# JACOBS DOUWE EGBERTS

# Soft Matter Challenges in Coffee Processing

Robert Farr, September 2019

# FACTS & FIGURES



## A global team of 16000 associates across 44 countries

## 2018 revenue

## ~€6BN

**Based on an average number of FTEs throughout 2018, including roundings*
***Including all completed M&A transactions as at 31 Dec 2018, at constant PEG rate , including roundings*

## A PORTFOLIO COMPRISING SOME OF THE MOST WELL-KNOWN HOUSEHOLD COFFEE NAMES

MOCCONA, JACOBS, L'OR, Senseo, MARCILLA, Super, TASSIMO, PILÃO, FRIELE, DOUWE EGBERTS, CAFÉ PRIMA, KENCO, GEVALIA

**AVAILABLE IN MORE THAN 143 COUNTRIES AROUND THE WORLD**


Position in 28 retail markets

Position in 14 professional markets

*(Source: Nielsen, 2018)*

# FROM LOCAL PIONEERS TO A GLOBAL PORTFOLIO OF HOUSEHOLD NAMES



1753 Douwe Egberts

1853 Gevalia

1895 Jacobs

1923 Kenco

1960 Moccona

1978 Pilão

1987 Super

1992 L'OR

2001 Senseo

2004 Tassimo

2016 Ti ORA

# COFFEE: History, agronomy and processing

# THE HISTORY OF COFFEE

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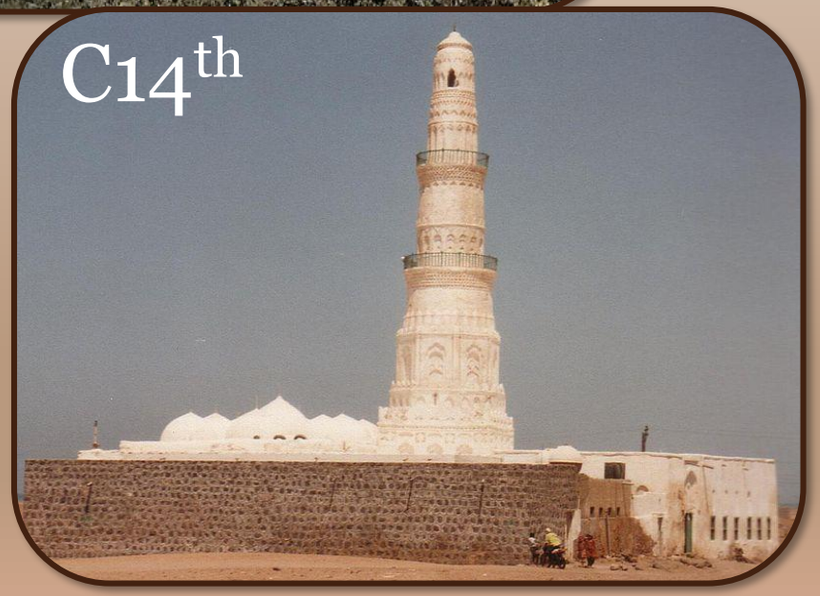

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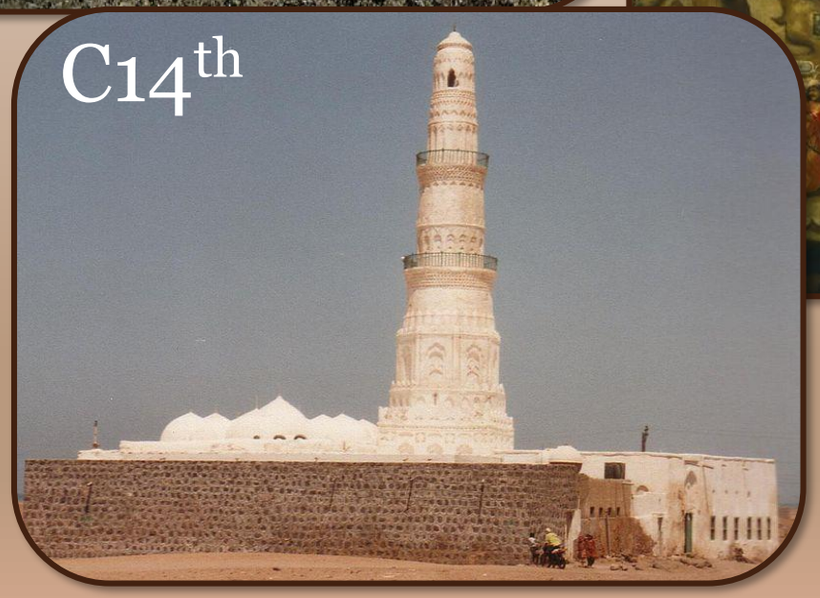

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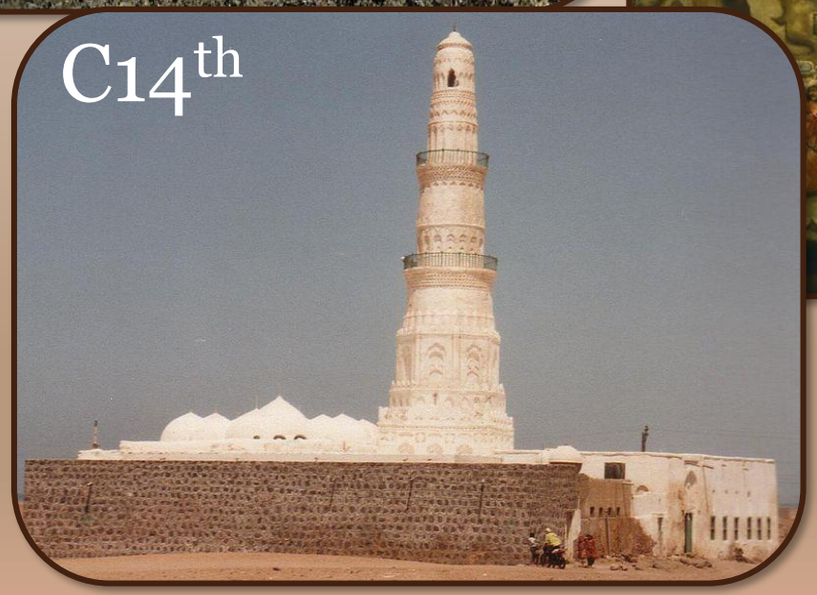
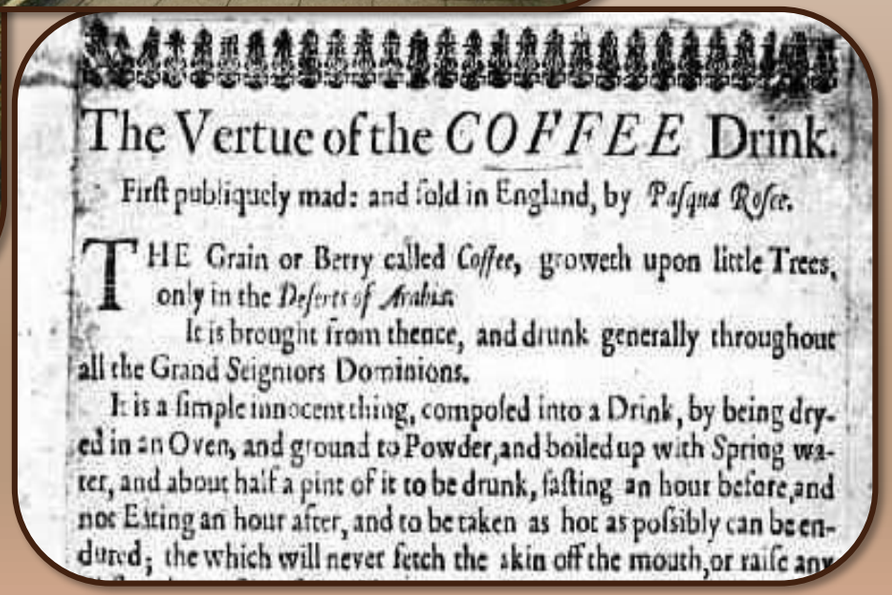


The Vertue of the *COFFEE* Drink.

First publiquely made and sold in England, by *Pasqua Rosee.*

THE Grain or Berry called *Coffee*, groweth upon little Trees, only in the *Deserts of Arabia.*

It is brought from thence, and drunk generally throughout all the Grand Seignors Dominions.

It is a simple innocent thing, composed into a Drink, by being dryed in an Oven, and ground to Powder, and boiled up with Spring water, and about half a pint of it to be drunk, fasting an hour before, and not Eating an hour after, and to be taken as hot as possibly can be endured; the which will never fetch the skin off the mouth, or raise any

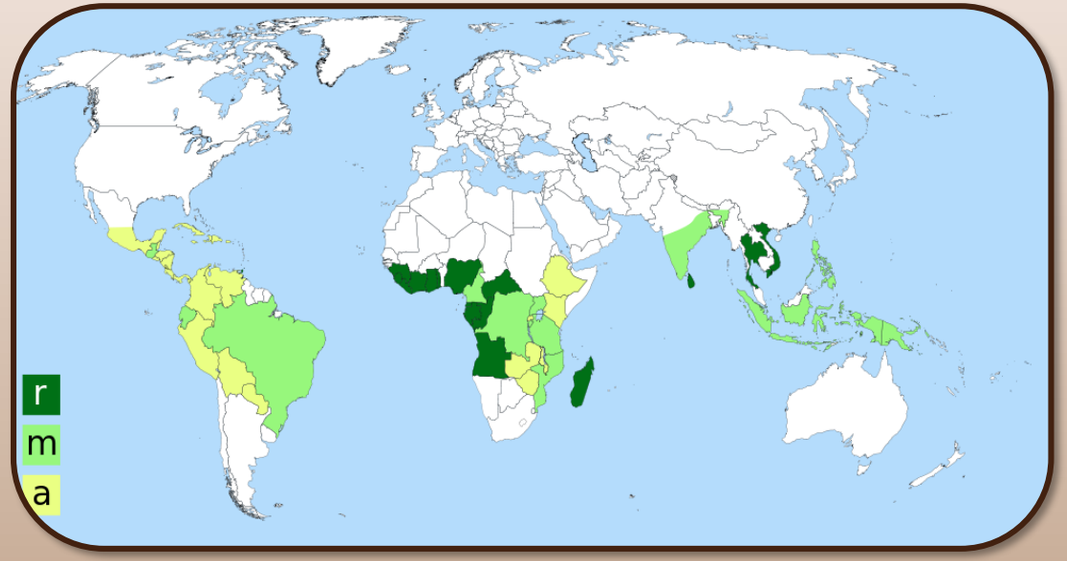
# AGRONOMY: COFFEE SPECIES

*Arabica*

## *Coffea arabica*

- Richer, more refined flavour
- Lower in caffeine
- Grows at higher altitude
- Lower yields
- More difficult to cultivate
- Higher value product

Coffee production around the world




75% of production is *arabica*.

Top producers: Brazil, Vietnam, Colombia, Indonesia, Ethiopia.

***Coffea liberica*** ***Coffea charrieriana***

*Robusta*

## *Coffea canephora*

- Stronger, more bitter flavour; high caffeine
- Grows lower altitude
- High yields
- Less susceptible to diseases
- Lower value product

# A THEME IN FOOD PROCESSING

# FROM BERRY TO GREEN BEANS

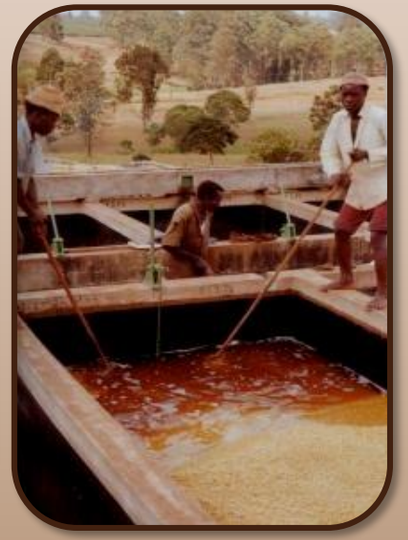
Coffee grows as trees, up to several metres tall

Harvesting either by hand, or mechanical

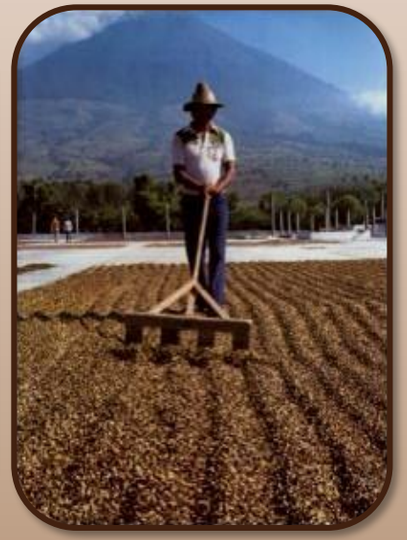
Need to remove flesh (pulp) and parchment of the coffee cherry, and end up with green beans

Pulping

Fermentation
12-36 hours



Washing



Drying

"Washed" process

# IN-FACTORY PROCESSES

Green beans

Banbury

# IN-FACTORY PROCESSES

Green beans

Roast whole beans

**Roasting** **Banbury**

# IN-FACTORY PROCESSES

Green beans

**Roasting** **Banbury**

**Grinding**

Roast whole beans


Roast & Ground

# IN-FACTORY PROCESSES

Green beans

**Roasting** **Banbury**

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**Industrial extraction**

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Roast & Ground

Professional solutions

# IN-FACTORY PROCESSES

Green beans

Roast whole beans

**Roasting** **Banbury**

**Grinding**

**Industrial extraction**

**Freeze-drying**


Roast & Ground

Professional solutions

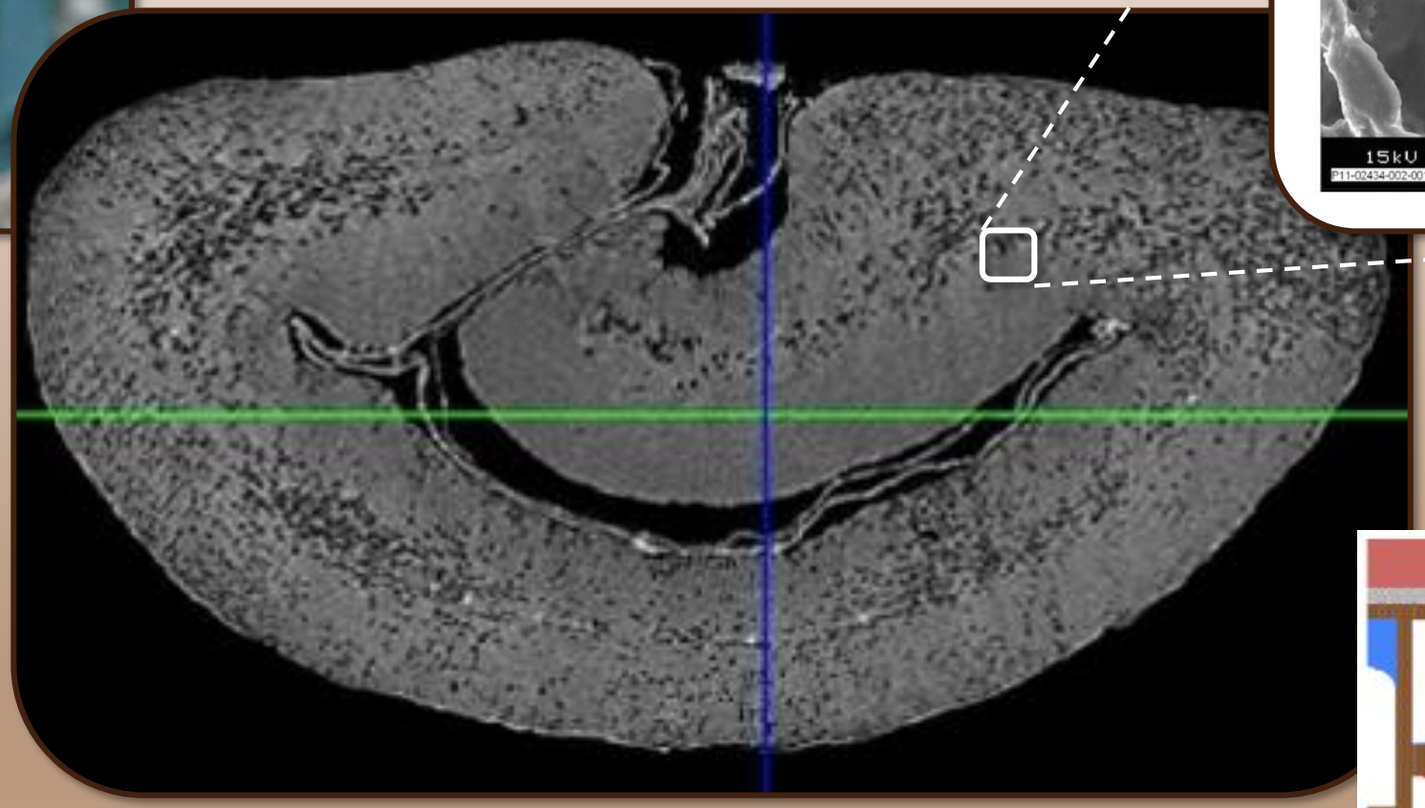

Instant coffee

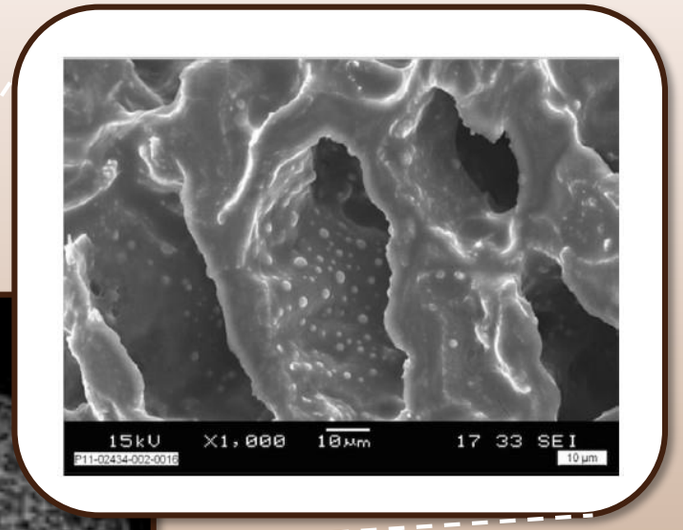
# ROASTING

# STRUCTURE OF GREEN COFFEE

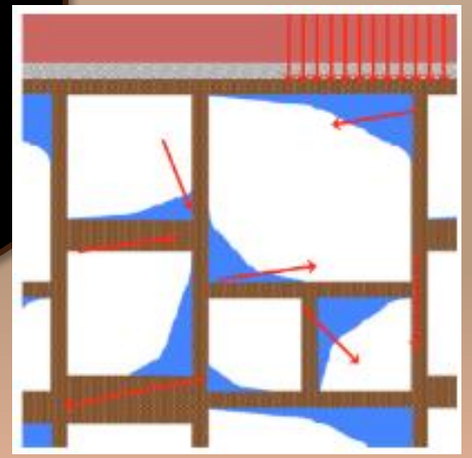
Section through unripe coffee cherry

X-ray tomographic section through green bean






Nano-gramme reactor

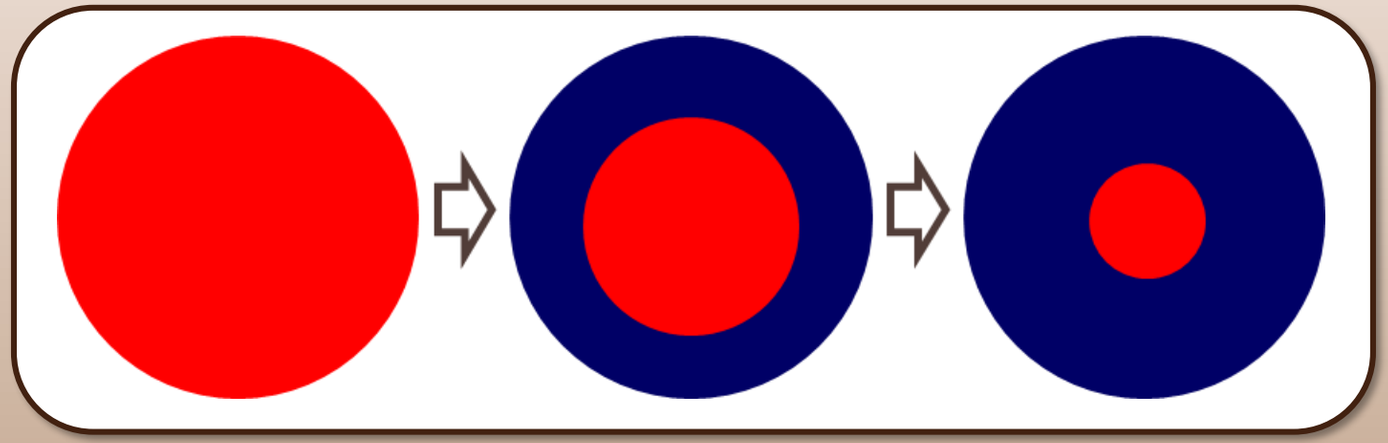


**On roasting: a pressurised, porous, plastic material**

# STAGES OF ROAST

# SIMPLIFICATION & ASYMPTOTICS

Under the approximation of vapour pressure set by the pure water steam table, there is a rather remarkable simplification.



Thermal diffusivity relatively high.

pressure drop from flow through porous material -> sets steam table temperature.

Then, if there were a trivial moisture isotherm, we end up with a boundary-layer problem leading to a simple shrinking-core between wet and “dry”. The boundary layer itself can be analysed asymptotically.

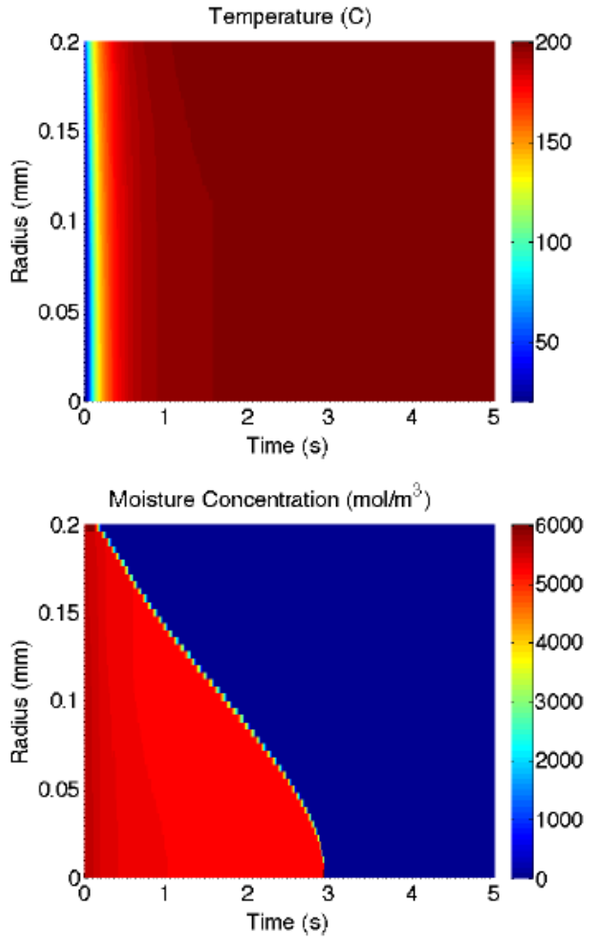



Figure from N. Fadai, SIAM Journal of Applied Math. 78(1), 418 (2017)

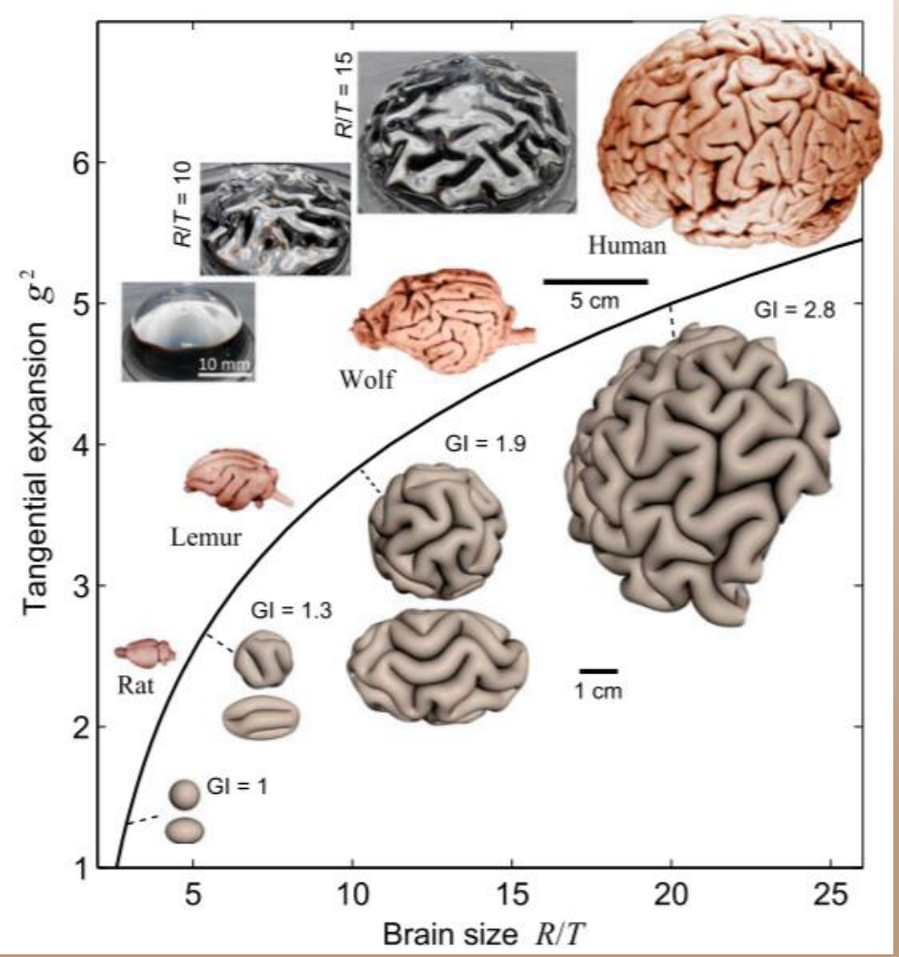
# LARGE PLASTIC DEFORMATIONS AND COMPETITION FOR $T_g$

Plastic + inhomogeneous high pressures from gas and vapour generation

Might expect to see something like sulcus & gyrus formation, as John Biggins has recently analysed in brain development

However, this is NOT seen: instead a growing pressure interacts with a race between heating and drying

Hoop stresses supported by a thickening layer of brittle material, until this fails by fracture: acoustic signal of first crack.

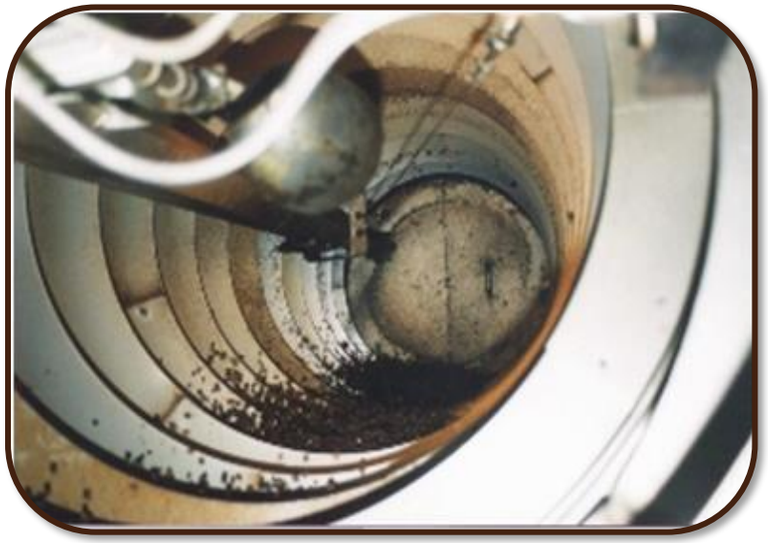



[T. Tallinin *et al.* PNAS 111(35) 12667 (2014)]

**There is also a second crack, later on, which is not at all understood!**

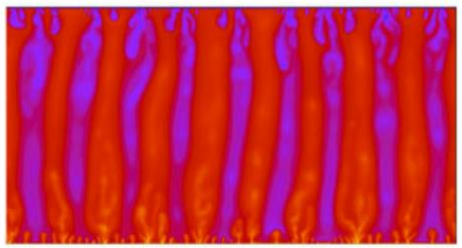
# GRANULAR FLOWS

## Wide range of roaster types

Drum roaster

Fluidised bed




Actually, this is *free* porous convection, from Hewitt et al, [JFM 737 p205 (2013)]

"Simple" granular flow ⟺ Forced porous convection ⟺ Gas-assisted granular flow ⟺ Suspension in air-stream

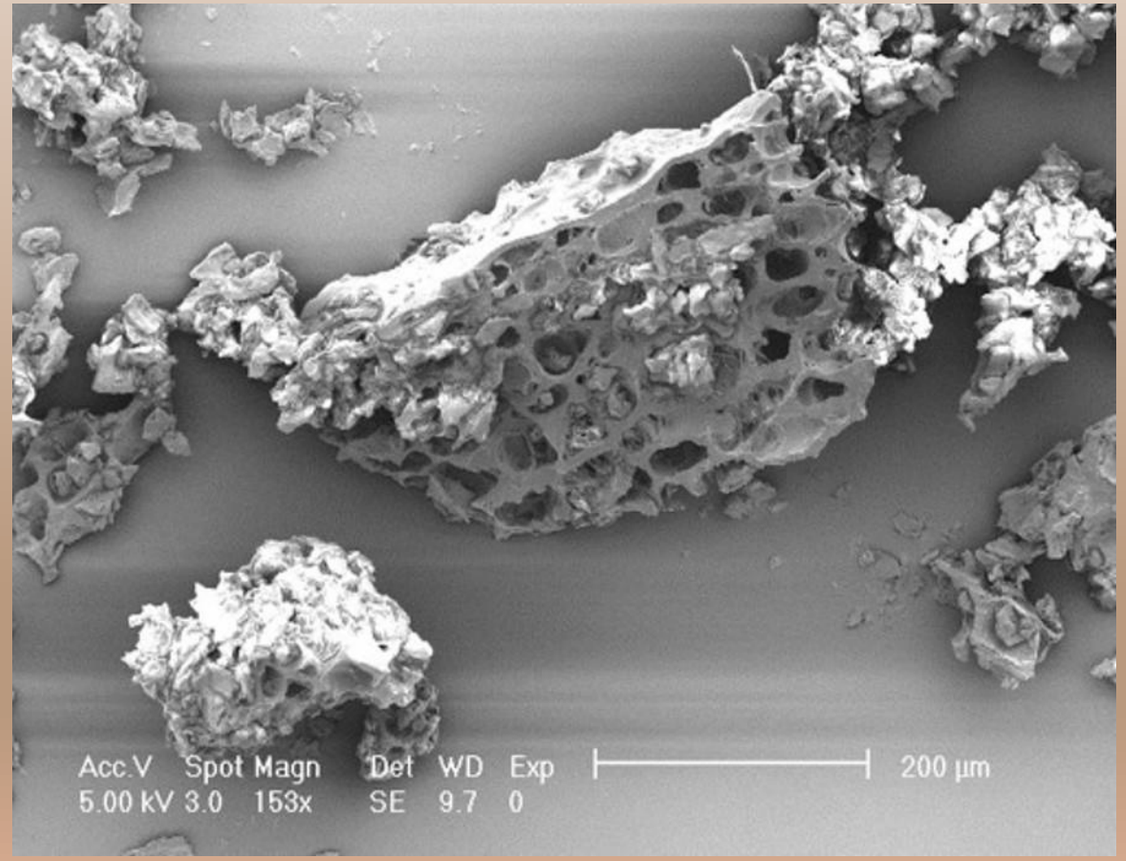
**Predicting behaviour of roasters needs better understanding of flow in these different regimes!**

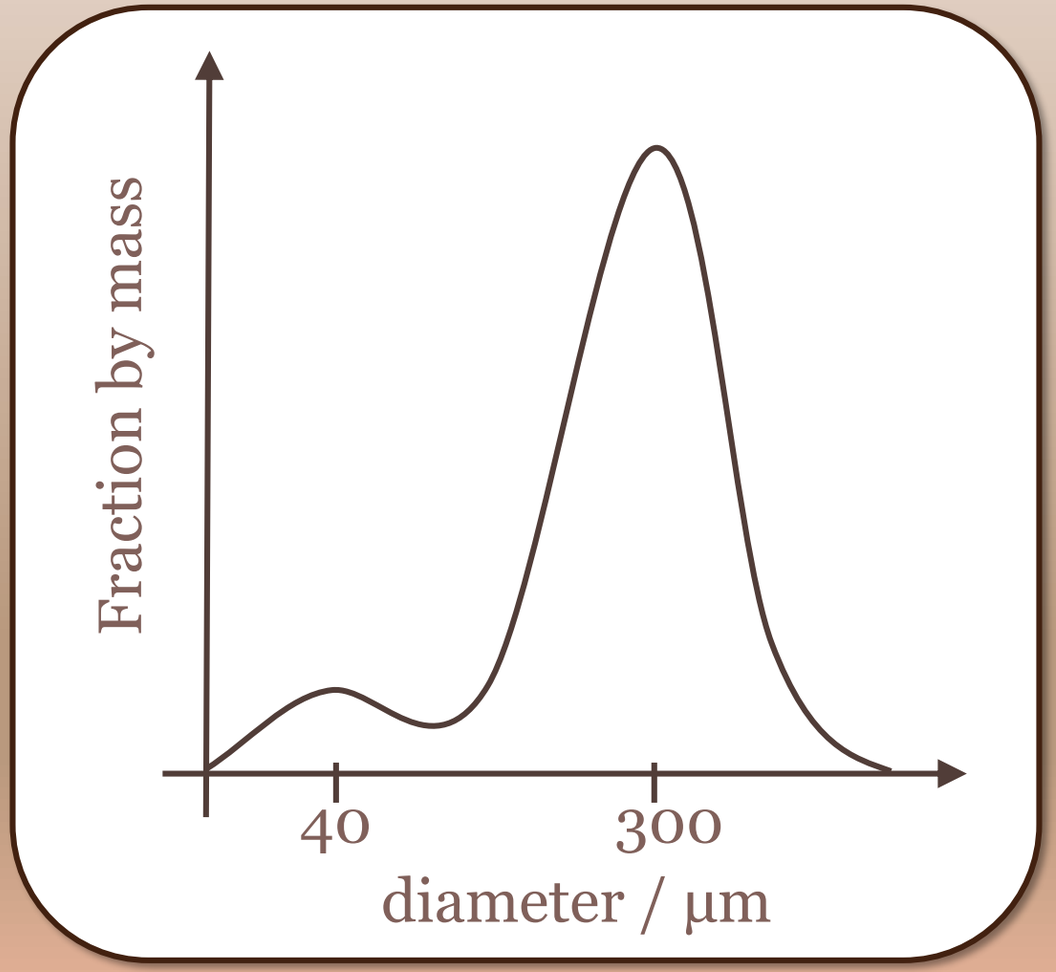
# GRINDING

# FRACTURE OF POROUS MATERIALS

Roasted coffee is a porous, brittle material; how does it fracture?

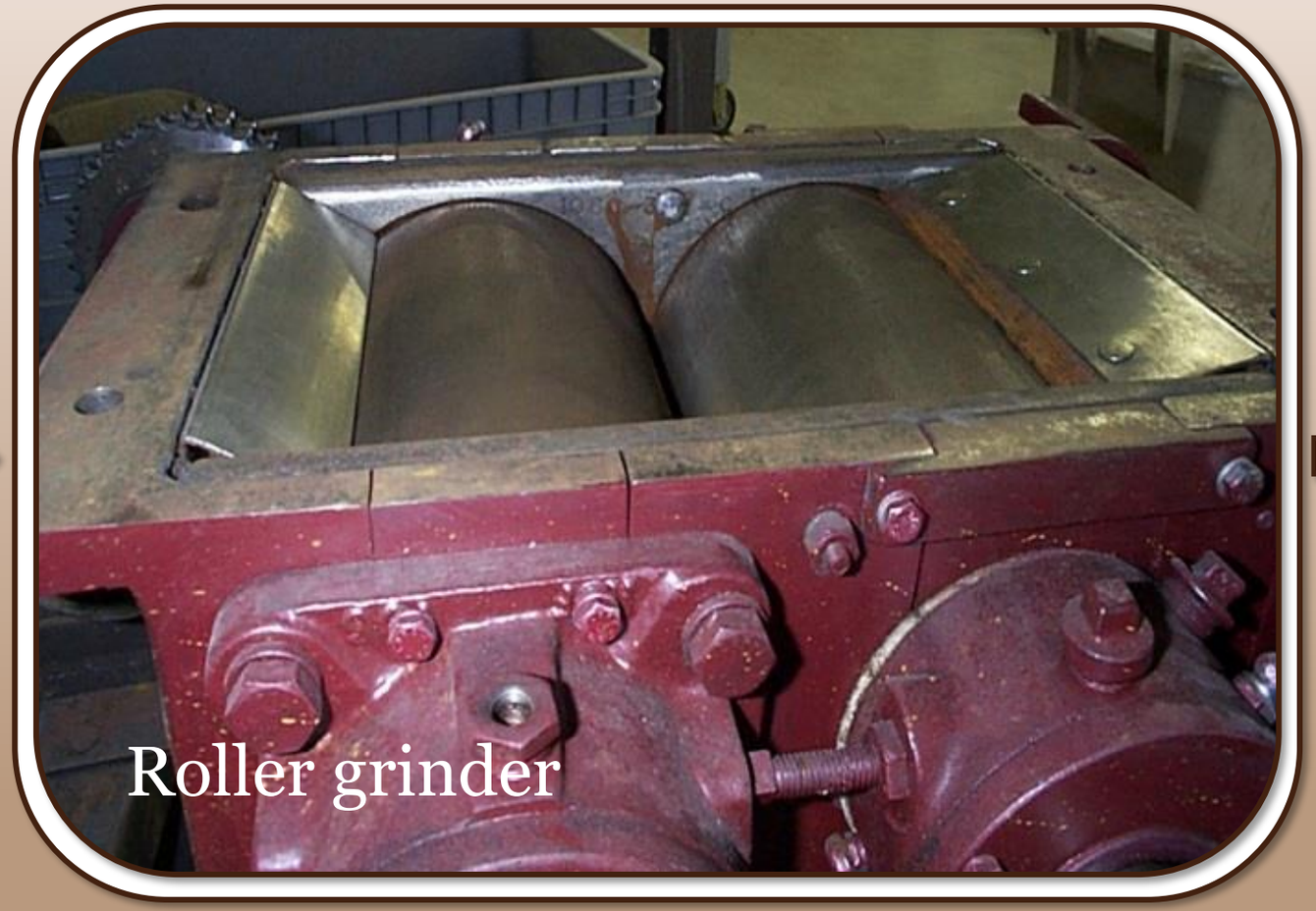
Typically interested in the size distribution, which is bimodal, but depends sensitively on grinding geometry.



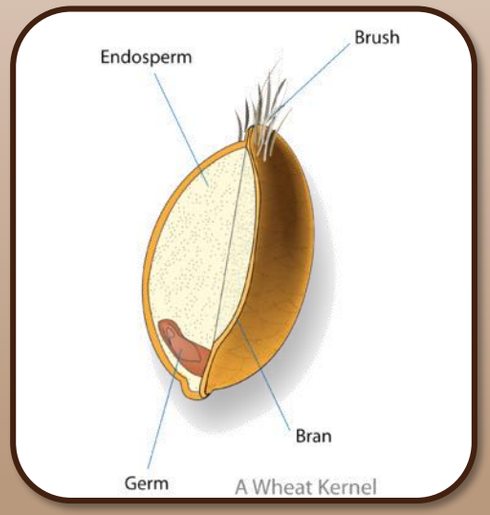
# COMMERCIAL GRINDING

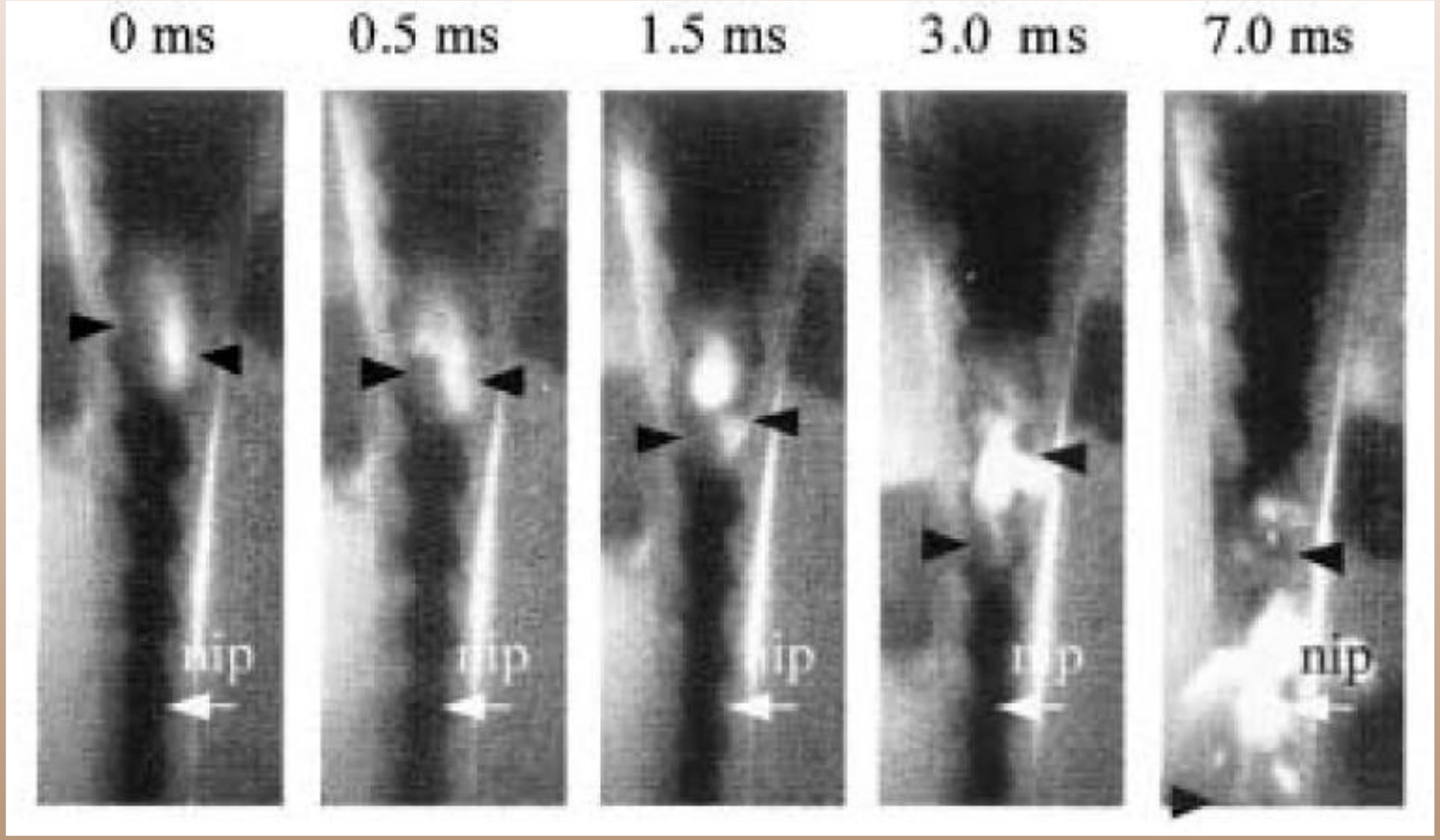
Roast whole beans




Roast & ground

# MOST PUBLICATIONS ARE ON CEREAL GRINDING

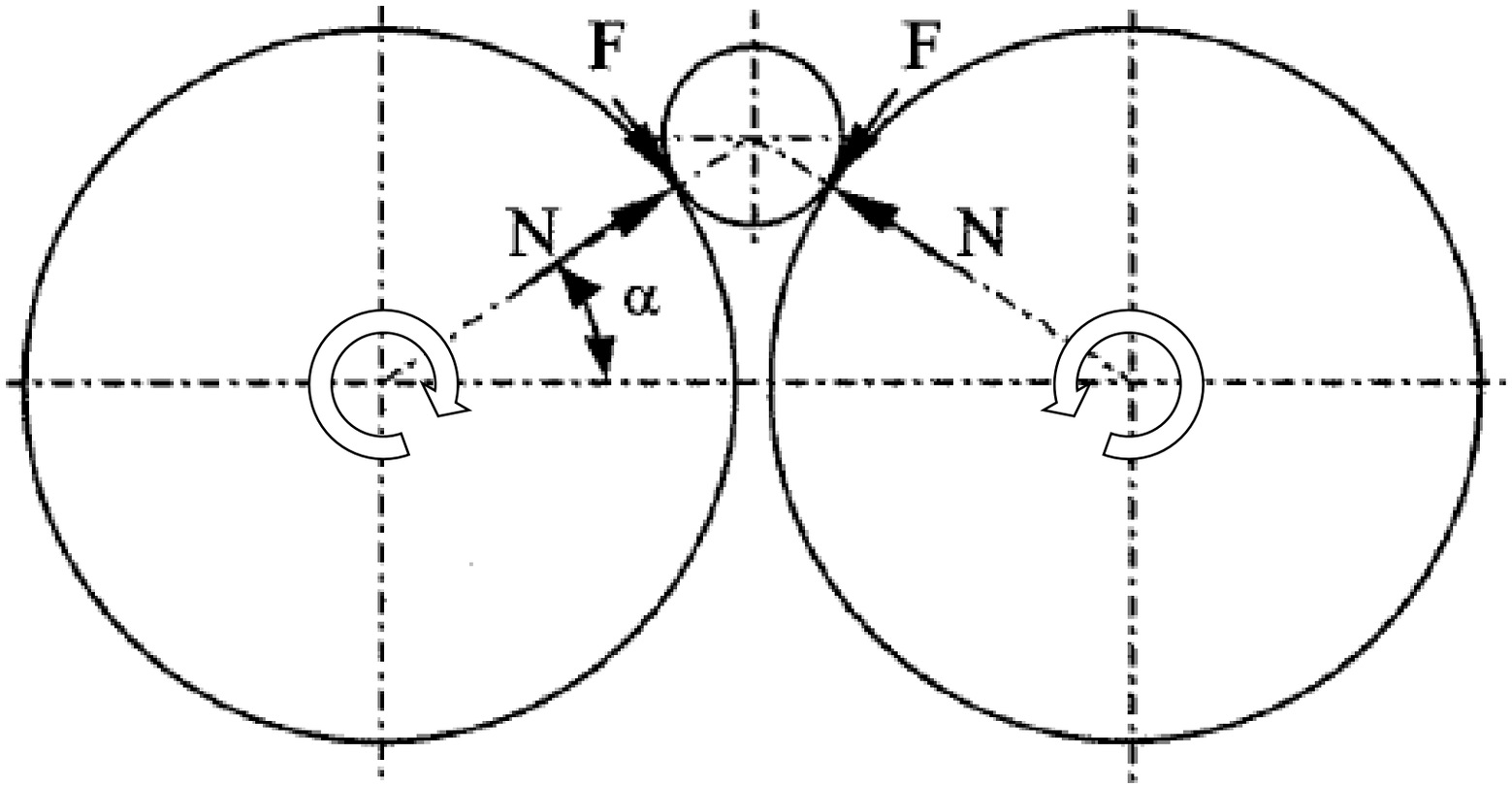



Behaviour strongly dependent on the plant histology: e.g. for wheat, have endosperm, germ, bran etc.

[C. Fang & G.M. Campbell, Cereal Chem., 79(4), p511 (2002)]

# SOME PRINCIPLES CARRY OVER TO COFFEE

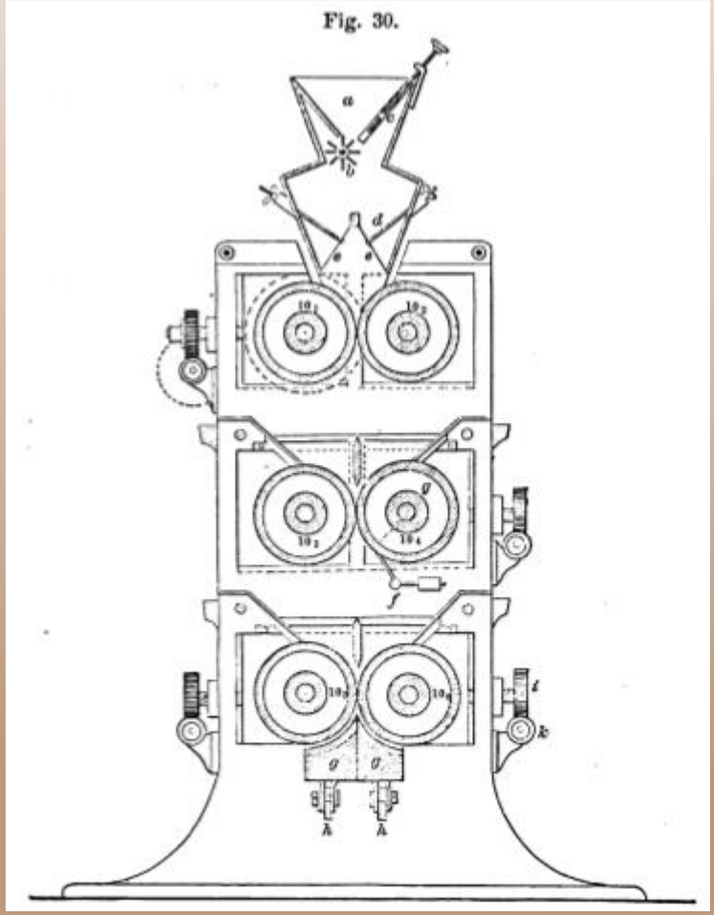



Grinding with fluted rolls is more complex …

[C. Fang & G.M. Campbell, Cereal Chem., 79(4), p511 (2002)]

# GREEN FUNCTION APPROACH (WHEAT)

Wheat milling is typically done through a cascade of different rollers, to separate as well as comminute the grains.




Early-modern 3-stage mill from Vienna (1873)

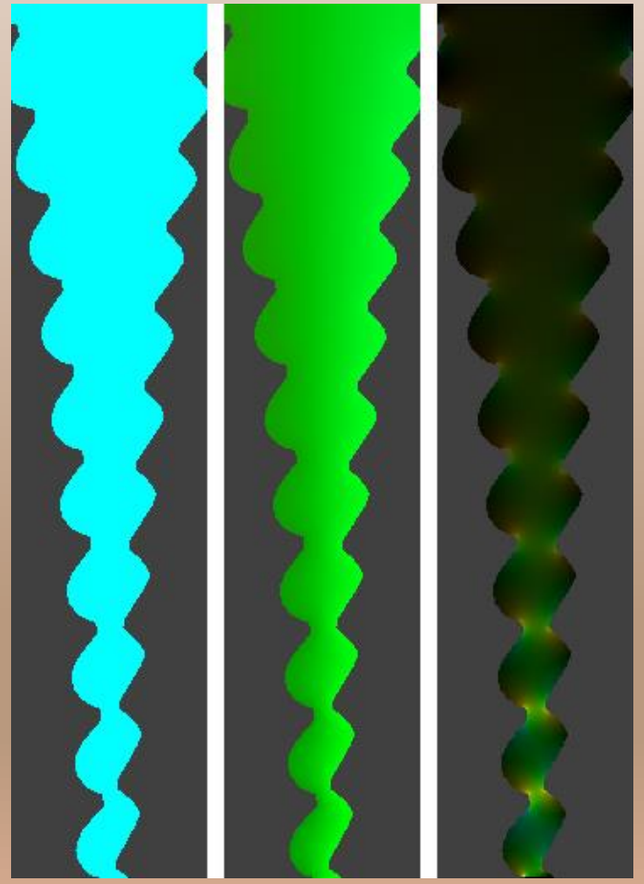
A common approach is to define a breakage function B for each roller, so that PSD out is a convolution:

$$\rho_1 \xrightarrow{B} \rho_2$$

$$\rho_2(D) = \int_{x=0}^{\infty} B(D,x)\rho_1(x)dx$$

# DENSE FLOWS OF ERODING MATERIALS

Probably too complex for a full DEM simulation, but might be susceptible to a continuum approach … if we knew the physics better.



Two interesting things that can be said on general principle:

Debris-flow, Himalayas

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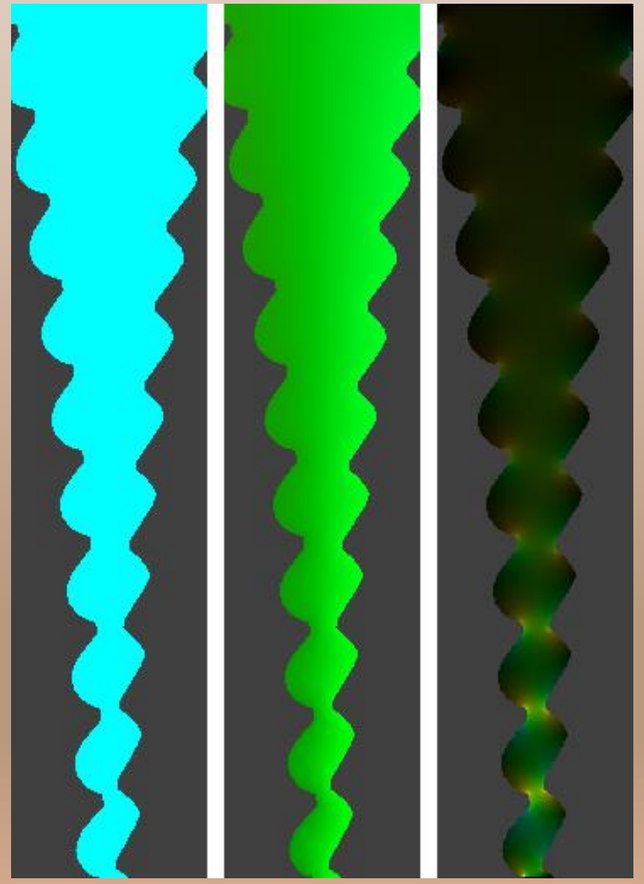

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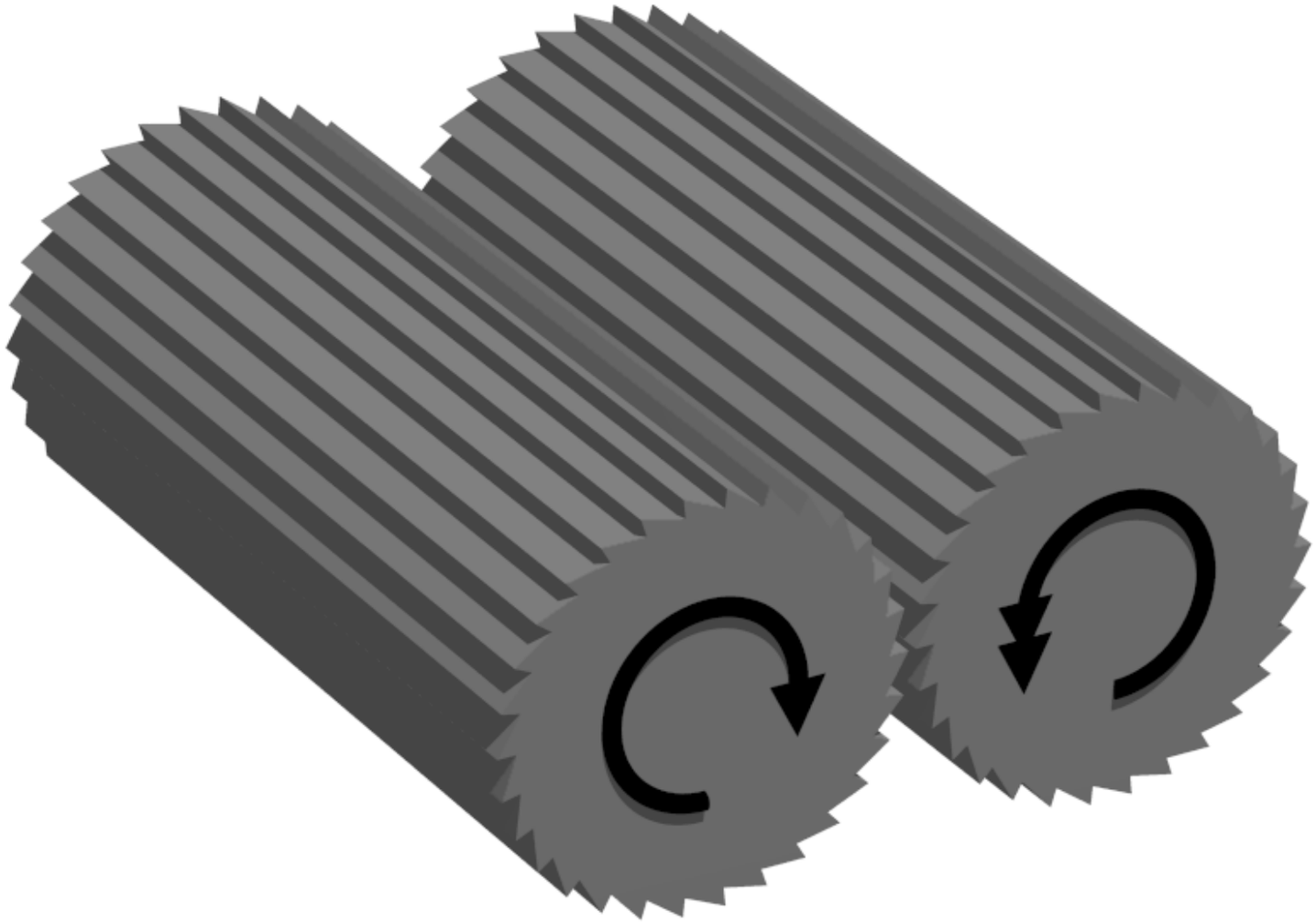
**(1) Roller speeds << fracture velocity**

Therefore, we expect the size distribution to not be very sensitive to roller speed

# GRINDING GEOMETRY (FLUTED)



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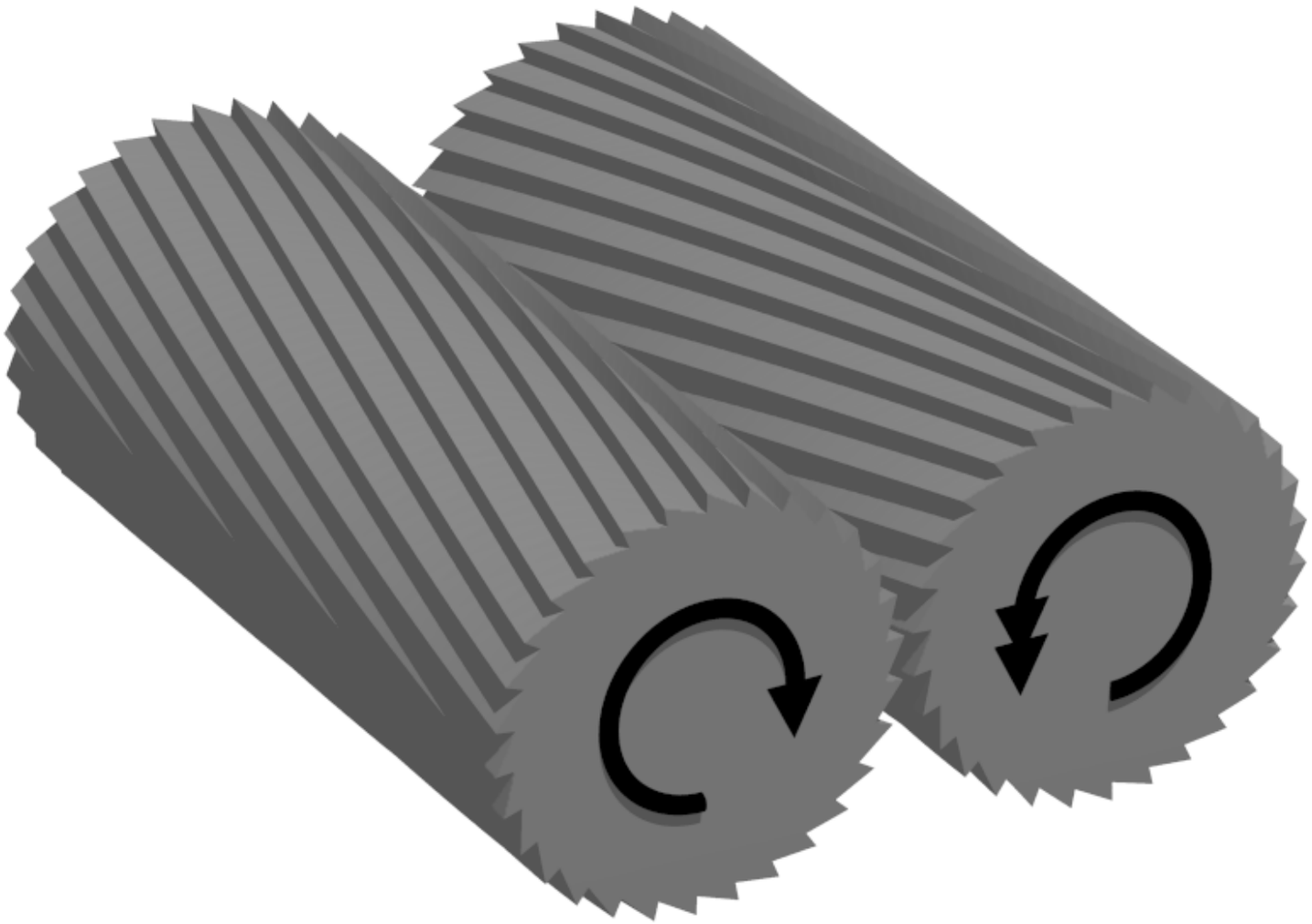
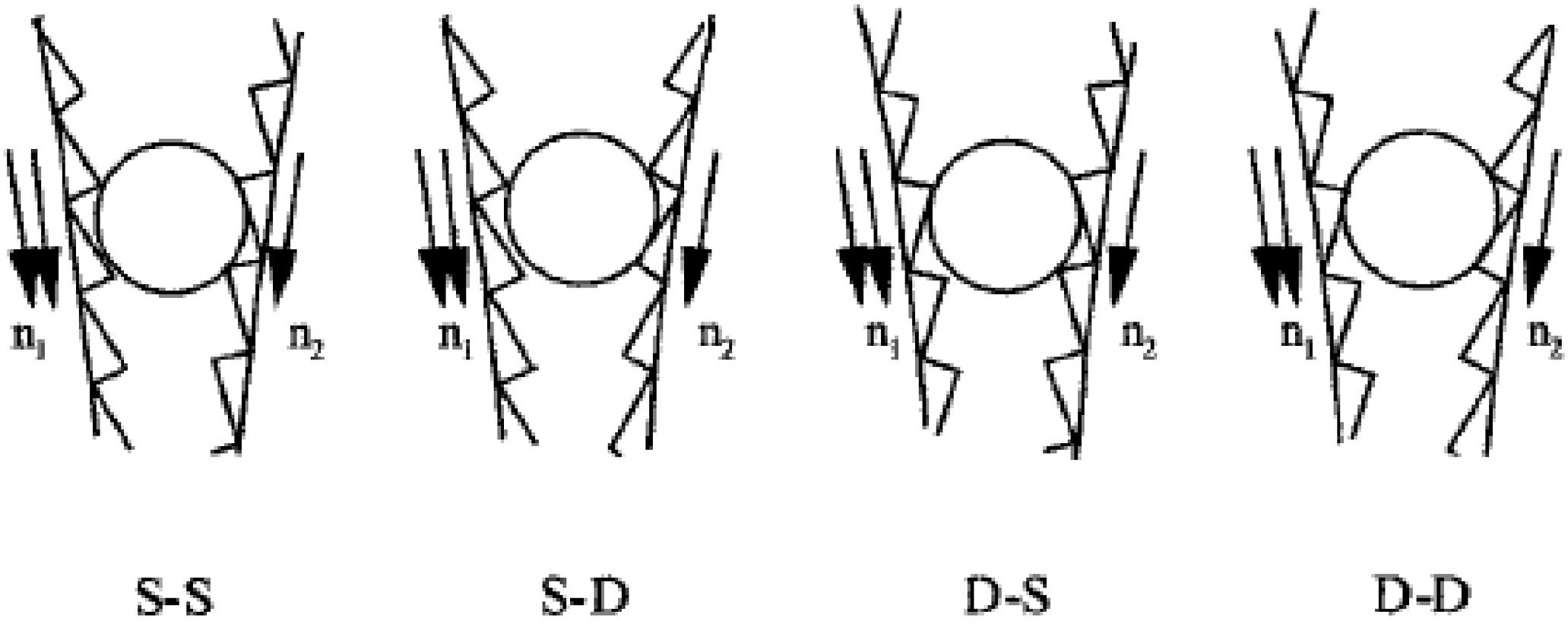


# (2) AN ARGUMENT FROM RELATIVITY

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# EXTRACTION

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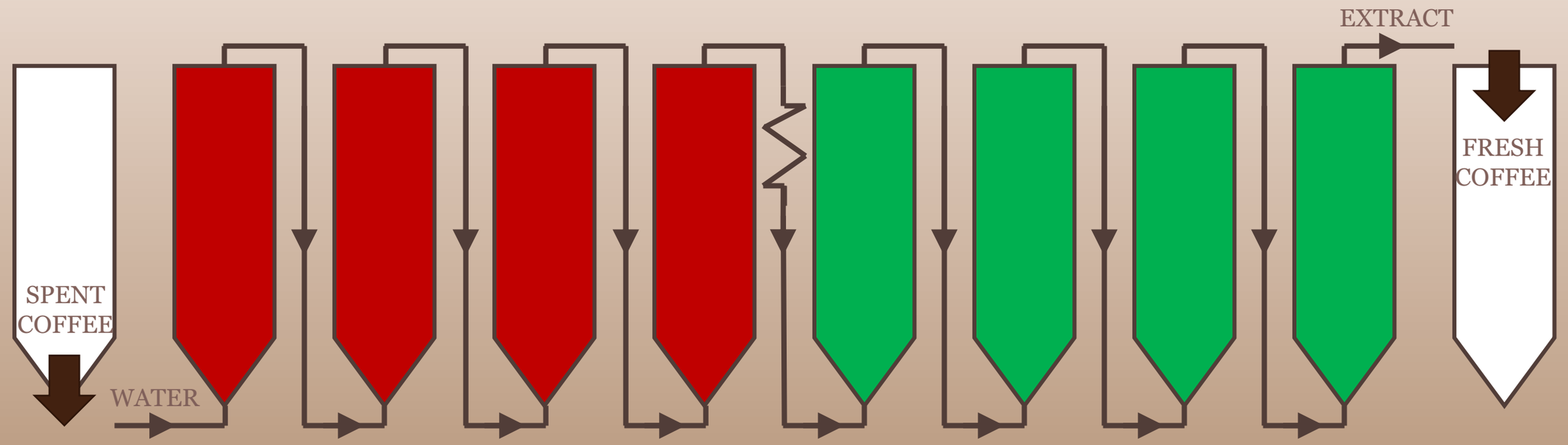

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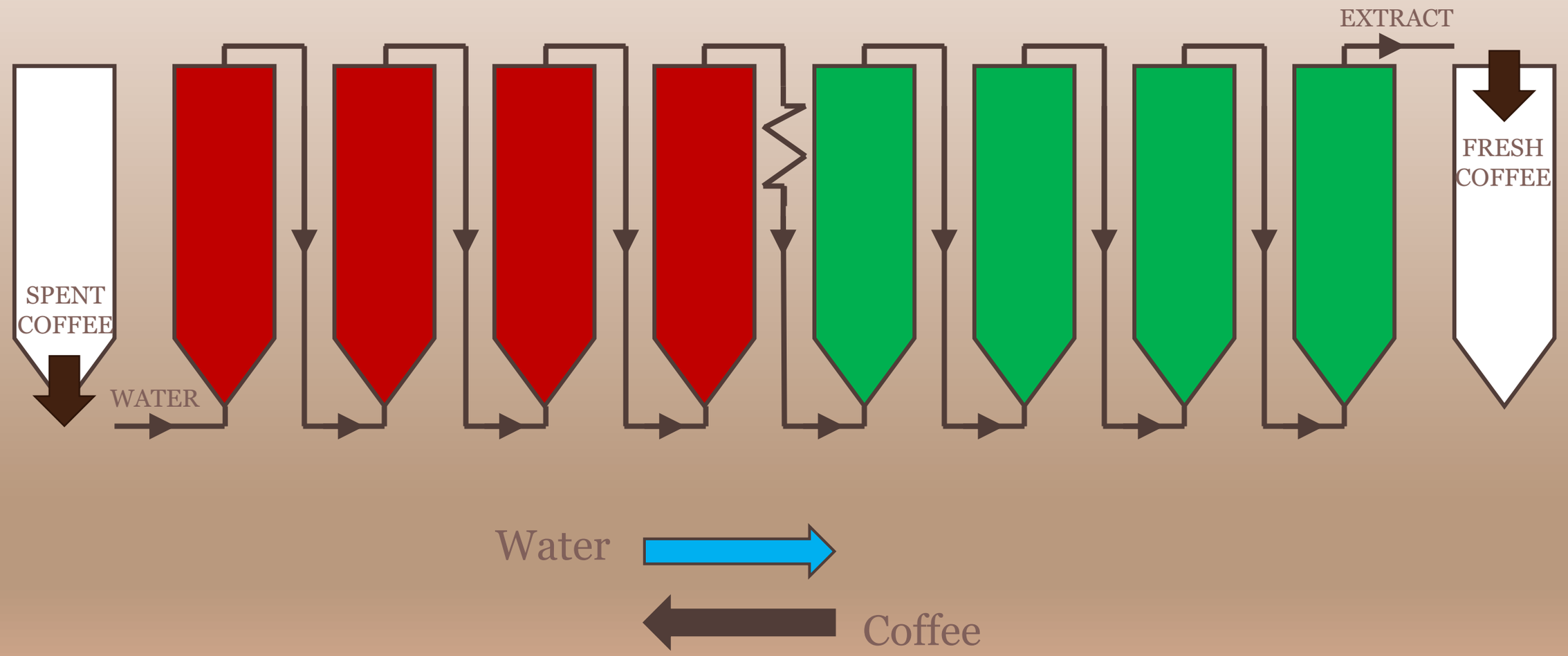
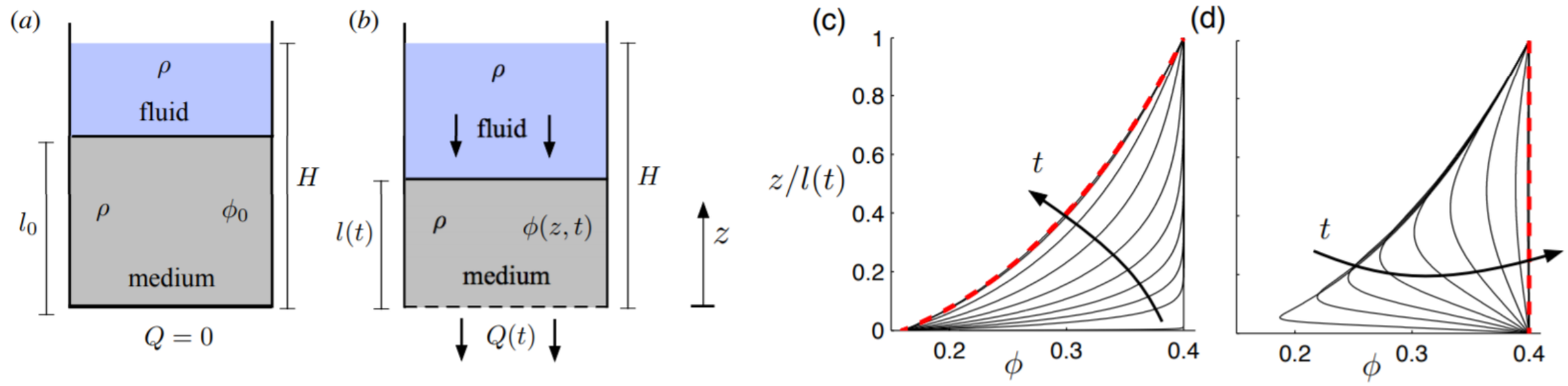


# PRESSURE DROP

One important aspect is the pressure drop across each of the array of columns.
At first blush, this is a problem of flow through a porous medium.

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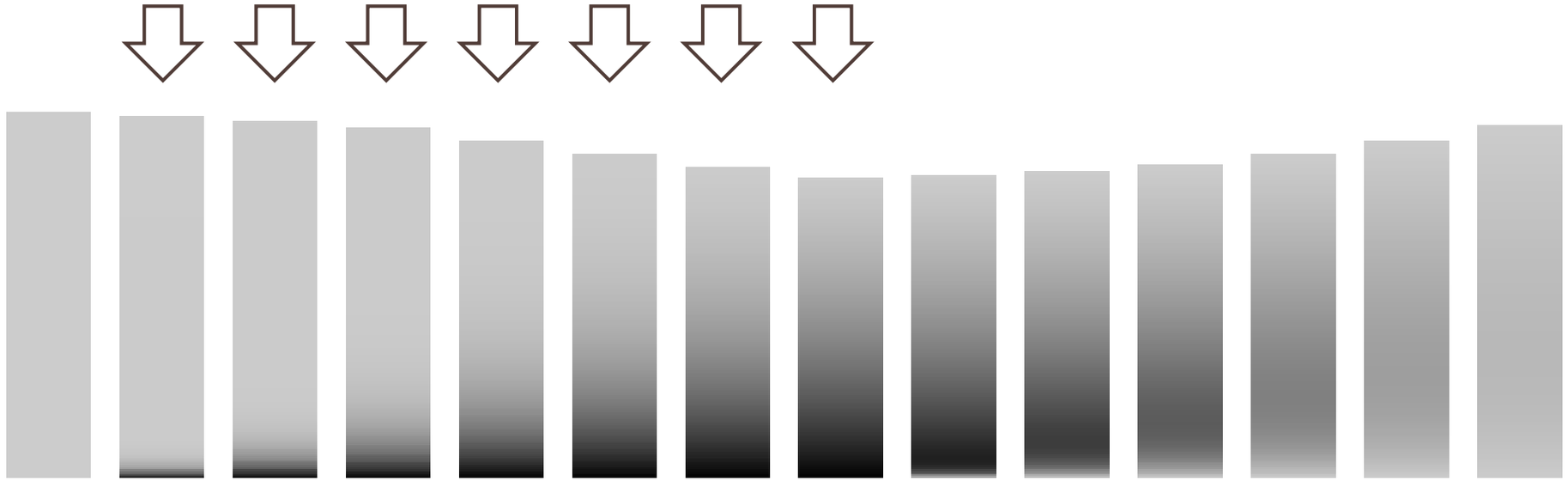

Sketch showing complex loading & unloading dynamics.

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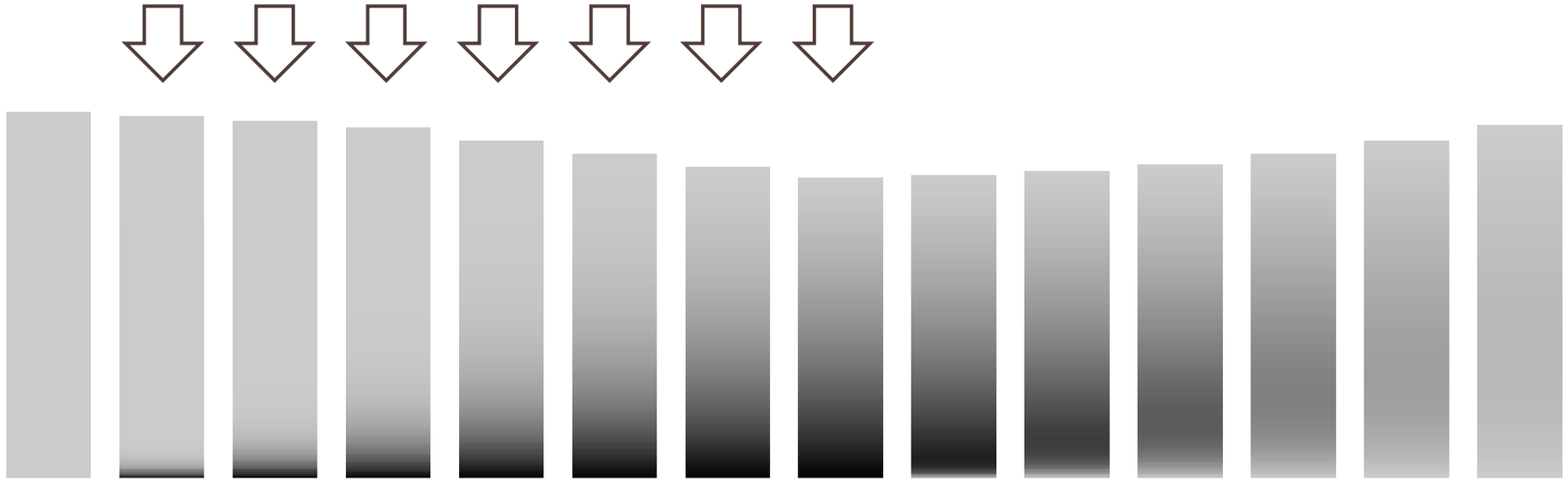

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**+ time-dependent hydrolysis (changing elastic properties)**
**+ extraction (mass of particles changes)**
**+ visco-elastic flows (at least at high extract concentration)**

# FREEZE-DRYING

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Conc. coffee solution

Freezing: most water to pure ice

Sublimation at low T & p


Packaging

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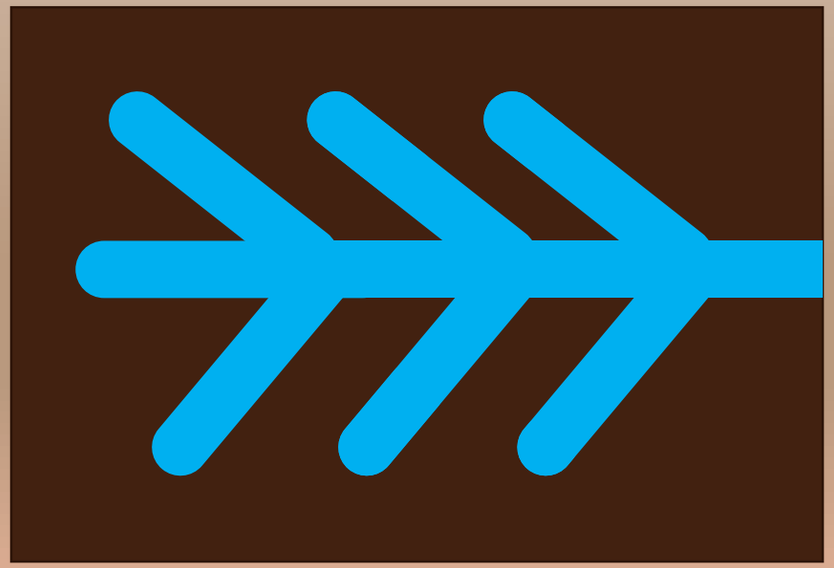

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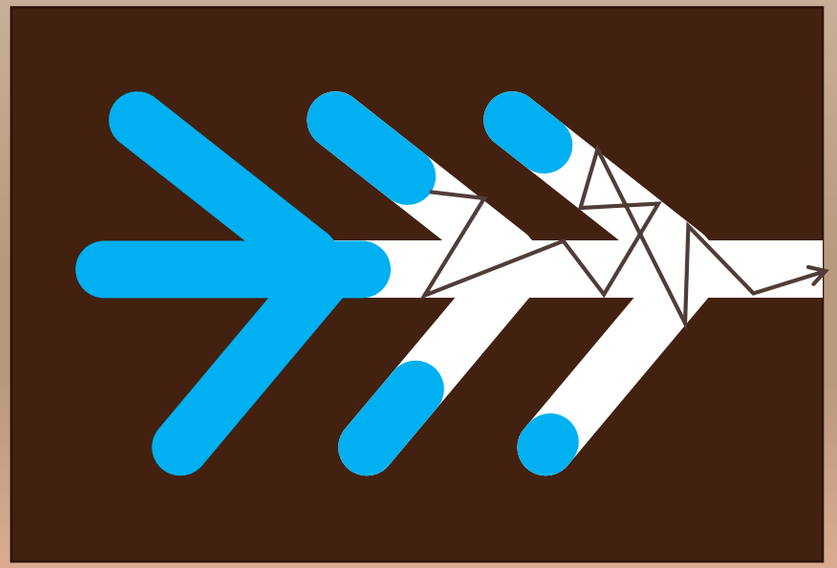

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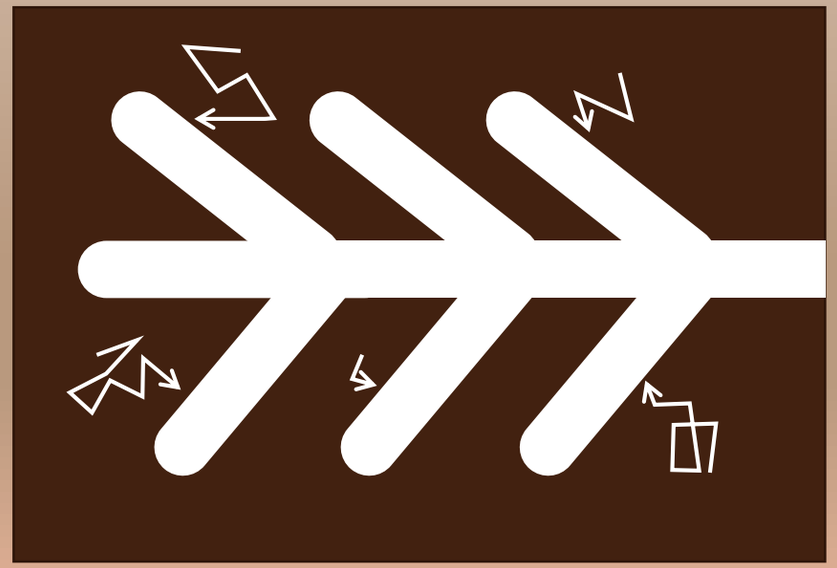


Glass transitions
Elastic instabilities at large deformation
THE WORLD IN A CUP OF COFFEE
Fracture of porous materials
Mass transport in the glassy state
Ripening dynamics
Statistical mechanics of fragmentation
Flow of granular materials
Forced flows in poroelastic media

JDE

A coffee for *every cup*

JACOBS TASSIMO TiLORA Senseo LÒR

DOUWE EGBERTS Super PILÃO MOCCONA KENCO GEVALIA