Phosphorus limitation during long-term ecosystem development

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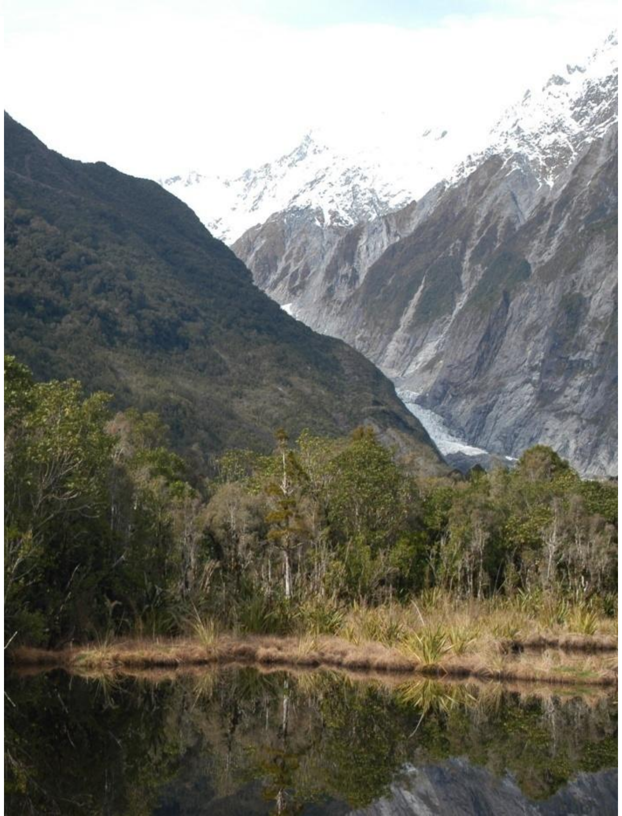


The final frontier?

“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?**

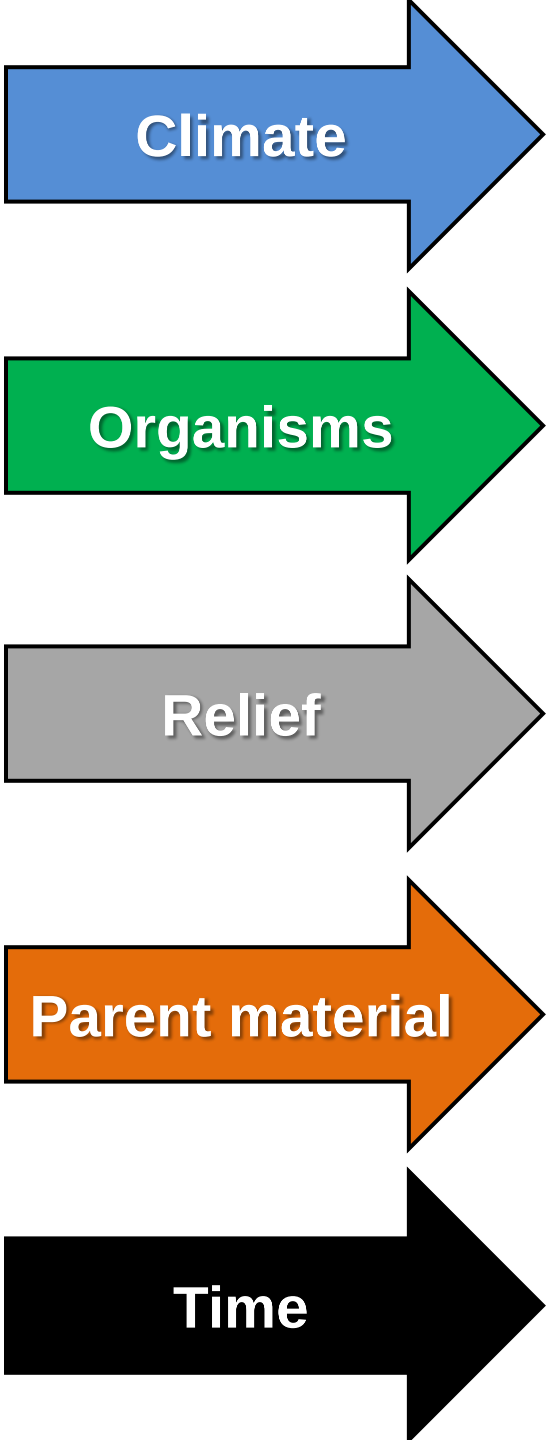
Phosphorus: The Devil's Element!

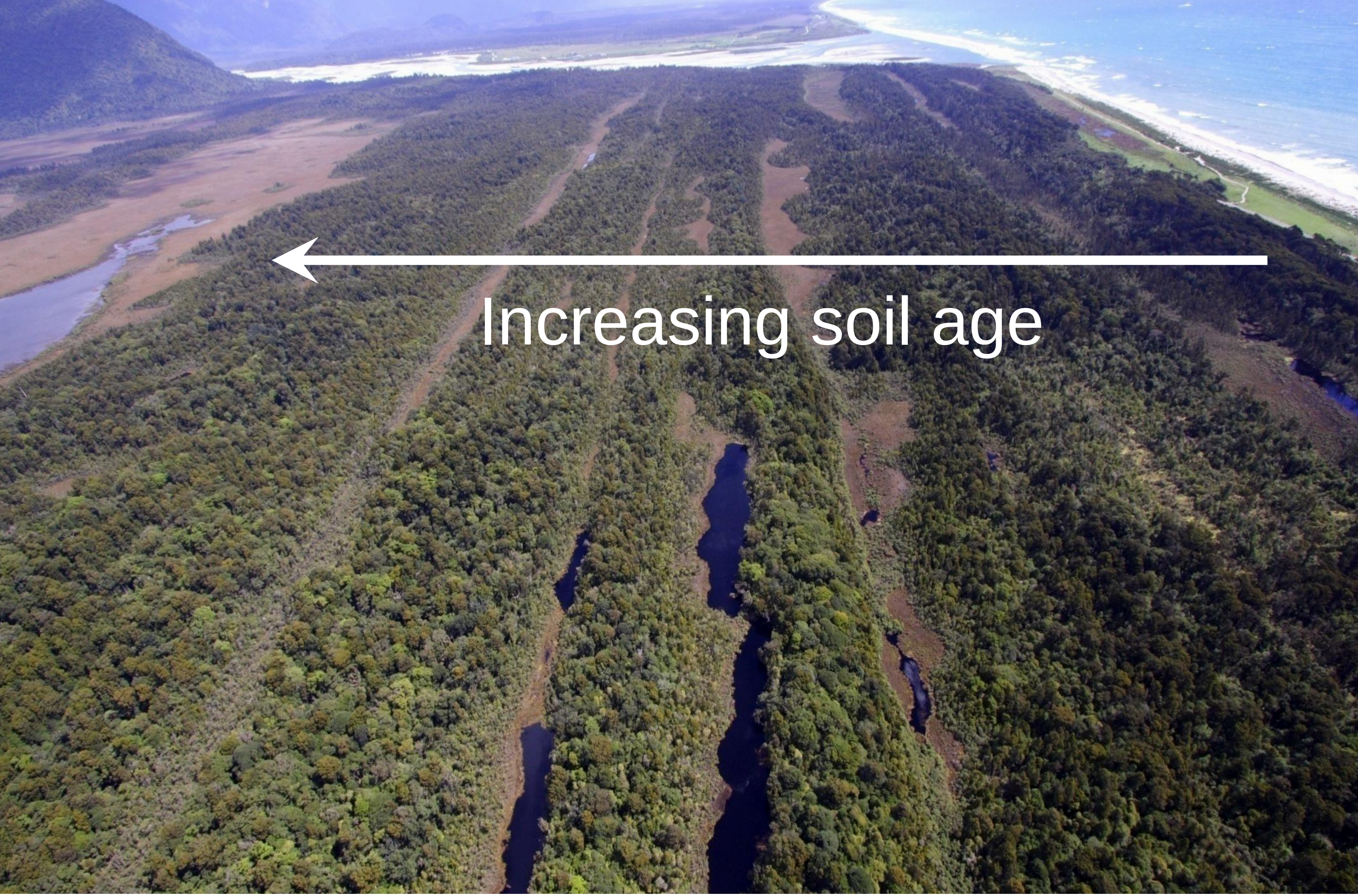
- **Fundamental to life on earth**
  - – protein synthesis (RNA)
  - – passage of genetic information (DNA)
  - – cell membranes (phospholipids)
  - – energy transfer (ATP)

- **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



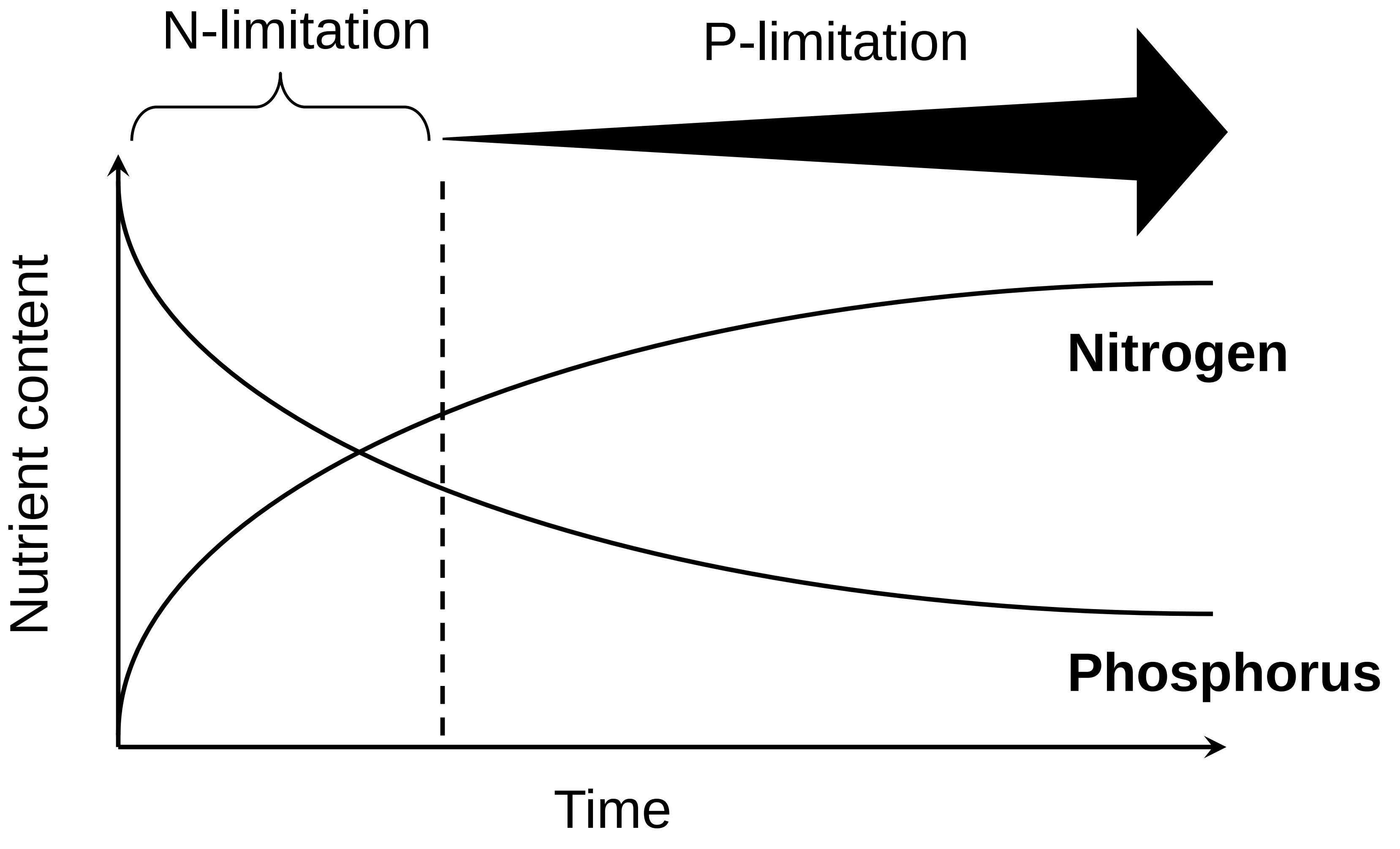


Soil chronosequence in coastal dunes at Haast, New Zealand

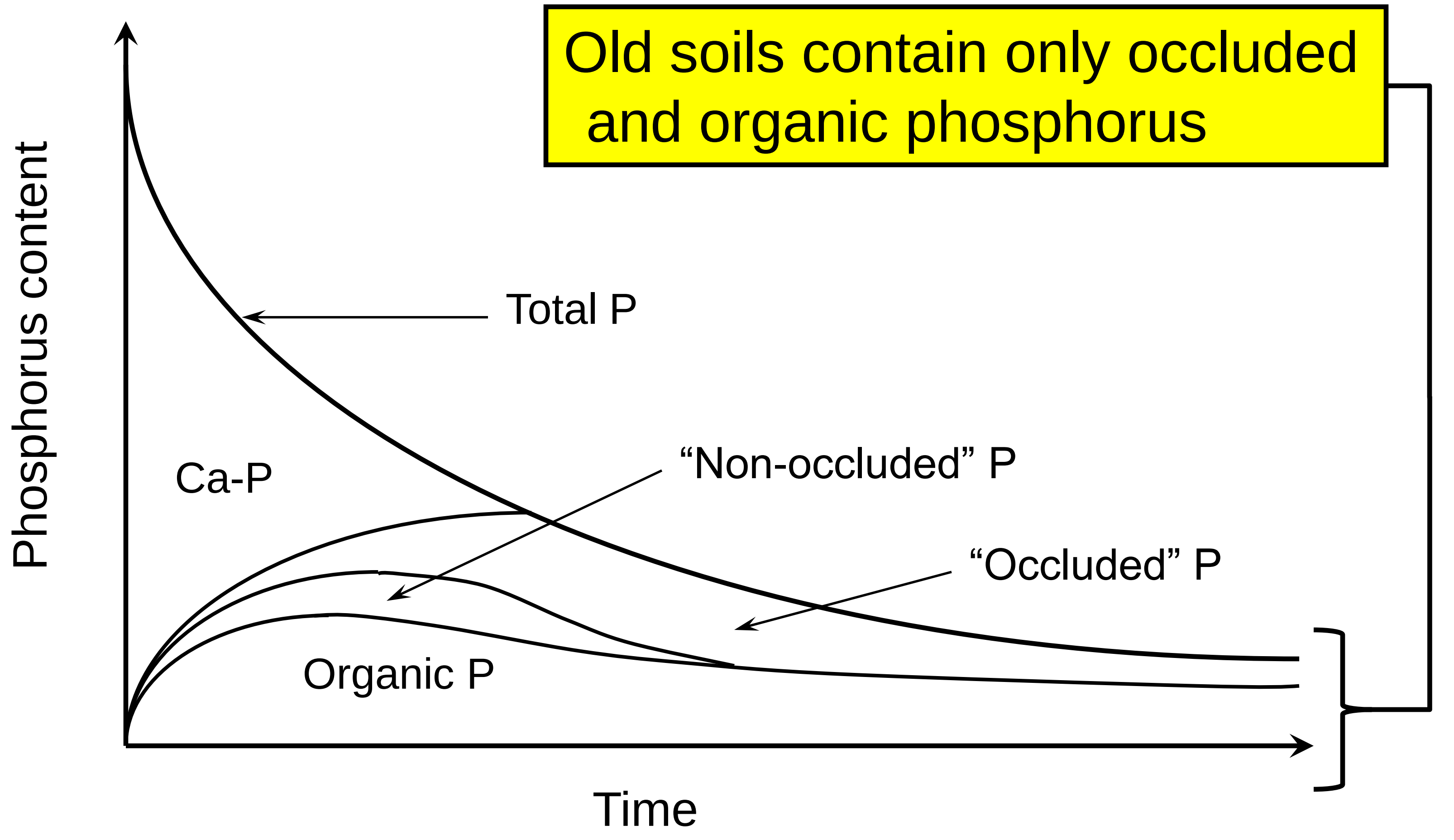

m
0·2
0·4
0·6
0·8
1·0
300 years old

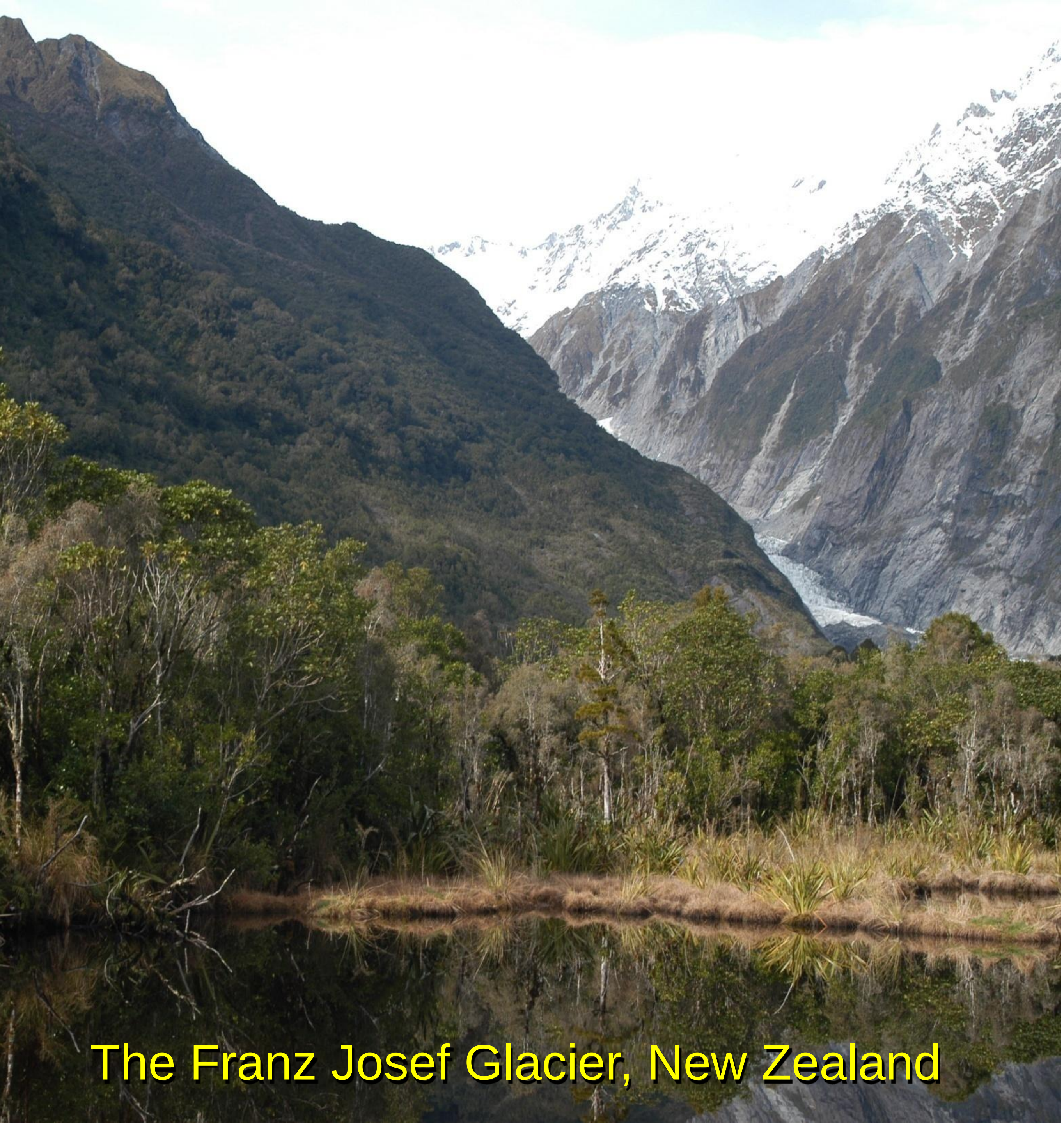

m
0·2
0·4
0·6
0·8
1·0
1·2
4000 years old

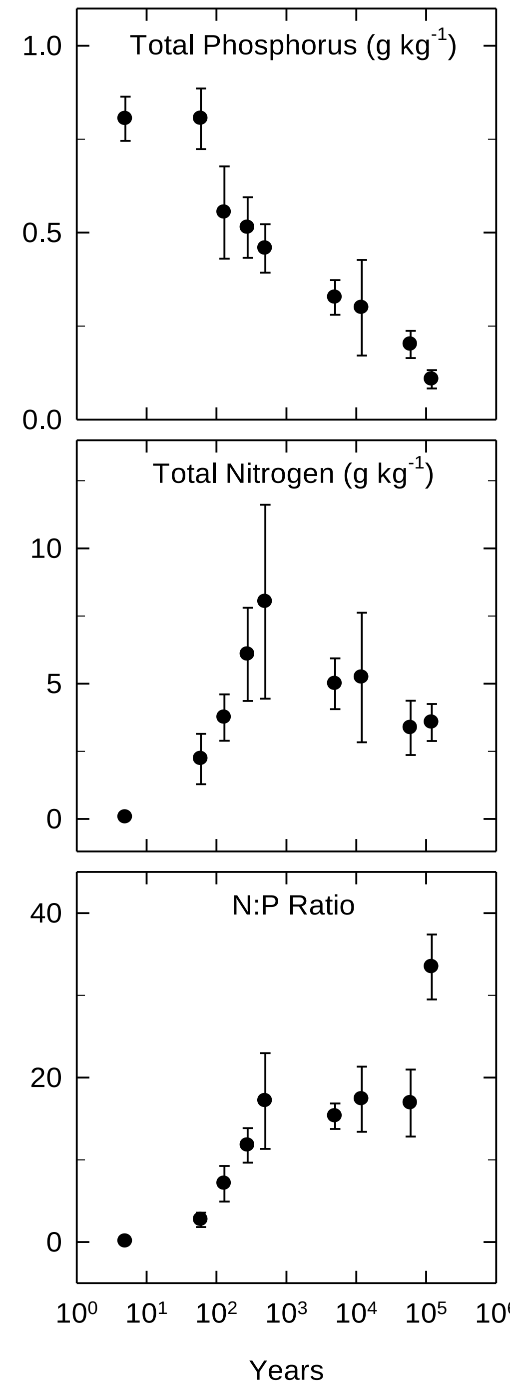
Changes in nutrient status during ecosystem development



Phosphorus transformations during pedogenesis (Walker and Syers, 1976)

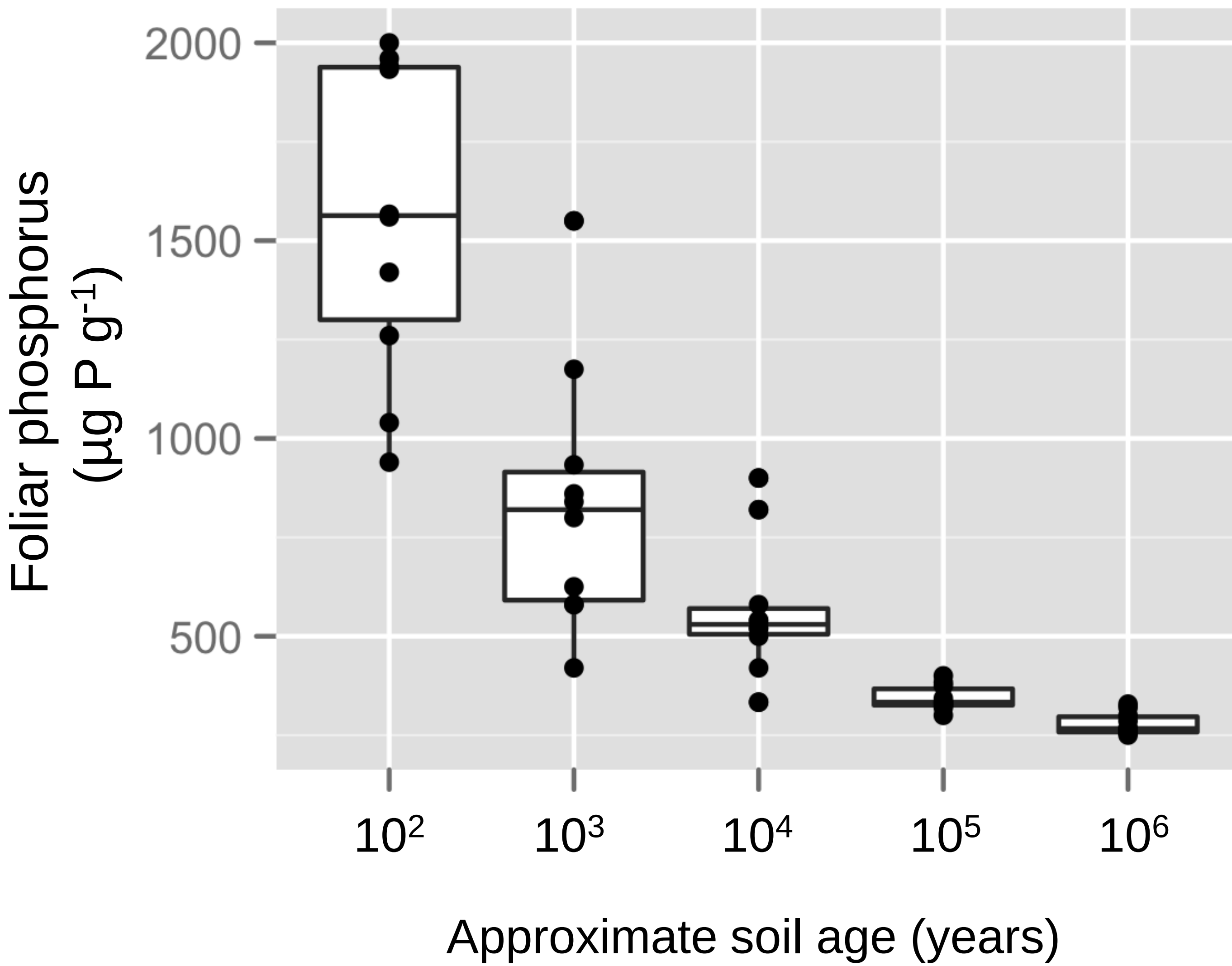



The Franz Josef Glacier, New Zealand

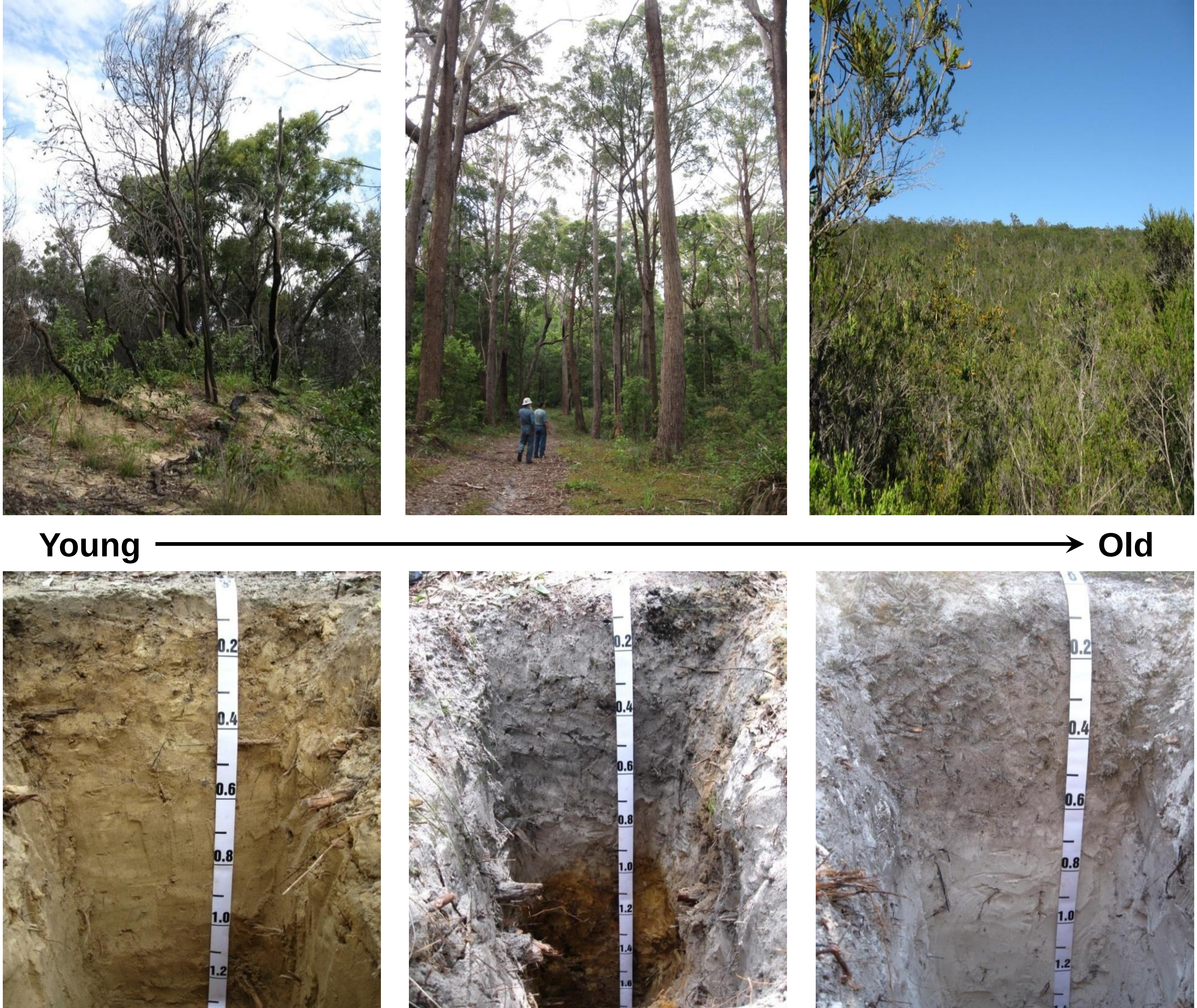

Total Phosphorus (g kg-1)
1.0
0.5
0.0
Total Nitrogen (g kg-1)
10
5
0
N:P Ratio
40
20
0
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Years


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.):

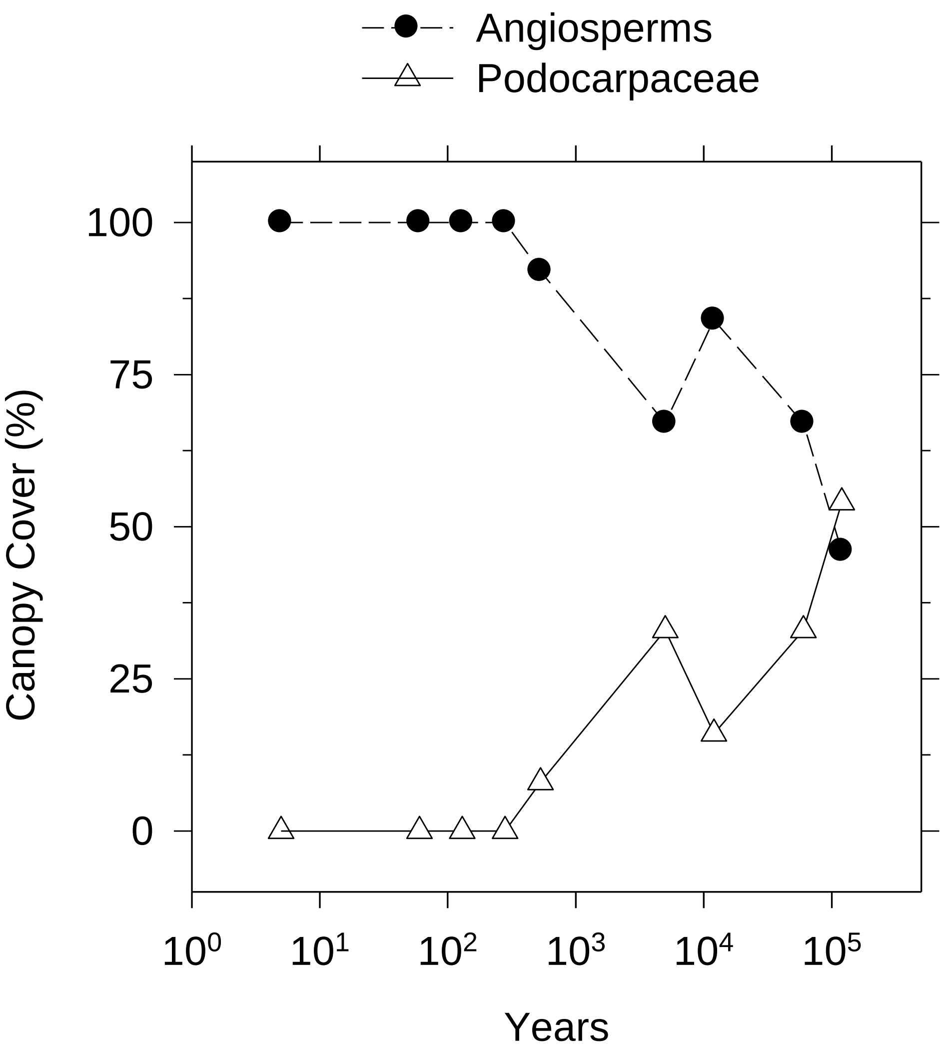
Weinmannia racemosa

Dicksonia squarrosa

Podocarpaceae (e.g.):

Dacrydium cupressinum

Podocarpus hallii



Plant strategies for acquiring soil phosphorus

- **Synthesis of phosphatase enzymes**

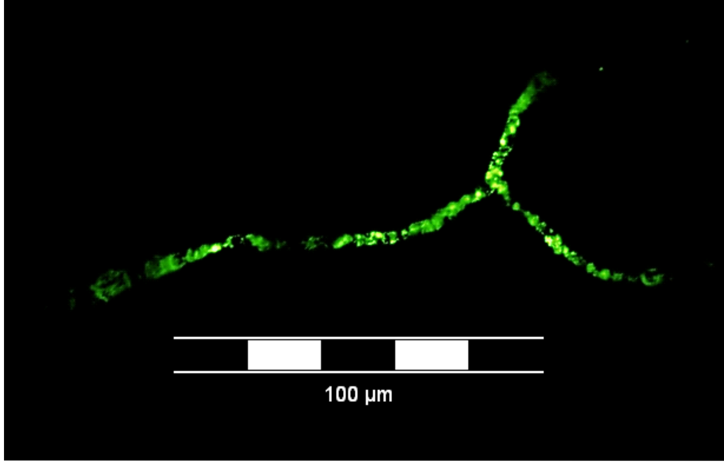
  – a ubiquitous response of plants to the need for phosphorus

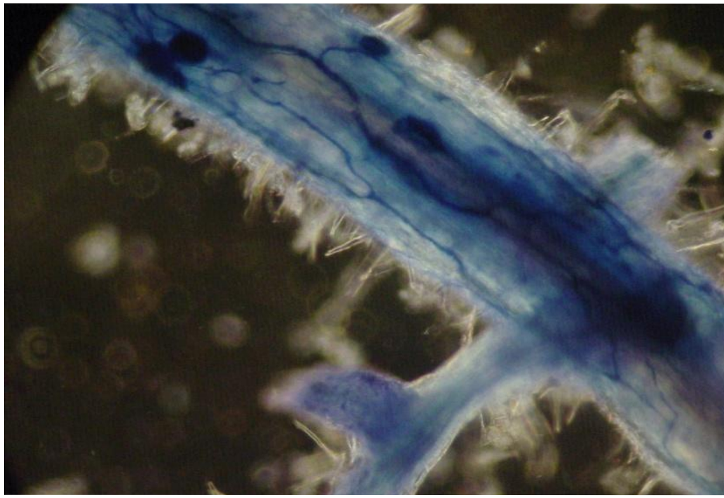
- **Formation of mycorrhizal symbioses**

  – some are extremely efficient at acquiring soil phosphorus

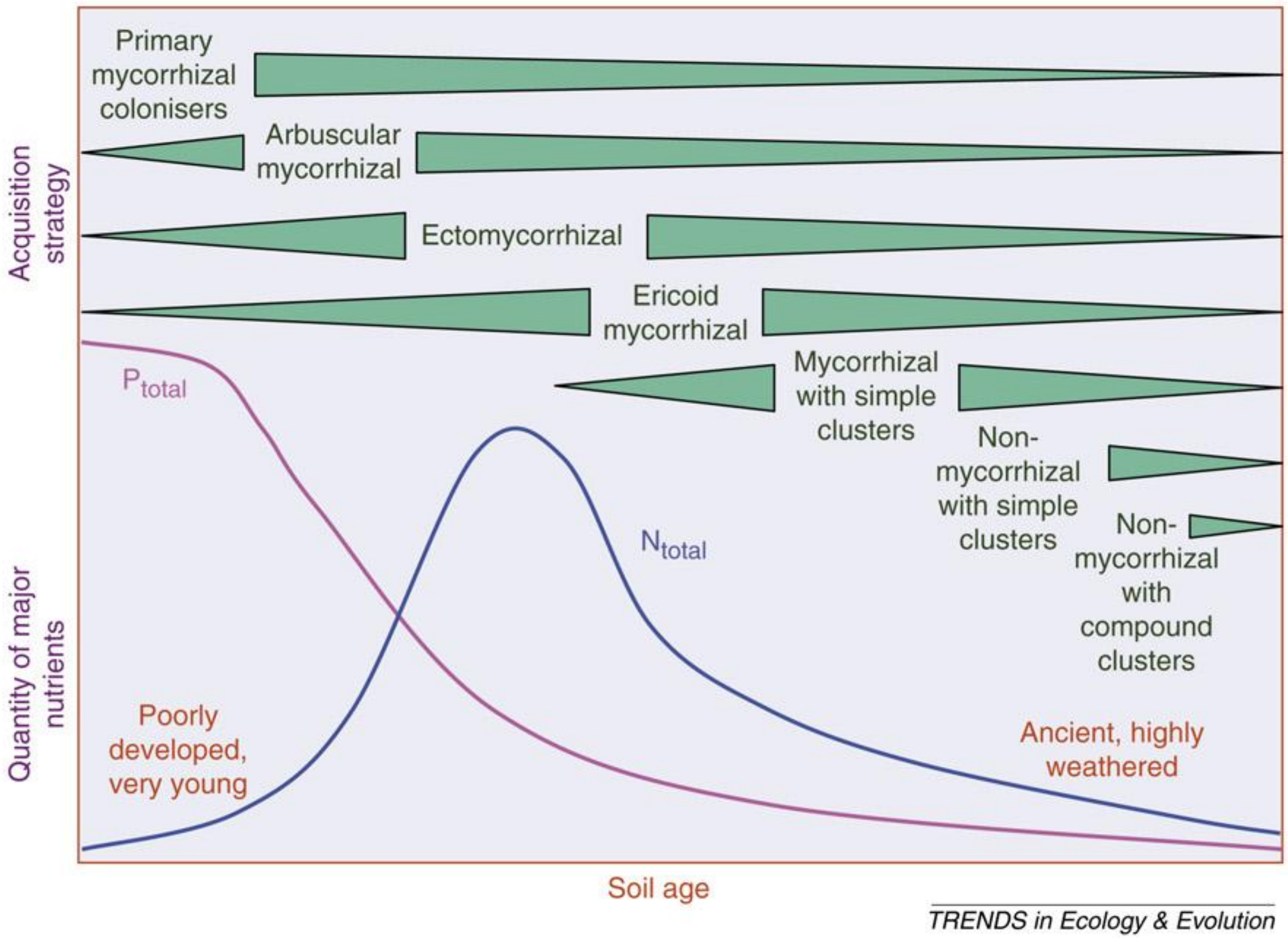
- **Cluster roots and organic anions**

  – compounds like citrate can solubilize large amounts of soil phosphorus



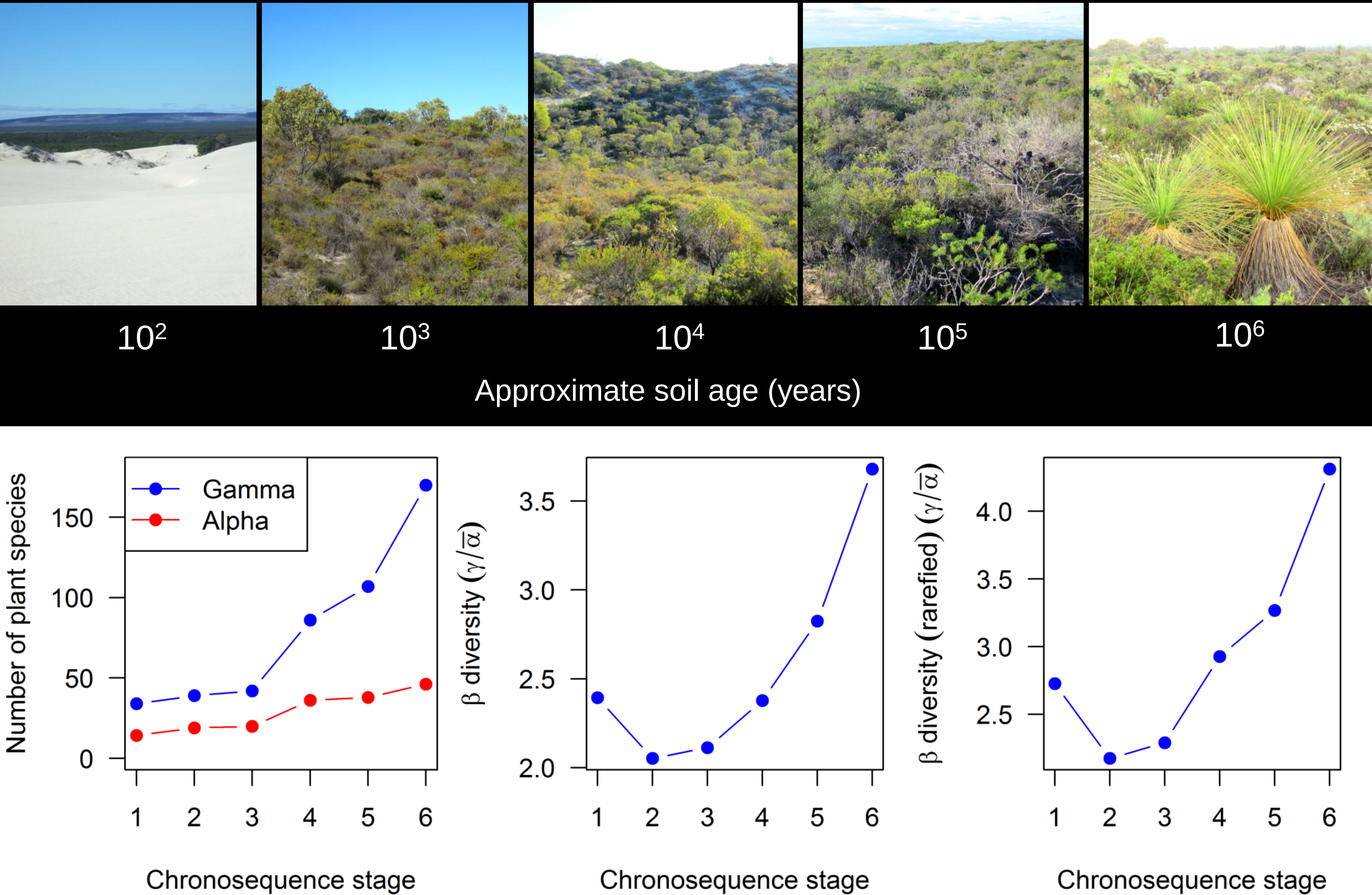


Changes in plant community composition during ecosystem development



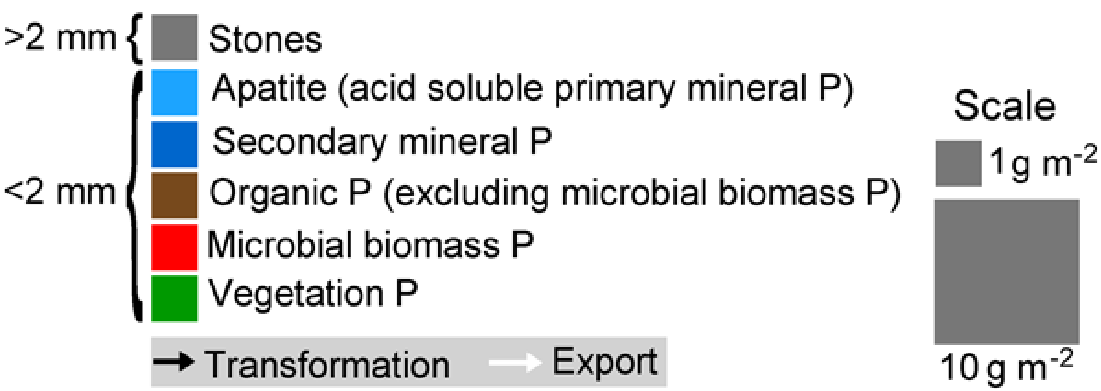
From: Lambers *et al*. (2008) *Trends in Ecology and Evolution* **23**, 95–103.

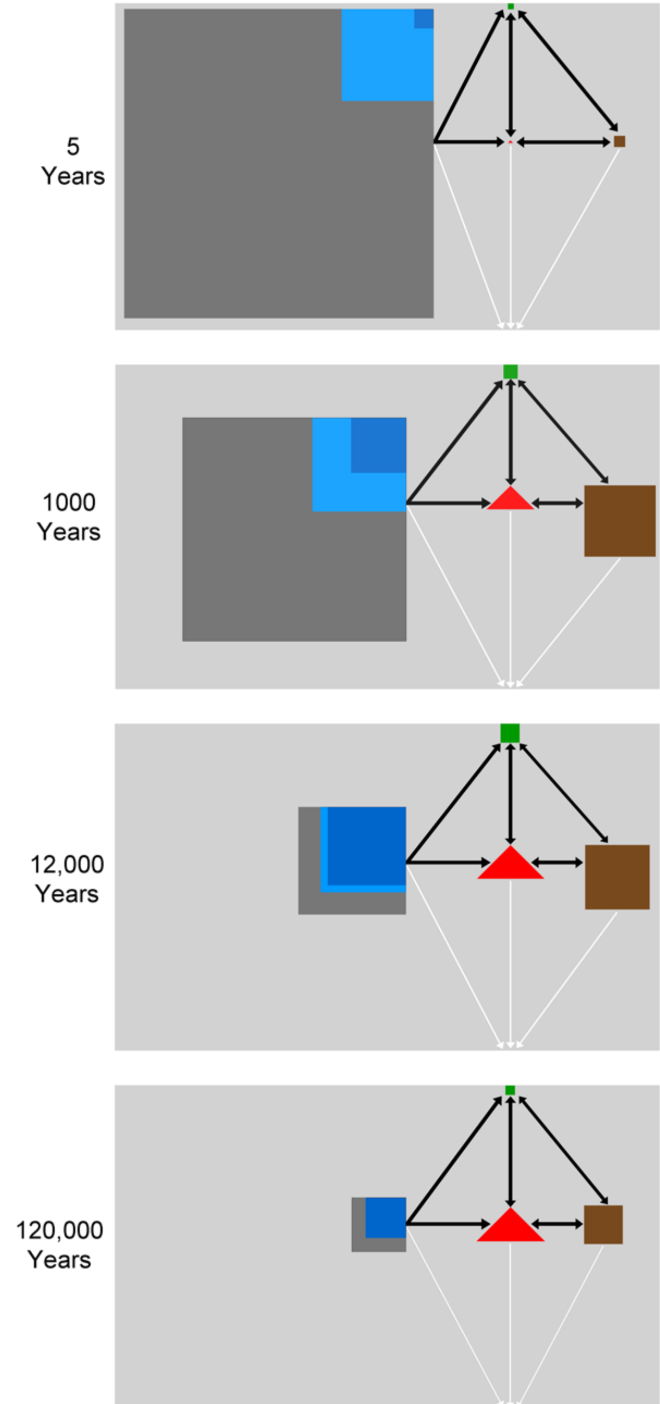
Greater plant diversity on ancient landscapes



Significance of the soil microbial biomass

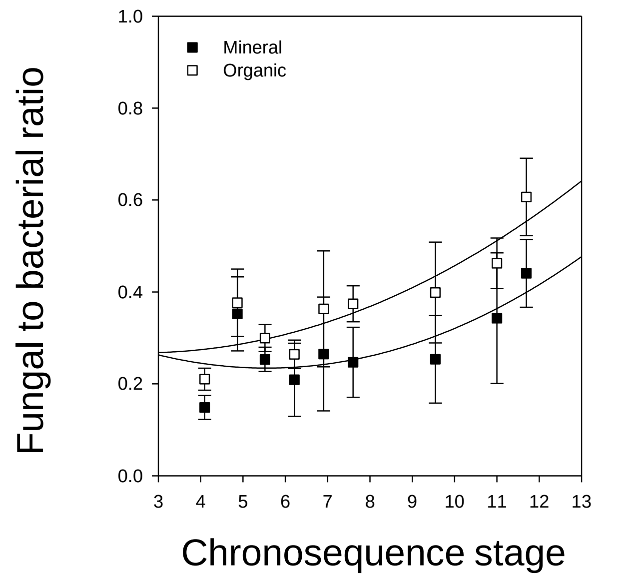
- Large phosphorus pool in microbial biomass
- Microbial phosphorus > plant phosphorus for most of the sequence
- Intense plant–microbe competition for phosphorus on old soils?



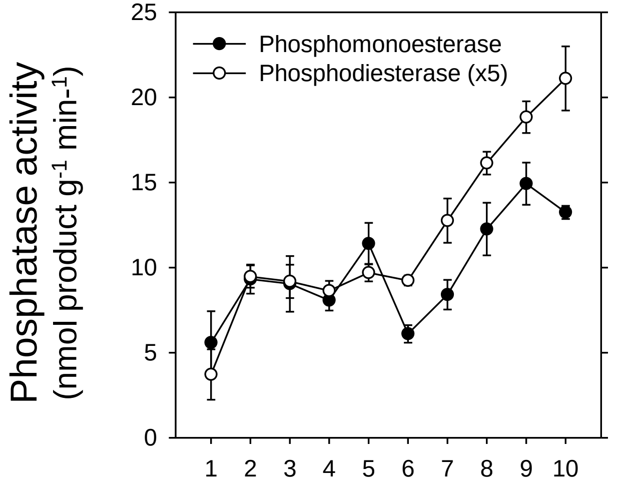


Changes in microbial communities with soil age

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



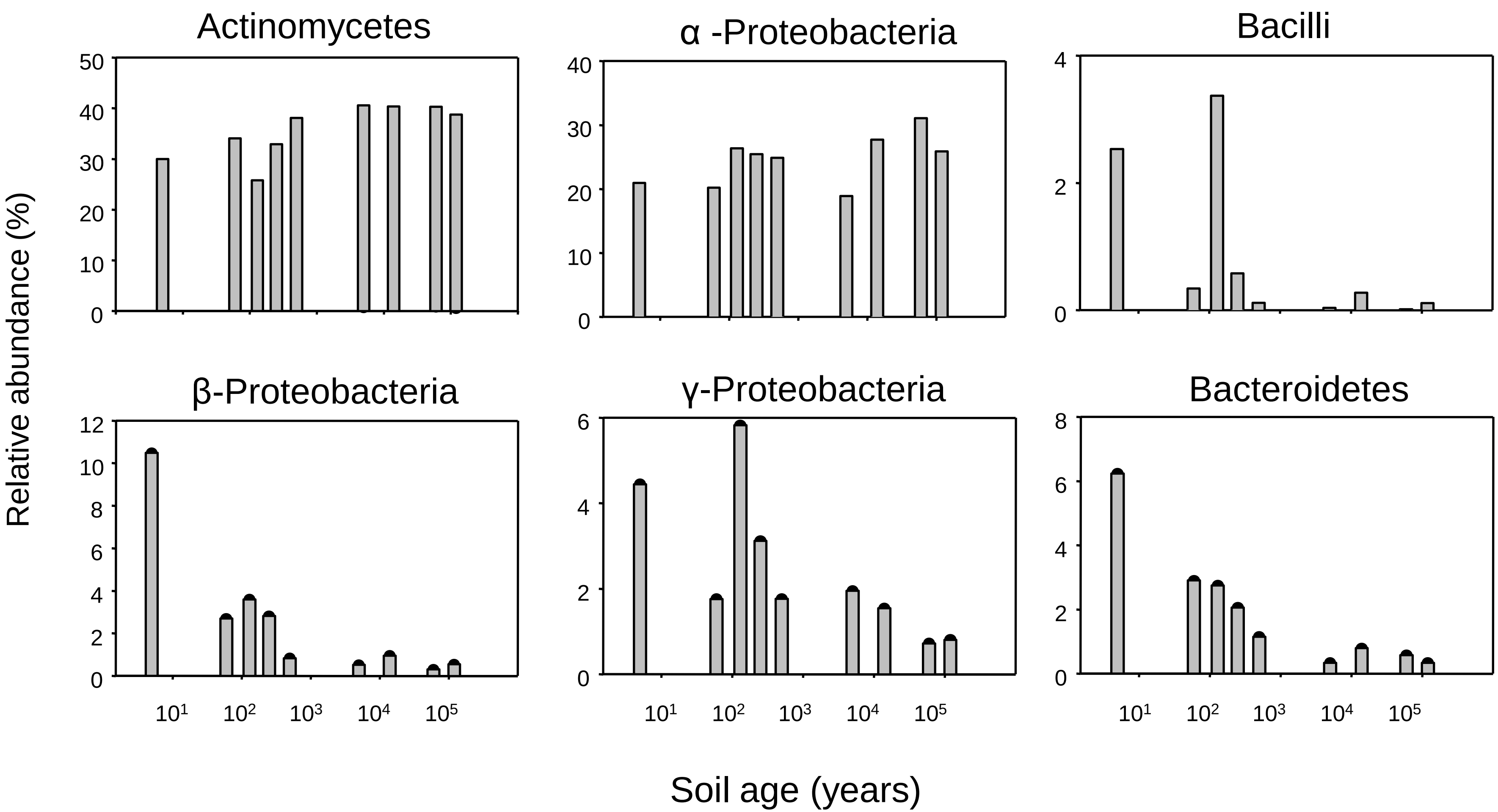
- **Investment in phosphorus acquisition**
  - – e.g., for two phosphatase enzymes along the Haast chronosequence



- **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?**