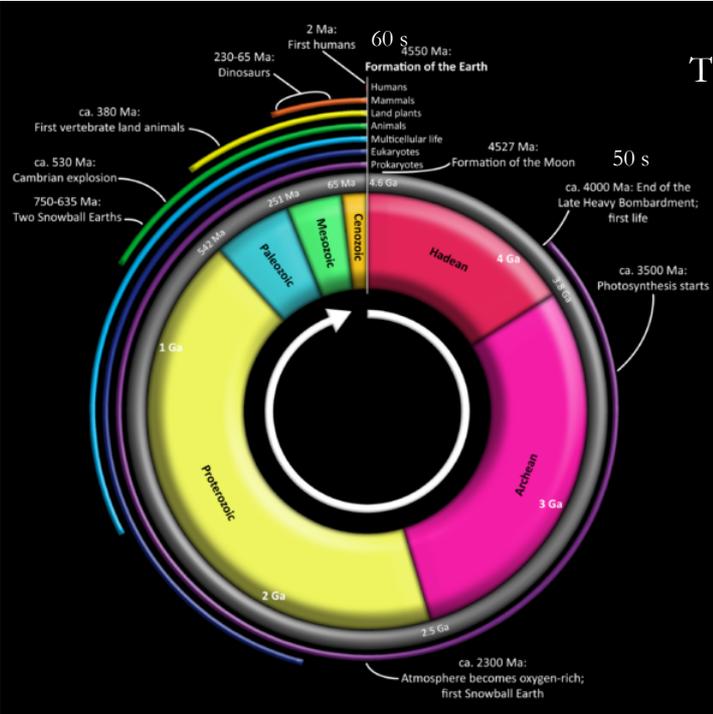


**Bacteria and Fungi**

A clod of earth seemingly simple and lifeless . . . its particles most elaborate in composition . . . inhabited by prodigious numbers of living organisms inconceivably small, . . . yet somehow linked up with our lives . . .

-- *Sir E. John Russell*

Scale bar= 4.3 micrometers



**The microbes will have the last word.**

-- *Louis Pasteur*

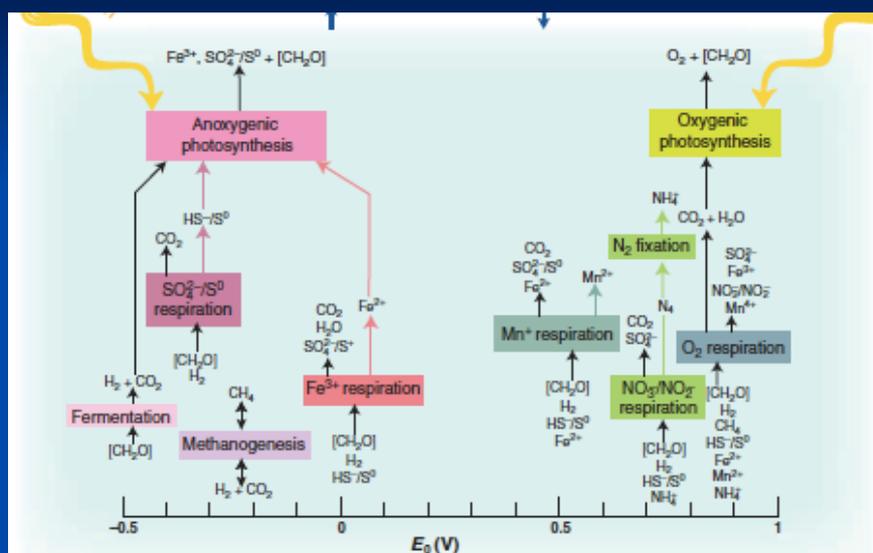
If earth's history was scaled to 60 seconds . . .

2 Ma: First humans  
 230-65 Ma: Dinosaurs  
 ca. 380 Ma: First vertebrate land animals  
 ca. 530 Ma: Cambrian explosion  
 750-635 Ma: Two Snowball Earths  
 2 Ga: Atmosphere becomes oxygen-rich; first Snowball Earth  
 4 Ga: Formation of the Earth  
 4527 Ma: Formation of the Moon  
 ca. 4000 Ma: End of the Late Heavy Bombardment; first life  
 ca. 3500 Ma: Photosynthesis starts  
 60 s: 3550 Ma: Formation of the Earth  
 50 s: 4 Ga: Formation of the Moon  
 3 Ga: Archean  
 2 Ga: Proterozoic  
 1 Ga: Proterozoic  
 500 Ma: Paleozoic  
 250 Ma: Mesozoic  
 65 Ma: Cenozoic  
 2 Ma: First humans  
 230-65 Ma: Dinosaurs  
 ca. 380 Ma: First vertebrate land animals  
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 2 Ma: First humans  
 230-65 Ma: Dinosaurs  
 ca. 380 Ma: First vertebrate land animals  
 ca. 530 Ma: Cambrian explosion  
 750-635 Ma: Two Snowball Earths

# What do microbes do?

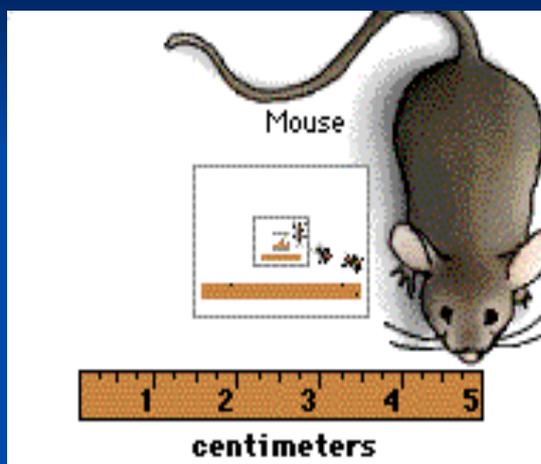
- You tell me!

## The Microbial Engines that Drive Earth's Biogeochemical Cycles Falkowski et al. 2008. Science 320:1034-1039



## How many microbes in soil?

- 1 million to perhaps 1 trillion bacterial cells per g
- 50 – 500 m of fungal hyphae per g
- Major determinants are clay and organic matter content



## Can they fit?

**Table 2-1** Relative size and surface areas of soil particles. For the sake of simplicity, the particles are assumed to be spherical and the largest size possible.

Particle	Diameter (mm)	No. of particles (no. g <sup>-1</sup> )	Surface area (cm <sup>2</sup> g <sup>-1</sup> )
Very coarse sand	2.00 to 1.00	90	11
Coarse sand	1.00 to 0.50	720	23
Medium sand	0.50 to 0.25	5,700	45
Fine sand	0.25 to 0.10	46,000	91
Very fine sand	0.10 to 0.05	722,000	227
Silt	0.05 to 0.002	5,776,000	454
Clay	<0.002	90,260,853,000	8,000,000

- Assume a bacterial spherical cell is 1  $\mu$  m in diameter
- Surface area =  $4\pi r^2 = 3.14 \mu\text{m}^2 = 3.14 \times 10^{-8} \text{cm}^2$
- Surface area of  $10^9$  cells =  $31.4 \text{cm}^2$

## How diverse are bacteria in soil?

Torsvik, V., L. Øvreås, and T.F. Thingstad. 2002. Prokaryotic diversity – Magnitude, dynamics and controlling factors. *Nature* 296:1064-1066

DNA source	Abundance (cells cm <sup>-3</sup> )	Genome complexity (bp)	Genome equivalents
Forest soil	$4.8 \times 10^9$	$2.5 \times 10^{10}$	6000
Forest soil, cultivated	$1.4 \times 10^7$	$1.4 \times 10^8$	35
Pasture soil	$1.8 \times 10^{10}$	$1.5 \times 10^{10}$ – $3.5 \times 10^{10}$	3500 – 8000
Arable soil	$2.1 \times 10^{10}$	$5.7 \times 10^8$ – $1.4 \times 10^9$	140-350

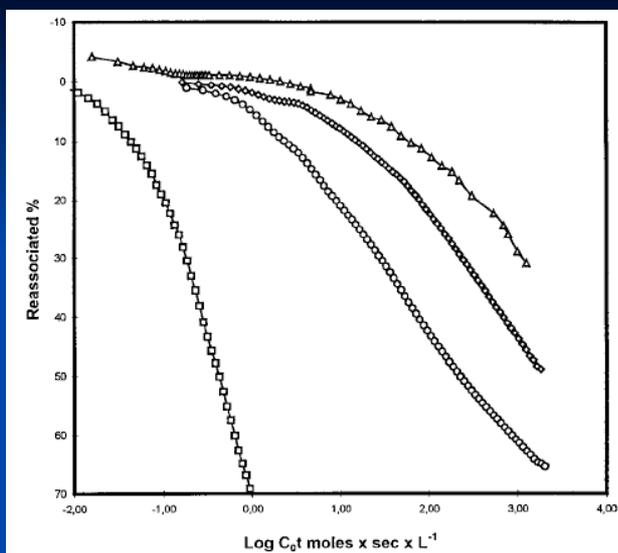


FIG. 2. Reassociation ( $C_0t$  plots) of DNA from bacterial fractions of control soil ( $\Delta$ ),  $N_2$ -perturbed soil ( $\diamond$ ),  $CH_4$ -perturbed soil ( $\circ$ ), and *E. coli* ( $\square$ ). The DNA was sheared to about 420,000 Da and reassociated at 49°C.

## But...

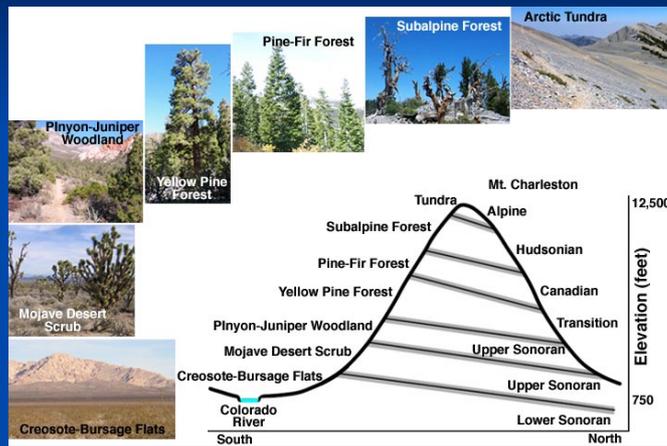
- Gans et al. 2005. Science 309:1387-1390 estimated there may be 1 million or more bacterial species per g
- Roesch et al. ISME Journal 1:283-290 estimated there are probably 20,000 to 60,000 bacterial species per g based on pyrosequencing
  - Forest soils were phylum rich
  - Ag soils were species rich but phyla poor
- Regardless... There are a lot!

## So WHY is microbial diversity so high in soil?

- Top-down and bottom-up factors  
*Escape from predation; host-specific viruses; diversity of substrates*
- Spatial heterogeneity  
*Plants vs. bulk soil; resource heterogeneity; gradients in substrate quality and availability, redox and pH*
- Temporal heterogeneity  
*Starvation, desiccation, freeze/thaw cycles*
- Evolutionary mechanisms  
*Mutations and lateral gene transfer, speciation rate > extinction rate*
- Physical isolation  
*Lack of competition allows for functionally redundant species to coexist*

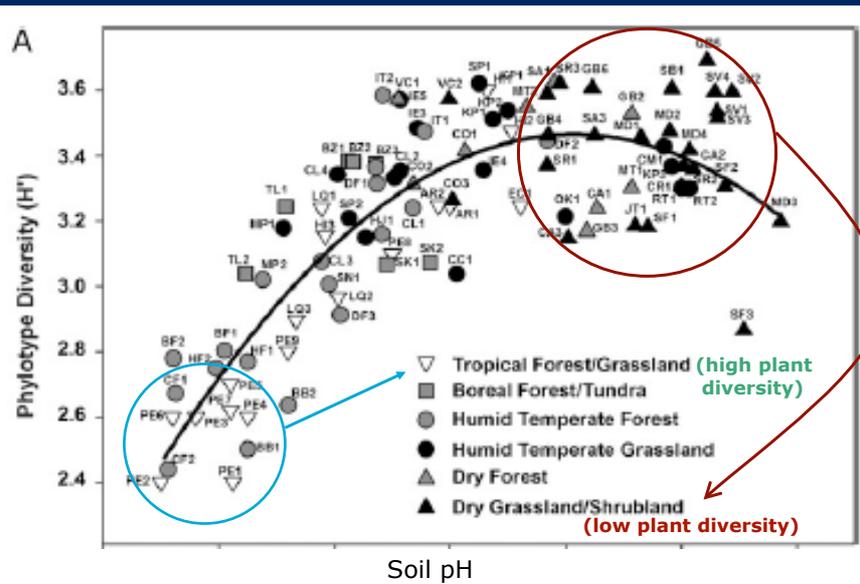
# What determines diversity and community composition?

- Are microbes influenced by the same factors (temperature, precipitation, PET) that influence plants and animals?

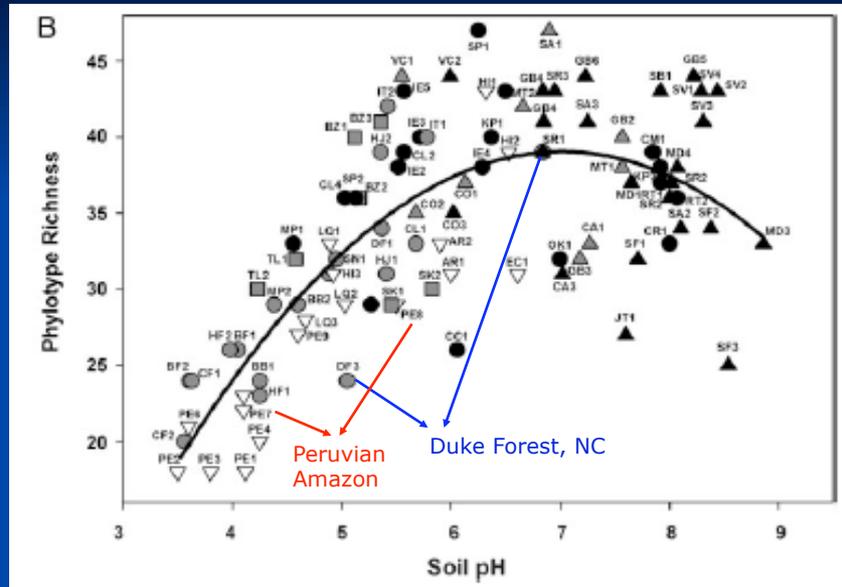


Life zones of Holdridge, 1947

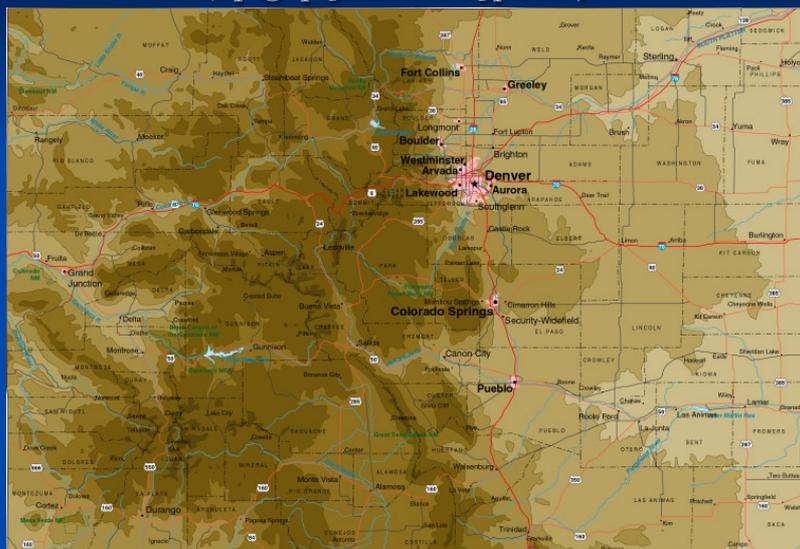
Fierer and Jackson. 2006. The diversity and biogeography of soil bacterial communities. PNAS 103:626-631



## For both continental and local scales



## Regional scale *(topography, land use type, etc.)*



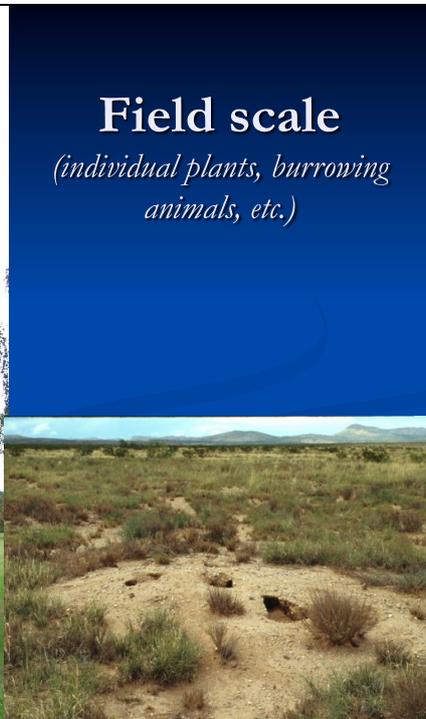
## Field scale

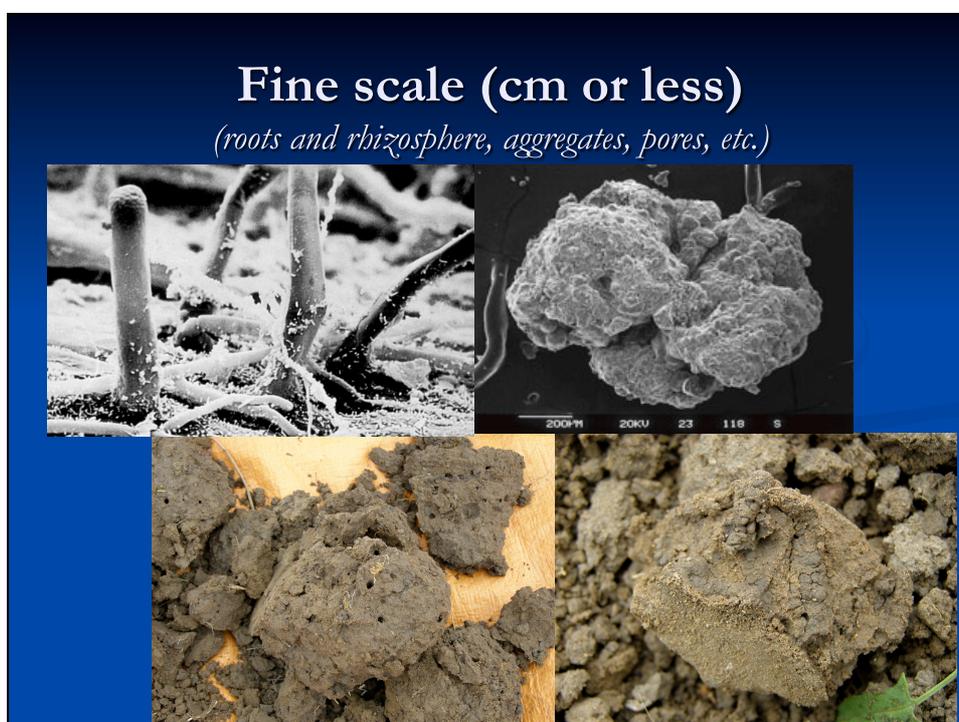
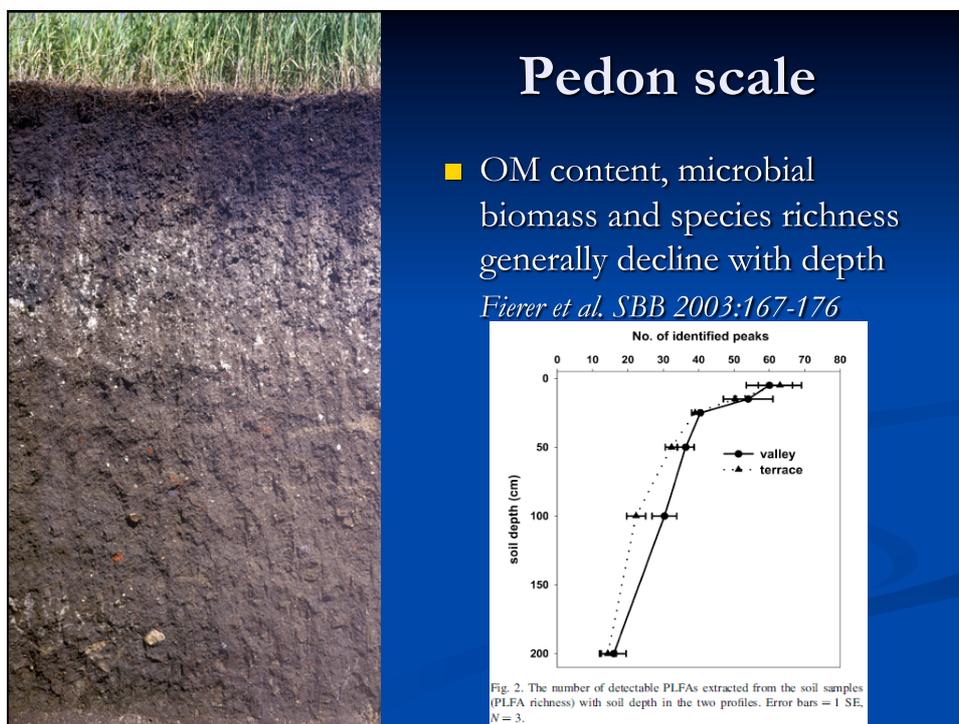
*(plant communities, management, etc.)*



## Field scale

*(individual plants, burrowing animals, etc.)*





## A nation that destroys its soil destroys itself.

-- F.D. Roosevelt

- Diversity is important to soil, biosphere and human sustainability  
*litter decomposition, OM formation, nutrient cycling*
- Microbial species are important to the conservation and restoration biology of higher organisms  
*mycorrhizal fungi, N<sub>2</sub>-fixing bacteria*
- Soil microbes have value to biotechnology  
*Bt insecticides, xenobiotic degraders, antimicrobial agents, plant growth-promoting rhizobacteria*
- Microbial diversity and community structure can be used to monitor environmental change