Bioavailability of Elements

Part II

Earth 281

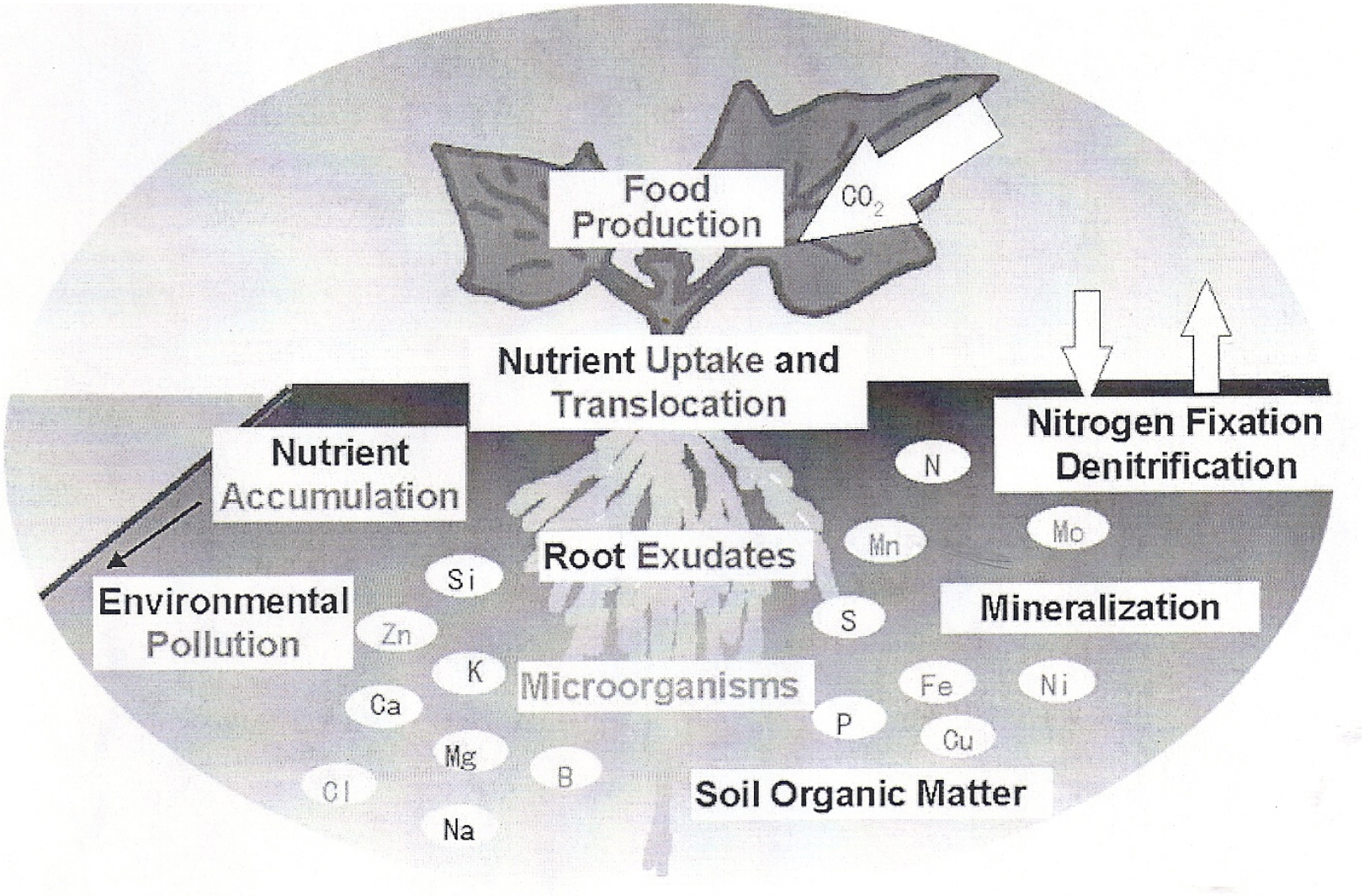
Main reference: Chapter 15 from Selinus O., Alloway B., Centeno J.A.,. Finkelman R.B, Fuge R., Lindh U., and Smedley P., 2013. *Essentials Of Medical Geology: Impacts Of The Natural Environment On Public Health.* p. 802. Academic Press.

Bioavailability of trace and major elements to plants

- Uptake of **Trace Elements** and **Major Elements** by Plants
- “They are what they eat, drink…”
- Key stage in soil-plant-animal/human pathway

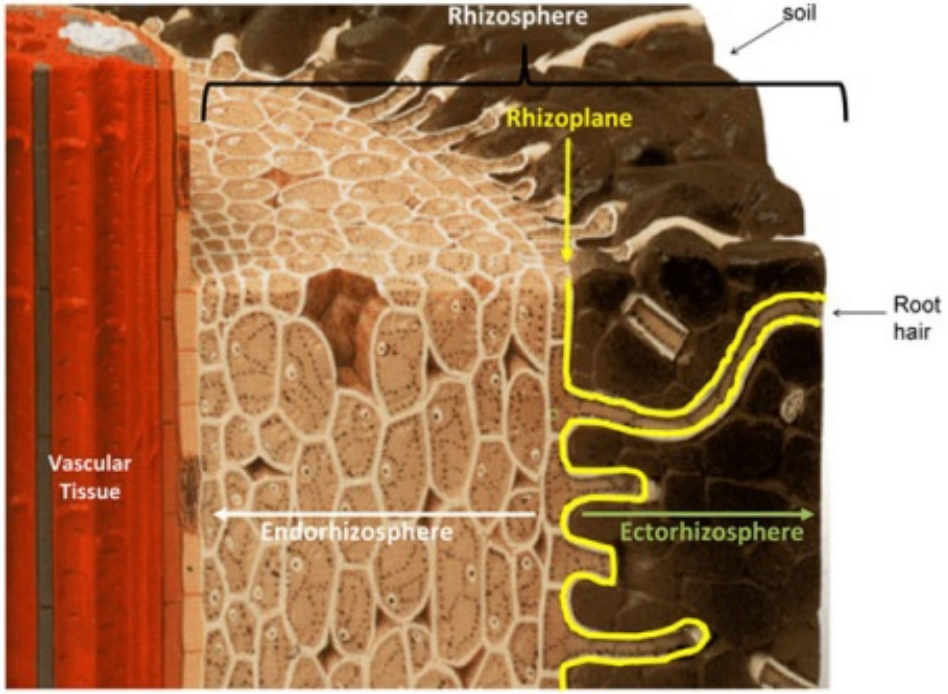
www.asknature.org/

Plant Uptake



Uptake Trace Elements by Plant

- The uptake occurs in a narrow zone next to the root → rhizosphere 1-2mm. The combination of pH, redox, microbes and fungi increase the absorptivity of trace elements.



www.nature.com/

www.ipb-halle.de/-the-rhizosphere/

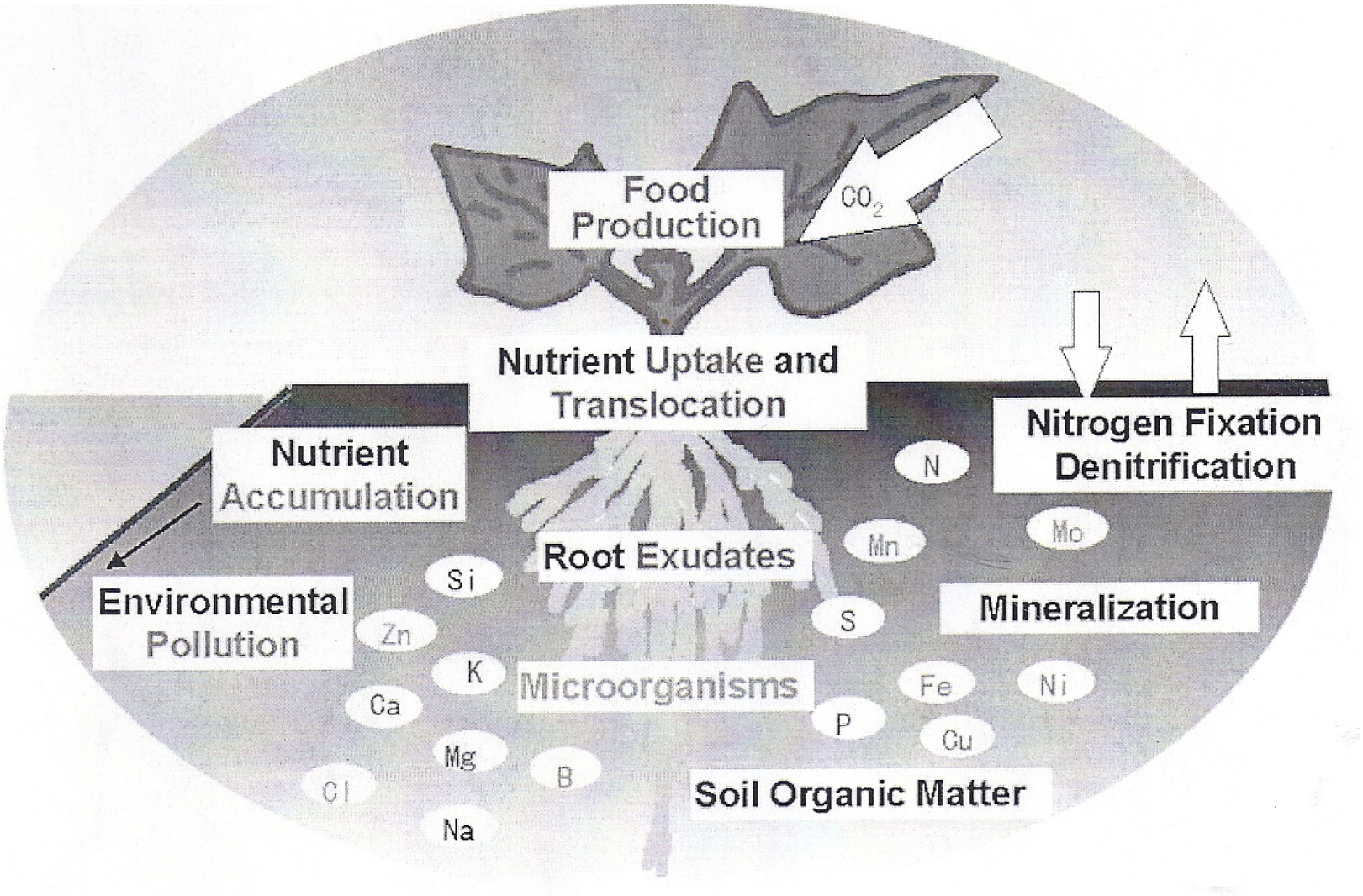
Uptake of Trace Elements by Plants

Credit: Eileen Straiton, Little Acorn Learning

Uptake of Trace Elements by Plants

- Factors affecting the amount of elements absorbed through the roots:
    1. Concentration and speciation of the elements
    2. Movement of elements from bulk soil to root surface (CEC, pH, redox)
        a) What if there are big exchangers adjacent, would this impede movement into the plant? e.g. Organics or Clay minerals
        b) Roots create their own cation exchange capacity, they have to compete or die.
    3. Transport from root surface into the root, seen previously.
    4. Translocation from root to shoot, e.g. coloured celery.

Plant Uptake



Uptake of Trace Elements by Plants

...some examples

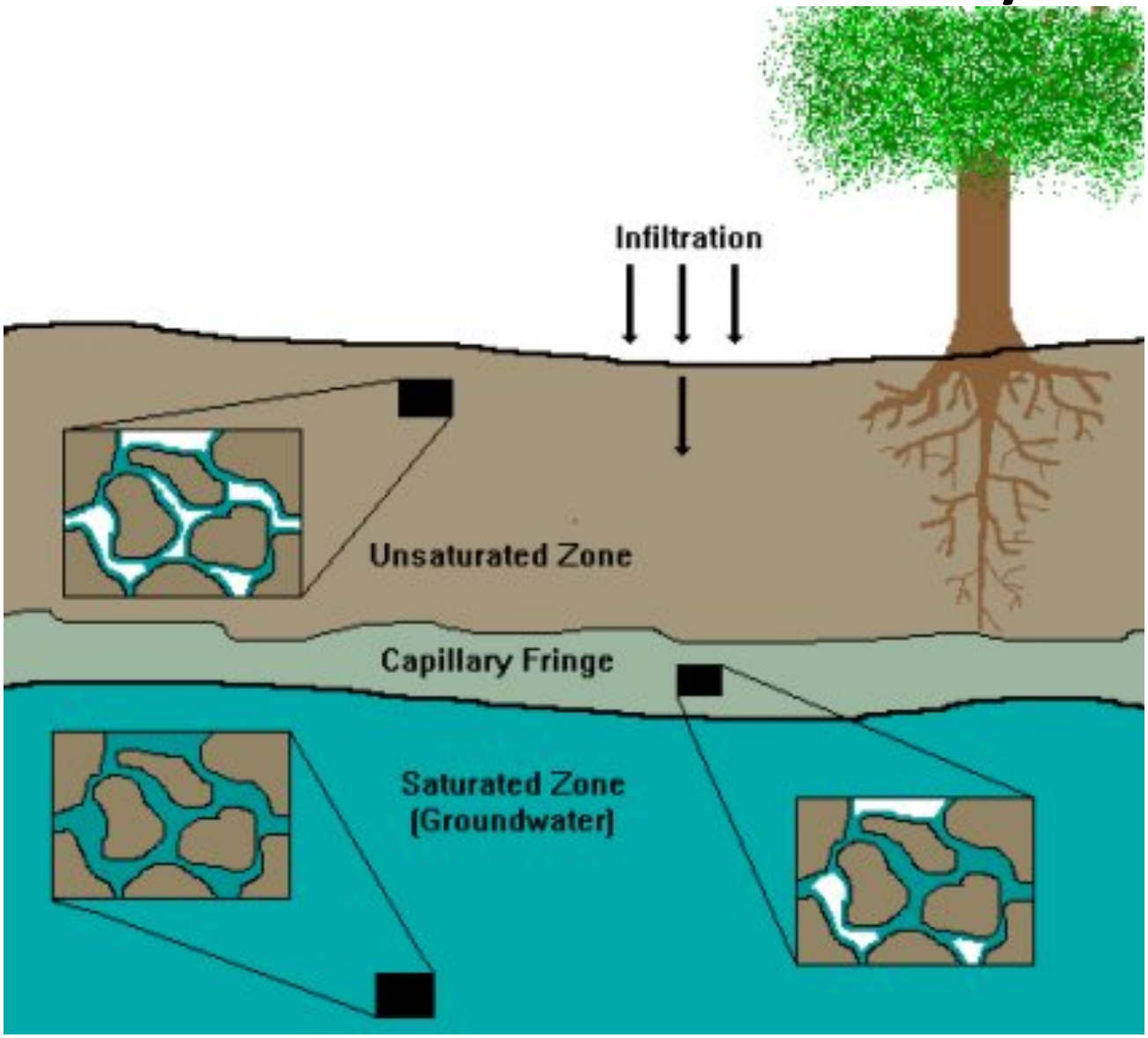
- Roots uptake either by passive or active controls (Pb passive uptake vs. Cu, Mo, Zn are active)
- ACTIVE controls: they compete if it is the same mechanisms (Cu vs Mo antagonistic – Pauling)
- Zn inhibited by Cu and H^+ but not by Mn, Fe
- Cu inhibited by Zn, NH_3, Ca and K

* Much still needs to be understood!

Uptake of Trace Elements by Plants

- Other factors are:
  - For strongly adsorbed ions:
    - Amount of roots produced and exploration ability of root system.
    - e.g. small flower pot vs open garden
  - Evapotranspiration:
    - More water evaporates; more soil solution will be absorbed.
    - Saturated vs unsaturated zone

Uptake of Trace Elements by Plants



http://oceanworld.tamu.edu/

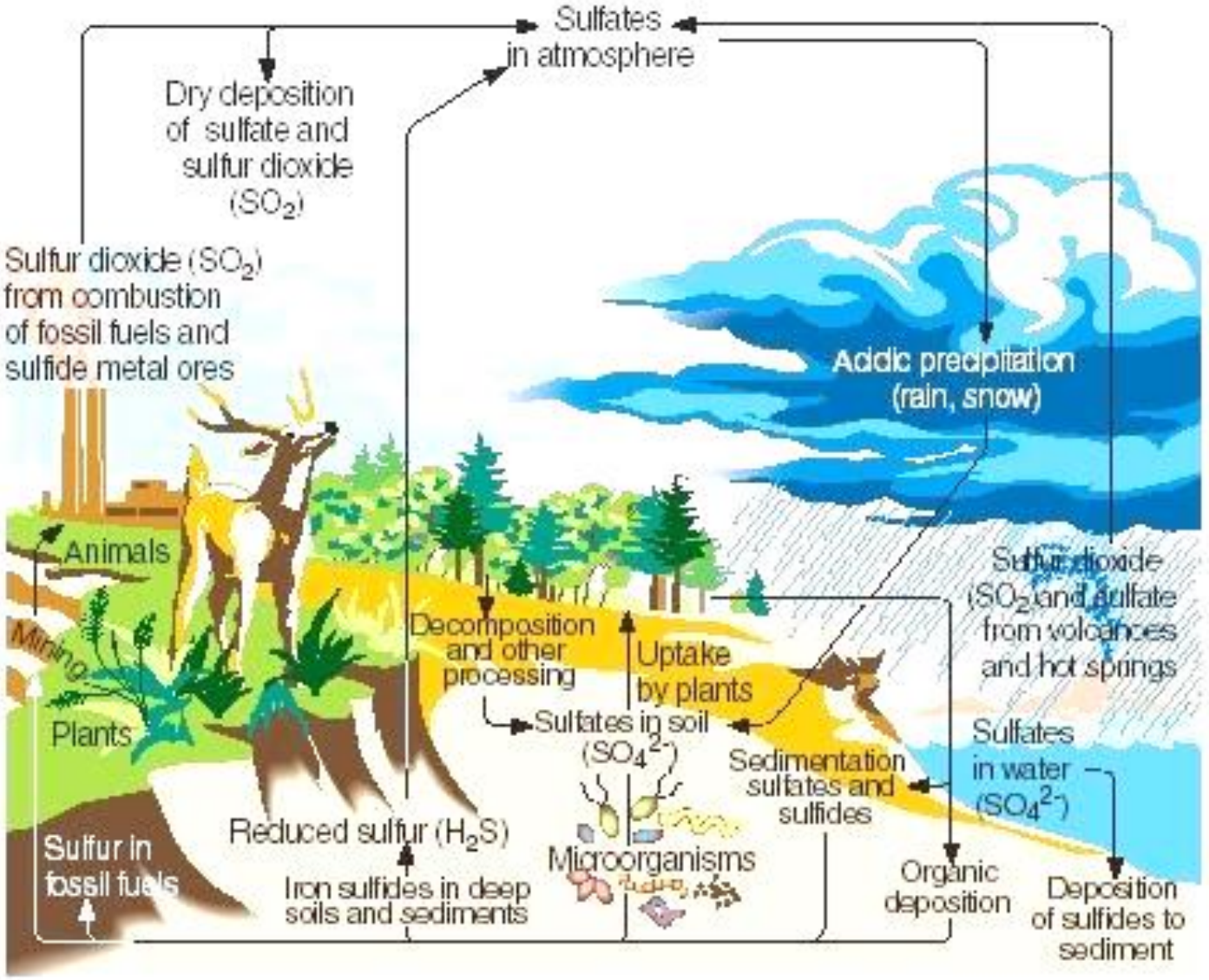
Uptake of Major Elements by Plants

- **Calcium (Ca):**
  - A normal concentration range for Ca is 0.1-2.5% in plant dry matter.
  - Ca has low mobility in plants and thus is not redistributed.
  - Ca plays a role in maintenance and integrity of the membranes.
- **Magnesium (Mg):**
  - Mg is more mobile than calcium.
  - Mg generally occurs in the dry matter at lower concentrations than calcium (0.2-0.56%)
  - Specific constituents in chlorophyll
  - Specialized plants dominate in ultramafic soils – rich in Mg.

Uptake of Major Elements by Plants

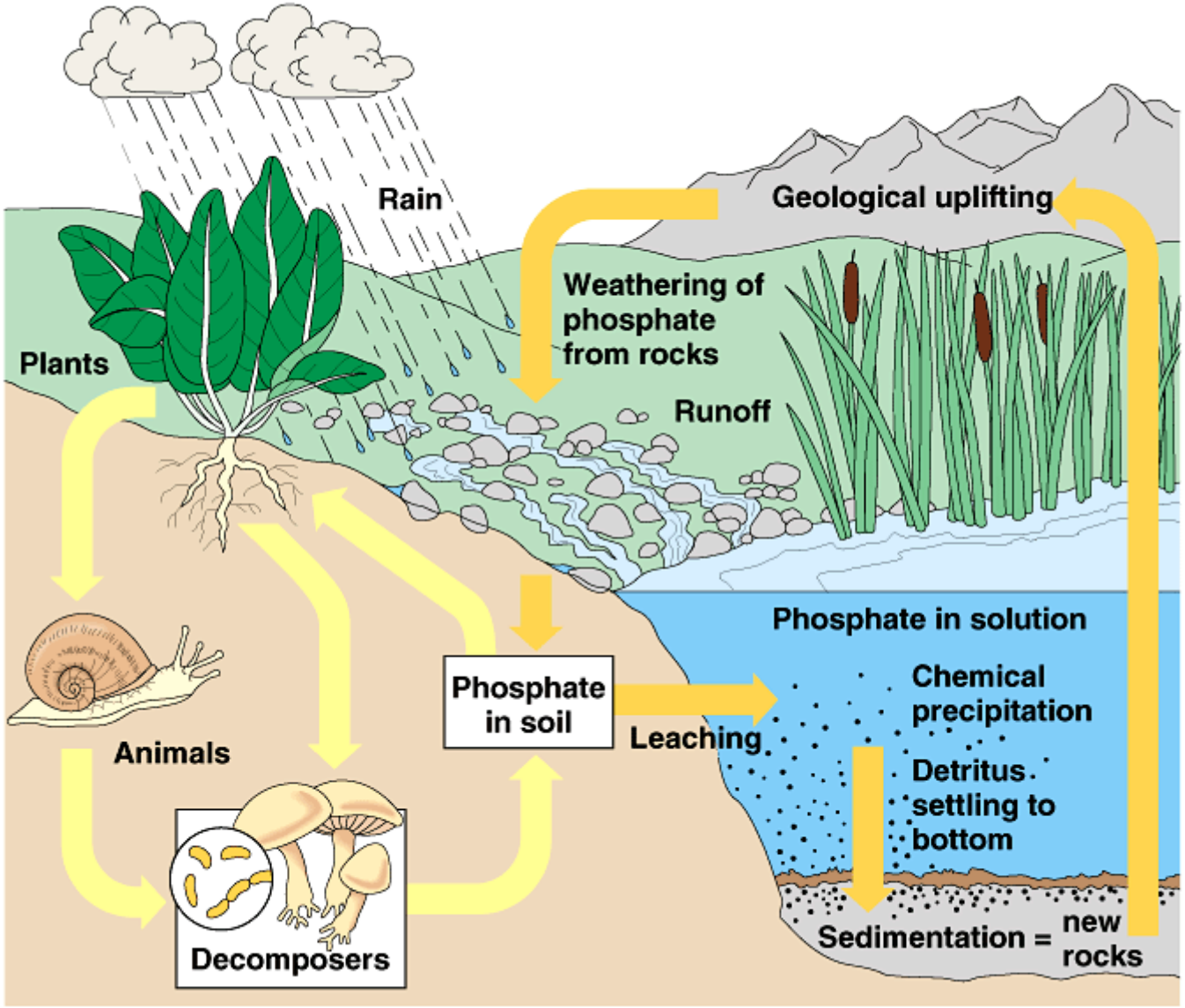
- **Sulfur (S):**
  - S is usually present at concentrations of 0.1-1% (dry matter)
  - S is a constituent of the amino acids: cysteine, cystine, and methionine, and therefore of proteins containing these.
  - S is a constituent of enzymes
- **Phosphorus (P):**
  - P is present in plants at around 0.2% in the dry matter of shoots
  - P is a key component in metabolic processes involving phosphorylation (e.g. ADP-ATP).

Sulphur Cycle



http://myweb.rollins.edu/

Phosphorus Cycle

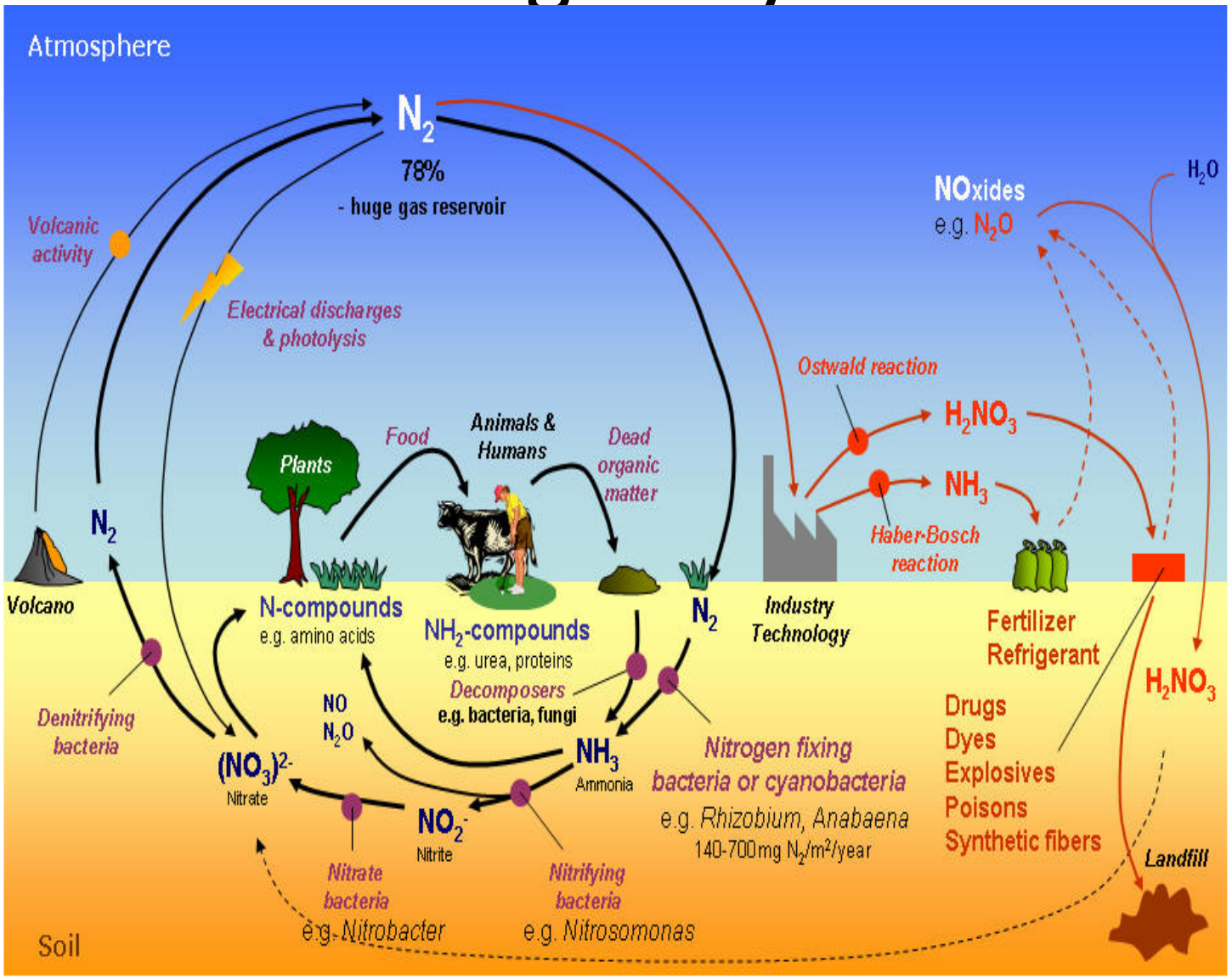


http://www.astrobio.net/

Uptake of Major Elements by Plants

- **Potassium (K):**
  - K occurs in similar concentrations as nitrogen in plants (1.4-5.6% in the dry matter)
  - K is the most abundant cellular cation.
  - K is often in short supply in crops.
  - K is critical in stomata “plant leaves breathing”.
- **Nitrogen (N):**
  - N can be present at 1.64% in the dry matter
  - N is the fourth most abundant element in plants after carbon, hydrogen, and oxygen.
  - N plays an essential role in proteins, nucleic acids, chlorophyll, etc.

Nitrogen Cycle



Differences in Trace Element Accumulation Between and within Plant Species

Remember ^{13}C differences in C_3 vs C_4 plants

- Most important plant factor is plant genotype or genetic makeup of the plant.
- Difference between plant species can occur within a plant family.
- In general:
  - Legumes are low accumulators of trace elements.
  - Grains are moderate accumulators of trace elements.

Differences in Trace Element Accumulation Between and within Plant Species

- For different plant species, different parts of a plant will accumulate trace elements variably.
- Dependent on:
  - Amount available.
  - Concentration in edible parts.
- Example: Cadmium (Cd)
  - Soybean
    - Roots have high Cd concentrations
    - Leaf, fruit low Cd concentrations
  - Lettuce
    - Roots have low Cd concentrations
    - Leaf, fruit high Cd concentrations

www.commodityonline.com

www.amateurgourmet.com

Differences in Trace Element Accumulation Between and within Plant Species

- Selective breeding or genetic manipulation in plants is to lessen the toxic accumulation.
- But we can often cause deficiencies; e.g. Cd out, but Zn an essential nutrient is also affected because Zn and Cd substitute readily. (Goldschmidt – Pauling)

Trace Metals in Soils
Other Examples

- **More Cadmium (Cd)…**
  - In some top soils (e.g. England – Wales) the Cd concentration can be up in the 10's of mg/Kg (usually <1mg/Kg). Causes can be from spreading of sewage sludge or atmospheric fallout.
  - Main diet providers of Cd are grains, potatoes, and lettuce (50% of your Cd intake). In UK, the diet is wheat-based (grains) so the Cd intake is up.
  - Cd levels have been falling as more and better crops are grown (dilution) and pollution goes down

Trace Metals in Soils

Other Examples

- **Lead (Pb):**
  - Pb can accumulate in rice and also millet.
  - In some parts of China, Pb in millet and millet based diets is directly linked to higher then average Pb in blood.

Trace Metals in Soils

Other Problems

- Pb in garden soil – car exhaust Pb in gas: Children are very susceptible and also ingest it in house dust. Pb however, has lower phytotoxicity.
  - Cd > Cu > Co, Ni > As > Zn > Pb
  - So it does not readily transport into edible plant.

http://melissamiksch.com/

http://3.bp.blogspot.com/

Trace Metals in Soils

Other Problems

- Cd in rice paddy fields near old smelter areas: The cycling of flooding and drying creates speciation problems.

- Wet – reducing conditions → precipitates as CdS, gleysoil, saturated O_2 has problems penetrating
- Drying – oxidizing conditions → oxidized as Cd^{2+} and SO_4^{2-} and Cd uptake into rice. Transports into rice and than into humans (600 mg/day in one area)

http://oregonstate.edu/

Carbon Cycle