Heap leaching of copper ores – opportunity through science

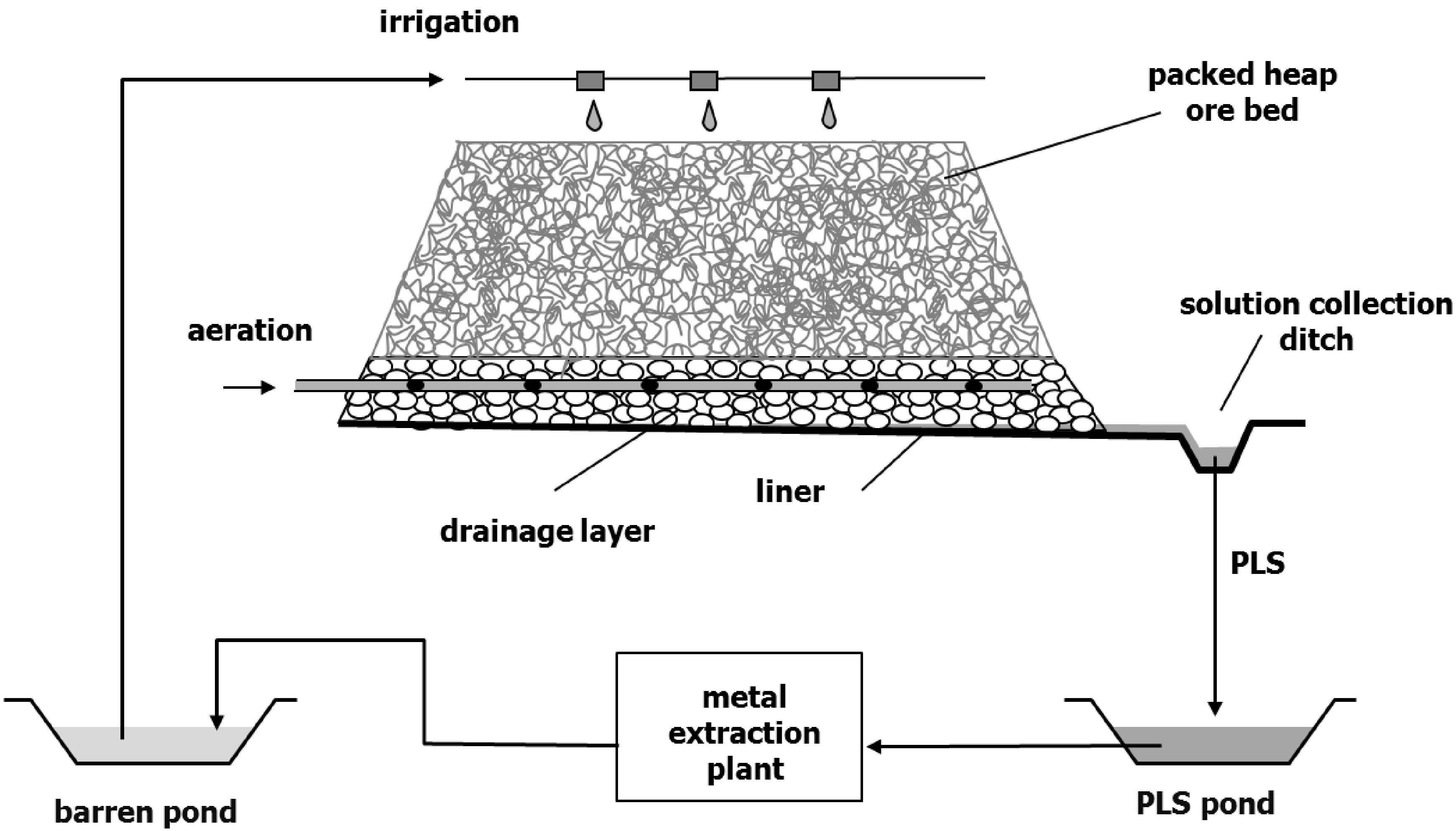
Jochen Petersen



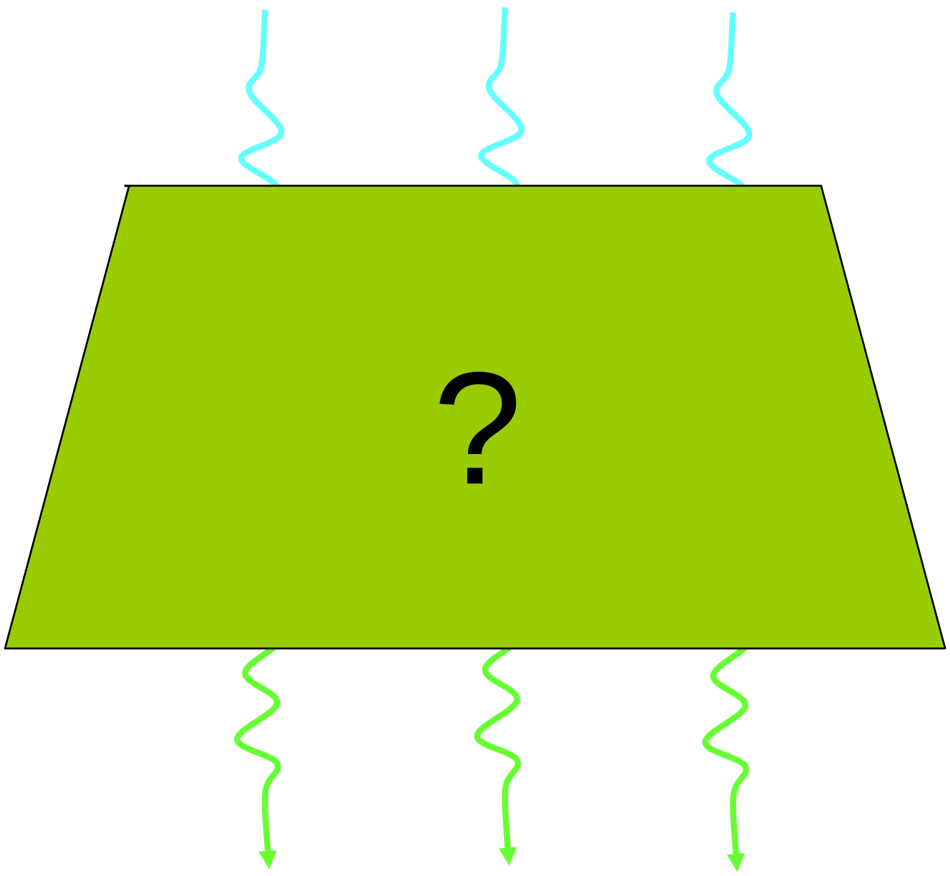


A typical heap leach operation

Heap leach process



What is going on inside a heap



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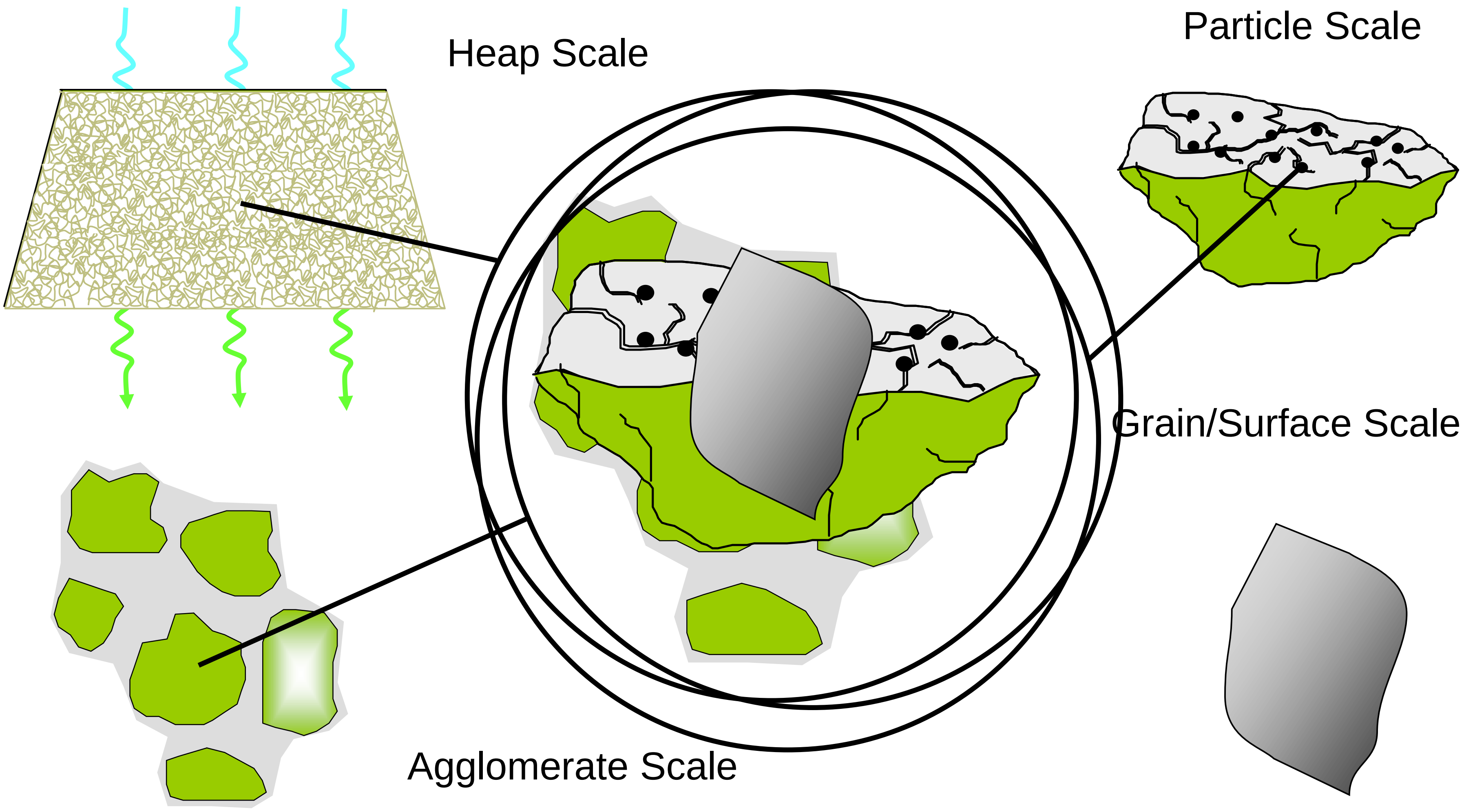
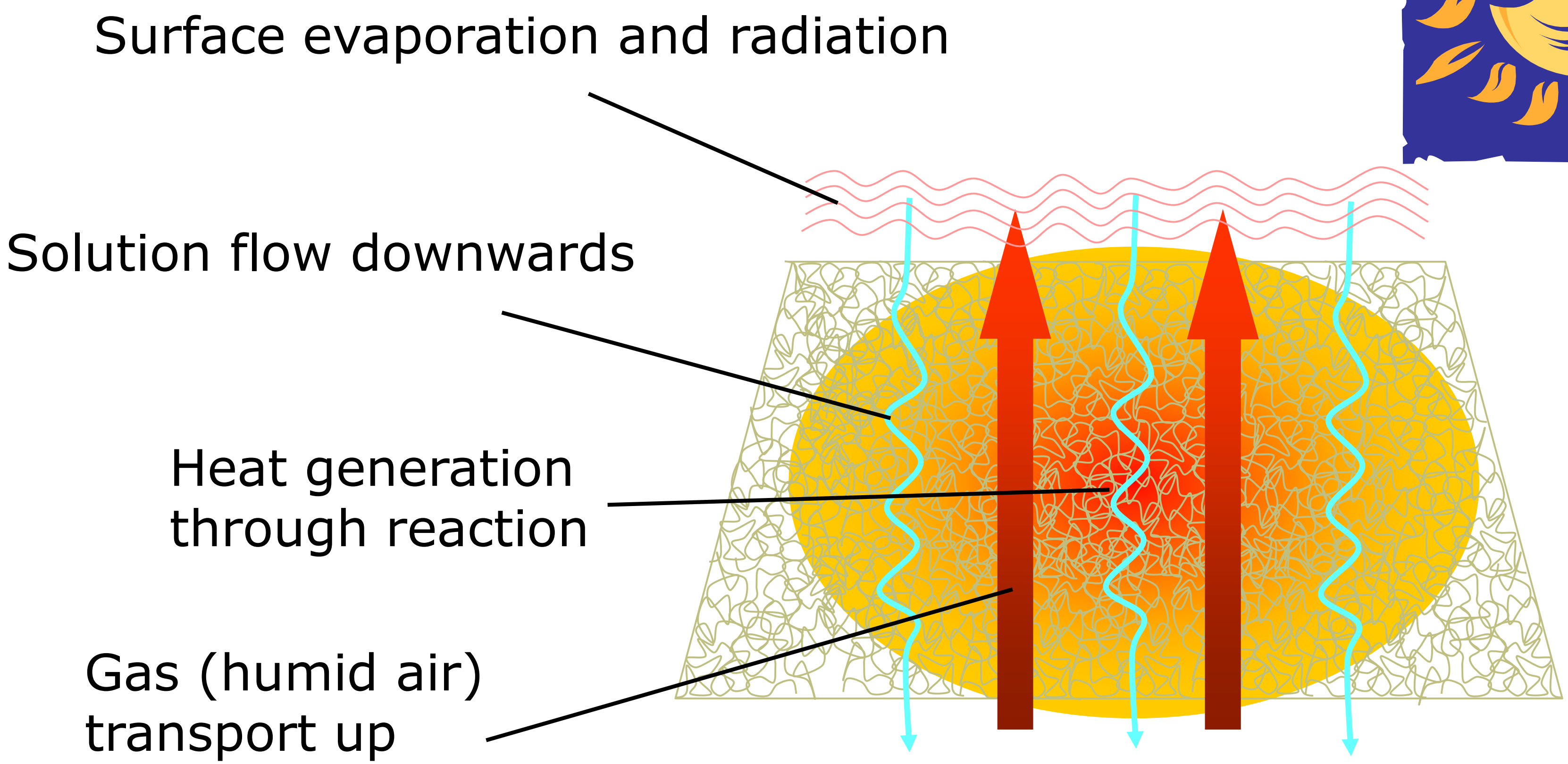
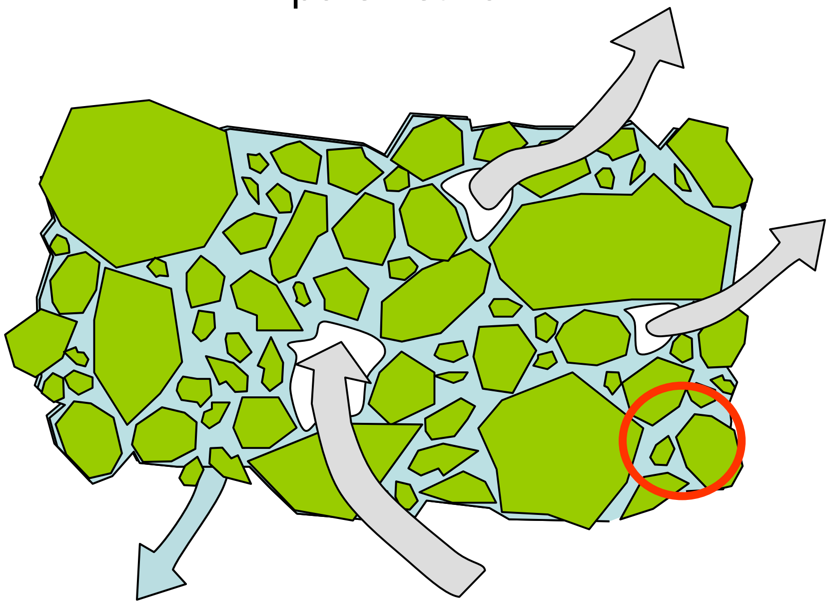


The heap scale in heaps

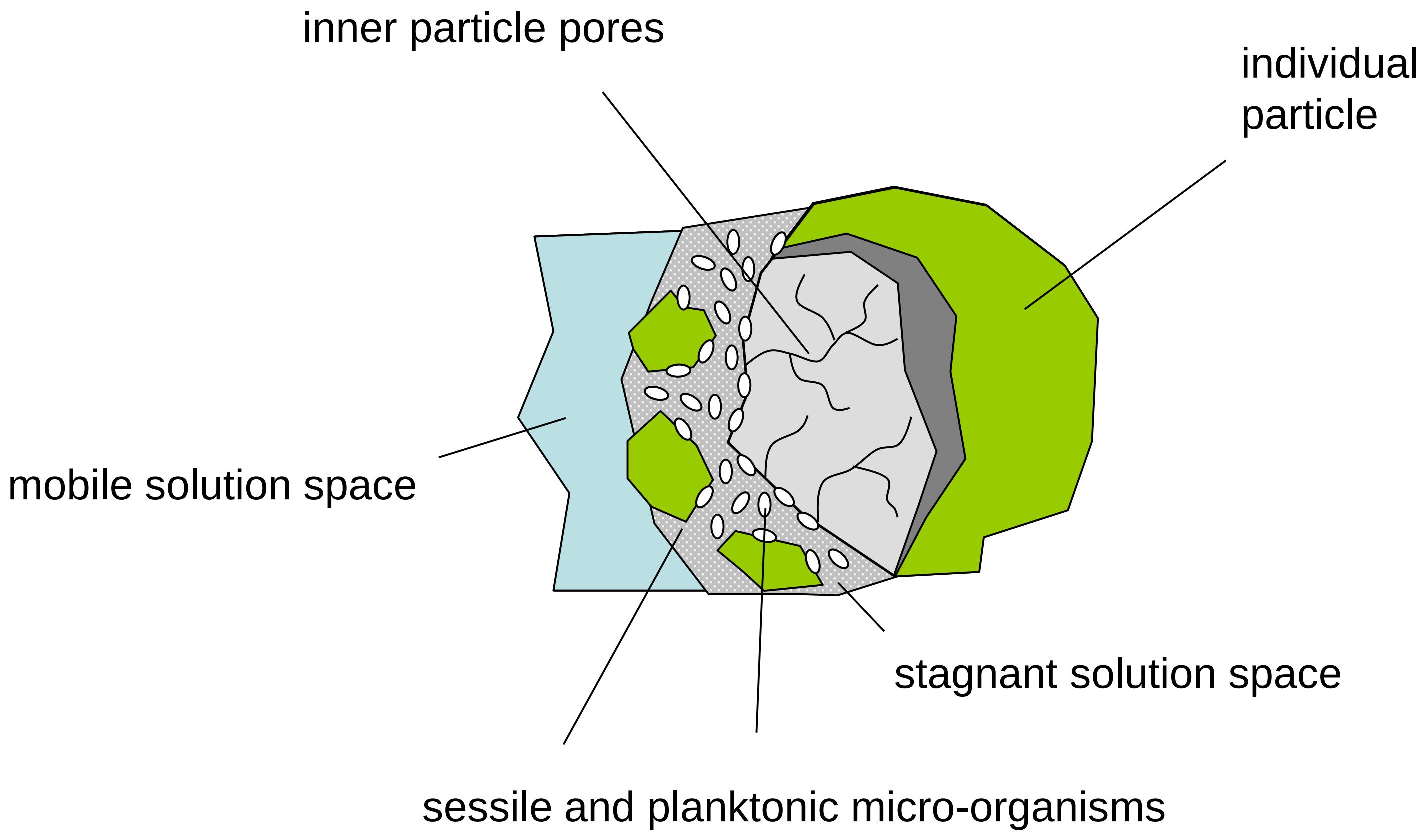


The agglomerate scale in heaps



Solution 'seeps' along preferential channels
on air-liquid contact surfaces

The particle scale in heaps



Key chemistry in copper heaps

Acid leaching of malachite

$$Cu_2CO_3(OH)_2+2H_2SO_4 \rightarrow 2CuSO_4 + CO_2 + 3H_2O$$

Ferric leaching of covellite

$$\mathrm{CuS} + 2\mathrm{Fe}^{3+} \rightarrow \mathrm{Cu}^{2+} + 2\mathrm{Fe}^{2+} + \mathrm{S}^{o}$$

Chloride facilitate leaching of chalcopyrite

$$\mathrm{CuFeS_2} + 3\mathrm{Cu}^{2+} - (\mathrm{Cl}^-) \rightarrow 4\mathrm{Cu}^{+} + \mathrm{Fe}^{2+} + 2\mathrm{S}^{o}$$

Ferrous re-oxidation (biologically accelerated)

$$4\mathrm{Fe}^{2+} + \mathrm{O_2} + 4\mathrm{H}^{+} \rightarrow 4\mathrm{Fe}^{3+} + 2\mathrm{H_2O}$$

Cuprous re-oxidation (rapid in chloride solution)

$$4\mathrm{Cu}^{+} + \mathrm{O_2} + 4\mathrm{H}^{+} - (\mathrm{Cl}^-) \rightarrow 4\mathrm{Cu}^{2+} + 2\mathrm{H_2O}$$

Sulfur oxidation (chemically or biologically facilitated)

$$2\mathrm{S} + 3\mathrm{O_2} + 2\mathrm{H_2O} \rightarrow 2\mathrm{H_2SO_4}$$

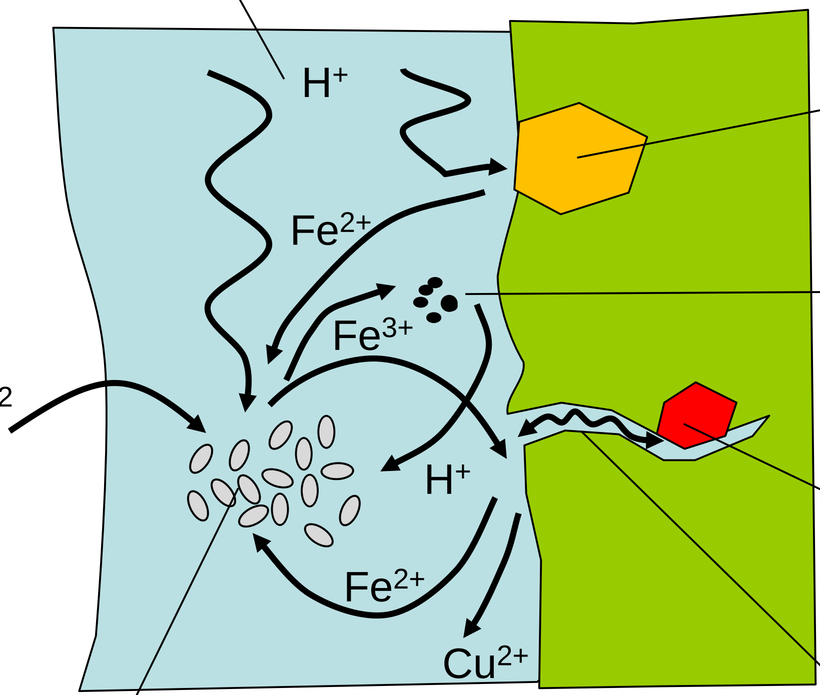
Reaction network at particle surface

acid migration or flow through liquid film

reaction with gangue grains

$$FeCO_3 + H_2SO_4 \rightarrow FeSO_4 + H_2O + CO_2$$

O_2, CO_2



$Fe(OH)_3$ precipitation

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

reaction with mineral grains

$$CuS + Fe_2(SO_4)_3 \rightarrow$$

$$CuSO_4 + 2FeSO_4 + S^0$$

gas phase

solution phase

solid phase

re-oxidation of ferrous (biological or direct)

diffusion through micro-pores

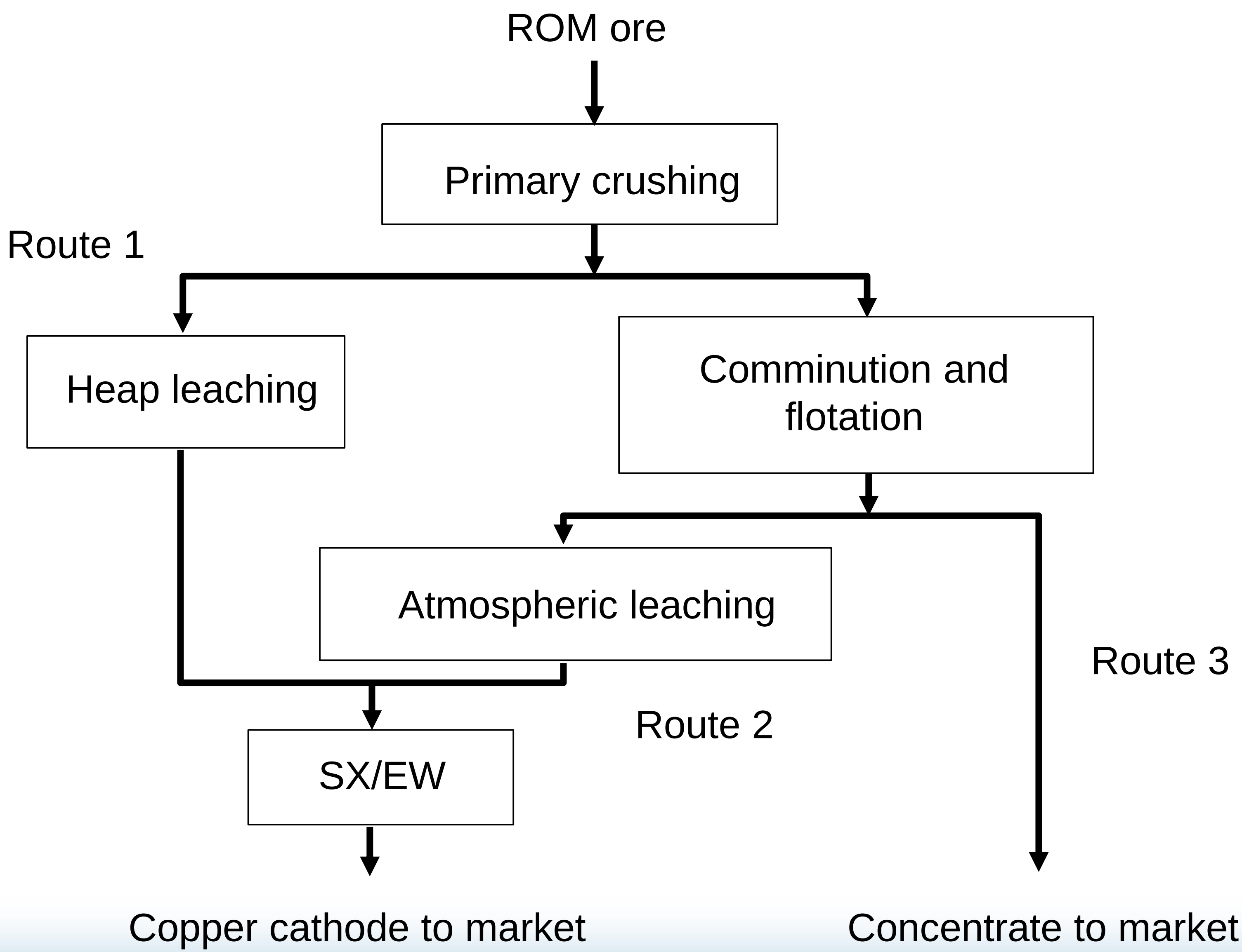
Is heap leaching a competitive technology?

- Slow process, residence time of months to years
- Poorer extraction (70-80%)
- Large physical footprint
- Long-term environmental burden uncertain

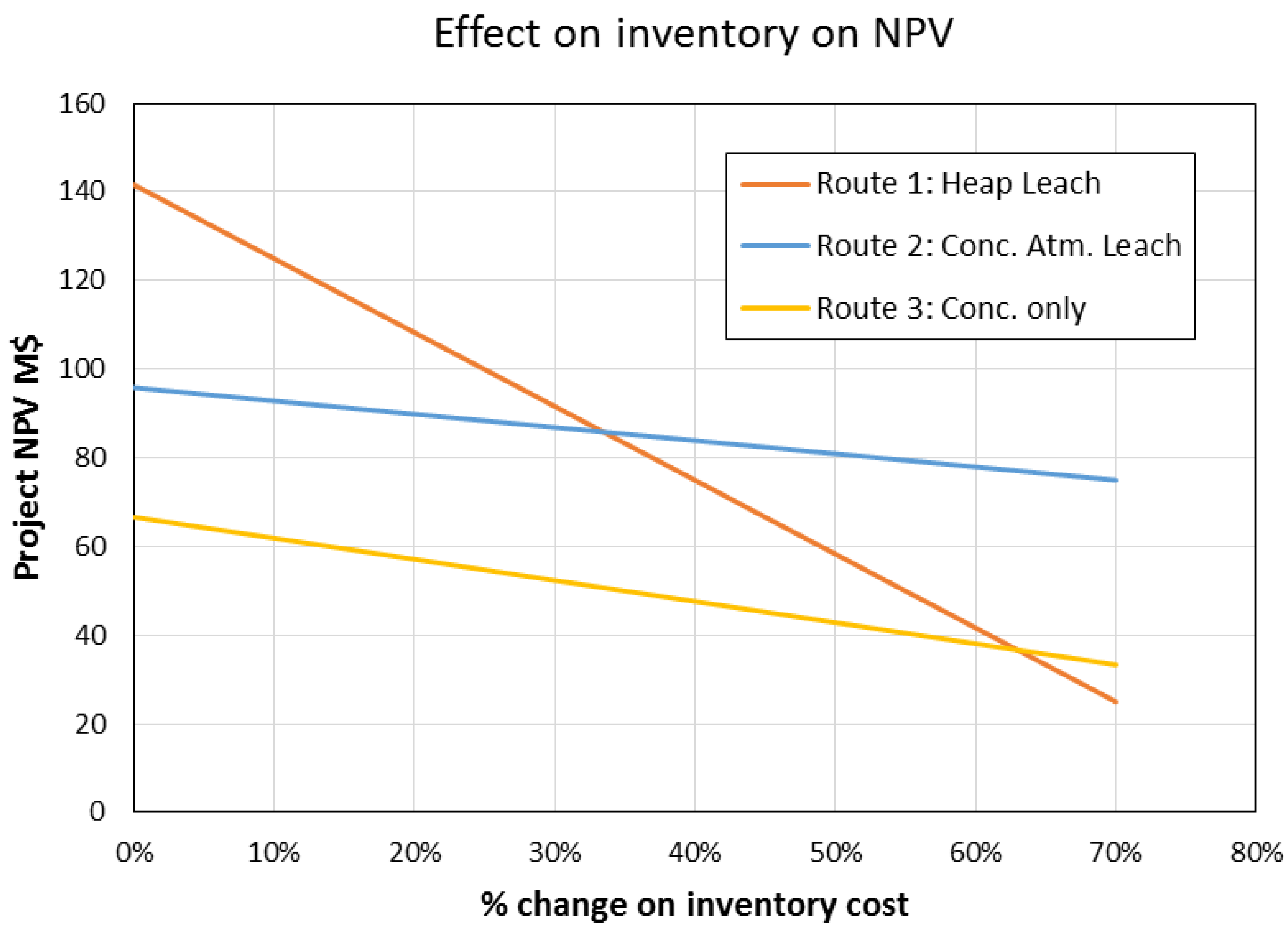
BUT

- Low energy requirements (crushing instead of milling)
- Simple, low-cost technology, can operate at remote sites
- Spent heaps comparable to tailings dams from minerals processing

Heap Leaching vs. Conventional Processing



Heap Leaching vs. Conventional Processing



In heaps, inventory cost is directly linked to tons of ore under leach/ leach time

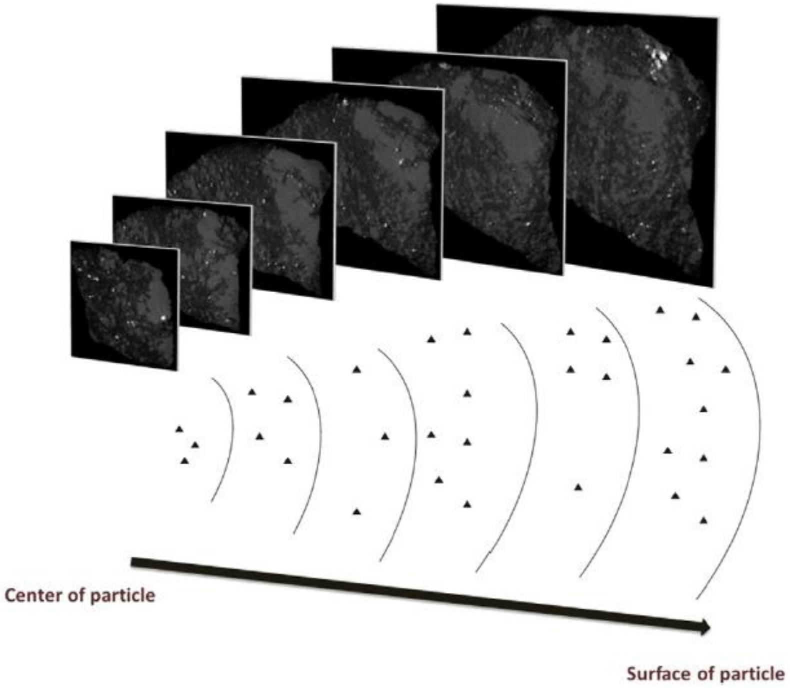
HYDROmet

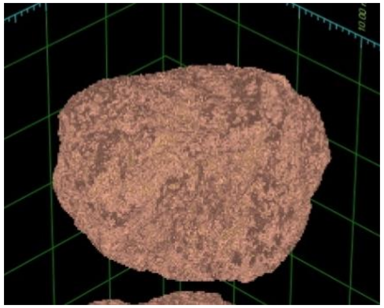
Why is heap leaching often so slow?

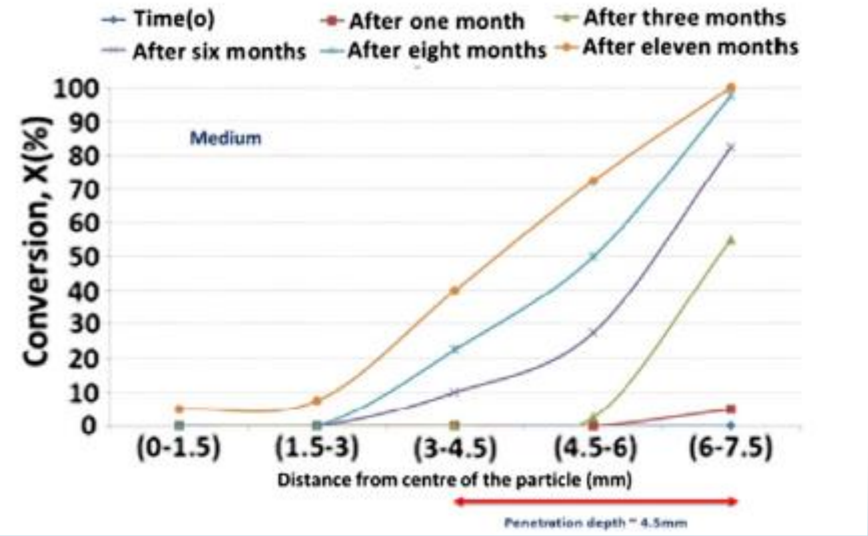
- Slow reaction kinetics at low temperatures
- Unliberated minerals in large particles
- Low aeration rates and poor gas-liquid mass transfer
- Solution channelling and stagnant zones
- re-adsorption of Cu onto precipitated Fe phases

Mineral extraction from large particles

- X-ray tomography shows shrinking shell and unreacted core

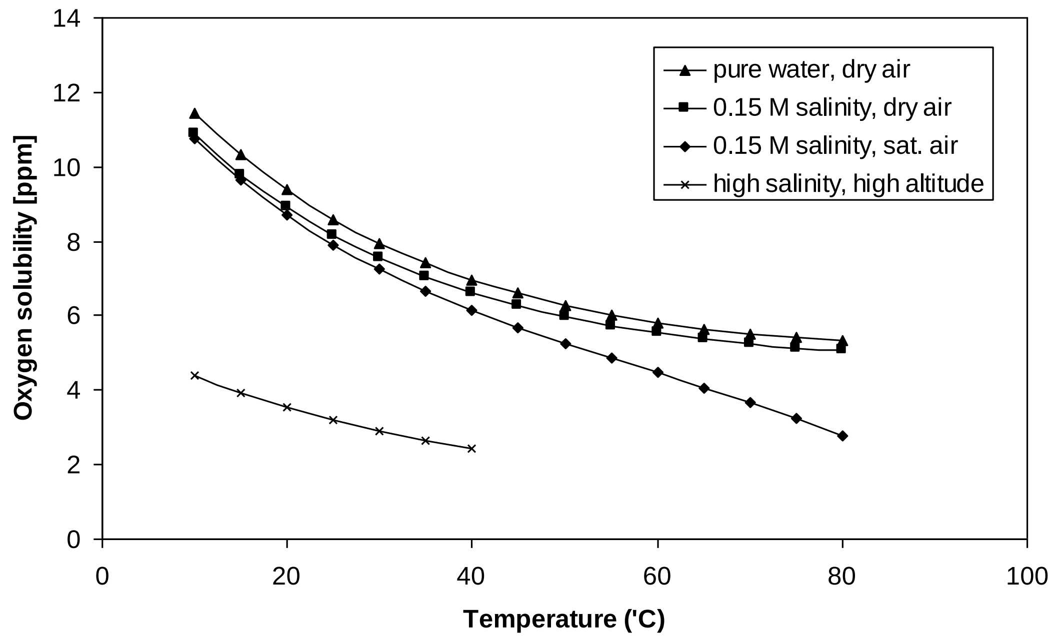




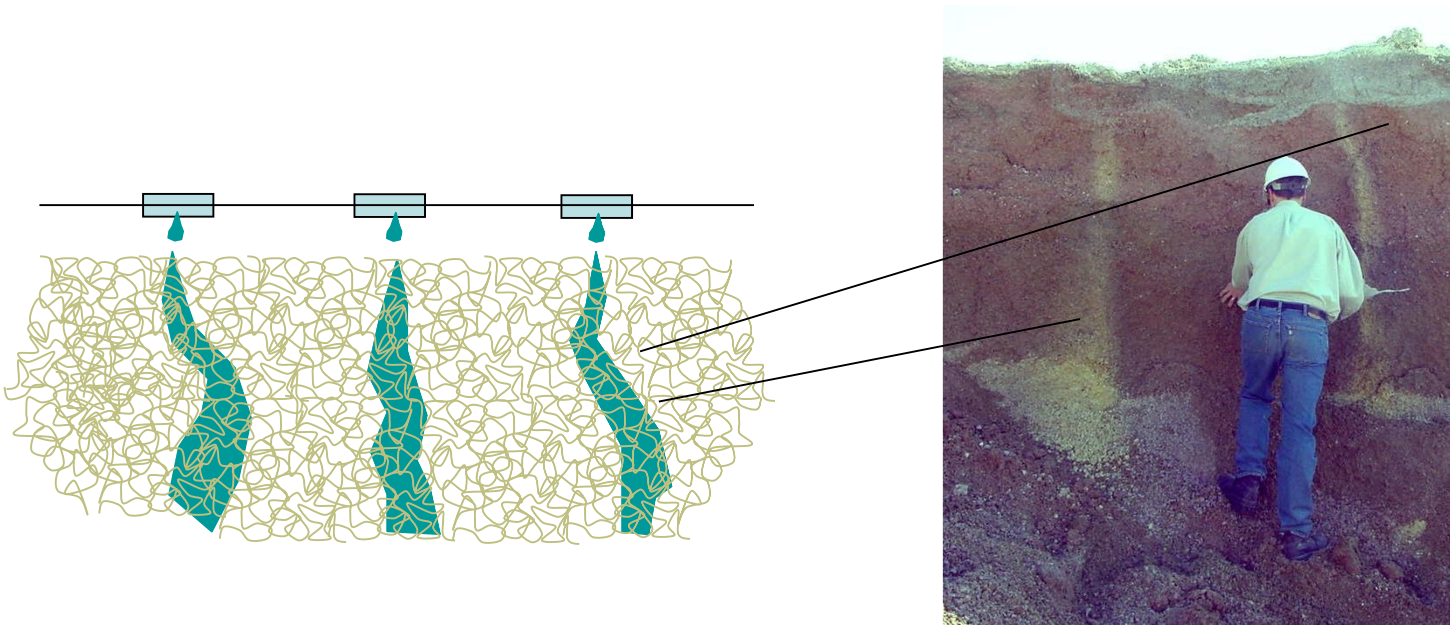


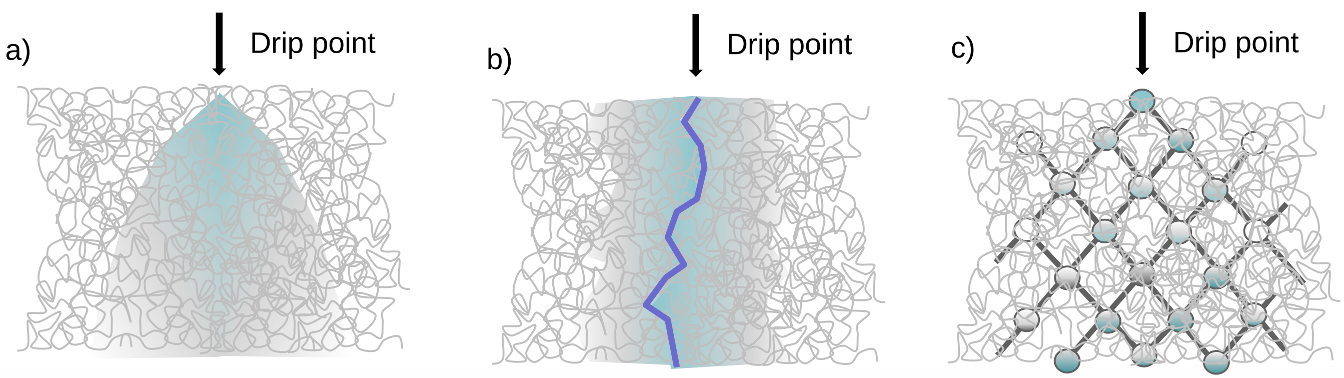
Gas-liquid mass transfer

- rate limited by low O_2 solubility and interfacial area
- O_2 solubility limited by temperature, solution salinity and air pressure

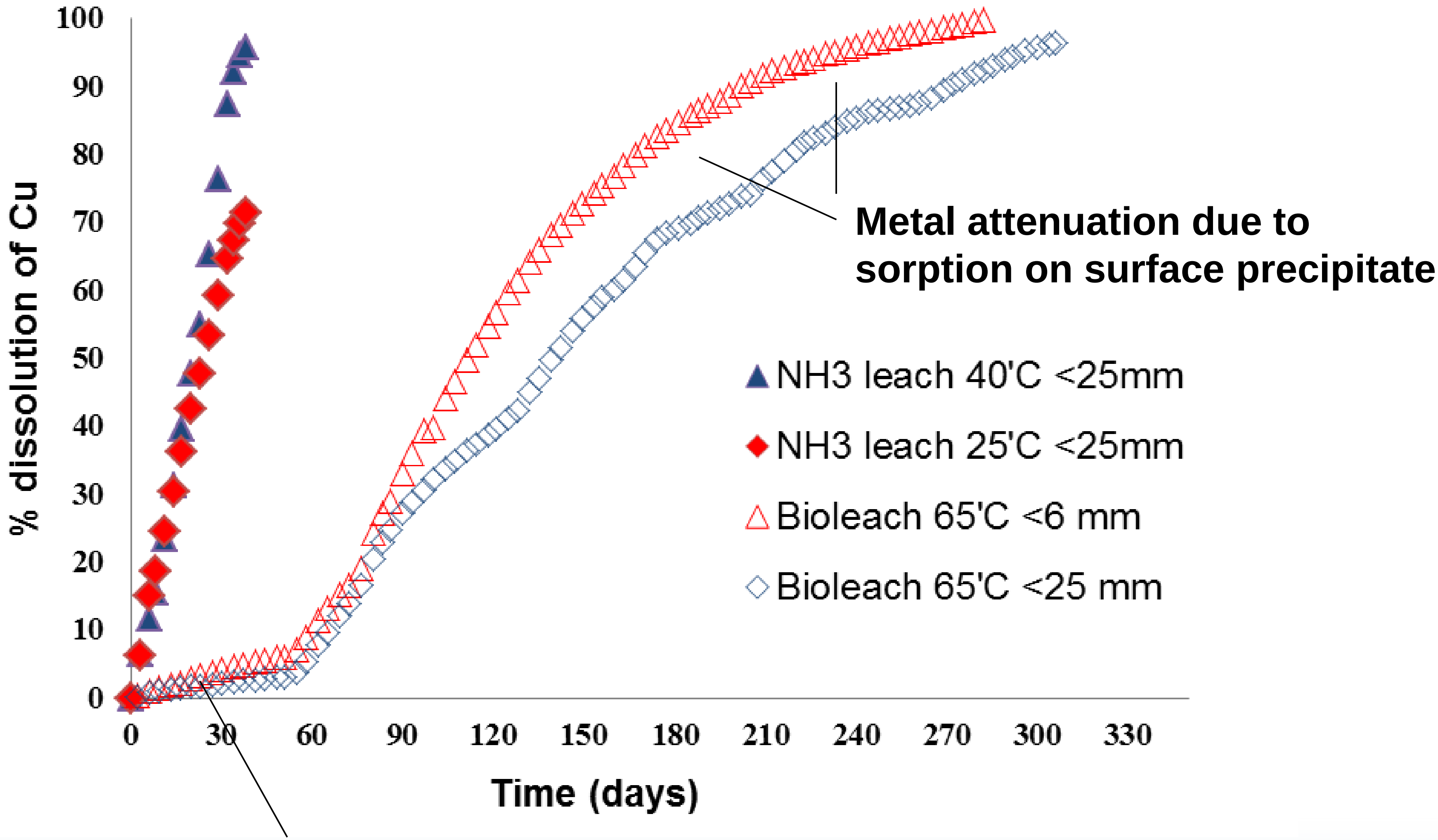


Solution Flow through Heaps





Copper attenuation on Fe precipitates



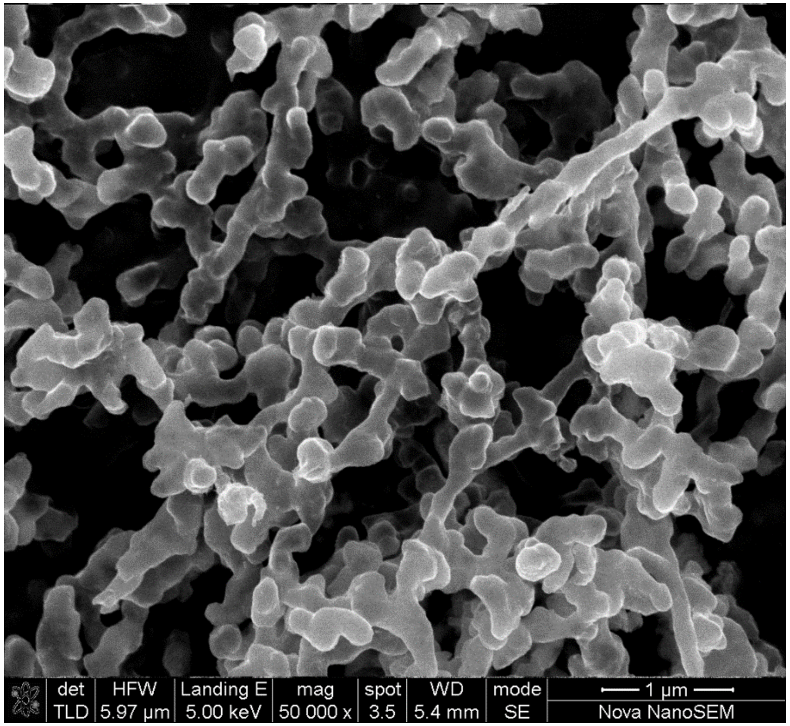
Lag due to bio-colonisation

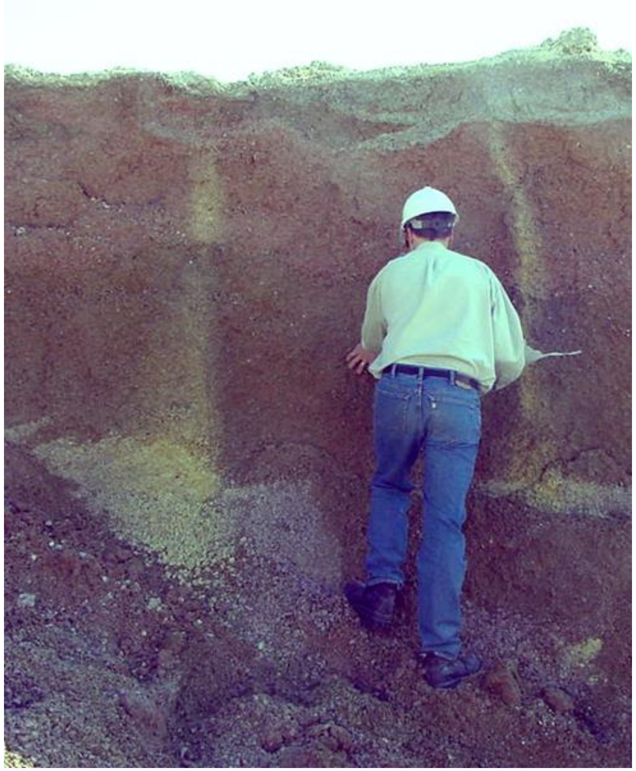
Fe precipitation in column bioleaching

- Progressive 'cementation' of heap ore by Fe-precipitates

Fe precipitation in column bioleaching

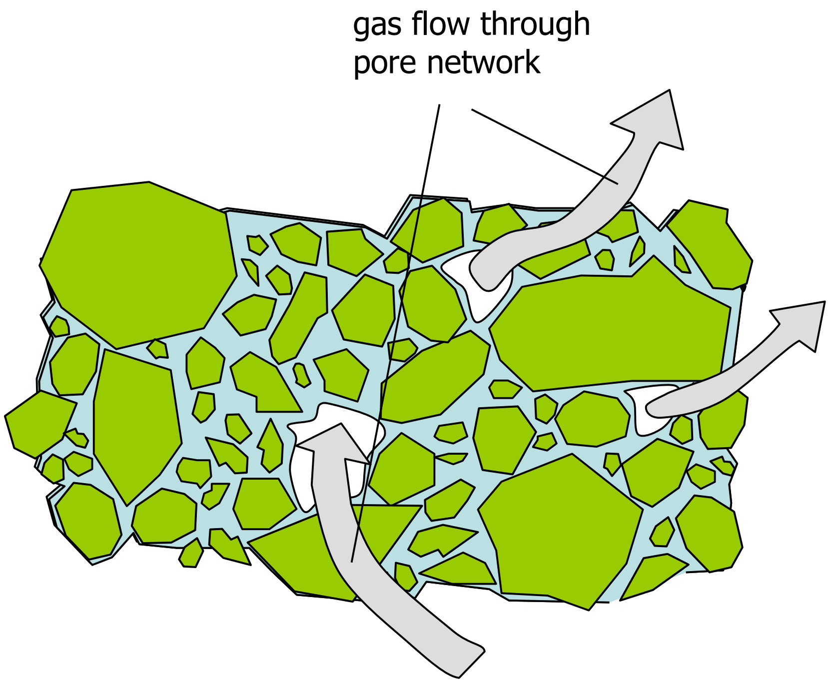
- Nano SEM studies of freshly precipitated Fe-OH
- Network structure of precipitate offers large surface for metal sorption and inhibits solution flow

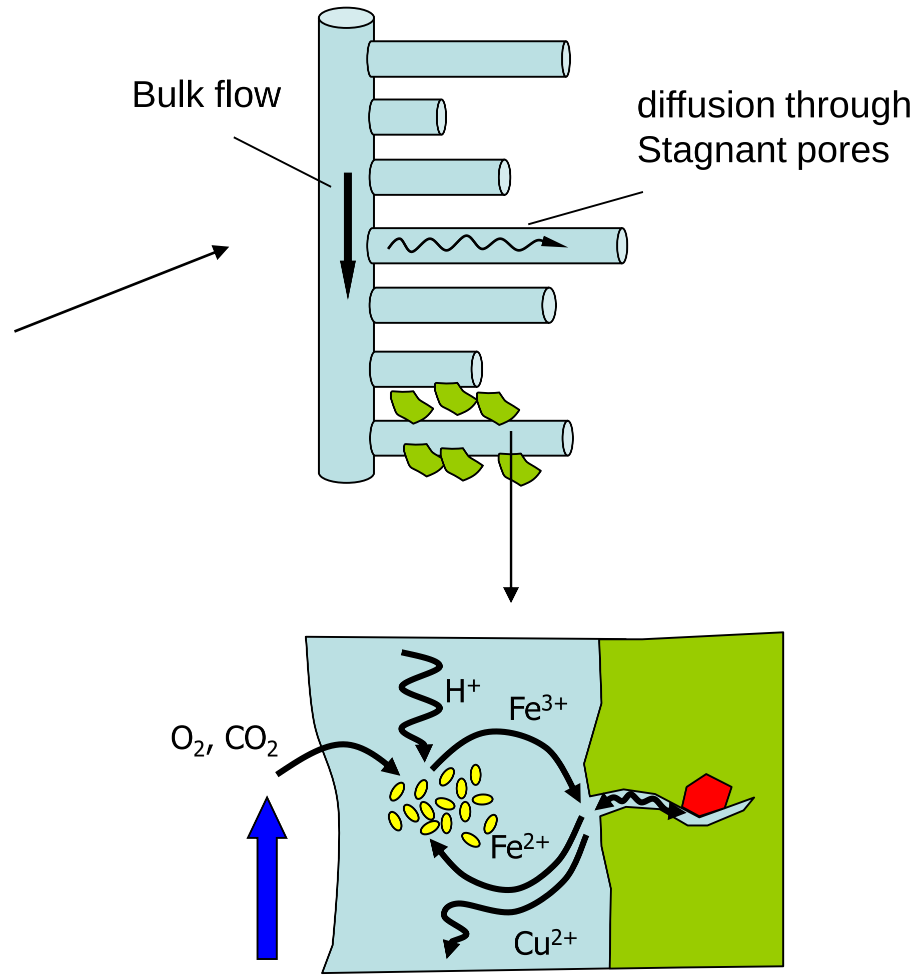




HYDROmet

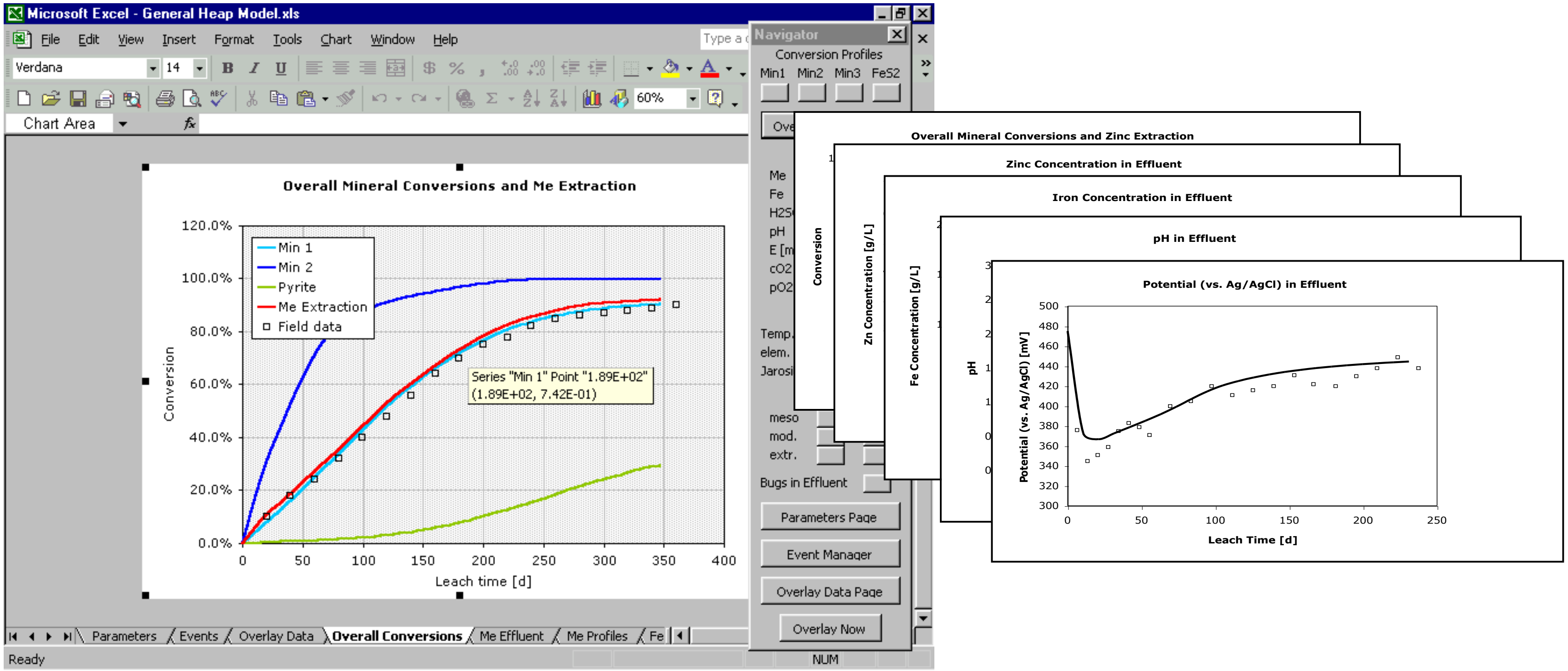
Transport-reaction modelling

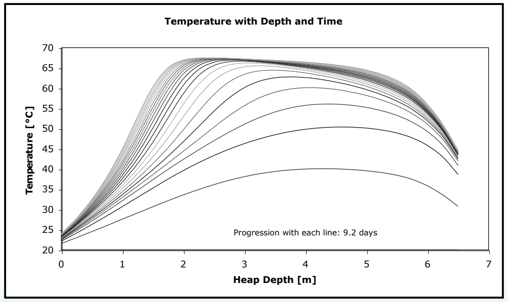


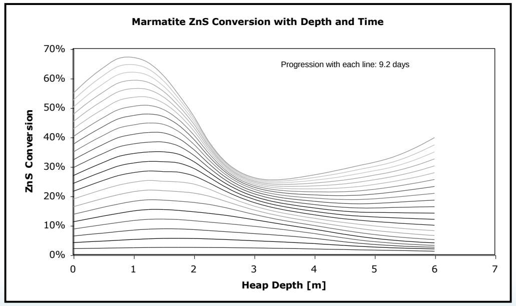


Solution ‘seeps’ through open pore spaces as a front

HeapSim Model







Key insights from modelling

- Complex distributions of reagent and heat distribution throughout heaps determines local rates of leaching;
- Ambient conditions have significant impact on oxidative heap leaching;
- Optimal heap design varies strongly with ore characteristics;
- There are ‘speed limits’ to the maximum rate of leaching:
    - Supply rate of acid (rare)
    - Reagent distribution through stagnant (diffusion) zones
    - Mineral liberation in large particles
    - Supply rate of oxidant (air) – gas liquid mass-transfer
    - Formation of adsorption buffers

Conclusions

- Heap leaching is a technically simple process, but of immense physical complexity at all scales.
- The interplay of these complexities is difficult to grasp, yet under-standing them offers opportunities to conduct the process efficiently.
- Economic analysis indicates if heaps can be made to operate reliably at their optimum, they would be a serious technology of choice.
- Heaps do have a future!

Thank You

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