Phosphorus limitation during long-term ecosystem development

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The final frontier?
“We know more about the movement of celestial bodies than about the soil underfoot.”

Leonardo da Vinci, c. 1500
Soils and terrestrial ecology

• **Soils support terrestrial life**
  – soils provide the structural support for plants
  – soils regulate water supply
  – soils provide a reservoir of nutrients

• **Soils are biologically diverse**
  – a handful of soil contains tens of thousands of distinct microbial species

• **How do soils influence the productivity, diversity, and distribution of organisms in the environment?**
Phosphorus: The Devil’s Element!

• **Fundamental to life on earth**
  – protein synthesis (RNA)
  – passage of genetic information (DNA)
  – cell membranes (phospholipids)
  – energy transfer (ATP)

• **Limitation of plant productivity**
  – widespread phosphorus deficiency in both terrestrial and aquatic ecosystems

• **Peak phosphorus?**
  – essential in modern agriculture, but are phosphorus reserves running out?
Soil forming factors

- Climate
- Organisms
- Relief
- Parent material
- Time

Aquic Hapludult, SERC, Maryland
Soil chronosequence in coastal dunes at Haast, New Zealand
300 years old

4000 years old
Changes in nutrient status during ecosystem development
Phosphorus transformations during pedogenesis (Walker and Syers, 1976)

Old soils contain only occluded and organic phosphorus

![Graph showing changes in phosphorus content over time.](image-url)
The Franz Josef Glacier, New Zealand

- Total Nitrogen (g kg$^{-1}$)
- Total Phosphorus (g kg$^{-1}$)
- N:P Ratio
- Years

Graphs showing data over time.
Cooloola, Australia
Hawaiian Islands
Franz Josef Glacier
Arawhata, New Zealand
Cooloola, Australia
Northern Arizona Volcanic Field
Jurien Bay, Western Australia
Hawaiian Islands
Karangarua Terraces, New Zealand
Mendocino Staircase, California
Haast Dunes, New Zealand
Foliar phosphorus along the Jurien Bay soil chronosequence, Western Australia
Cooloola chronosequence, eastern Australia
Shift towards stress-tolerant tree species along the Franz Josef chronosequence

**Angiosperms (e.g.):**
*Weinmannia racemosa*
*Dicksonia squarrosa*

**Podocarpaceae (e.g.):**
*Dacrydium cupressinum*
*Podocarpus hallii*
Plant strategies for acquiring soil phosphorus

- **Synthesis of phosphatase enzymes**
  - a ubiquitous response of plants to the need for phosphorus

- **Formation of mycorrhizal symbioses**
  - some are extremely efficient at acquiring soil phosphorus

- **Cluster roots and organic anions**
  - compounds like citrate can solubilize large amounts of soil phosphorus
Changes in plant community composition during ecosystem development

Greater plant diversity on ancient landscapes
Significance of the soil microbial biomass

- Large phosphorus pool in microbial biomass
- Microbial phosphorus > plant phosphorus for most of the sequence
- Intense plant–microbe competition for phosphorus on old soils?
Changes in microbial communities with soil age

• Increase in fungal to bacterial ratios
  – e.g., in mineral and organic horizons along the Franz Josef chronosequence

• Investment in phosphorus acquisition
  – e.g., for two phosphatase enzymes along the Haast chronosequence

• Change in microbial communities
  – decline in bacterial diversity and richness along the New Zealand chronosequences
Bacterial community composition during pedogenesis

- Relative abundance of bacterial phyla along the Franz Josef chronosequence
Ancient soils: an extreme environment for microbes?
Summary: relevance to astrobiology?

• Long-term decline in phosphorus availability
  – extremely low phosphorus concentrations in old soils
  – phosphorus rejuvenation by tectonic activity (or other major disturbance)

• Consequences for terrestrial life
  – intense biological phosphorus limitation
  – decline in productivity, greater specialization, greater diversity (plants)

• Life on ancient terrestrial landscapes as an analogue for low-tectonic worlds?