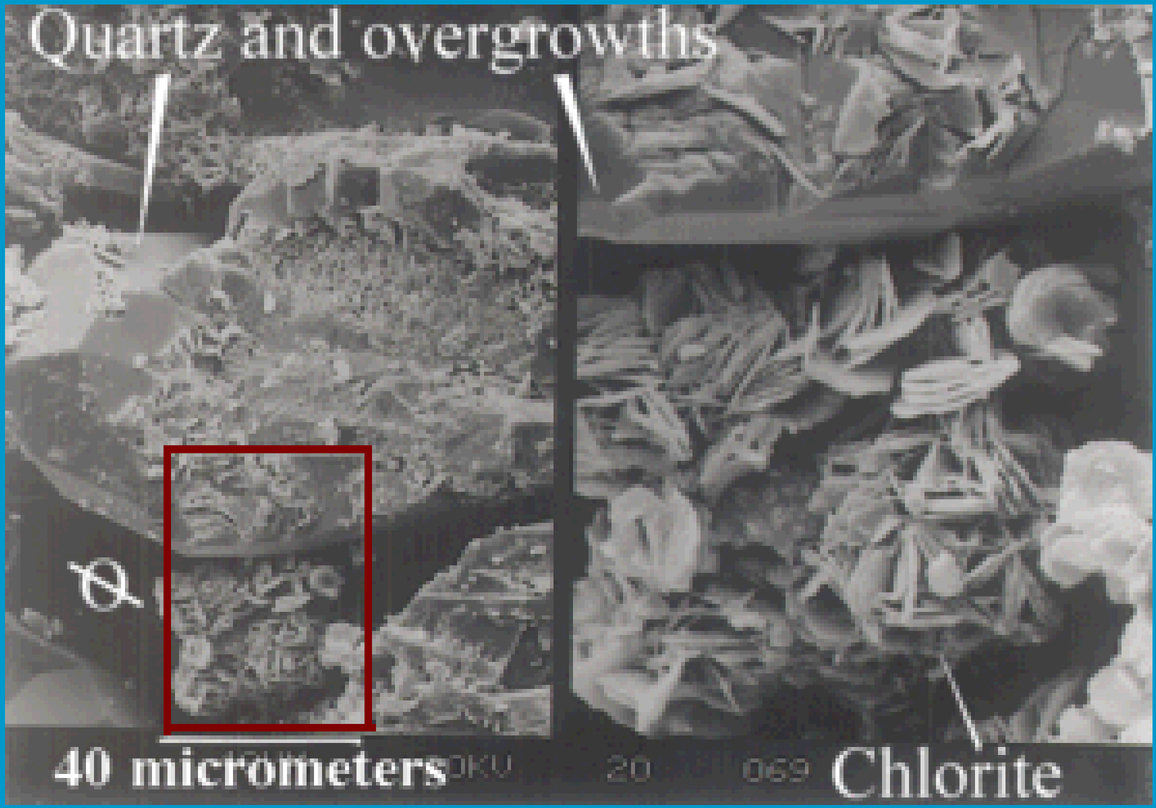
Intreerede prof.dr. W.R. Rossen hoogleraar Reservoir Engineering

‘Complexity and Simplicity in Modeling Oil Reservoirs’

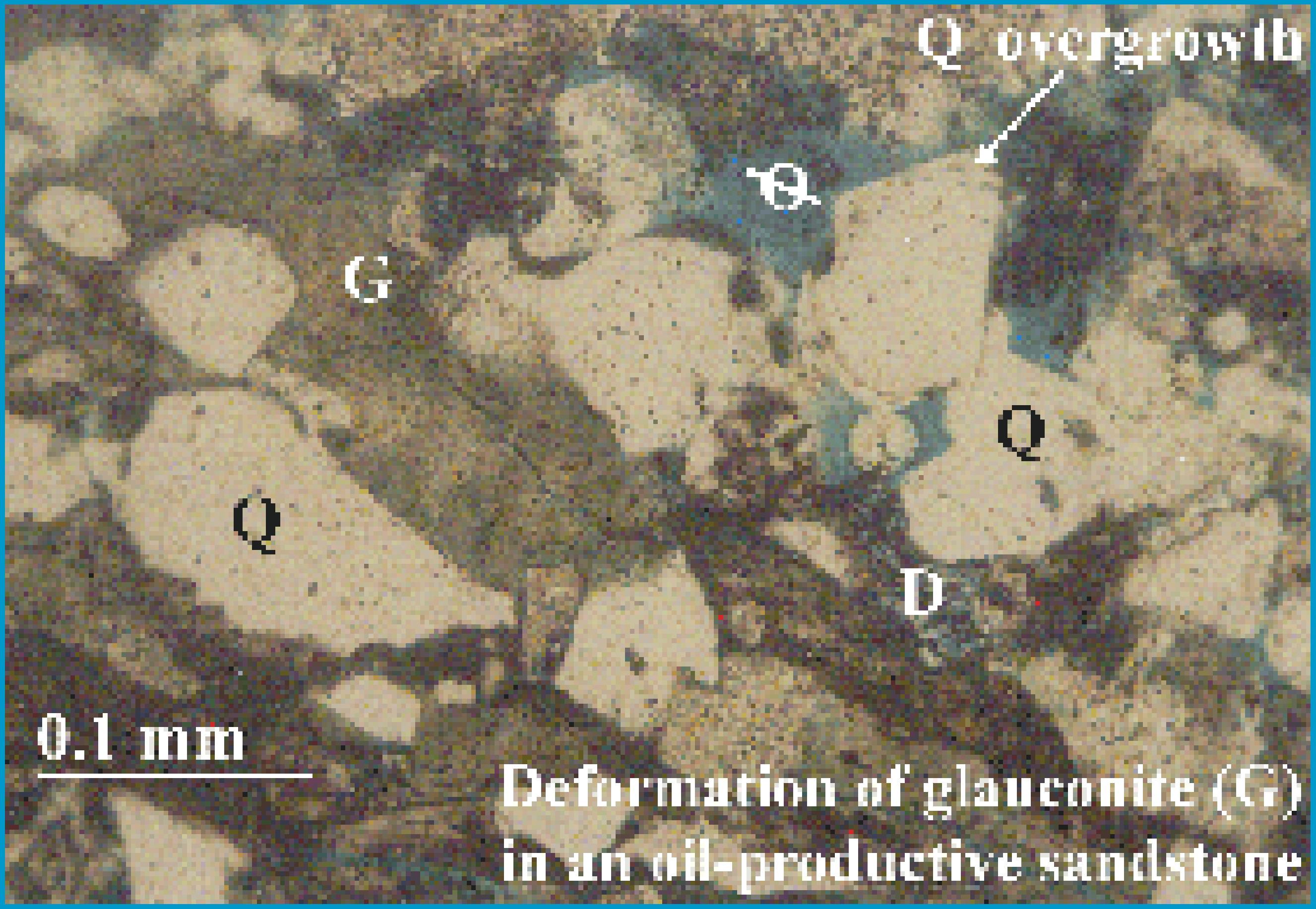
Technische Universiteit Delft

Geological Complexity

Scale: μm



Scale: mm



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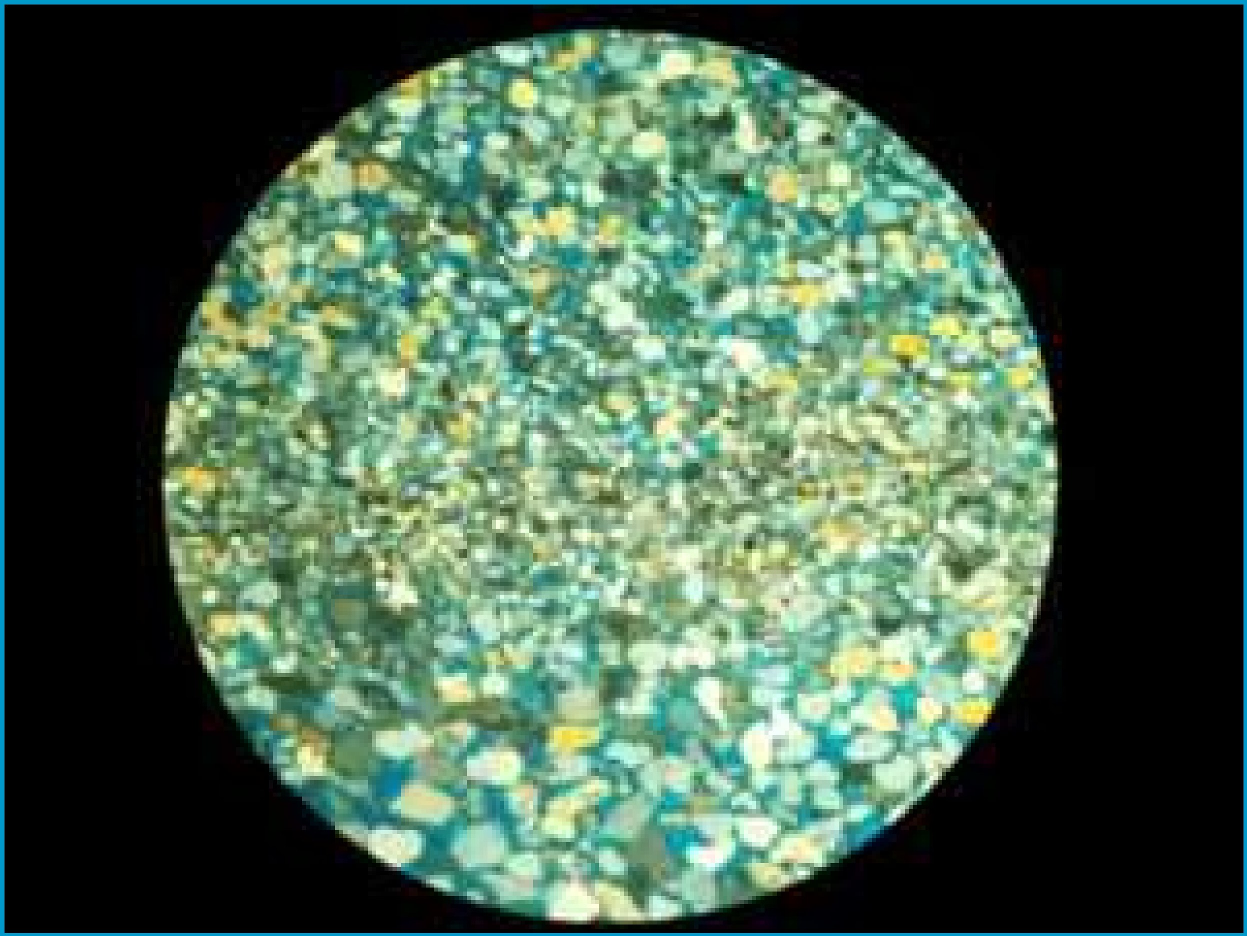
Representing the pore network

Scale: cm



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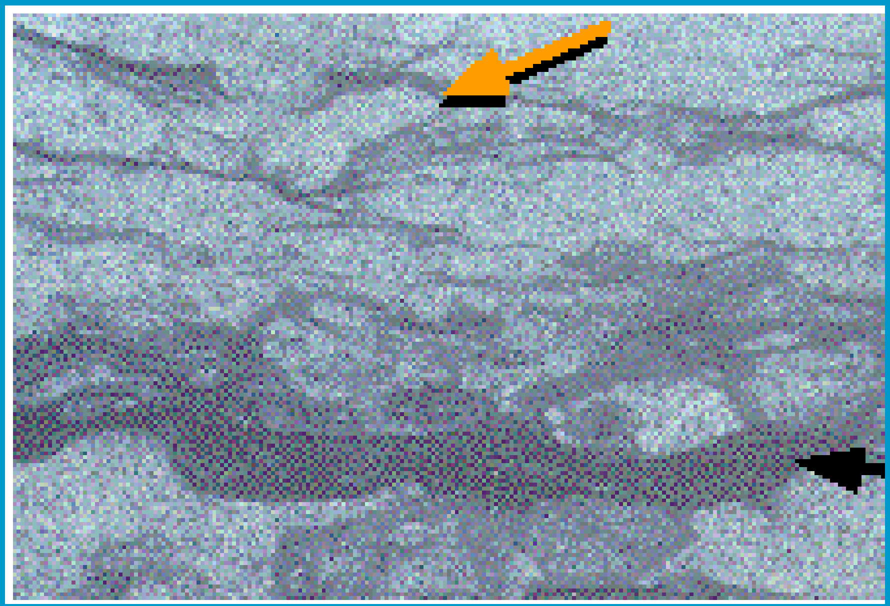
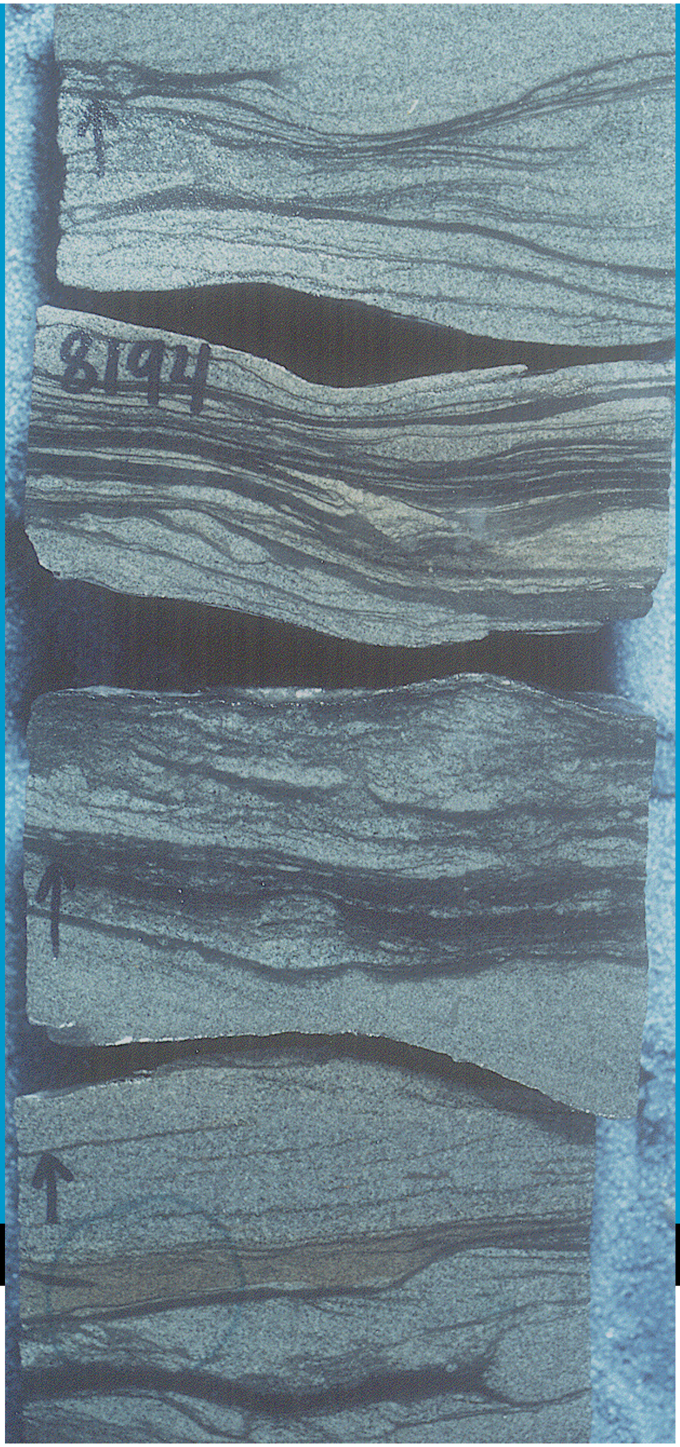
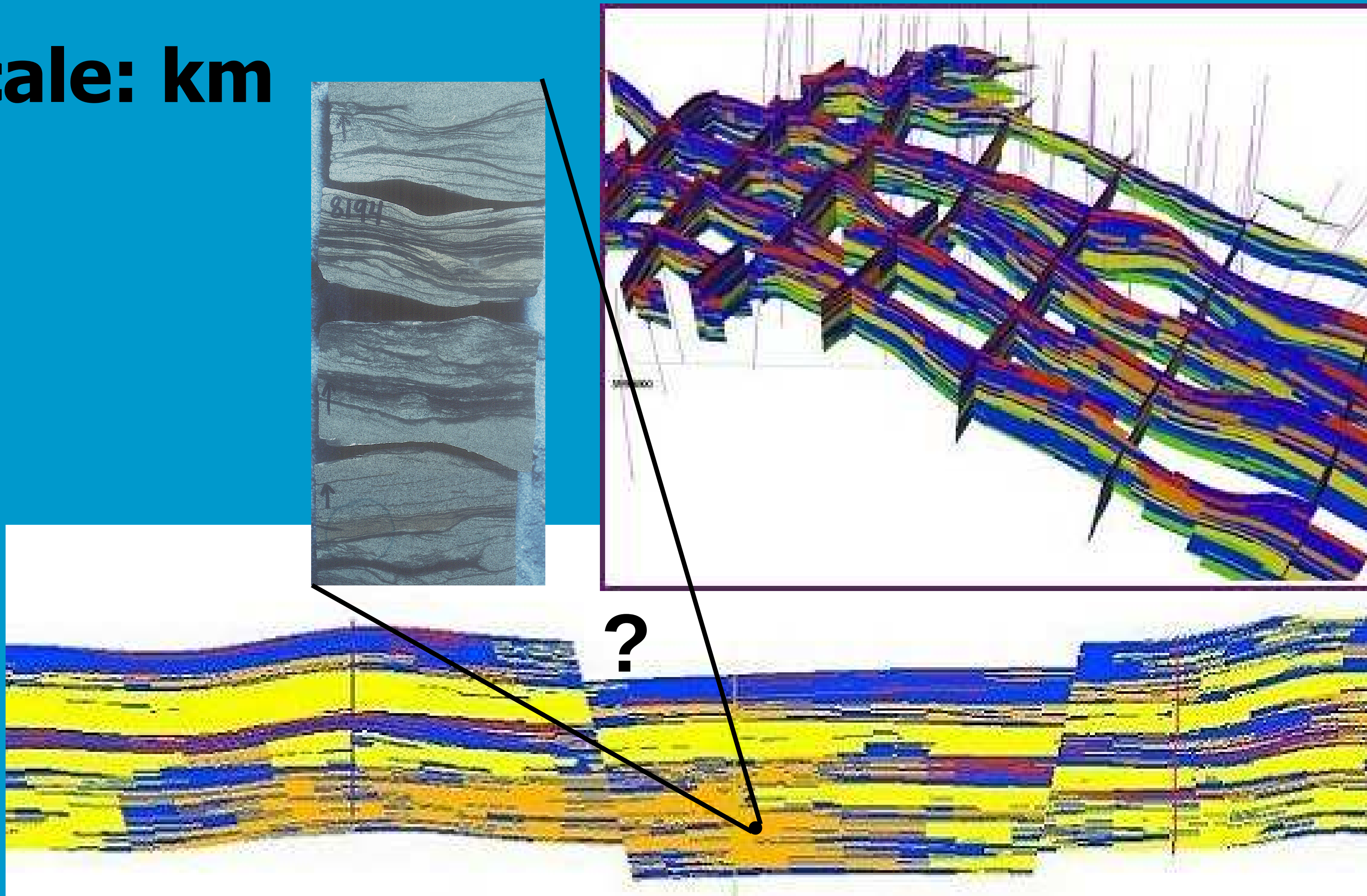
Scale: 10 cm





Scale: km



"All models are false, but some models are useful."

- George E P Box

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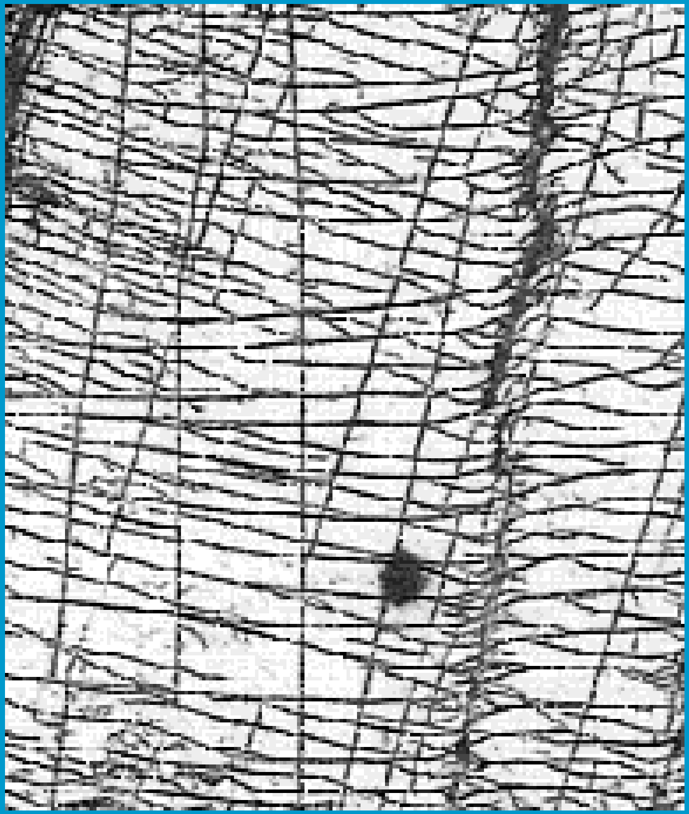
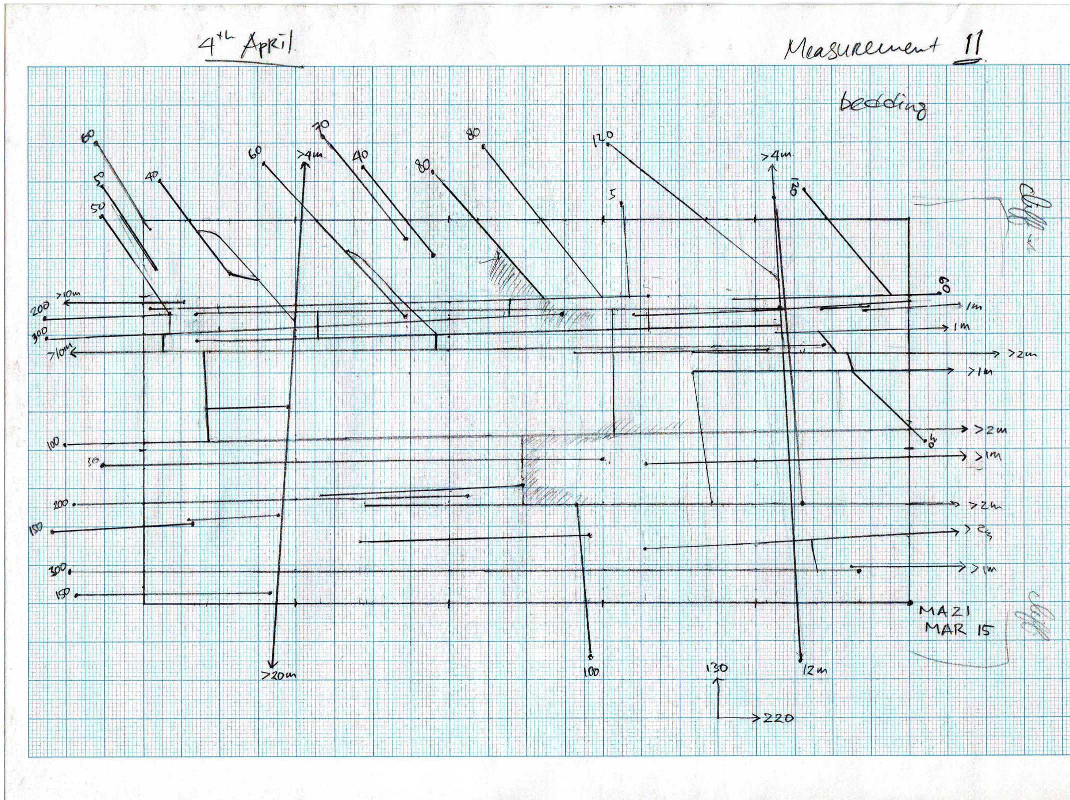
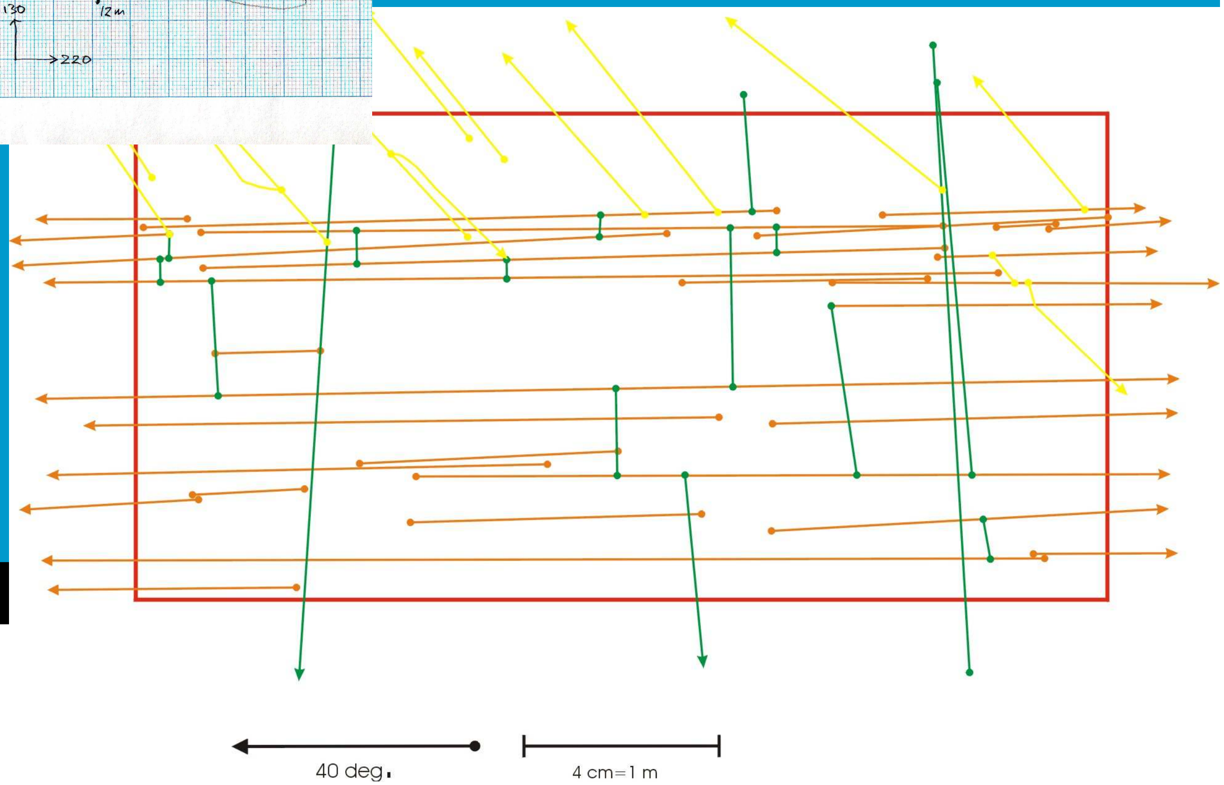
Fractured Oil and Gas Reservoirs

Fractures



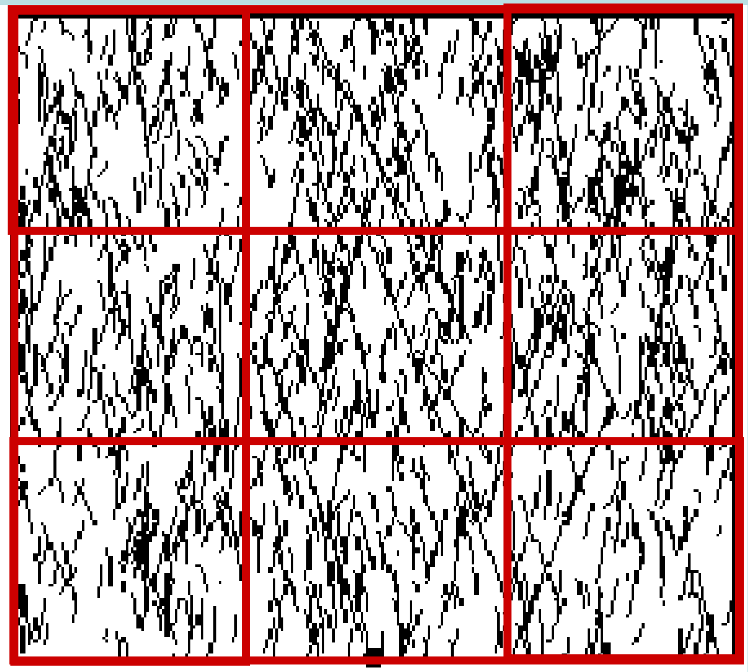


4th April
Measurement 11
bedding
MA21
MAR 15

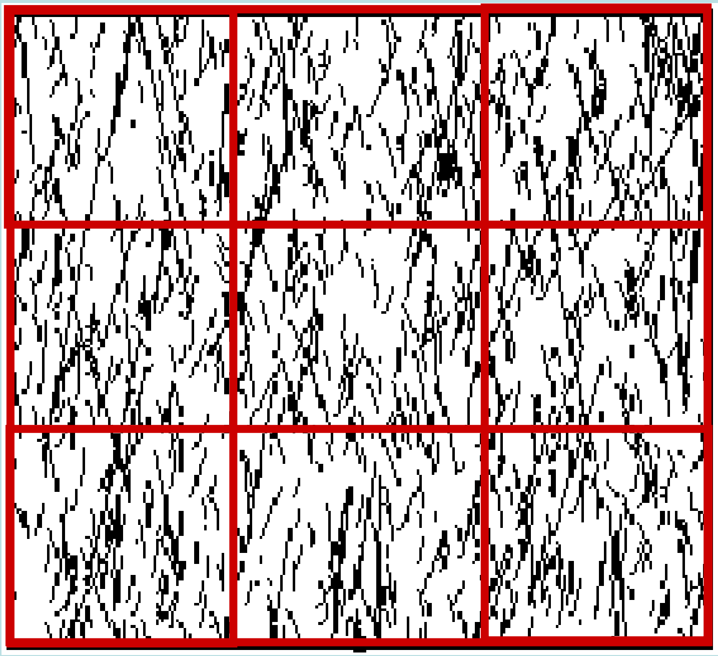


40 deg.
4 cm=1 m

connectivity at large scale, not small



connectivity at small scale, not at large



What is essential in describing fractured reservoirs?

1. almost all flow is through network of small-volume fractures; almost all the fluids reside a much larger volume of low-conductivity matrix between fractures
2. fluids in fractures exchange slowly with the matrix; time for exchange ~ distance between fractures
3. exchange between matrix and fractures varies in time
4. fractures are themselves 2D porous media, with complex flow and storage properties
5. flow is not uniform in the fracture network; even some fractures are "left out" of the main flow path
6. exchange is not uniform in the matrix; some matrix exchanges rapidly; other regions are either far from any fracture or far from the fractures conducting flow

Issues in modeling fractured reservoirs

1. what is the average conductivity for the fracture network in a given region? How does this vary from region to region?
2. how does this average relate to the measurable properties of the fractures (length distribution, aperture distribution, orientation distribution, clustering properties…?)
3. what is the average distance between fractures in a given region? How does this vary from region to region?
4. what is the correct mathematical form to represent the matrix-fracture exchange process? how much historical information needs to be saved to represent this exchange accurately?
5. is it essential to represent the variability of fracture participation in the flow? the variability of accessibility of matrix to fractures?
6. is this complexity essential, or of a second-order importance?

Gravity Segregation in Improved Oil Recovery

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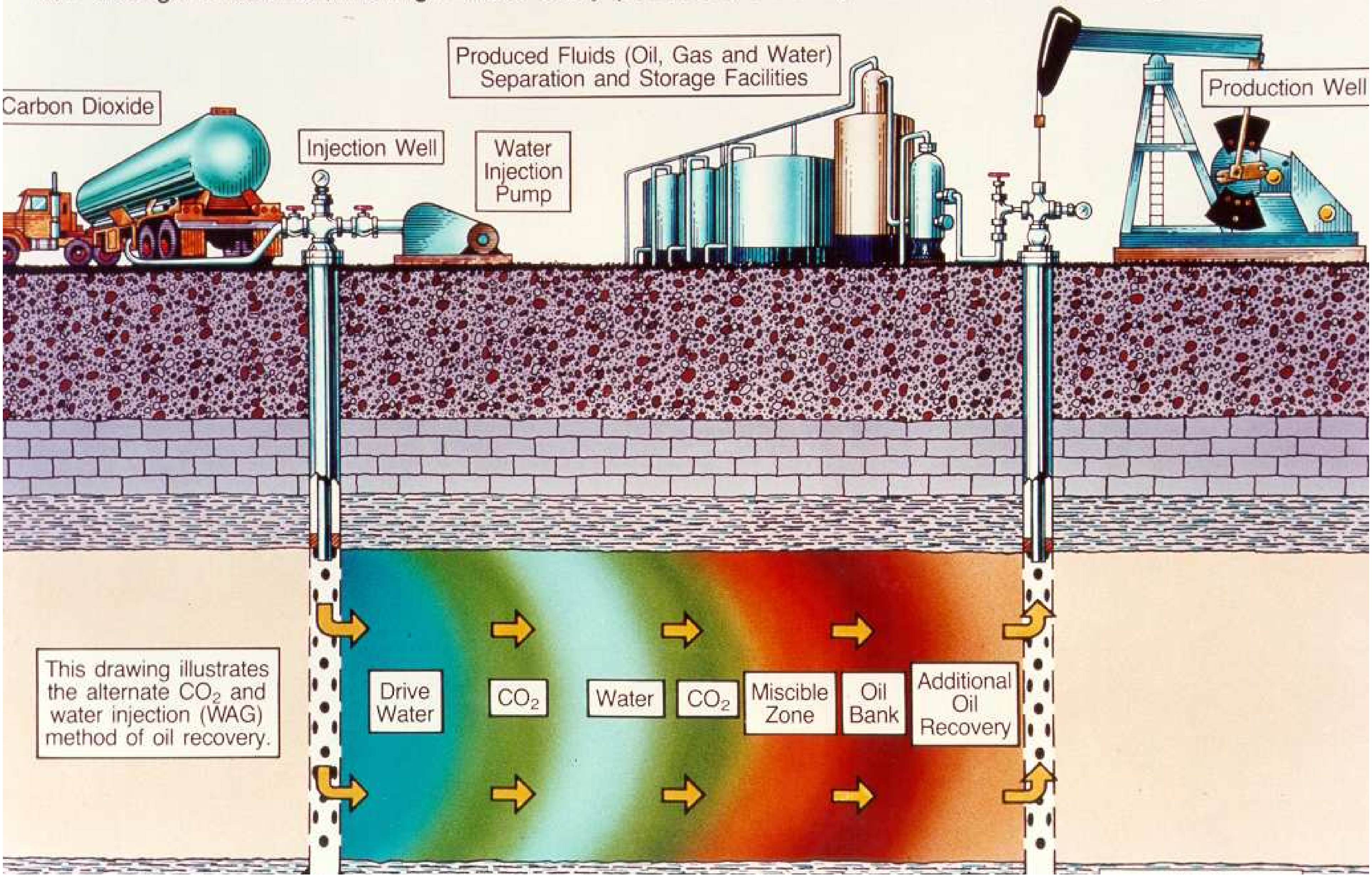
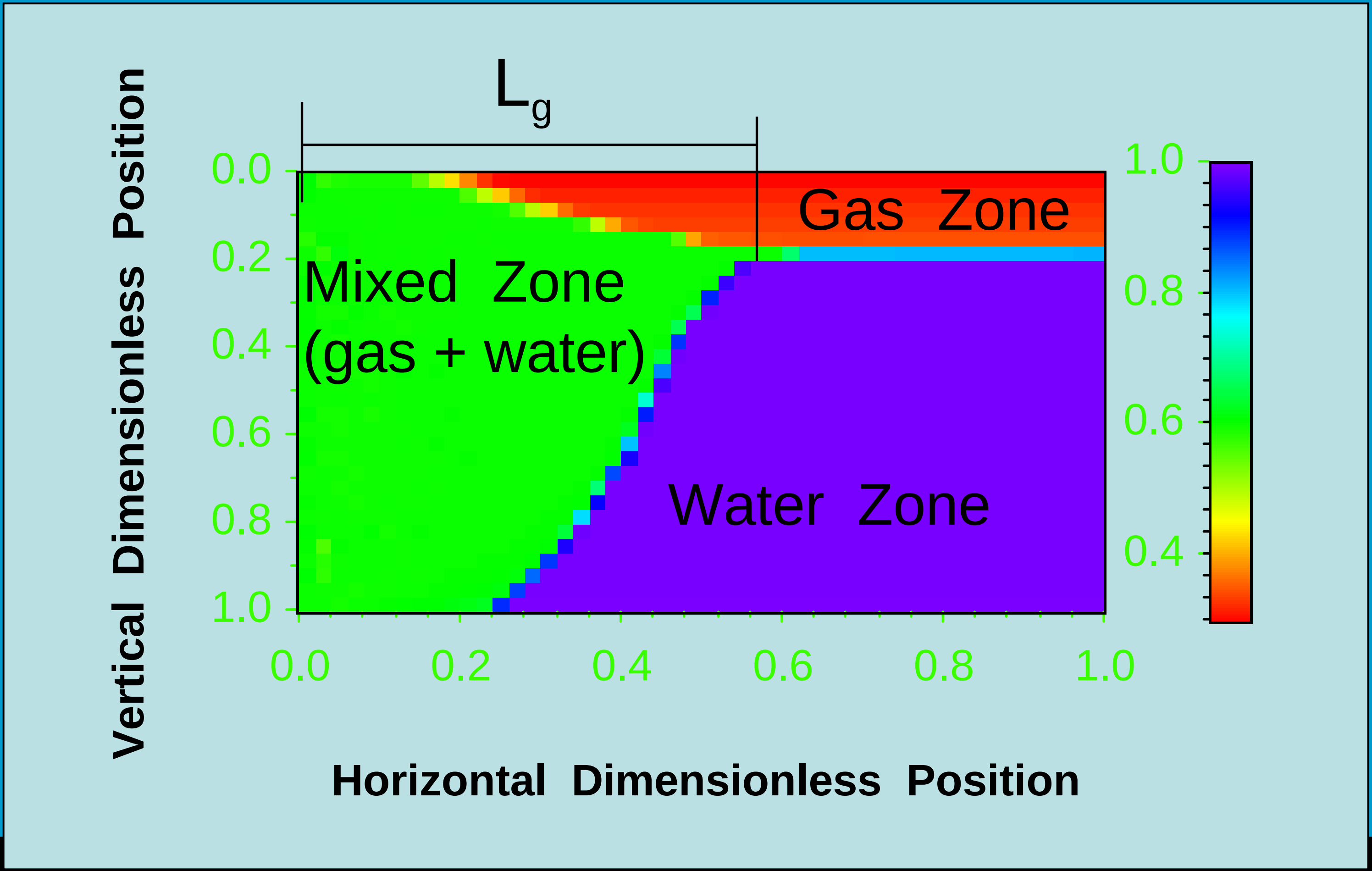
MISCIBLE RECOVERY

Recovery methods in this category include both hydrocarbon and non-hydrocarbon miscible flooding. These methods involve the injection of gases (carbon dioxide, nitrogen, flue gases, etc.) that either are or become miscible (mixable) with oil under reservoir conditions. This reaction lowers the resistance of oil to flow through a reservoir, making it more easily produced, either by water drive or injected gas pressure.



Gravity segregation in gas IOR



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Analytical model for gravity segregation

- Ignores
  - geological complexity
  - details of flow properties of gas and liquids
  - presence of oil
- Prediction: what matters most is pressure drop across front where gas displaces liquid

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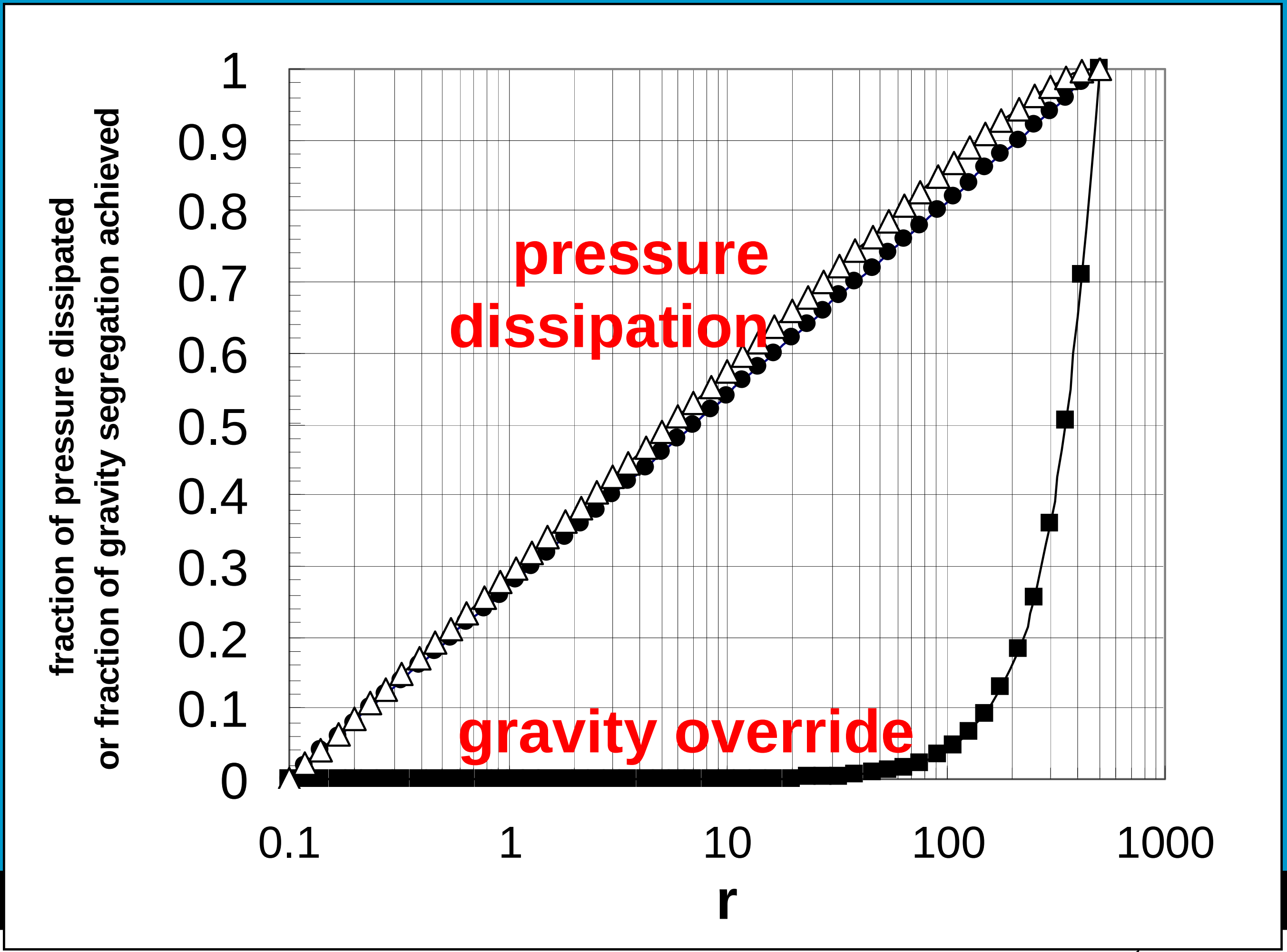
Analytical model for gravity segregation



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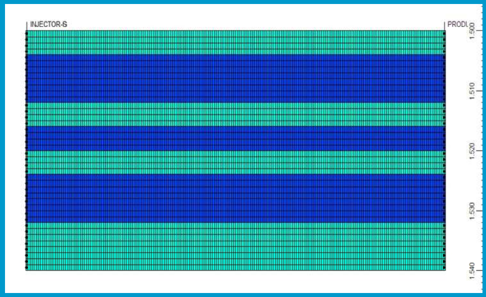
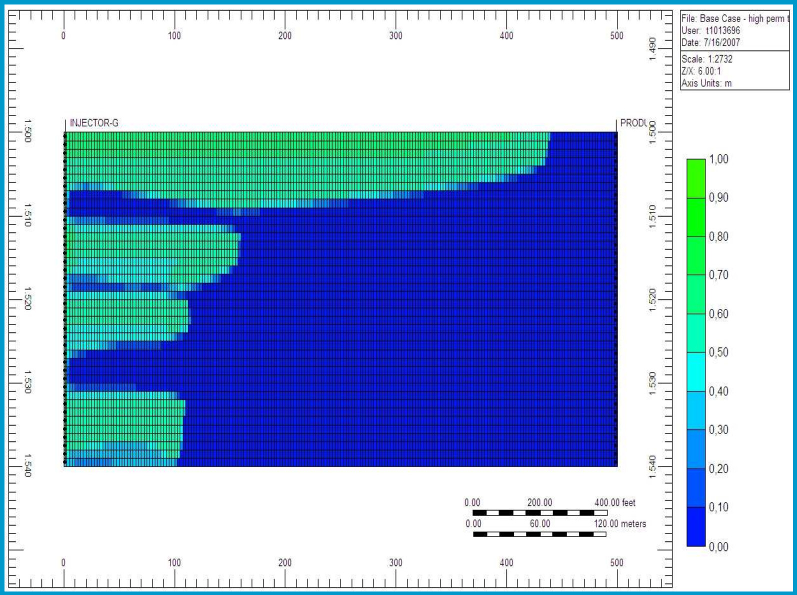
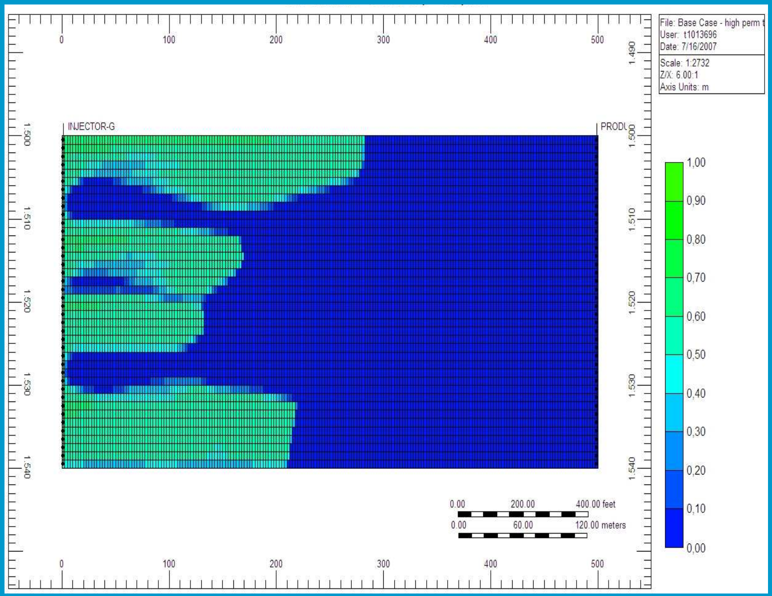
Analytical model: injection pressure *is* important





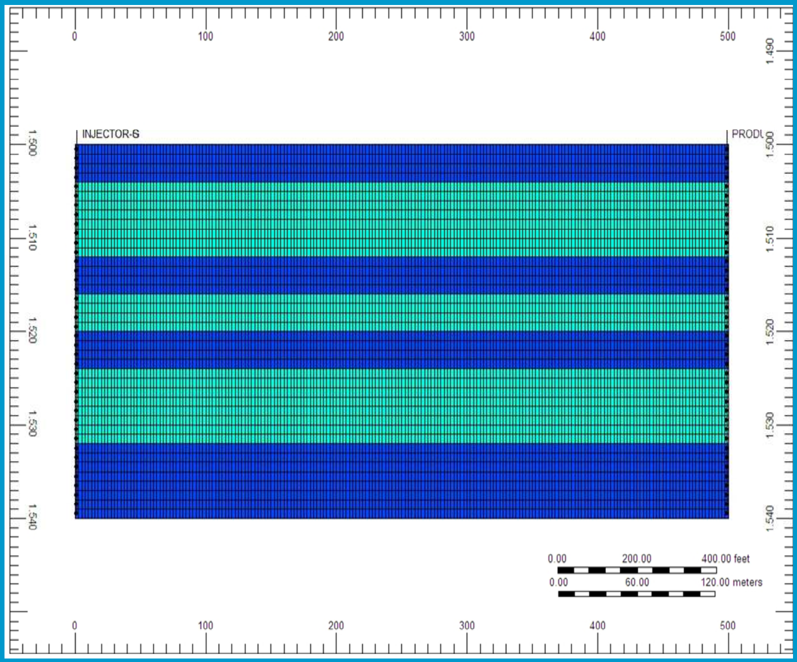
20 bar

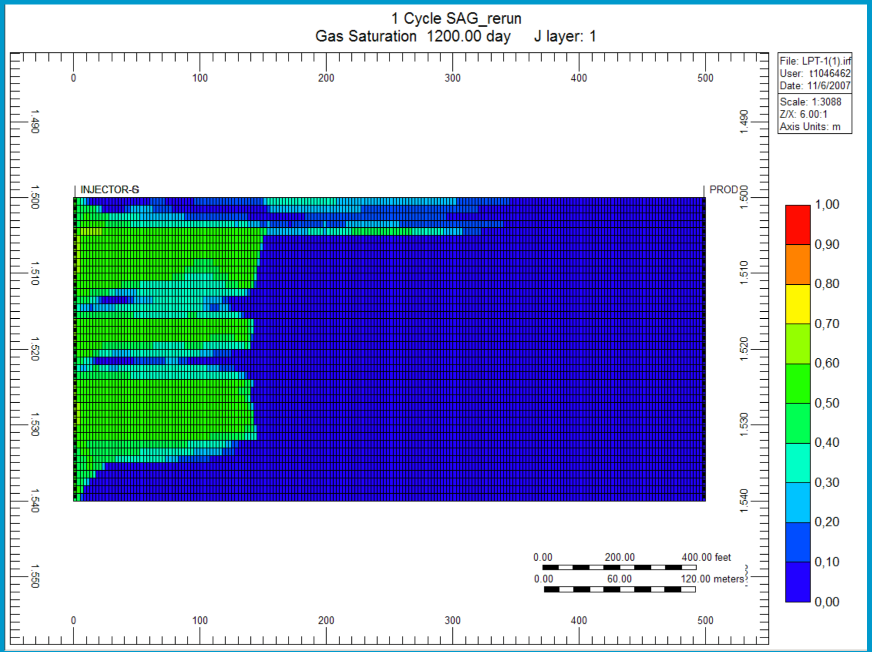


100 bar

Analytical model for gravity segregation

- Sometimes simple models don't tell the whole story …





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Foam in Improved Oil Recovery

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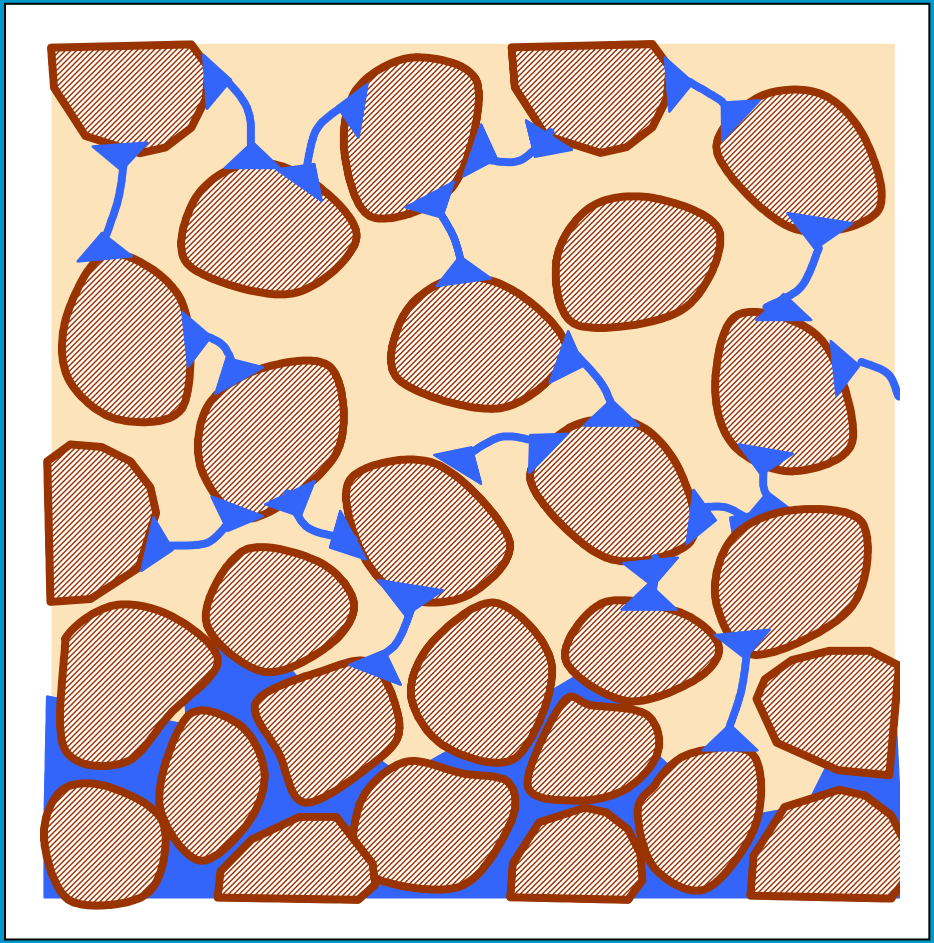
Foam: an example of complexity



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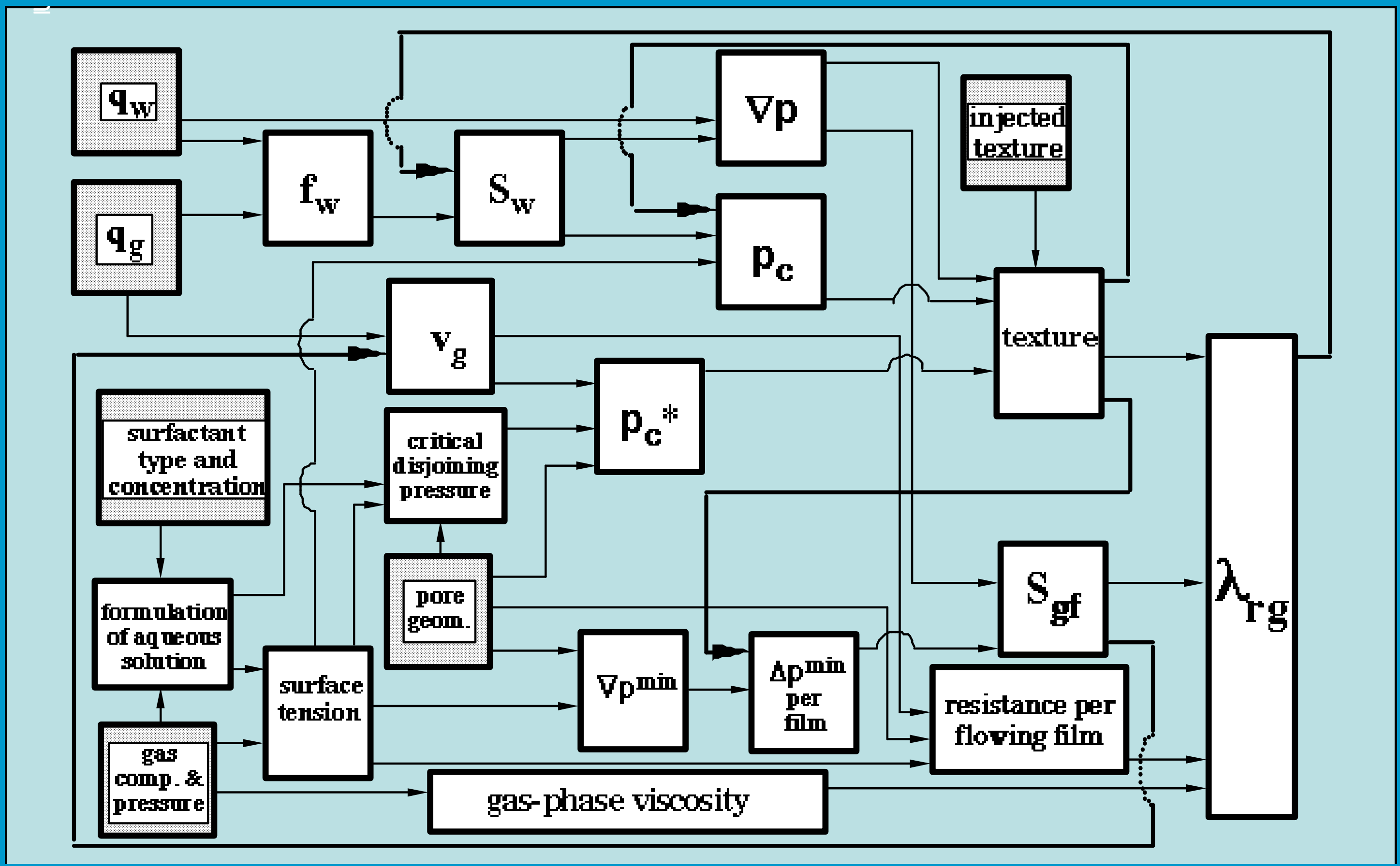
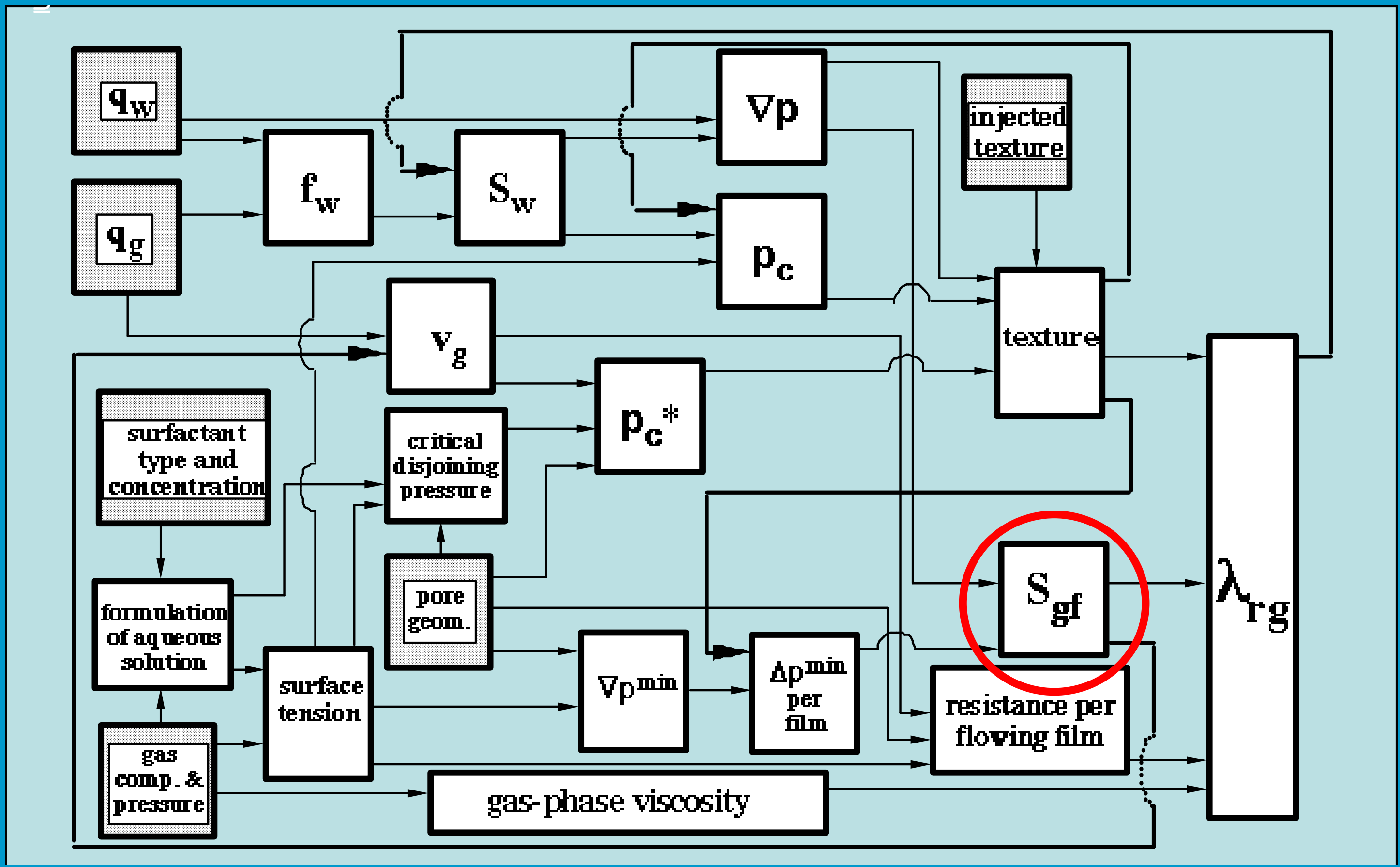
Relation between factors controlling foam properties



Relation between factors controlling foam properties



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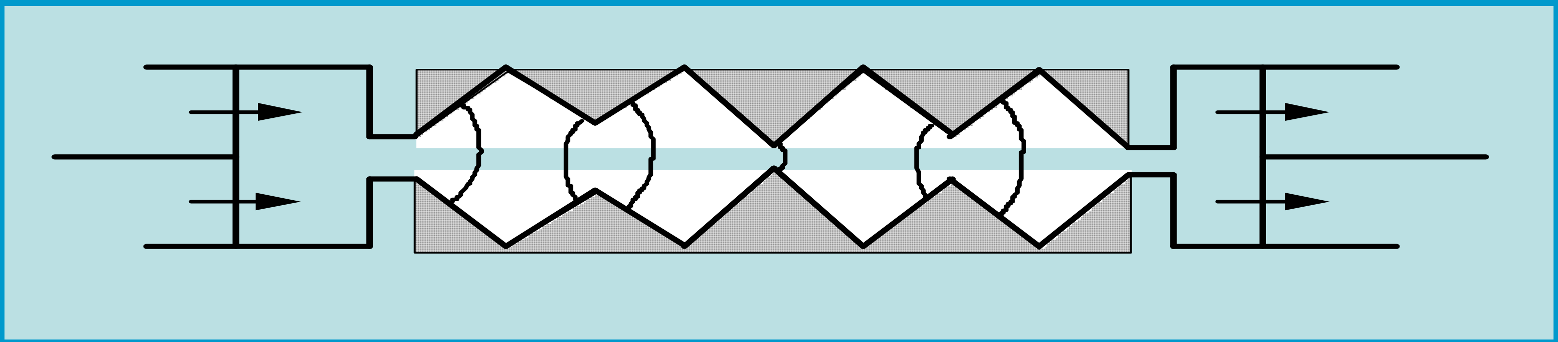
Yield stress of foam in porous media

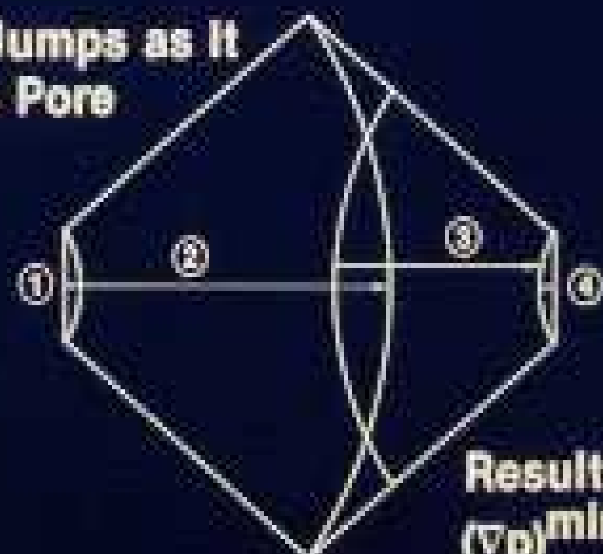
- Model:



$(\nabla p)^{min}$ for Bubble Trains

Focus on Capillary Δp as One Lamella Crosses One Pore

Lamella Jumps as It Traverses Pore



$(\nabla p)^{min} = (\Delta p)^{avg}\, n_L$

Result:
$(\nabla p)^{min} \cong 20$ psi/ft


1:5

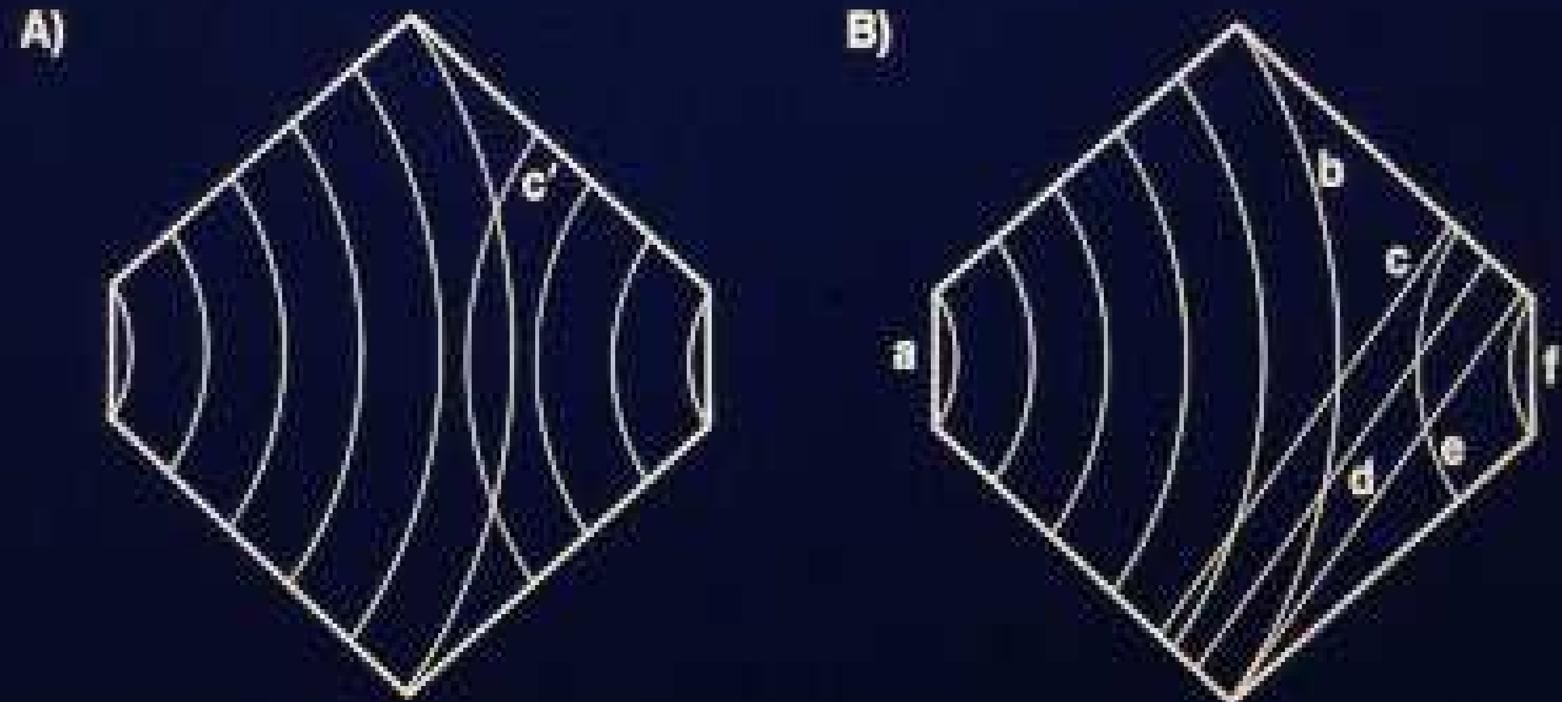

15


31

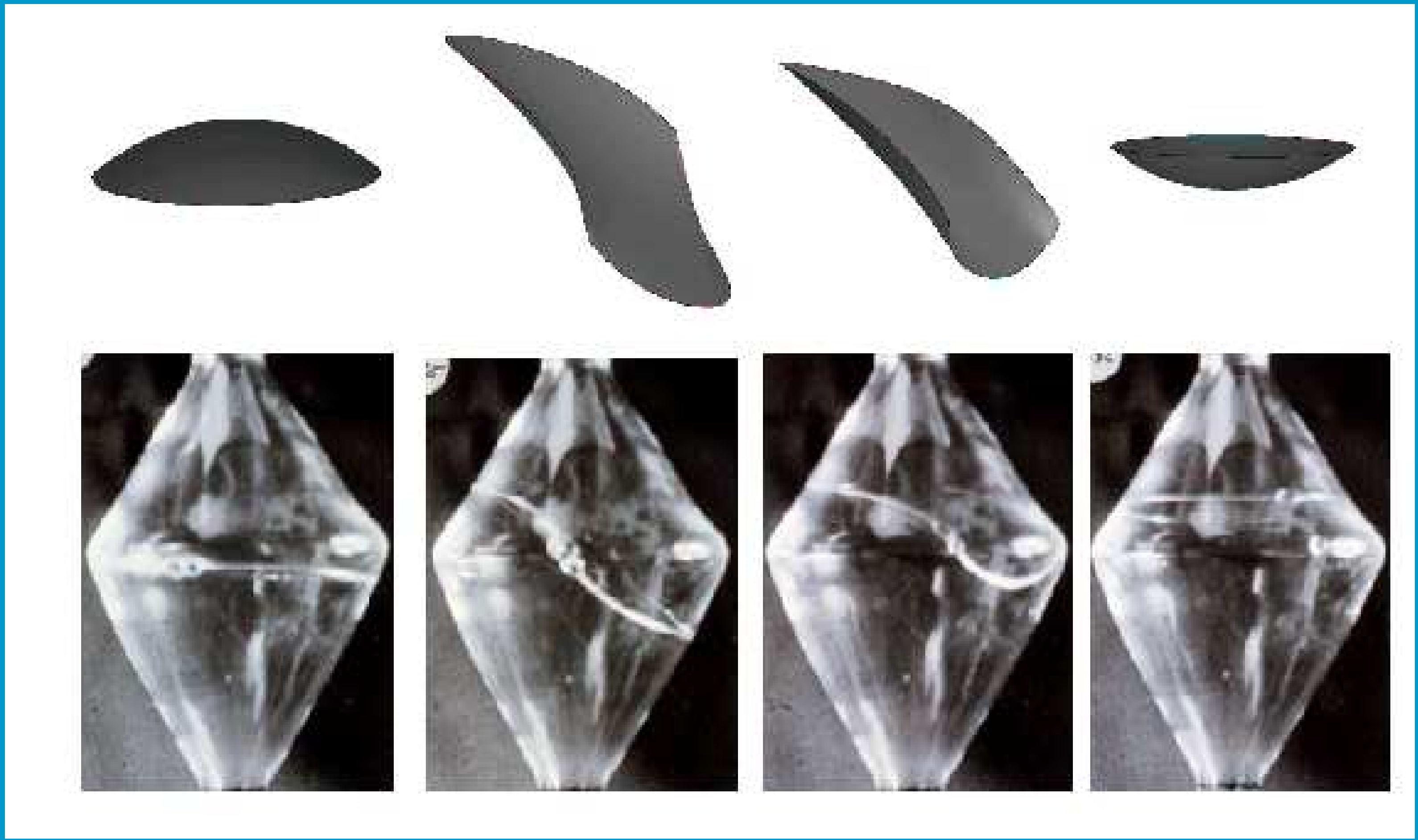

32


2:29

Lamella Shapes During Passage Through a 2-D Cuneal (Wedge-Shaped) Pore With $\rho_b = 0.5$, $\rho_t = 0.1$. A) Assuming Radial Symmetry. B) Actual Shapes, Observed in the Sequence abcdef



Complex bubble shapes in 3D



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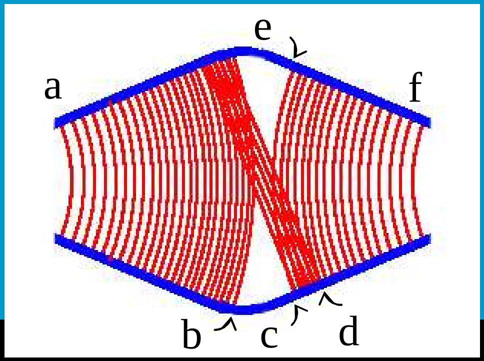
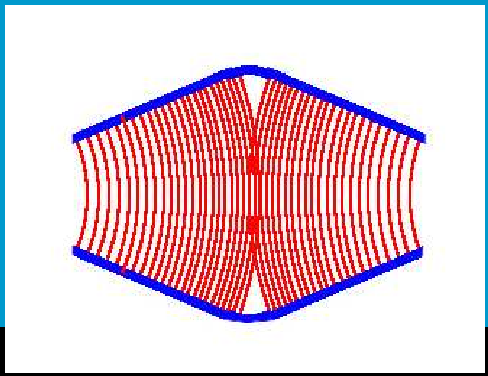
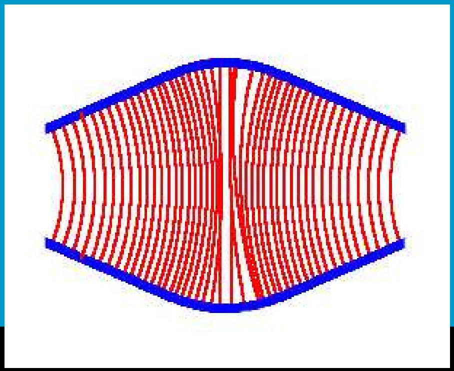
Results

- Whether jump appears depends on pore shape
- Jump disappears at high velocity
- How jump disappears depends on pore shape







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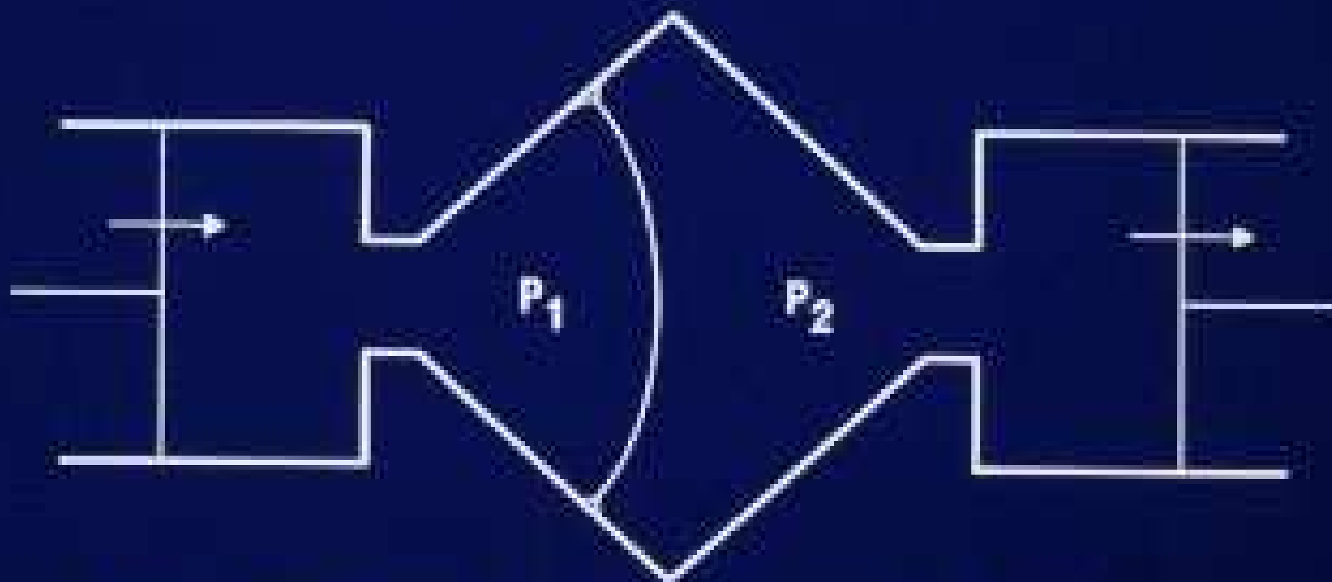
Gas Compressibility Raises $(\nabla p)^{min}$



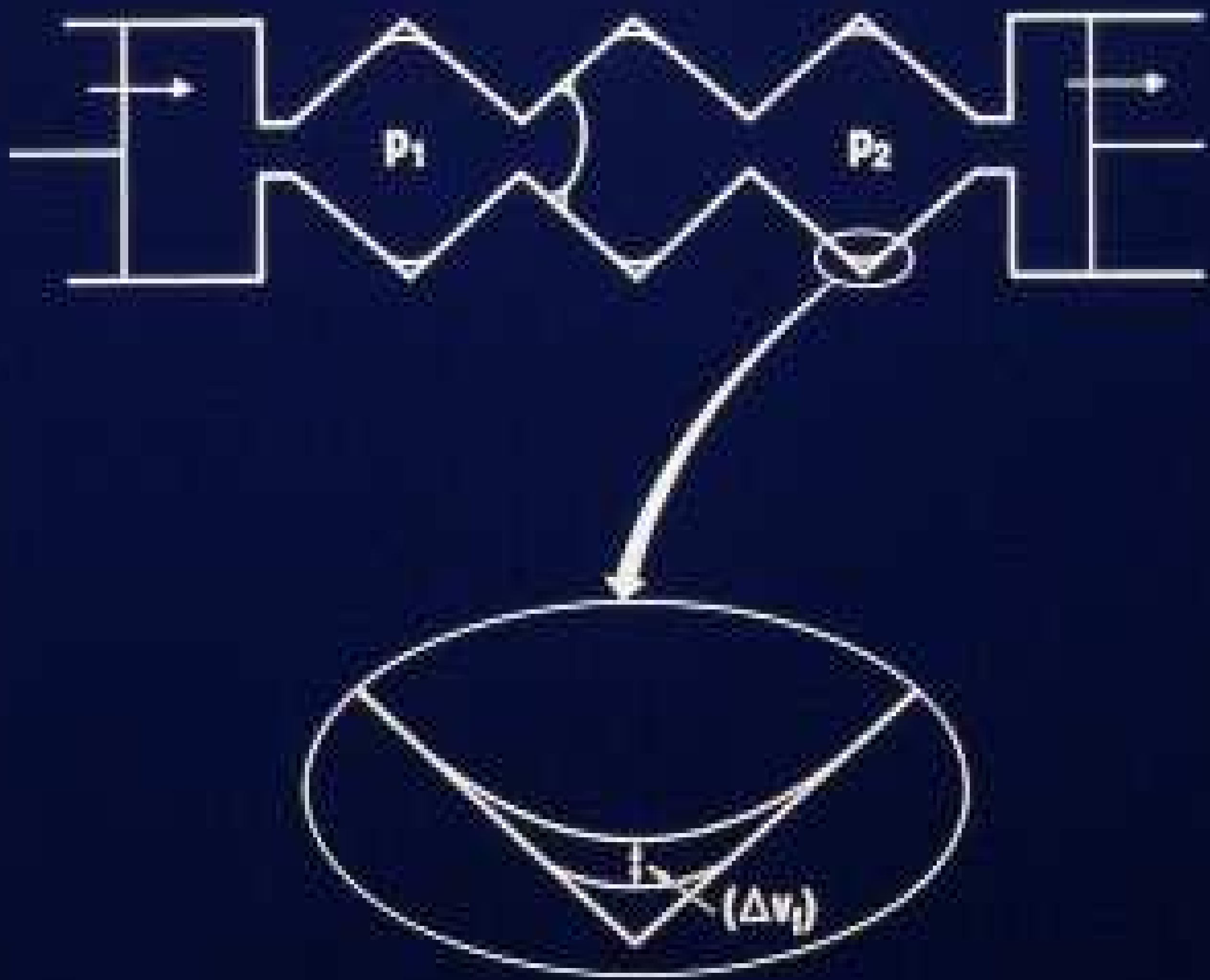
- EOS for Bubble: $\partial P_i/\partial V_i = k \equiv k_t^\circ V_i^\circ$ = Constant
- Behavior Governed by Parameter K

$$K = \left(\frac{2\sigma}{\ell}\right)\left(\frac{V^\circ_{bubble}}{V_{pore}}\right)k_t$$

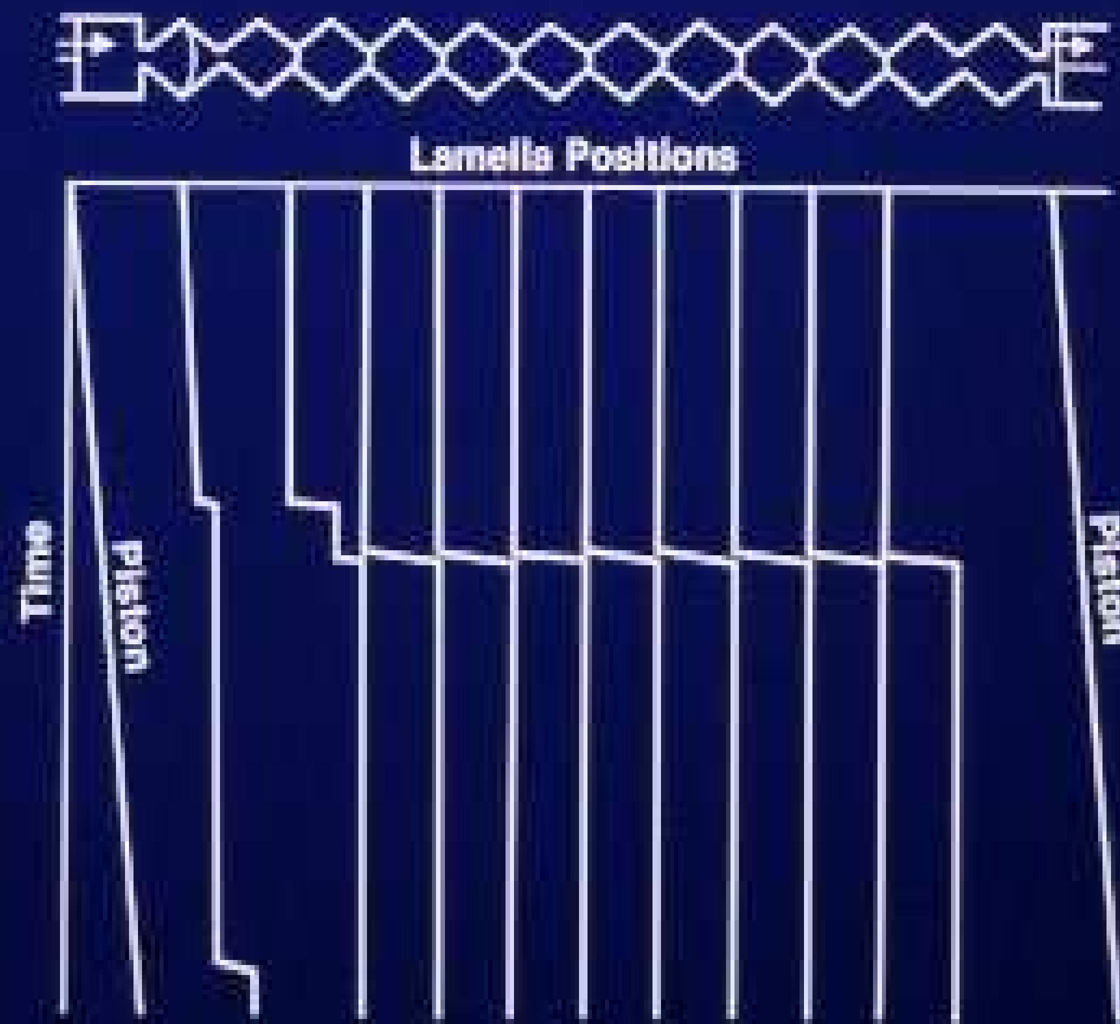
- Steam Foams Have Large K
- CO_2 Foams Have Small K

Model for Effect of Trapped-Gas Bubbles Alongside the Bubble Train

Model for Effect of Liquid Films on Effective Compressibility

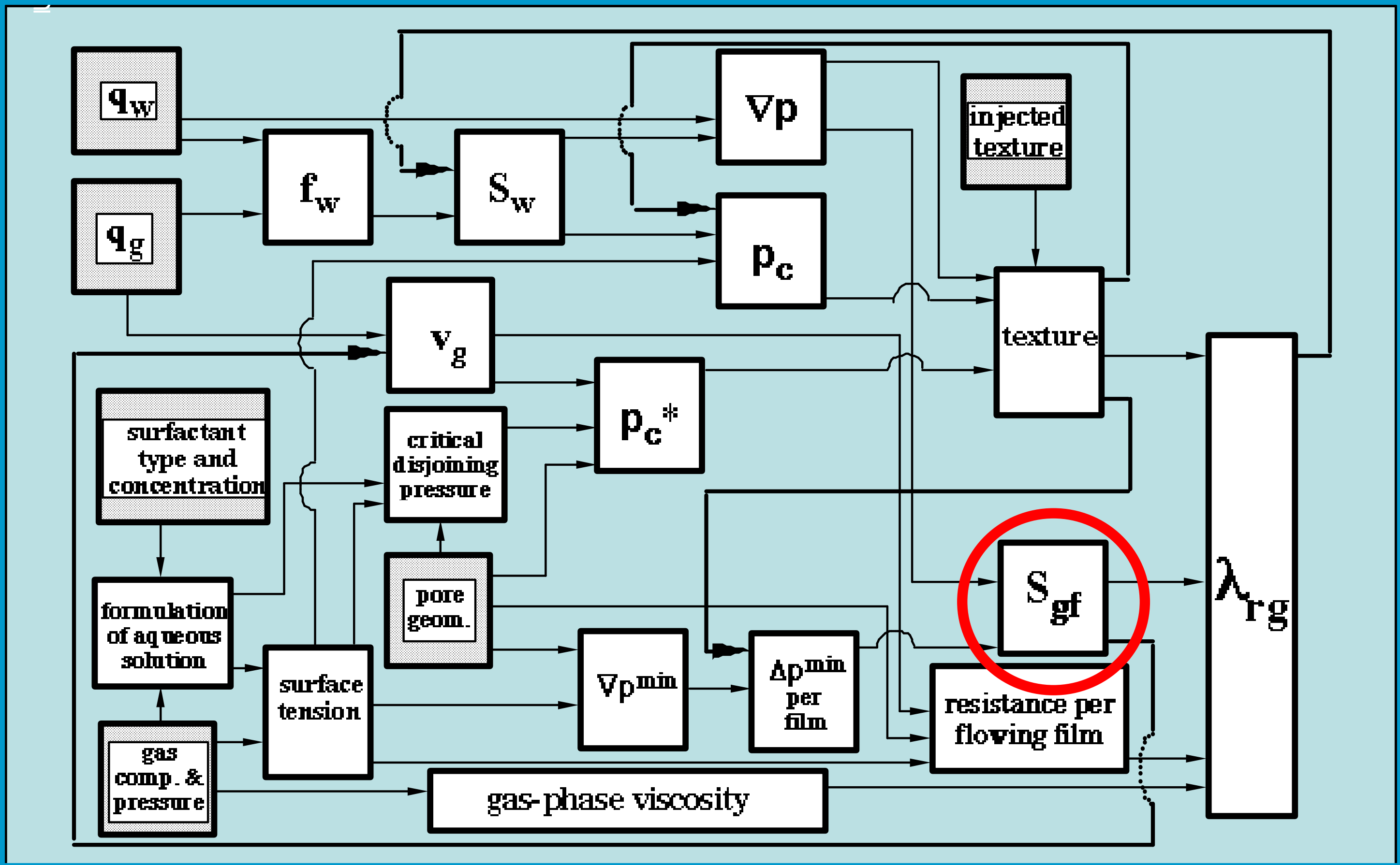


Compressible Bubbles in a Train Jump Together . . .



. . . Further Raising $(\nabla p)^{min}$

Relation between factors controlling foam properties



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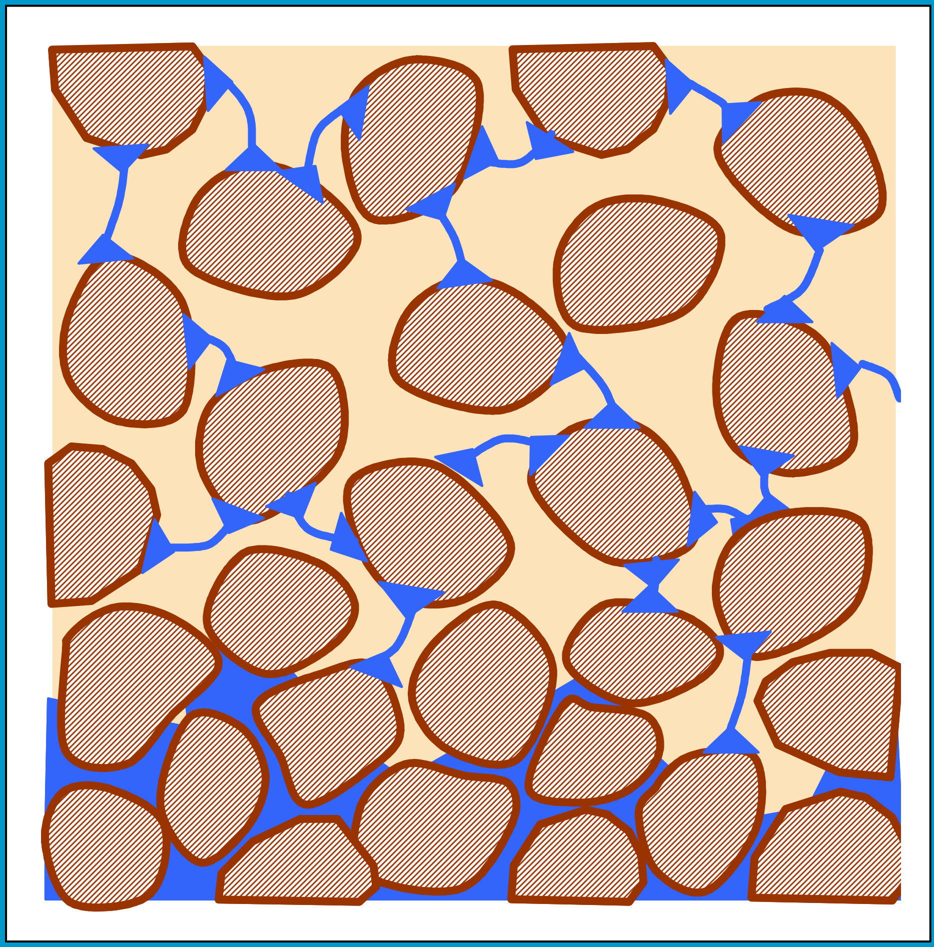
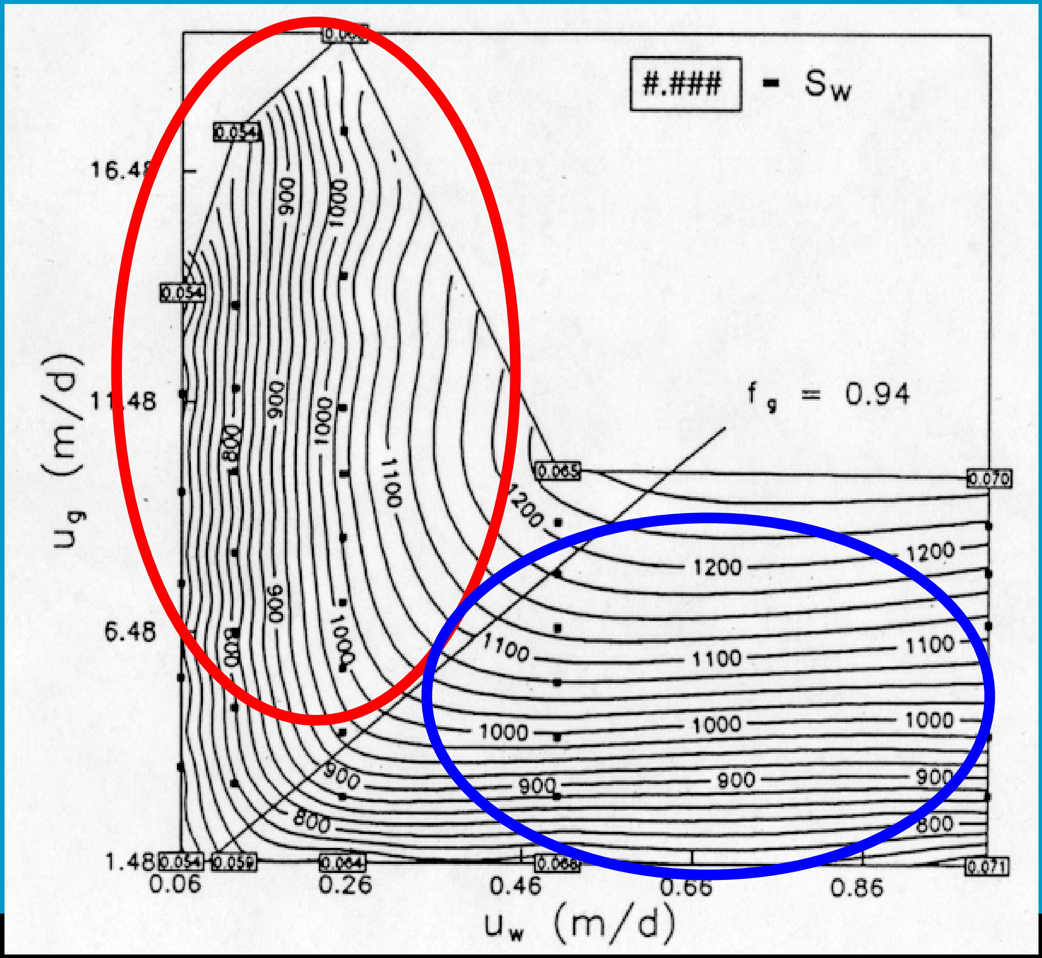
Foam: an example of simplicity



Foam's two regimes: inherently complex, or simple?



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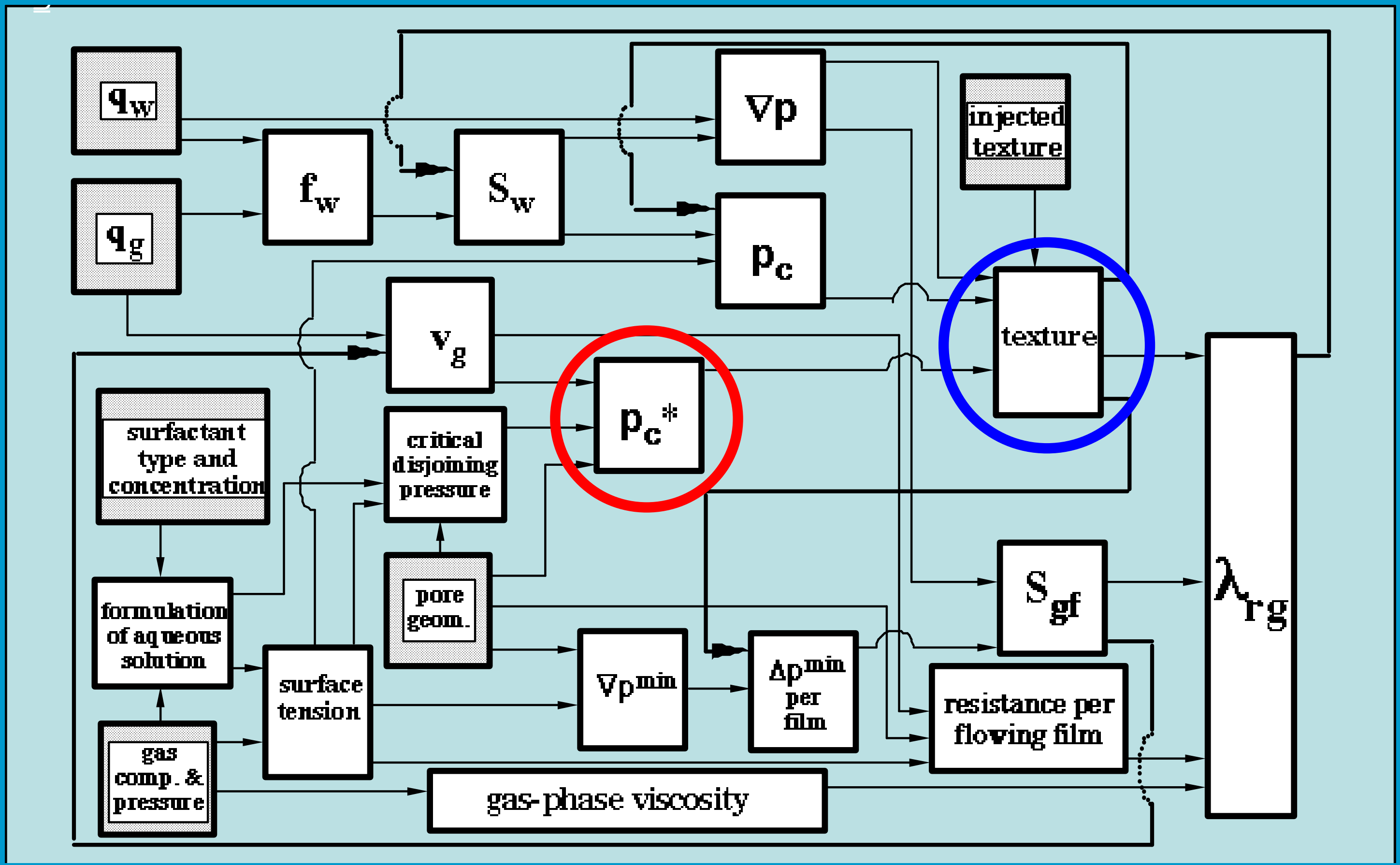
Only two properties control the two foam regimes



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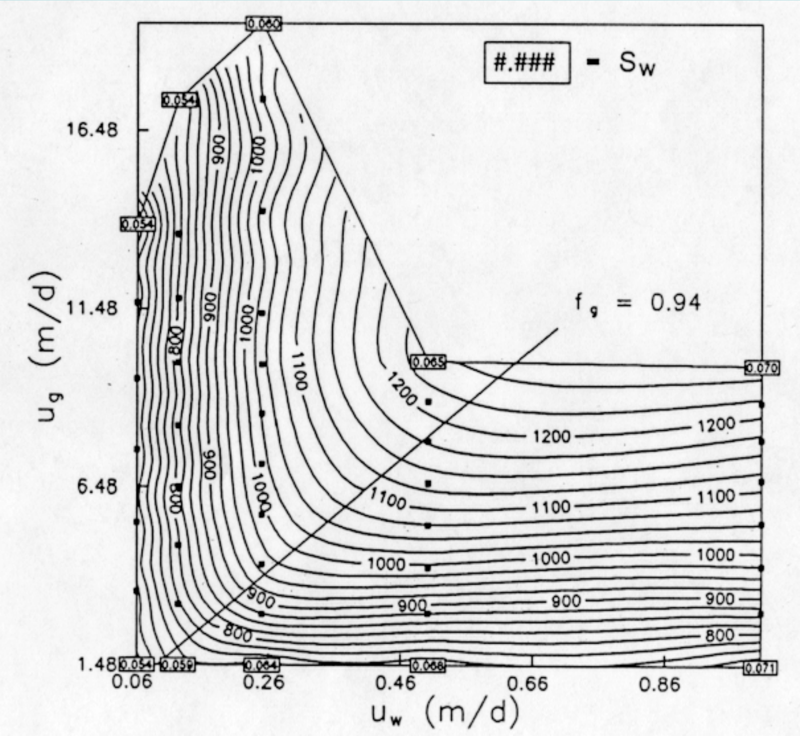
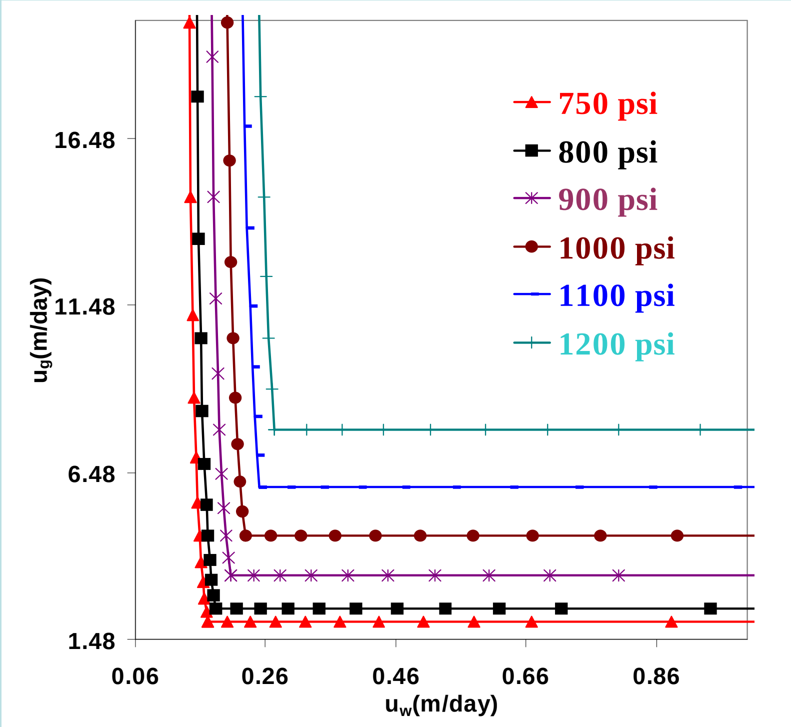
Relatively simple model fits two regimes



Data



Model Fit

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“All models are false, but some models are useful.”

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