# Morphological transitions in mineral dendrites

Dawid Woś*, Piotr Szymczak, Zhaoliang Hou

*Email: dd.wos@uw.edu.pl

EGU General Assembly 2025

UNIVERSITY OF WARSAW

# What are mineral dendrites?

- **Branched structures** that resemble tree-like or fern-like patterns.
- Commonly composed of **manganese** oxides or **iron** oxides.
- Often found on **rock surfaces**, **fossils**, or between **sedimentary layers**.
- Not actual fossils or plant remains – **inorganic growth**.

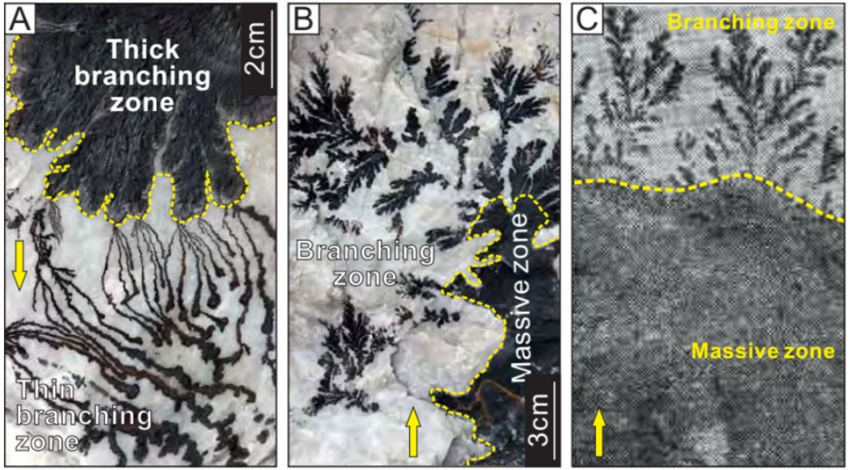
Manganese and ferric dendrites on limestone

Manganese dendrites on quartz

Mineral dendrites in Agate

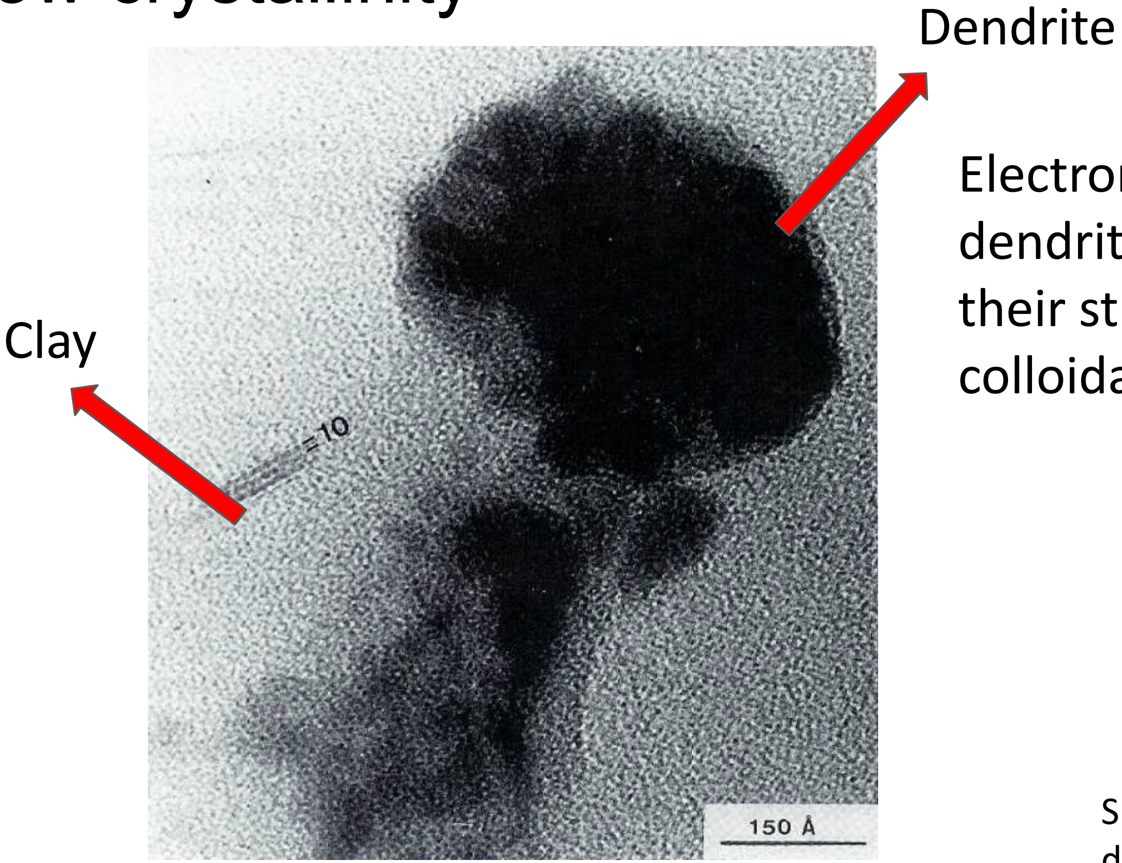
# Morphological transitions

Changes in shape within a single growing dendritic structure.




What is the physical mechanism underlying these morphological transitions?

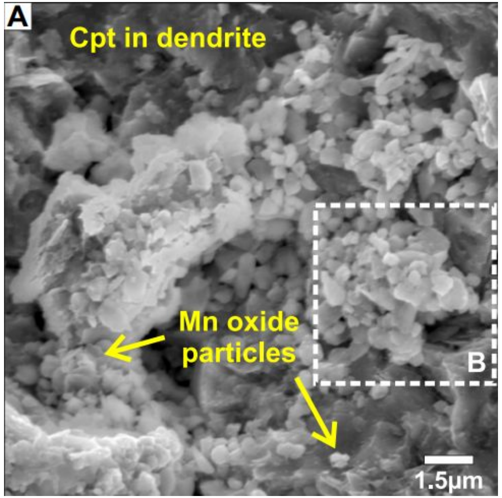
# Low crystallinity




Electron microscopy view of Mn oxide particles showing the lack of long-range order.

Electron microscopy reveals that Mn dendrites lack long-range order in their structure, highlighting their colloidal nature.

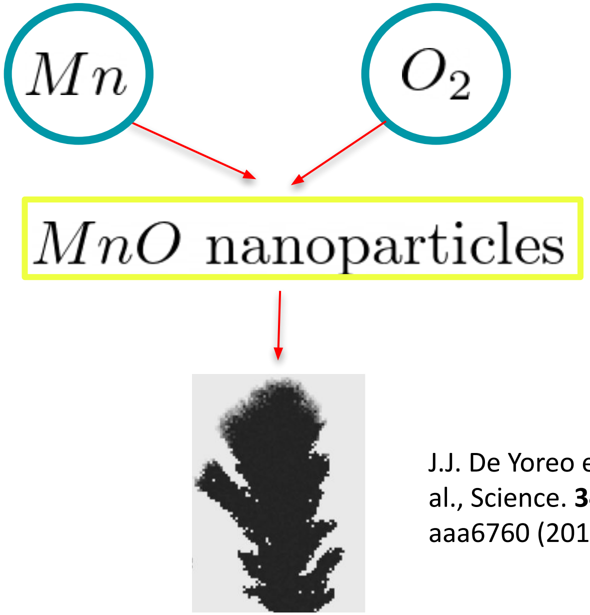
SEM data




Garcia-Ruiz et al. (1994). 10.1007/978-3-662-07304-9_23.

# Crystallization by particle attachment

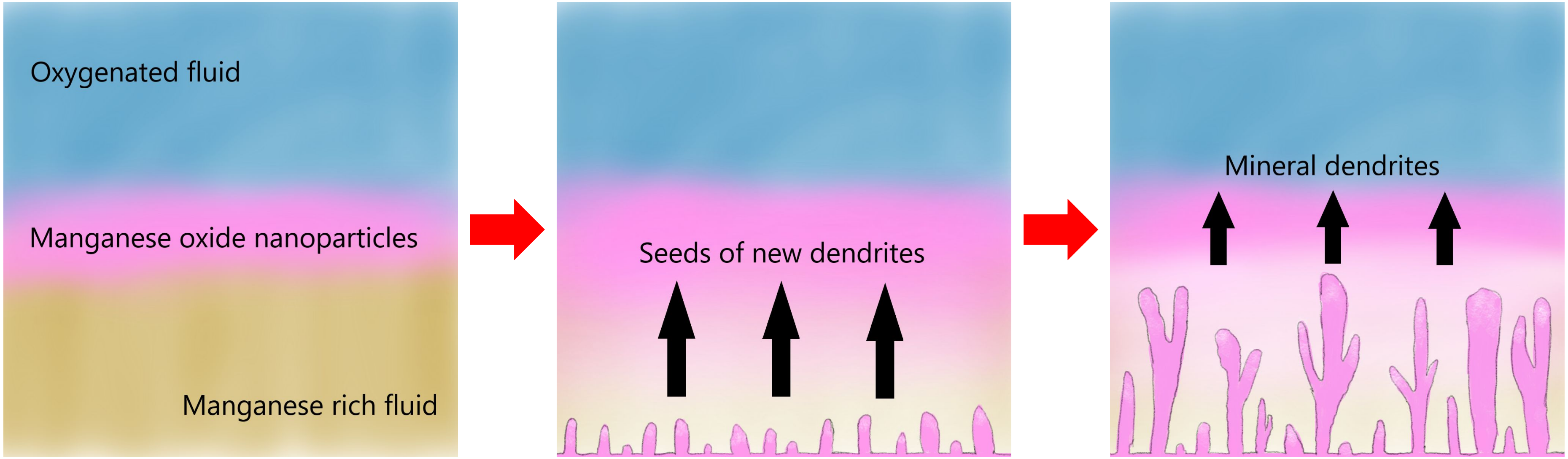
Mineral dendrite growth results from a **reaction-diffusion system**. It includes transport of reactants as well as chemical reactions.




J.J. De Yoreo et al., Science. **349**: aaa6760 (2015)

# Particle attachment model

The model assumes an initial growth of small nanoparticles which then aggregate into branched structures.



# Numerical model

Reaction-diffusion equations for concentrations:

- oxygen

$$\frac{\partial}{\partial t} c_{O_2} = D_{O_2} \nabla^2 c_{O_2} - k c_{O_2} c_{Mn}$$

- Mn ions

$$\frac{\partial}{\partial t} c_{Mn} = D_{Mn} \nabla^2 c_{Mn} - k c_{O_2} c_{Mn}$$

- manganese oxide particles

$$\frac{\partial}{\partial t} c_{MnO} = D_{MnO} \nabla^2 c_{MnO} + \nu k c_{O_2} c_{Mn} - \lambda^* c_{MnO}$$

- dendrite growth (on the dendrite surface)

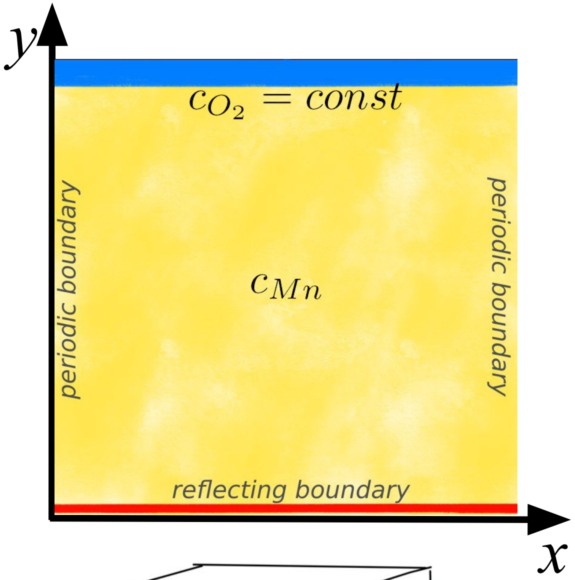
$$\frac{\partial}{\partial t} v_p = \lambda^* V_m c_{MnO}$$

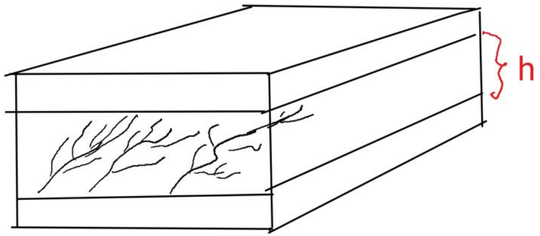
+ noise

volume fraction

molar volume

boundary and initial conditions




modeled by the lattice-Boltzmann method

# Phase diagram

- With increasing **surface energy**, dendrites are more compact and have fewer branches
- Increasing the ratio of **initial concentrations** of manganese to oxygen makes the dendrites thicker and more packed
- Diffusive and capillary lengths:

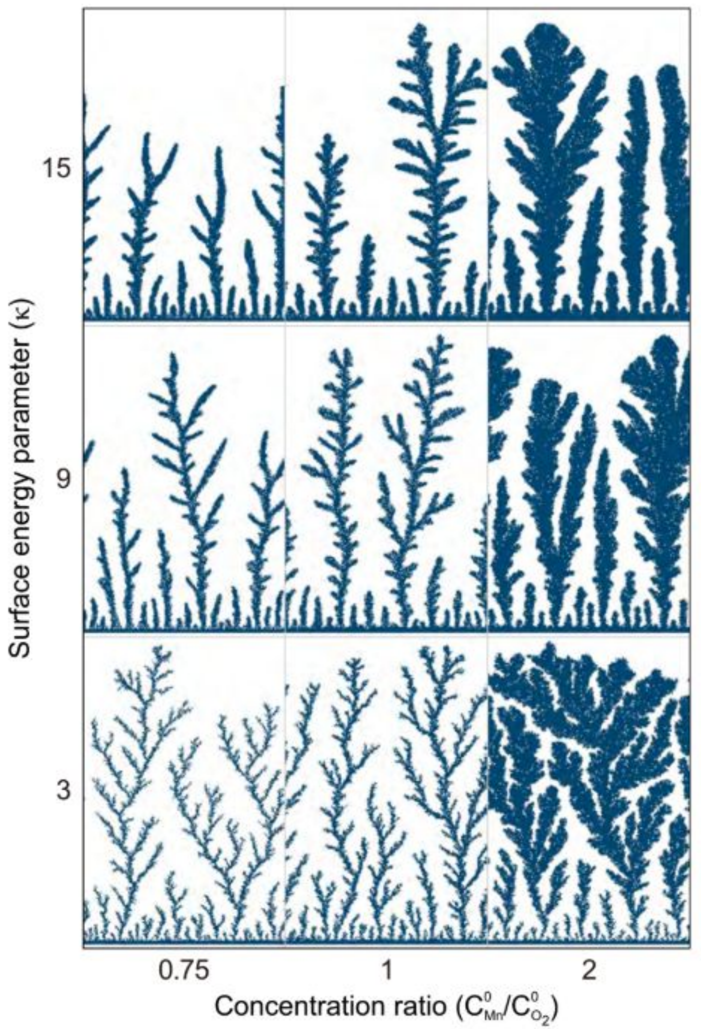
$$l_d = D/U \qquad l_c = \nu \frac{\sigma v_m}{kT} \qquad \kappa = l_c/l_d$$

Ratio of diffusion constant and average growth velocity

σ - surface energy density
ν - acid capacity number

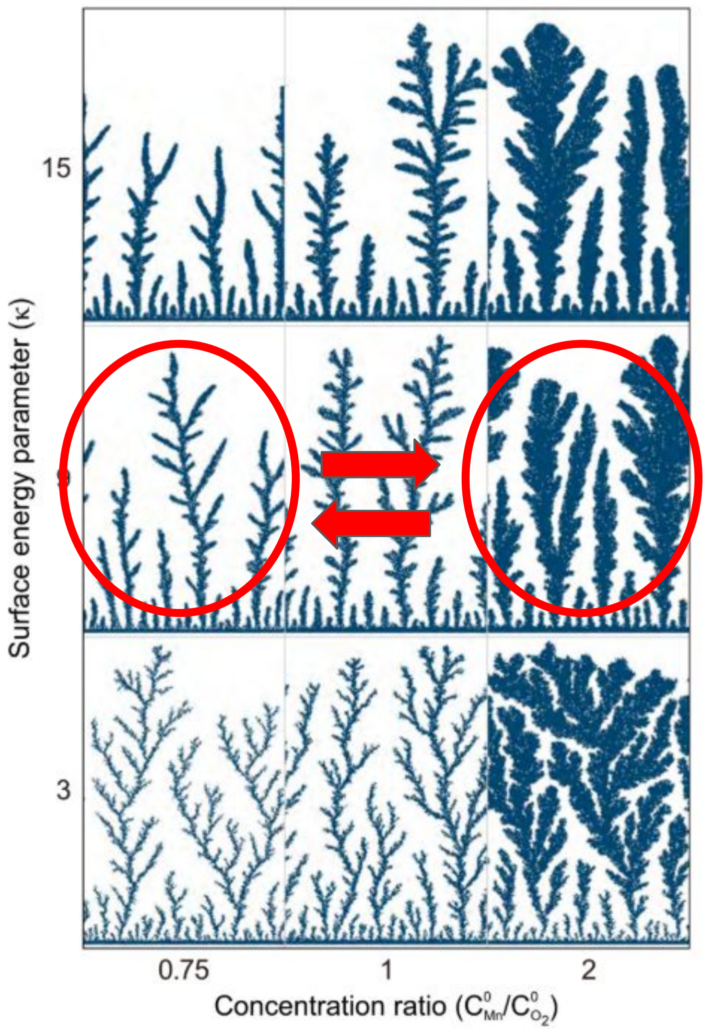
κ – surface energy parameter

$c^0_{Mn}$ , $c^0_{O_2}$ initial concentrations



# Multiple infiltrations

- Multiple **infiltrations** of **manganese-bearing** fluids with varying concentrations can occur during growth.
- Since dendritic shape depends on **Mn to $\mathbf{O_2}$** initial **concentration ratio**, such variations may induce morphological transitions.

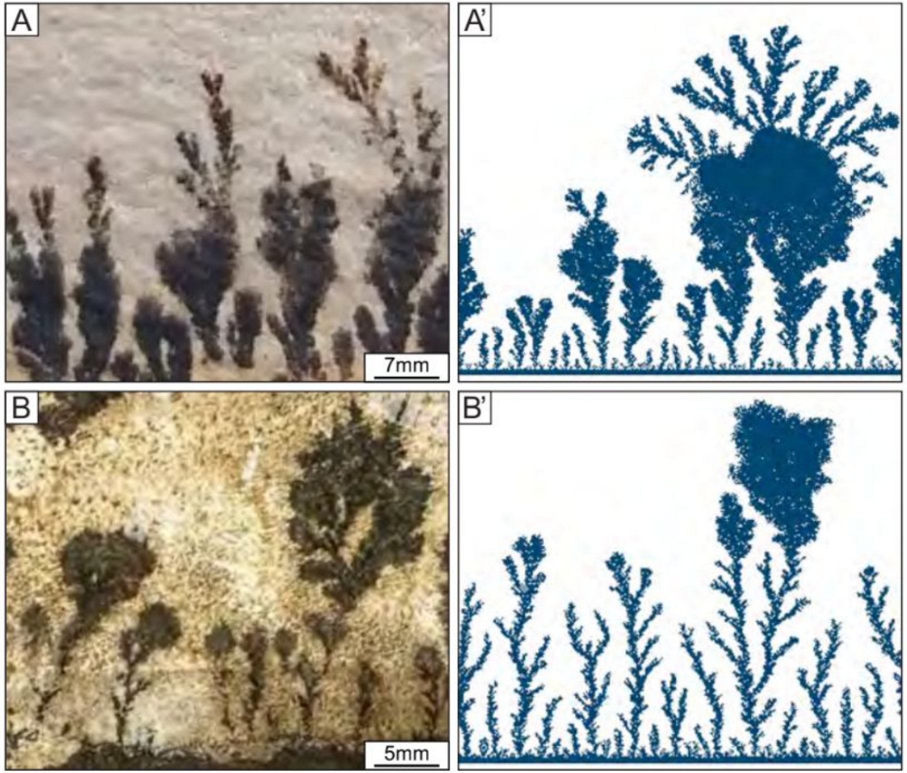



κ – surface energy parameter

$c^0_{Mn}$ , $c^0_{O_2}$ initial concentrations

# Transitions due to multiple infiltrations

Rock samples




In the simulation, the manganese to oxygen concentration ratio was **reduced from 10 to 1**

In the simulation, the manganese to oxygen concentration ratio was **increased from 1 to 10**

# Fracture aperture - phase diagram

- Aperture of the fracture ***h*** influences dendrite morphology.
- Increase of aperture ***h*** results in thicker dendrites, with shorter, bulkier branches.

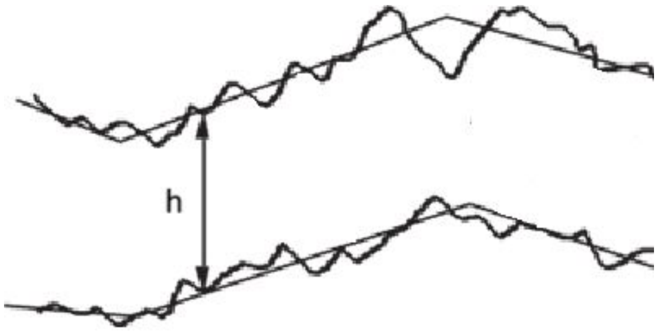
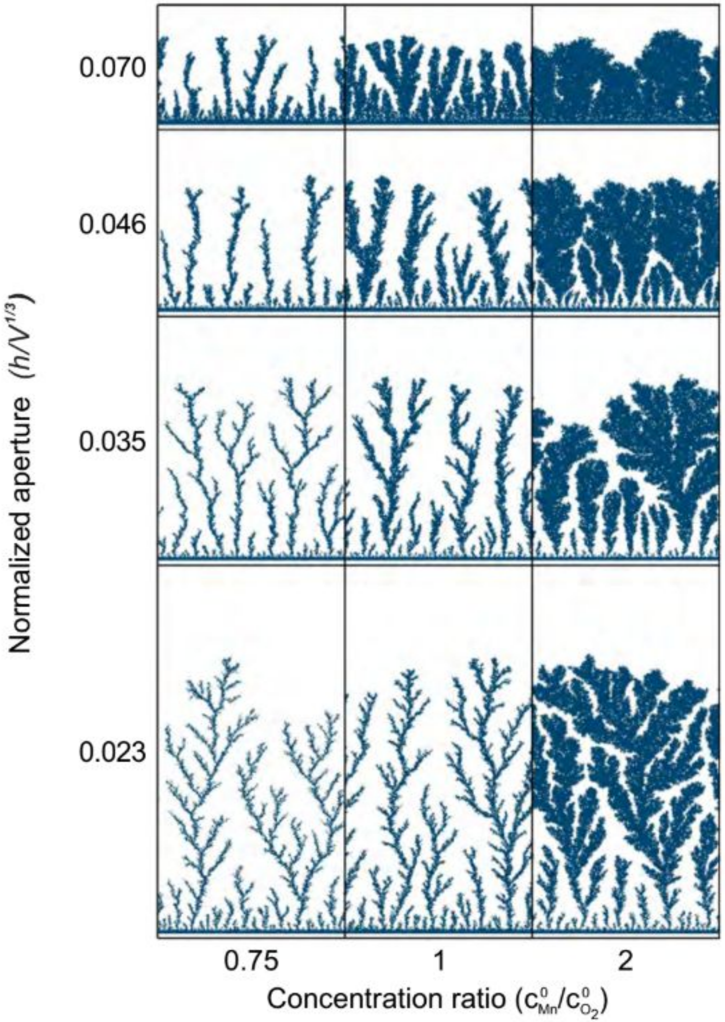



Illustration of aperture of the fracture



# Fracture aperture - morphological transitions

- Variations in fracture aperture ***h*** within a single rock system may lead to morphological transitions in dendrites due to altered growth conditions along the fracture.

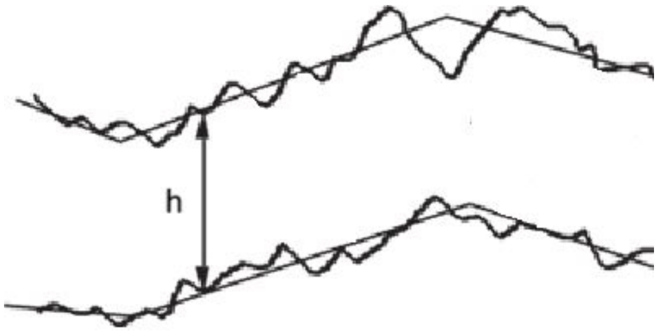
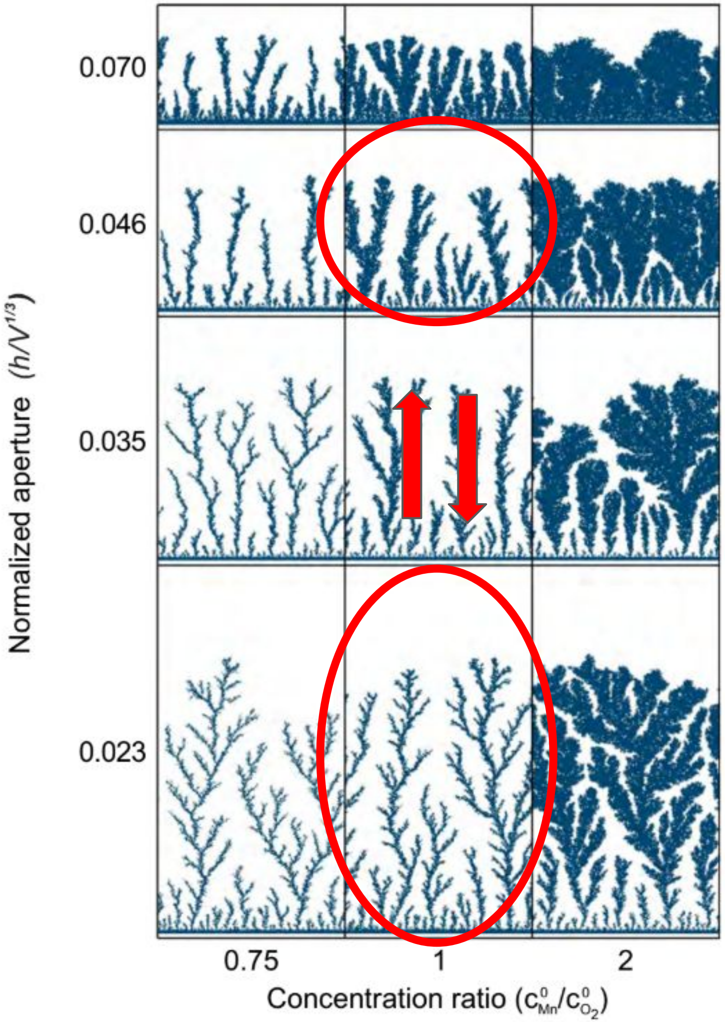
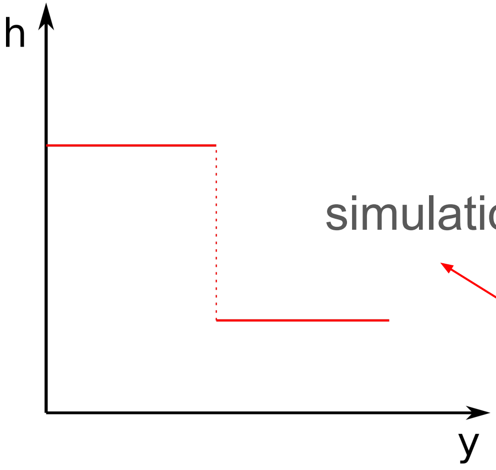


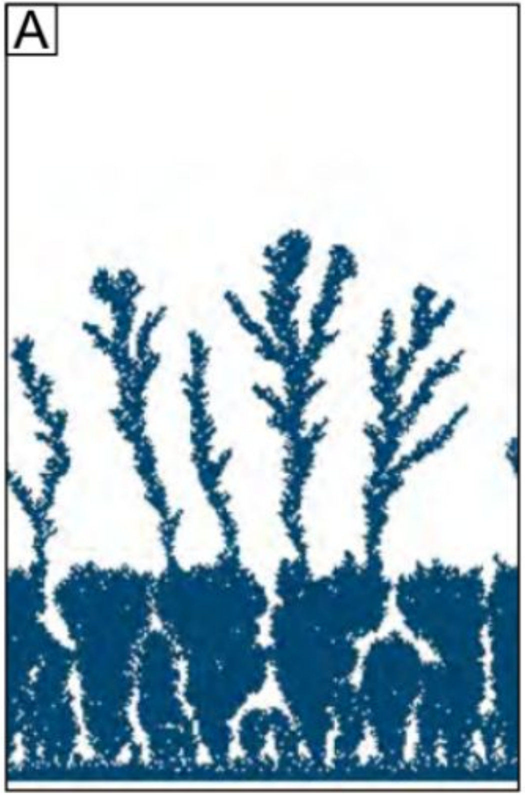

Illustration of aperture of the fracture

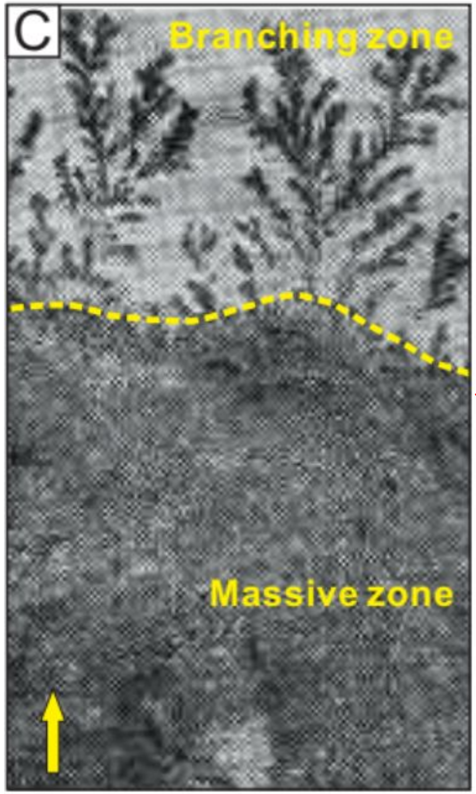


# Transitions due to the variation of aperture




simulation




rock sample

In the simulation aperture was **three times greater** at the bottom half than at the top half

# Conclusions

- Mineral dendrite morphology is influenced by factors such as **surface energy** and the **ratio of initial concentrations** of manganese to oxygen.
- Variations in **manganese** and **oxygen** concentrations during growth can induce **morphological transitions** in dendrites.
- The **aperture of the fracture** where dendrites grow affects their morphology, with larger apertures leading to thicker, bulkier branches.
- Alternation of **fracture aperture** within a rock system can also cause **morphological transitions** in dendrites.
- Mineral dendrites record the chemical and physical **history of the rock**, preserving evidence of fluid movements, fracture alteration, and environmental changes over geological time.