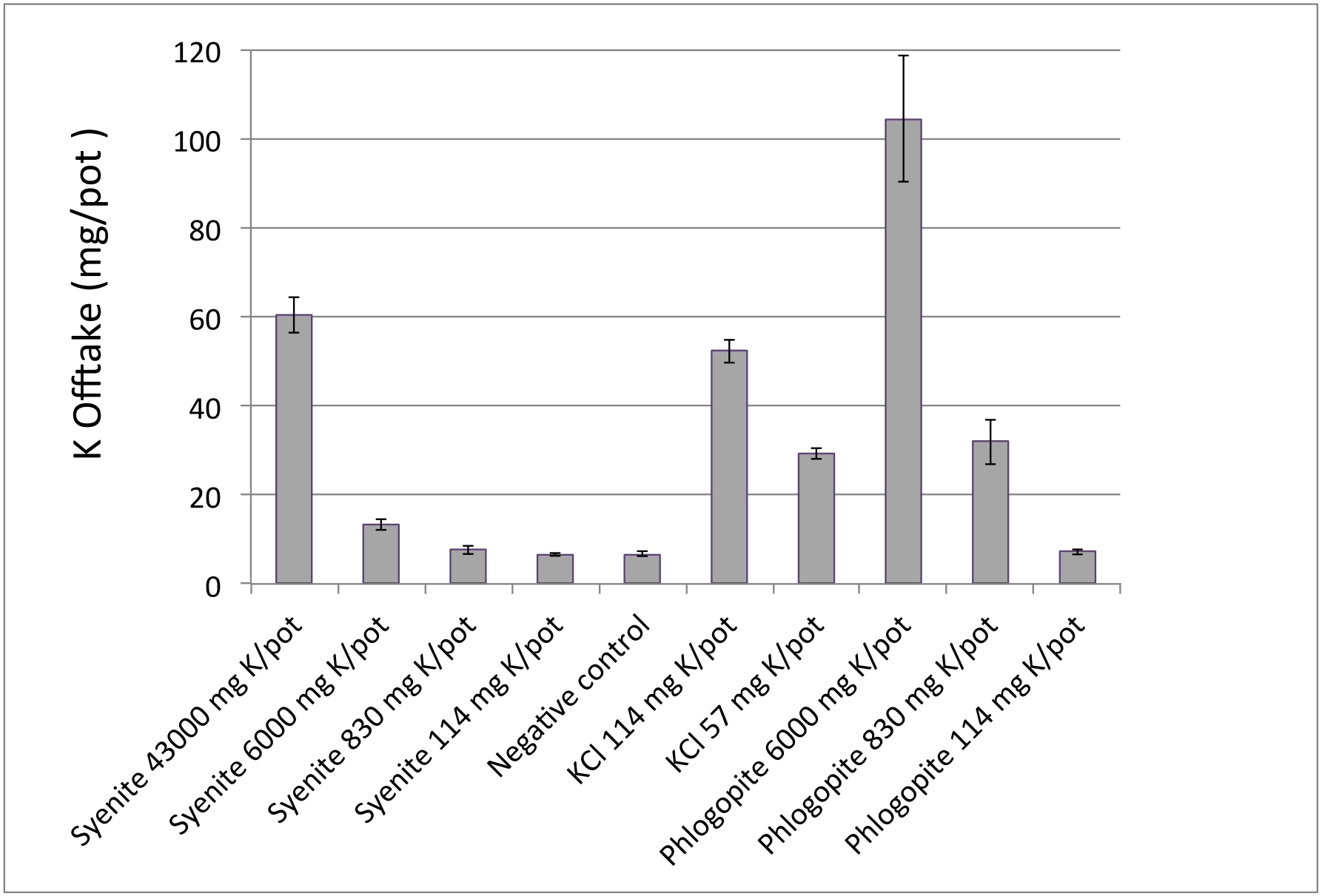
Mica is as good as KCl



K is available from syenite (feldspar)



K is available from syenite (feldspar)



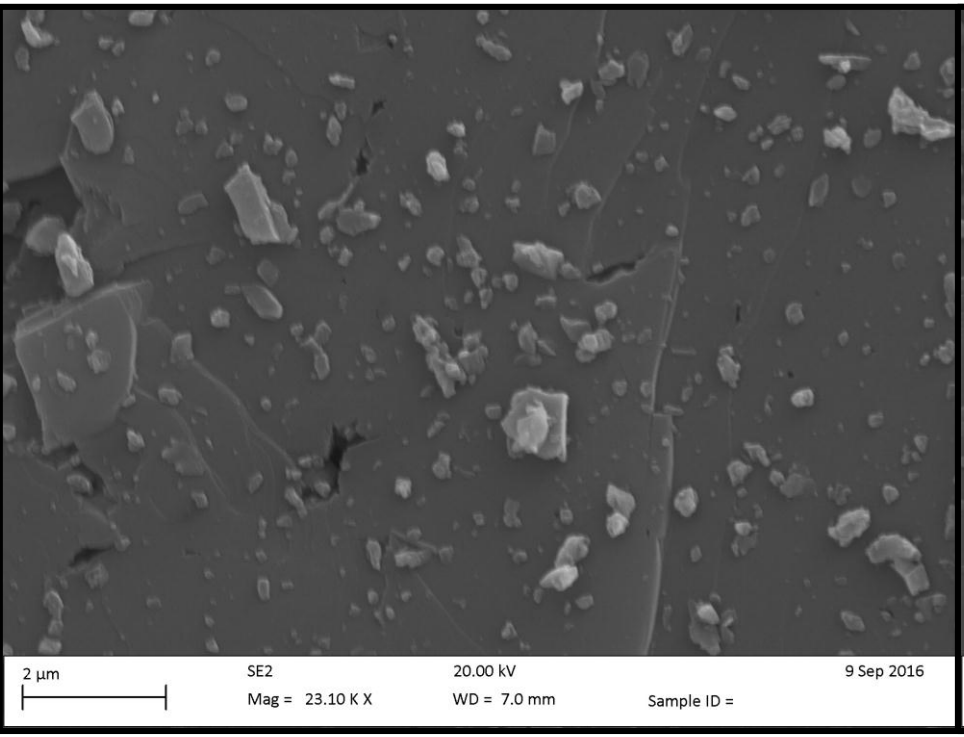
The problem with feldspars

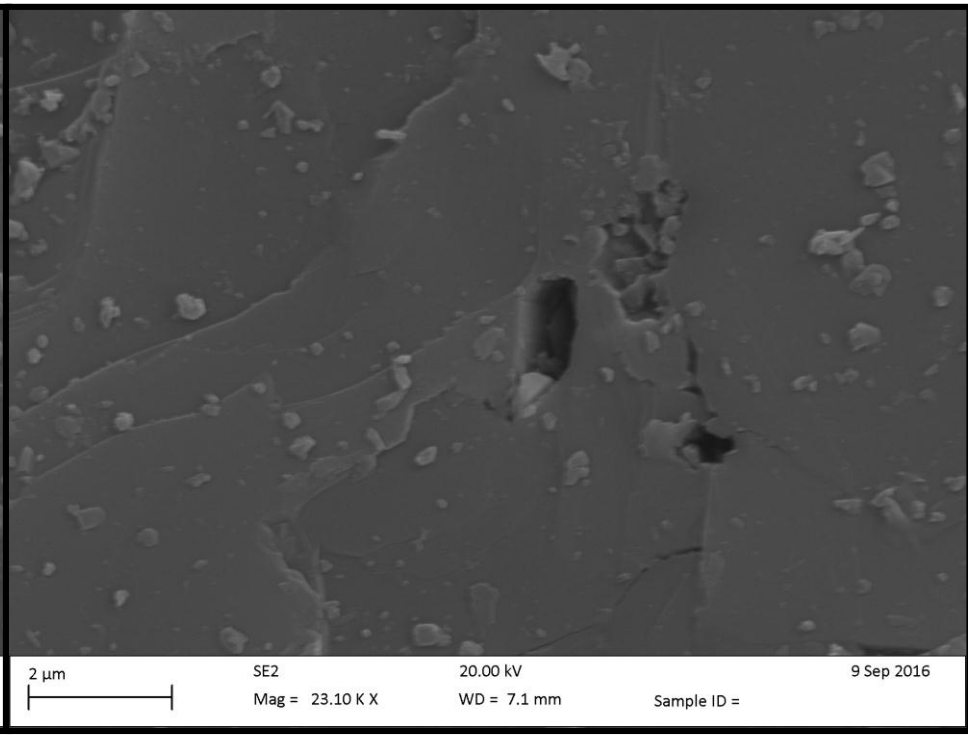
- So, why do feldspars decompose in a soil, but not in the laboratory?

Investigation of soil feldspars

- Feldspar grains taken from soil:
  - UK, Aberdeen (<150 years in soil)
  - UK, Northern England (10 years in soil)
  - Brazil, Triunfo, Pernambuco (X? years)
- Examined using scanning electron microscopy
- Compared with feldspar from experiment (10 weeks)

Feldspar from experiment

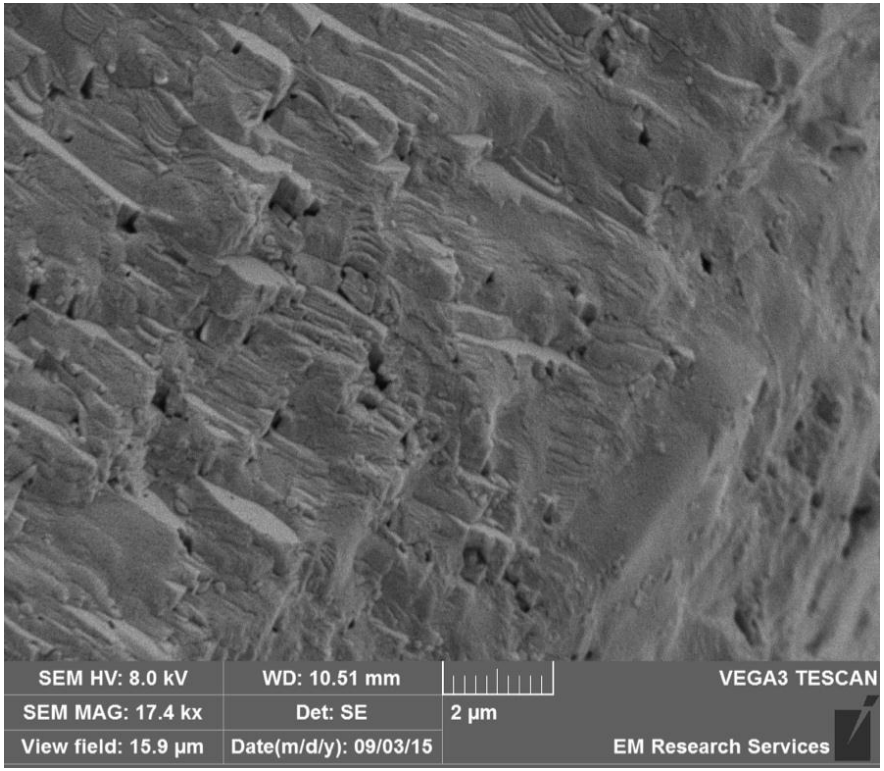




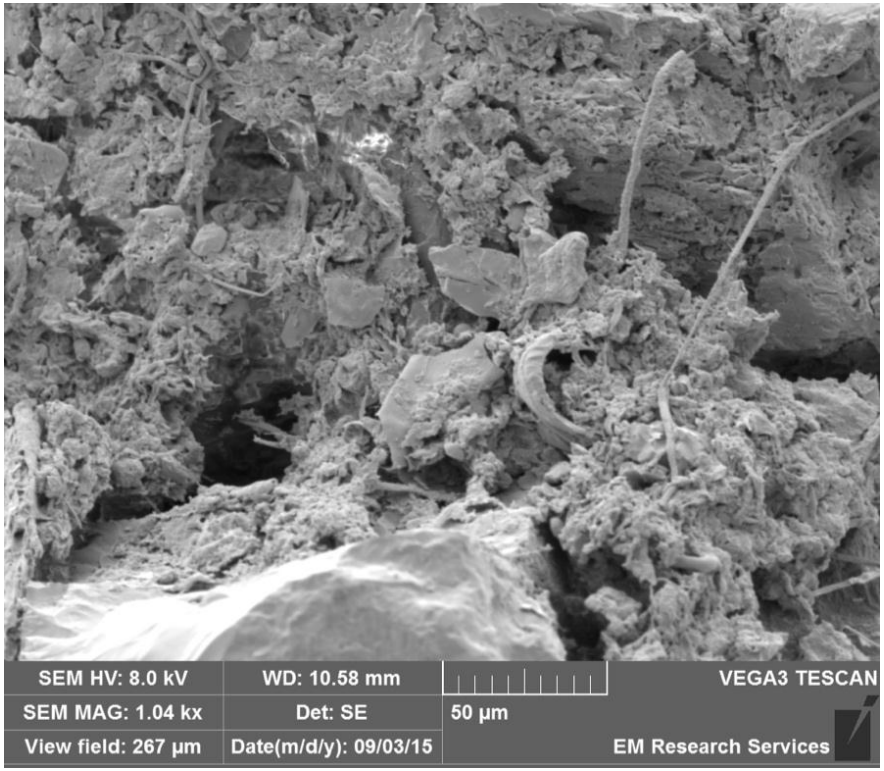
Before *After 10 weeks*

The surface coating of fine particles has been removed

Feldspar from soil: 10 years exposure



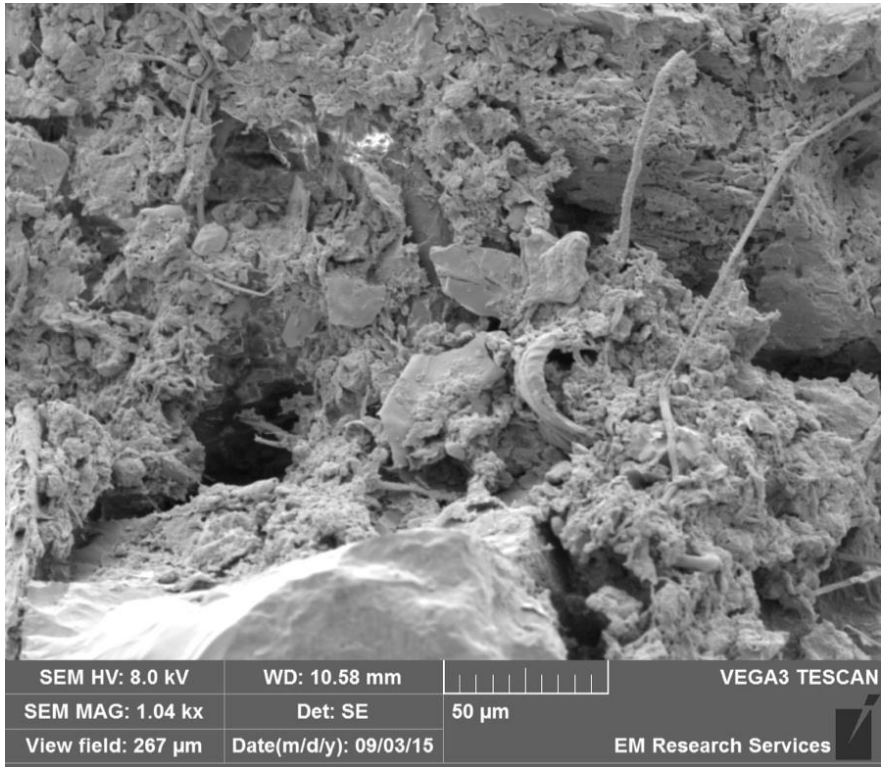
Poorly corroded grains

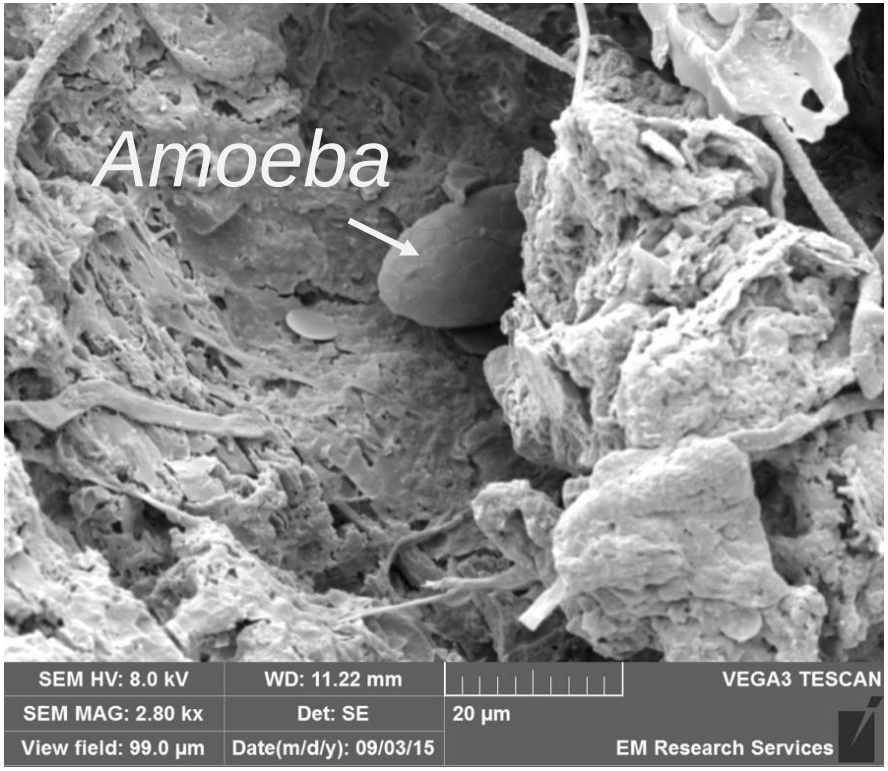


Heavily corroded grains

Irregular corroded surface, with fungal filaments

Feldspar from soil: 10 years exposure

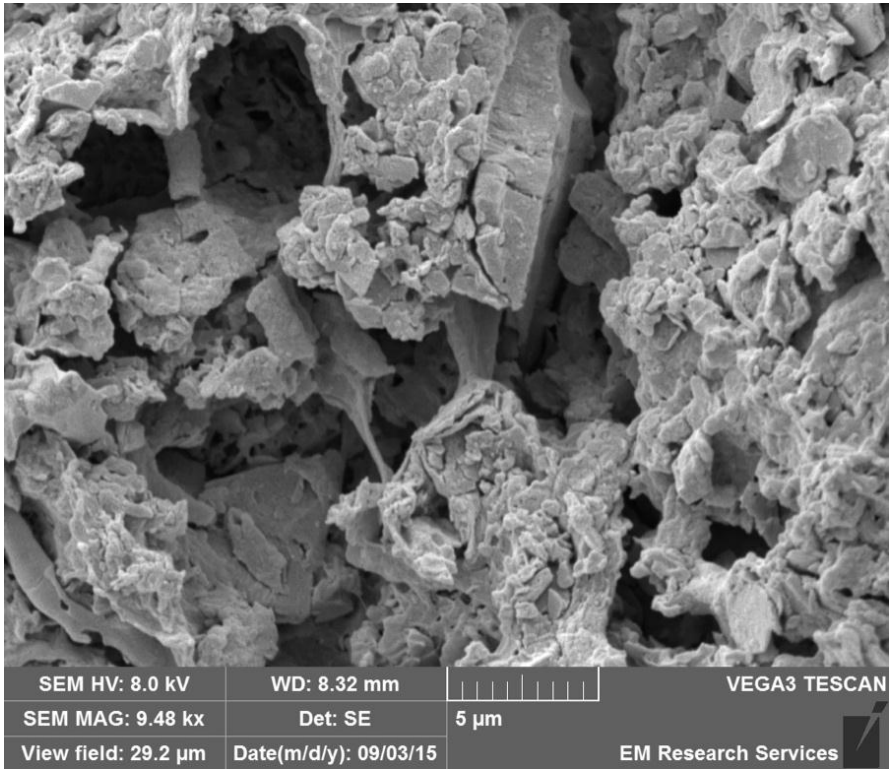


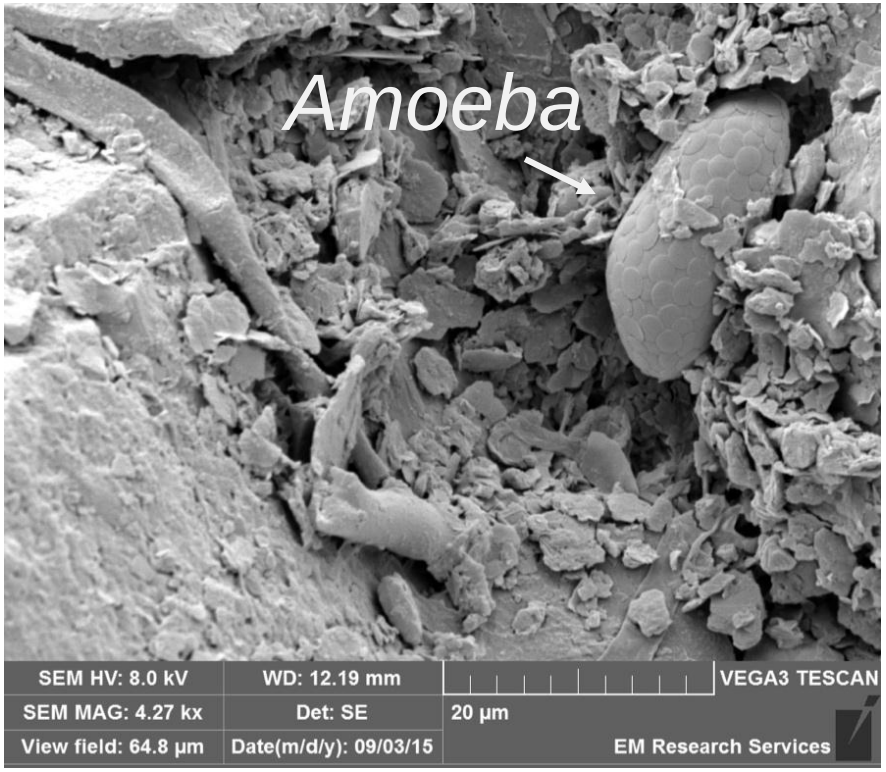


Heavily corroded grains with testate amoeba

The shells of testate amoeba (a type of protozoa) are made of silica

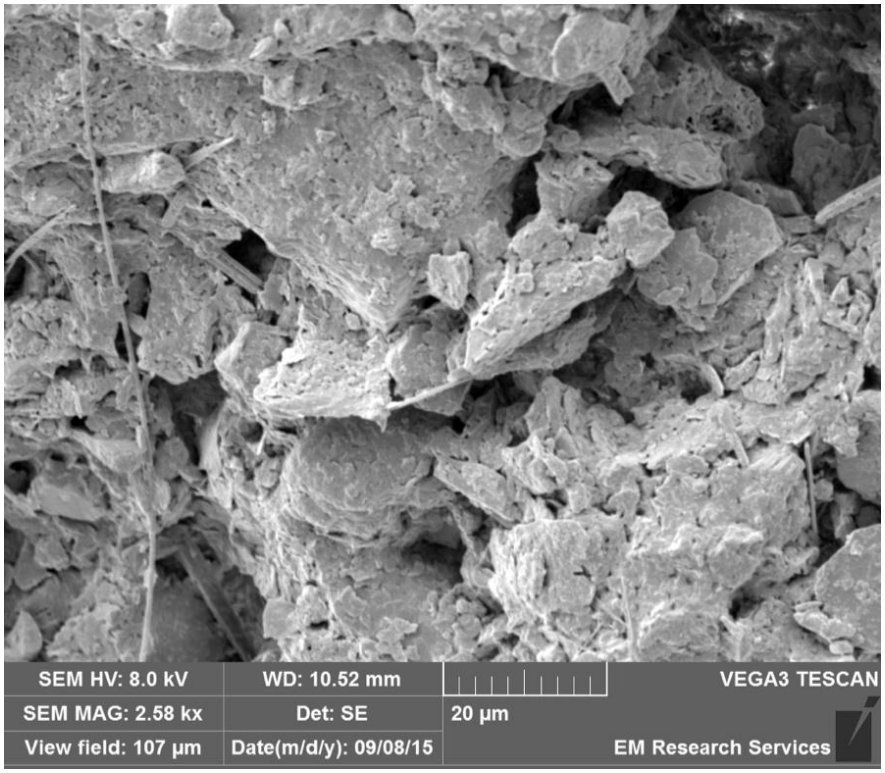
Feldspar from soil: <150 years exposure

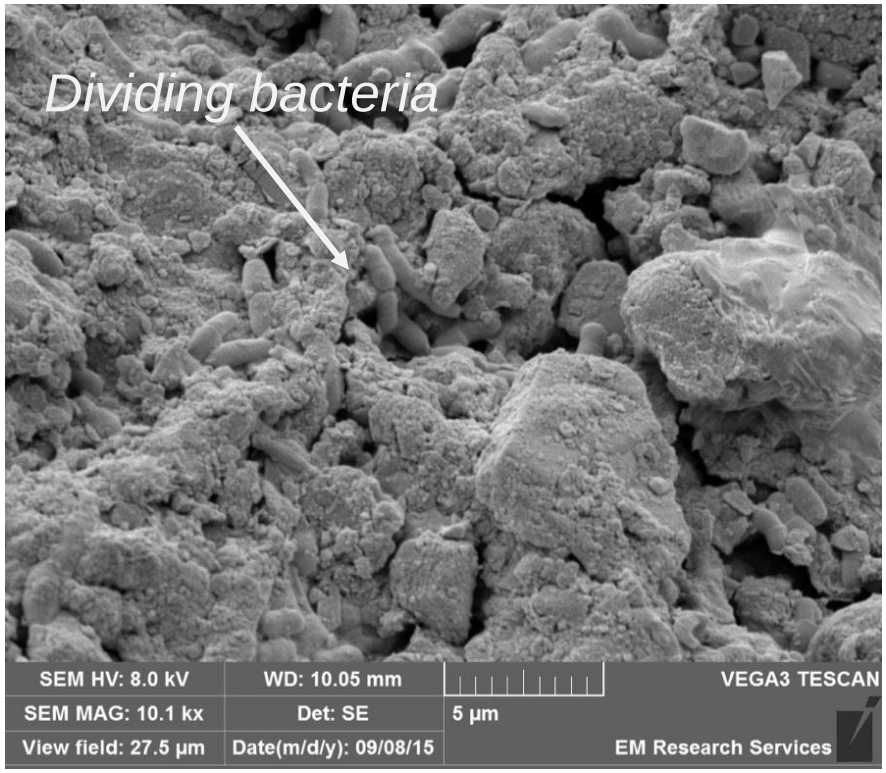




Heavily corroded grains *with testate amoeba*

Feldspar from Triunfo soil: unknown exposure



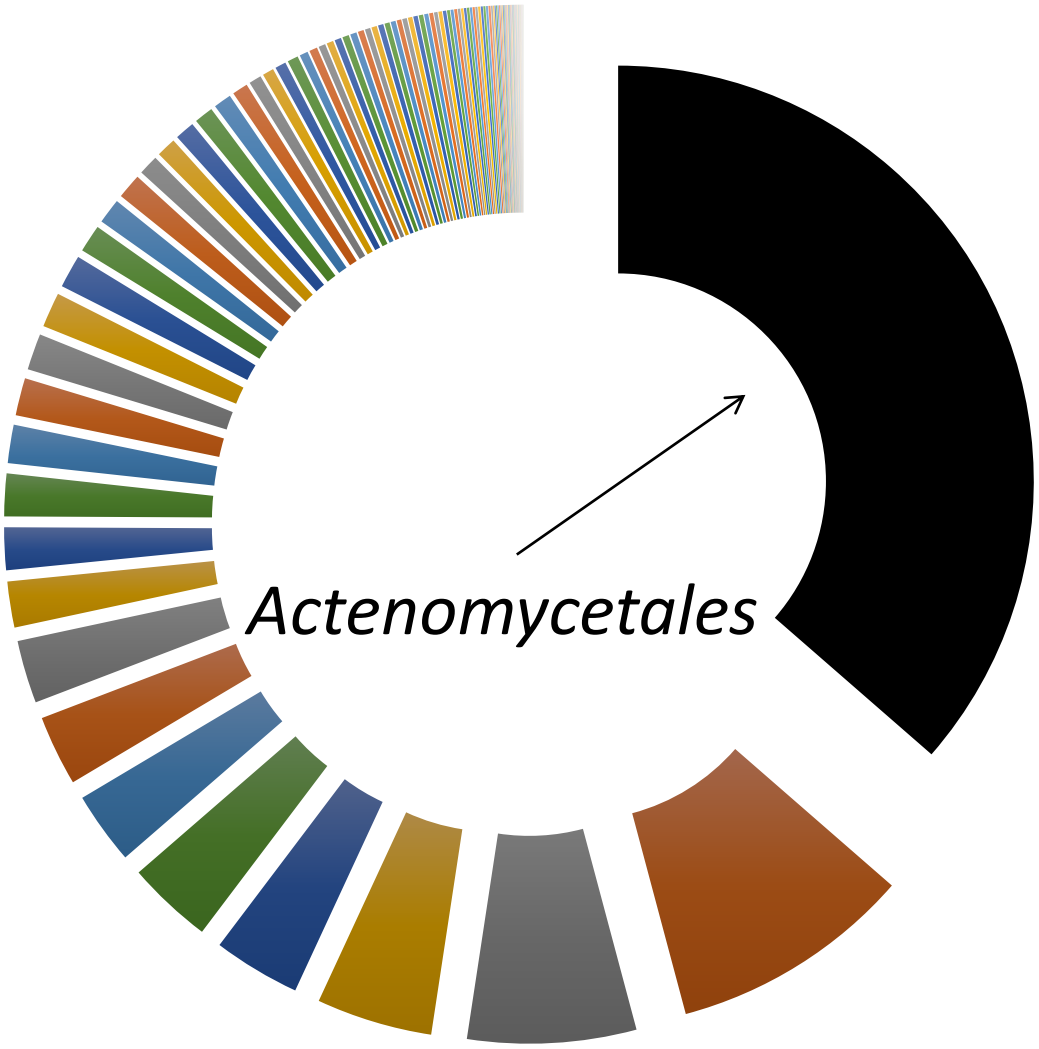


Heavily corroded grains *with dividing bacteria*

How do soil feldspars differ?

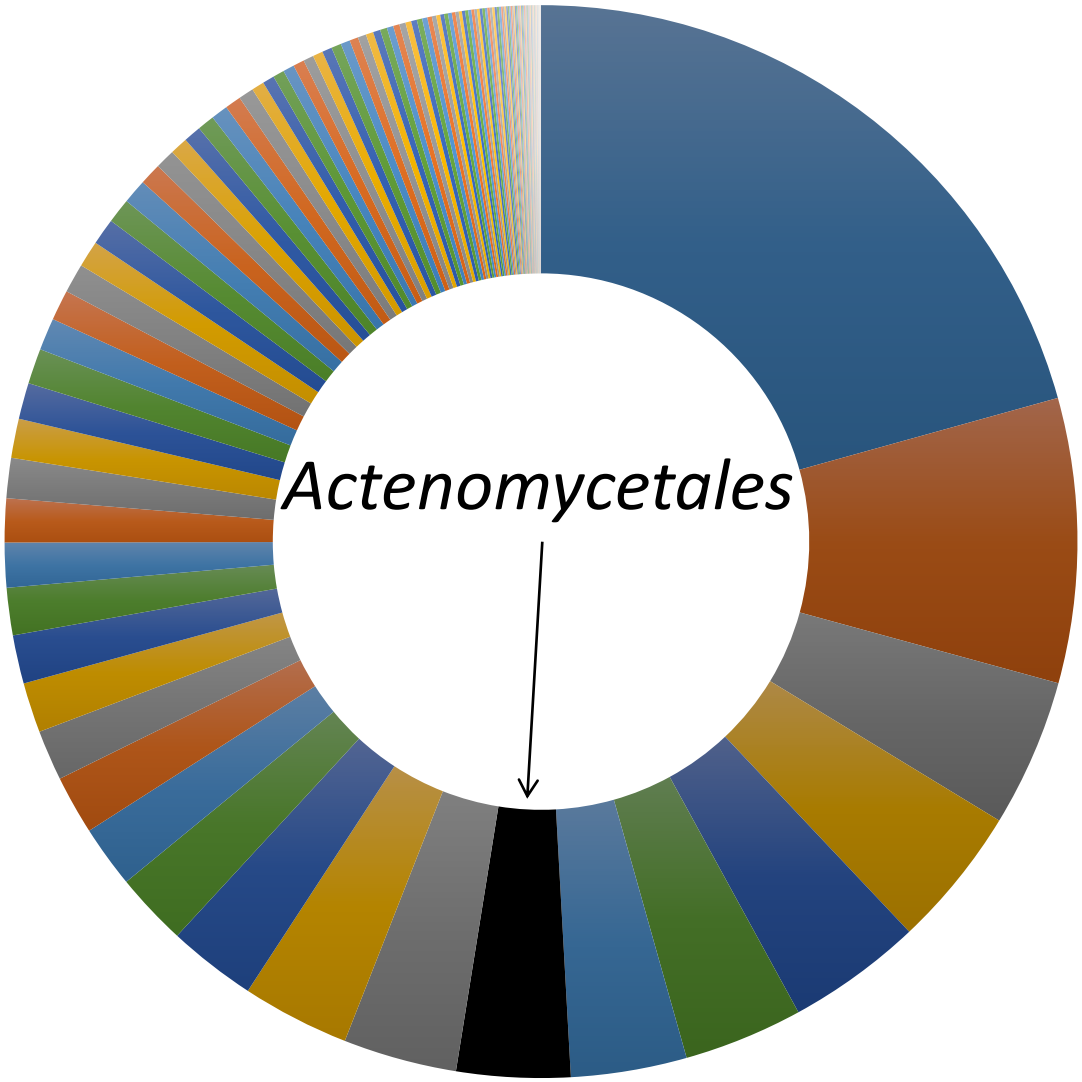
- Surfaces are colonised by a community
  - Bacteria
  - Fungi
  - Protozoa
- Is this community as a whole more important than its individual parts?

Bacterial community analysis: joints in weathered rock



- k__Bacteria;p__Actinobacteria;c__Actinobacteria;o__Actinomycetales
- k__Bacteria;p__Proteobacteria;c__Alphaproteobacteria;o__Rhizobiales
- k__Bacteria;p__Firmicutes;c__Bacilli;o__Bacillales
- k__Bacteria;p__Actinobacteria;c__Thermoleophilia;o__Solirubrobacterales
- k__Archaea;p__Crenarchaeota;c__Thaumarchaeota;o__Nitrososphaerales
- k__Bacteria;p__Actinobacteria;c__Rubrobacteria;o__Rubrobacterales
- k__Bacteria;p__Bacteroidetes;c__Sphingobacteriia;o__Sphingobacteriales
- k__Bacteria;p__Proteobacteria;c__Alphaproteobacteria;o__Rhodobacterales
- k__Bacteria;p__Chloroflexi;c__Thermomicrobia;o__JG30-KF-CM45
- k__Bacteria;p__Chloroflexi;c__Chloroflexi;o__
- k__Bacteria;p__Proteobacteria;c__Alphaproteobacteria;o__Sphingomonadales
- k__Bacteria;p__Proteobacteria;c__Betaproteobacteria;o__Burkholderiales
- k__Bacteria;p__Actinobacteria;c__Thermoleophilia;o__Gaiellales

Bacterial community analysis: soil



k__Bacteria;p__Chloroflexi;c__Ktedonobacteria;o__Thermogemmatisporales

k__Bacteria;p__Planctomycetes;c__Planctomycetia;o__Gemmatales

k__Bacteria;p__Proteobacteria;c__Alphaproteobacteria;o__Rhizobiales

k__Bacteria;p__Verrucomicrobia;c__[Spartobacteria];o__[Chthoniobacterales]

k__Bacteria;p__Acidobacteria;c__Acidobacteria;o__Acidobacteriales

k__Bacteria;p__Firmicutes;c__Clostridia;o__Clostridiales

k__Bacteria;p__Firmicutes;c__Bacilli;o__Bacillales

k__Bacteria;p__Actinobacteria;c__Actinobacteria;o__Actinomycetales

k__Bacteria;p__Nitrospirae;c__Nitrospira;o__Nitrospirales

k__Bacteria;p__Acidobacteria;c__Acidobacteria-6;o__iii1-15

k__Bacteria;p__Armatimonadetes;c__S1a-1H;o__

k__Bacteria;p__AD3;c__ABS-6;o__

k__Bacteria;p__Actinobacteria;c__Thermoleophilia;o__Gaiellales

Importance of protozoa

- Protozoa are predators
- They eat bacteria, fungi, anything smaller than them
- Testate protozoa have silica tests (shells)
- They represent a sink for silica
- Their presence demonstrates that silica is mobile

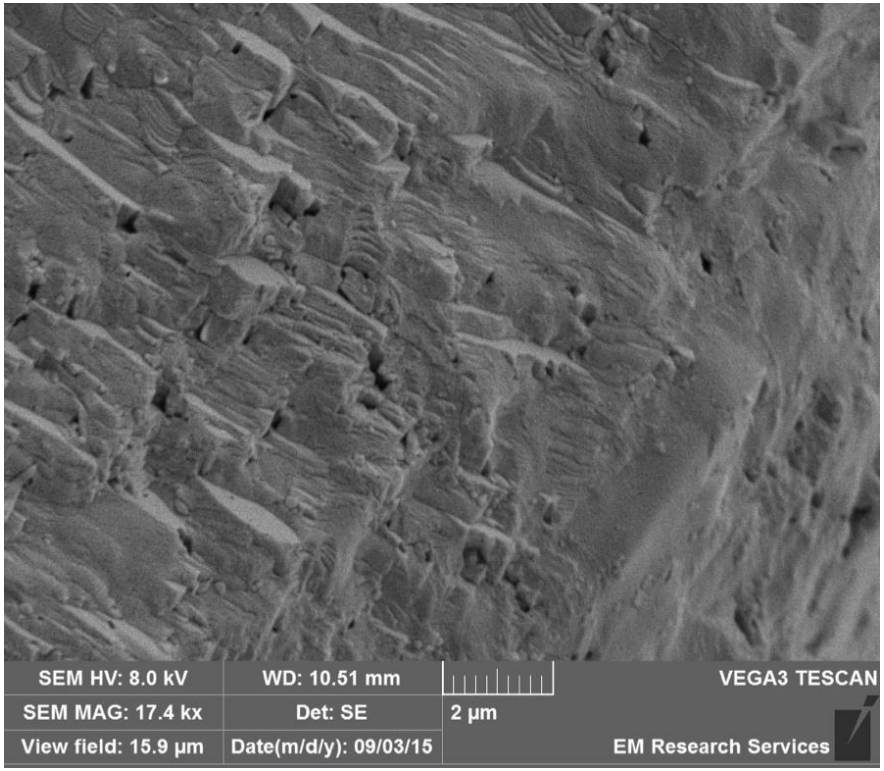
Feldspar corrosion

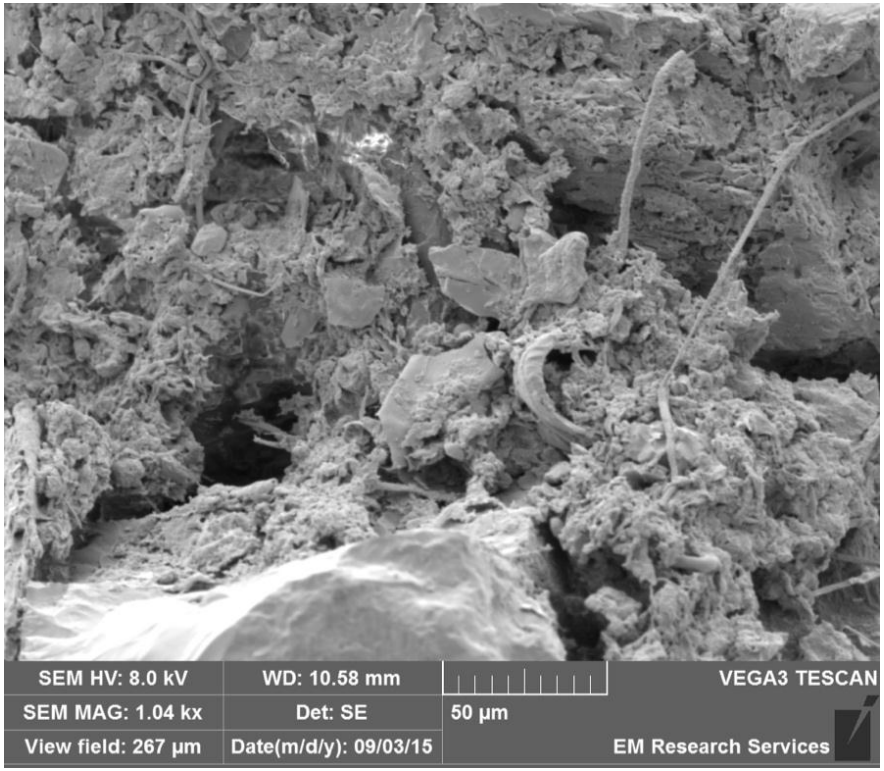
- A 1 mm diameter grain will last 1,000,000 years, according to lab-derived dissolution rates (which are faster than field).
- We observe that corrosion after 10 years gives cavities of the order of 0.1 mm – so a 1 mm grain would last of the order of 100 years.

Feldspar corrosion

- A 1 mm diameter grain will last 1,000,000 years, according to lab-derived dissolution rates (which are faster than field).
- We observe that corrosion after 10 years gives cavities of the order of 0.1 mm – so a 1 mm grain would last of the order of 100 years.
- Or if lab-based rates are correct, a 1mm grain would lose only 0.01 μm from its surface in 10 years – invisible using SEM

Feldspar from soil: 10 years exposure





Typical of lab rates

Exceeds lab rates

Deeper corrosion than predicted links with biology

Feldspar corrosion

- A 1 mm diameter grain will last 1,000,000 years, according to lab-derived dissolution rates (which are faster than field).
- **We observe that corrosion after 10 years gives cavities of the order of 0.1 mm – so a 1 mm grain would last of the order of 100 years.**
- Such corrosion is normally associated with the development of a complex biological community
- Is the key to this corrosion the community that we observe on a feldspar surface?

Conclusions

- K-feldspars evidently release K for plant growth
- The surfaces of K-feldspars from soils are inhabited by a diverse community of microbes and the protozoa that feed upon them
- The presence of testate amoeba demonstrates that silica is mobile in this environment
- To understand how feldspar performs as a fertilizer, we need to consider the microecology of the soil
- We need to develop the concept of *microecosystem services*

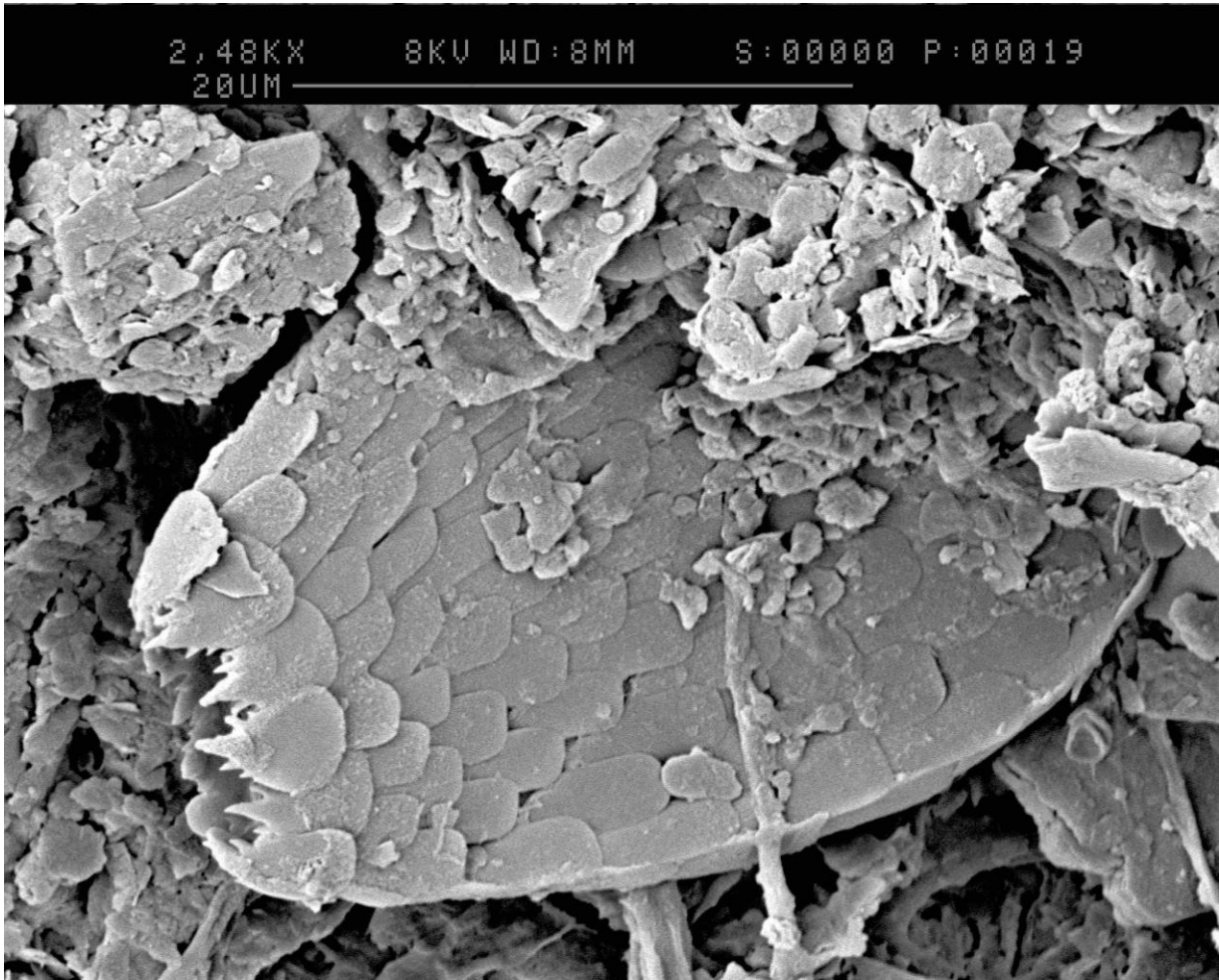
It’s a zoo out there

When we talk about ‘ecosystem services’, we think about the things we can see

It’s a zoo down there

In soils, we can’t see the community, but it is vital to recognise that it is complex, with predators and prey

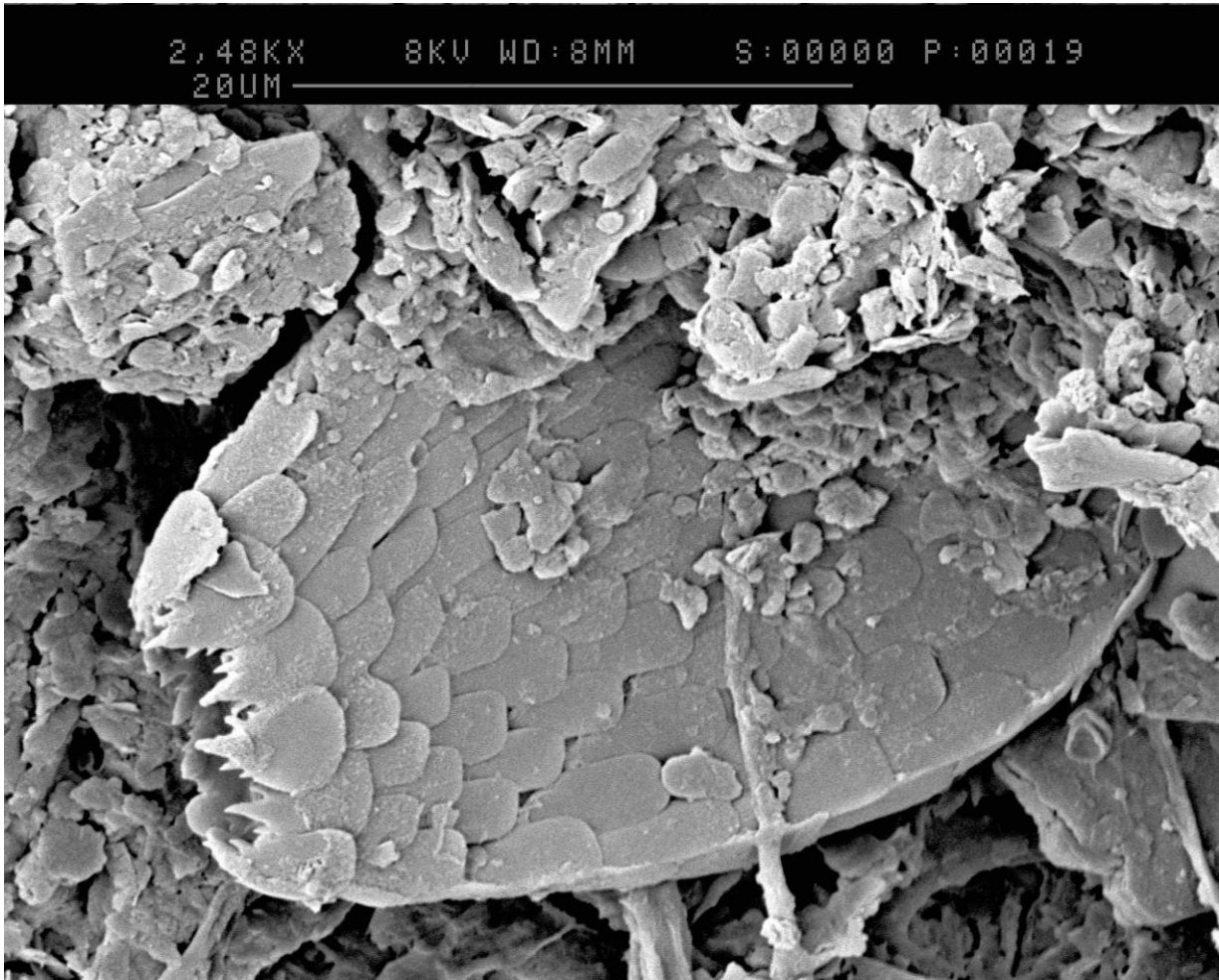
a *microecosystem* providing services that are just as important to mankind



There’s a whole world

Waiting in feldspars, and no doubt other silicate mineral surfaces

Exploration is just beginning

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