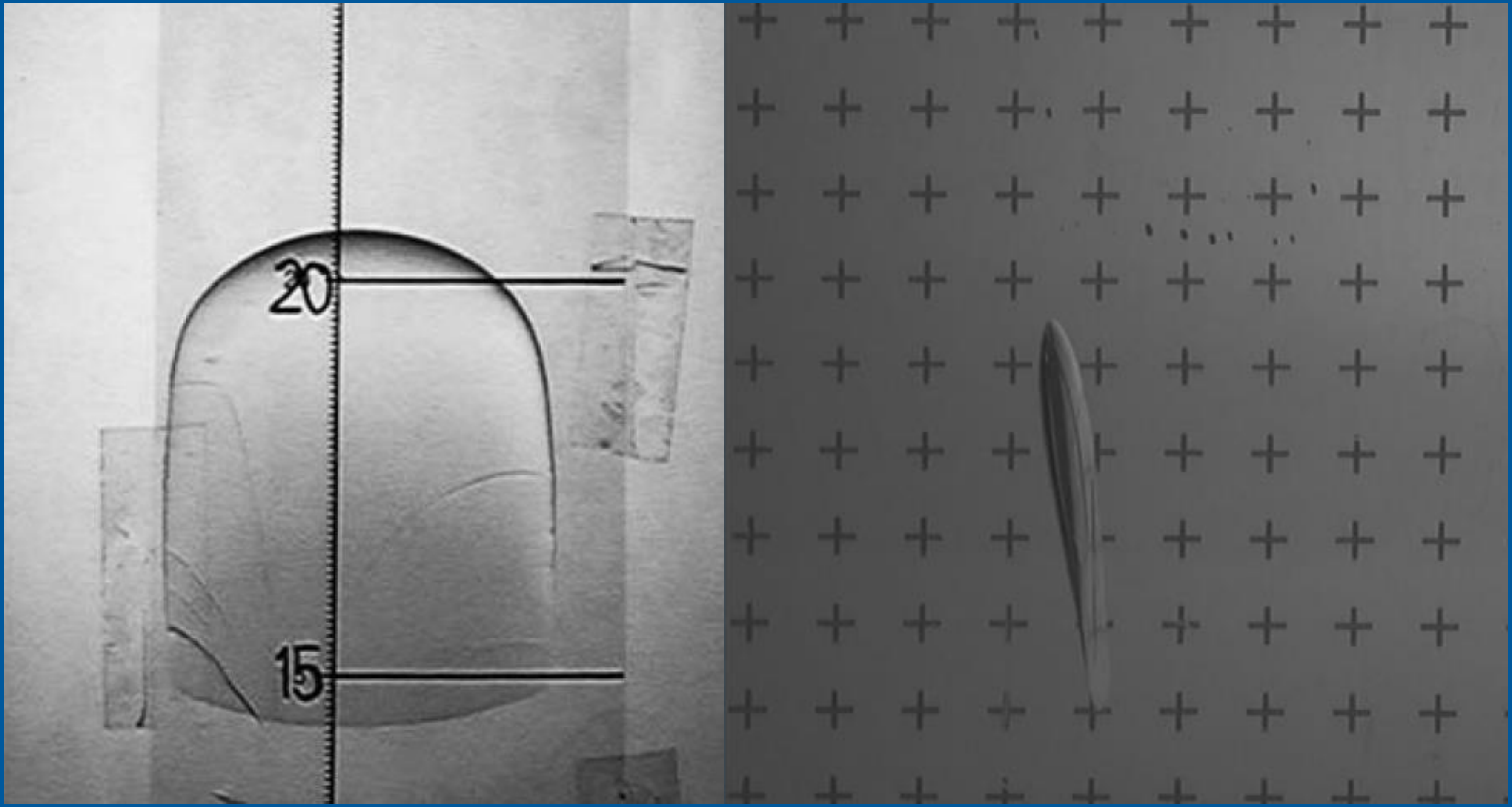
Critical fluid volumes and the start of 'self-sustaining' fracture ascent



Tim Davis and Eleonora Rivalta

EPA fracking executive summary 2016:

"...fracture growth during hydraulic fracturing can be controlled by limiting the rate and volume of hydraulic fracturing fluid injected…"

"...thousands of feet of rock between hydraulically fractured rock formations and underground drinking water resources can reduce the frequency of impacts on drinking water resources..."

EPA-600-R-16-236ES p24, p29
December 2016
www.epa.gov/hfstudy

EPA fracking executive summary 2016:

"...fracture growth during hydraulic fracturing can be controlled by limiting the rate and volume of hydraulic fracturing fluid injected…"

Do volumetric limits/rates exist in the literature?

"...thousands of feet of rock between hydraulically fractured rock formations and underground drinking water resources can reduce the frequency of impacts on drinking water resources..."

Can fractures propagate vertically thousands of metres?

EPA-600-R-16-236ES p24, p29
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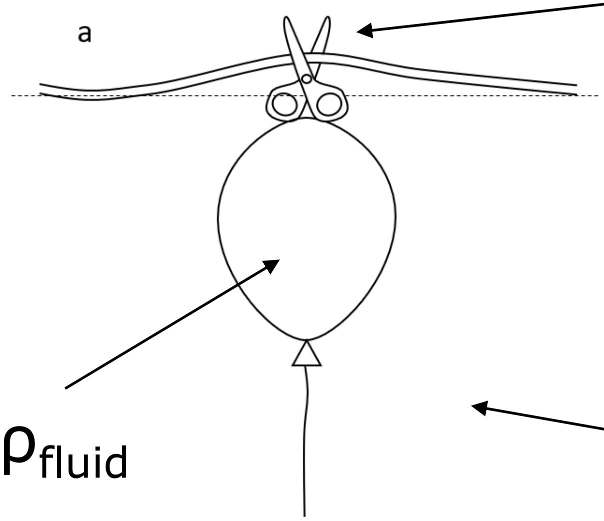
Theory

'K_{IC}' = ribbon strength



ρ_{fluid}

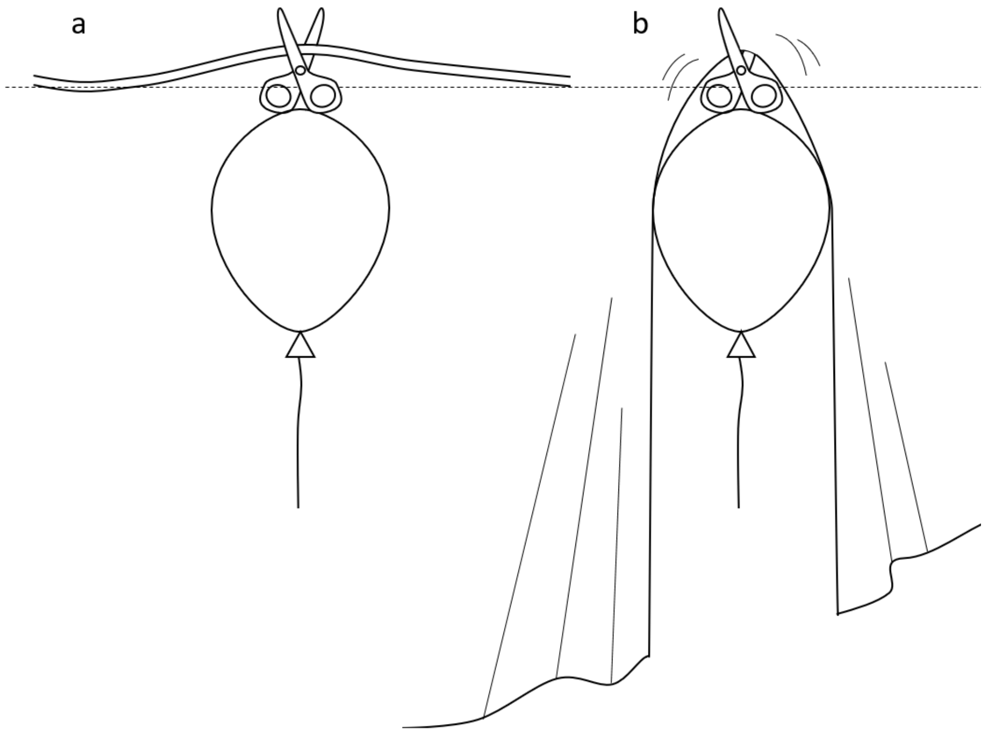
ρ_{air}

$\Delta\gamma = (\rho_{air} - \rho_{fluid})g$

Cut when:

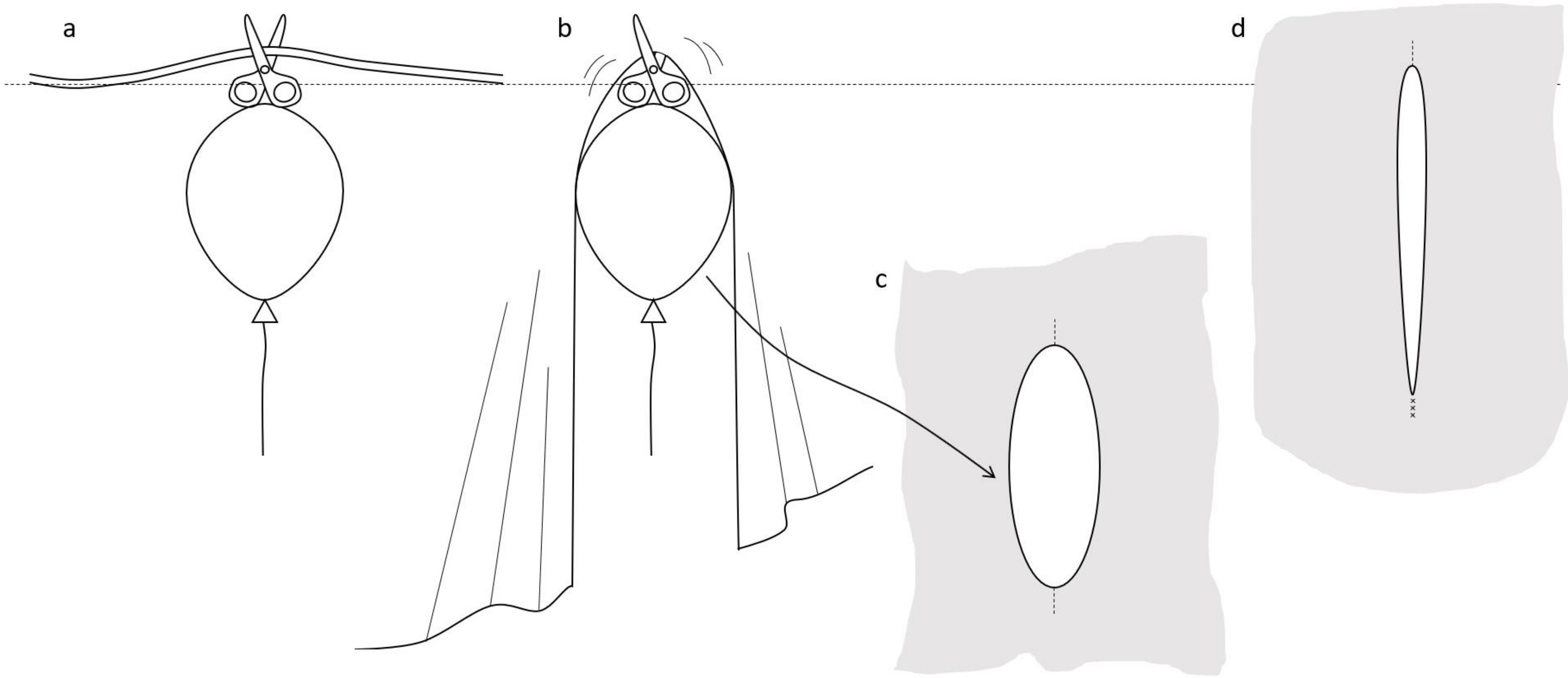
$\Delta\gamma * V > K_{IC}$

Theory



For a given volume (V_c) the balloon will begin to rise indefinitely.

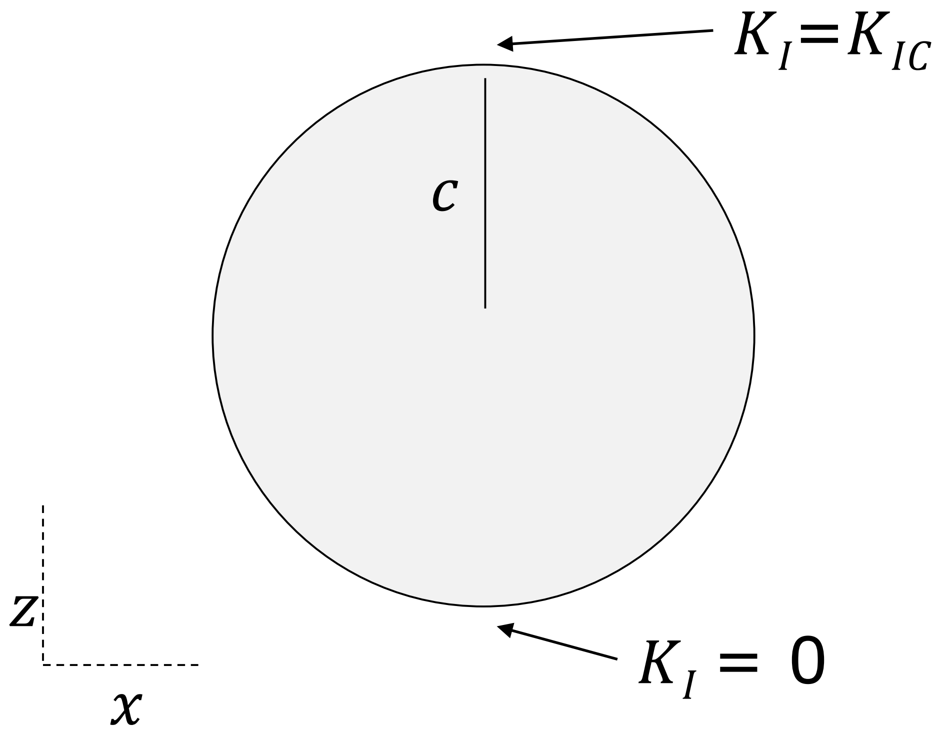
Theory



New solution: Boundary conditions

'Critical' fracture length (3D) can be described by:

$$c = \left(\frac{3\sqrt{\pi} K_{IC}}{8 \Delta \gamma} \right)^{2/3}$$



Retrieving volume

‘Critical’ fracture length (3D) can be described by:

$$c = \left(\frac{3\sqrt{\pi} K_{IC}}{8\Delta\gamma} \right)^{2/3}$$

Volume of a crack due to internal pressure (p) 3D.

$$p = \frac{2\Delta\gamma c}{3}$$

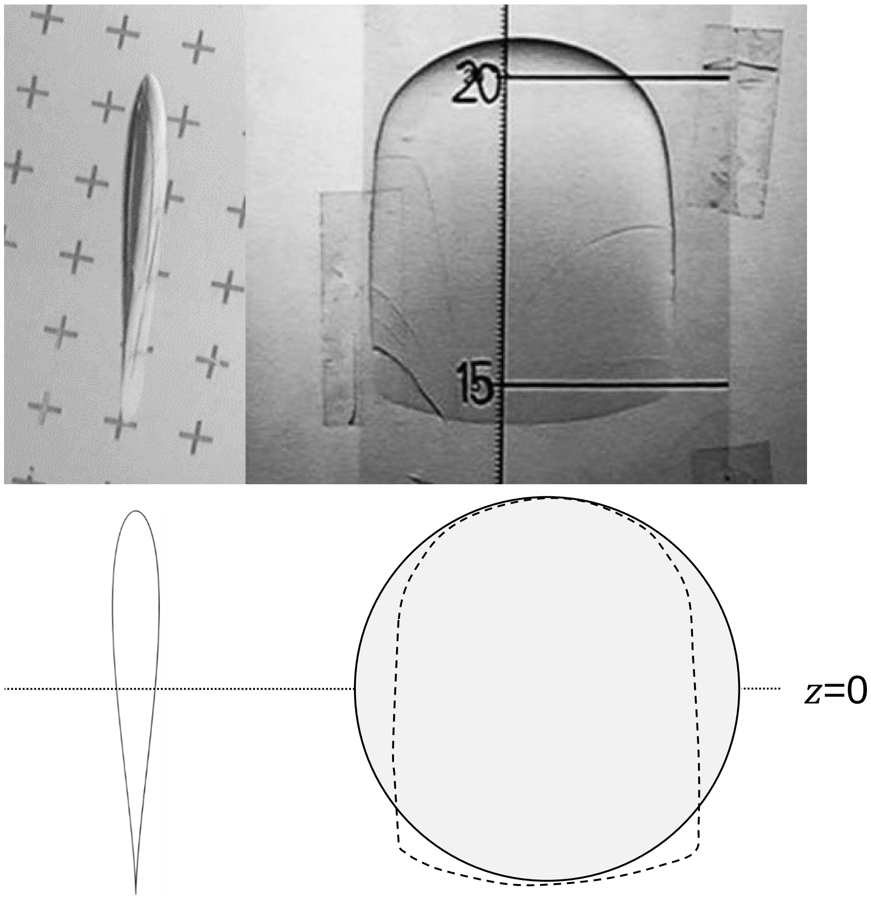
$$V = \frac{8(1-\nu)}{3\mu} p c^3$$

Substituting ‘c’ and ‘p’

$$V_{min} = \frac{(1-\nu)}{16\mu} \left(\frac{9\pi^4 K_{IC}^8}{\Delta\gamma^5} \right)^{1/3}$$

Independent of shape

Is that all?



Differences:

V too low?

- Our boundary conditions are such that the fracture is trapped

V too high?

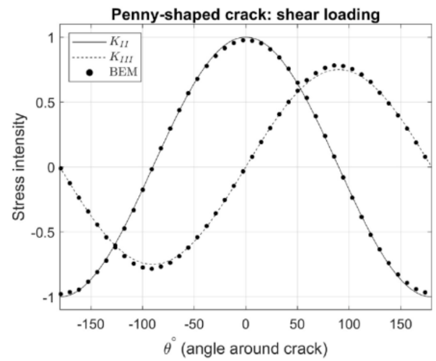
- Circle has greater area towards upper tip

How to test?

Numerically:

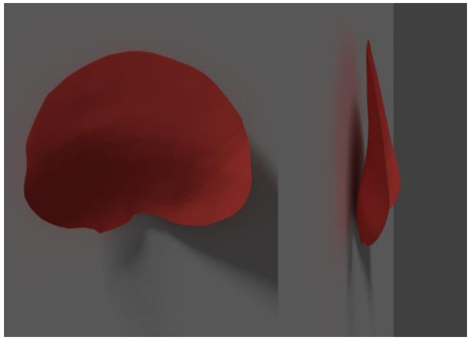
- Typical buoyant ascent methods 2D (BEM).

Davis et al 2019.
3D K calculation



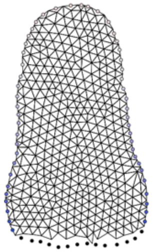
- 3D propagation code that can mesh on the fly as front changes

CutAndDisplace
+ CGAL



- Efficiently compute closing of multiple tail elements

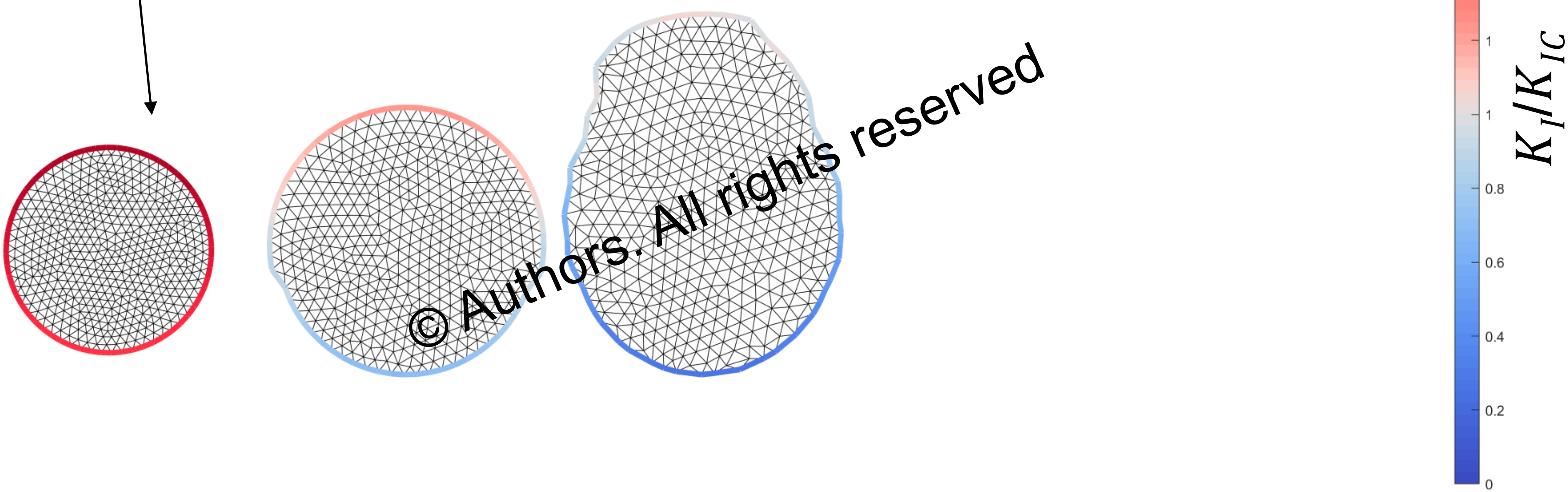
Complementarity conditions
2D Ritz et al 2012 -> 3D Davis et al 2019.



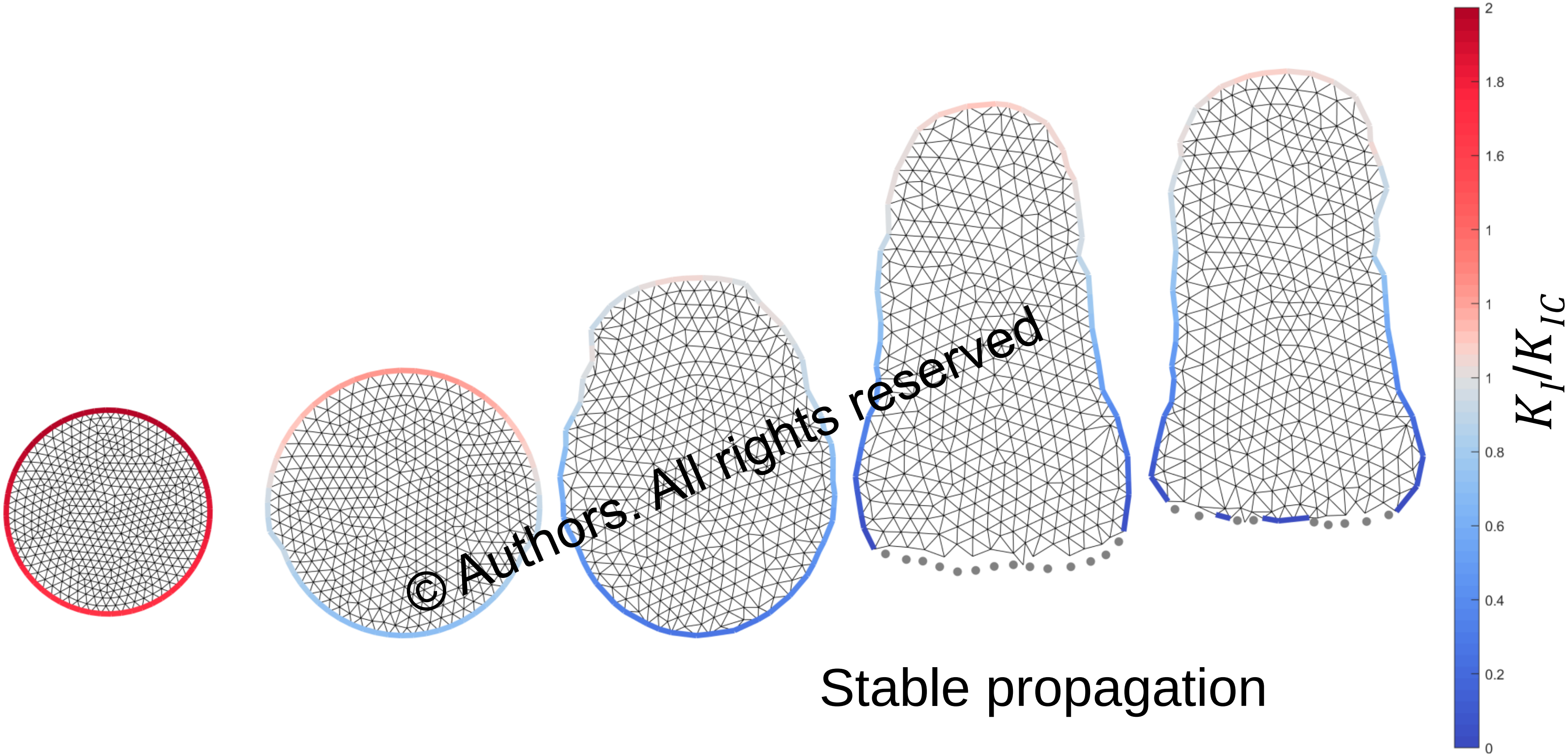
Numerical scheme

Volume inserted

Δγ acts as it grows



Numerical scheme



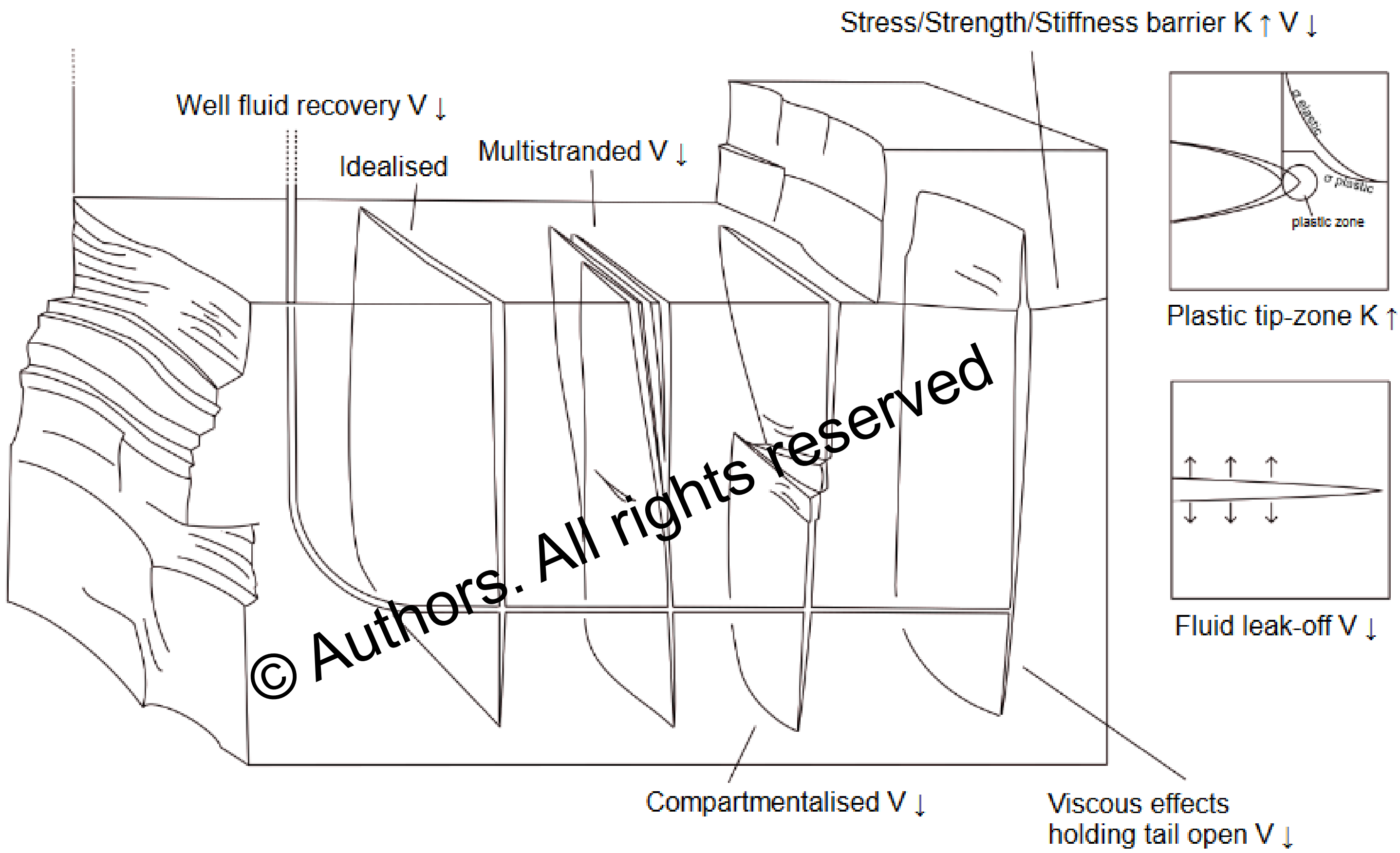
Numerical results

Numerical critical volume is 0.75* analytical formula.

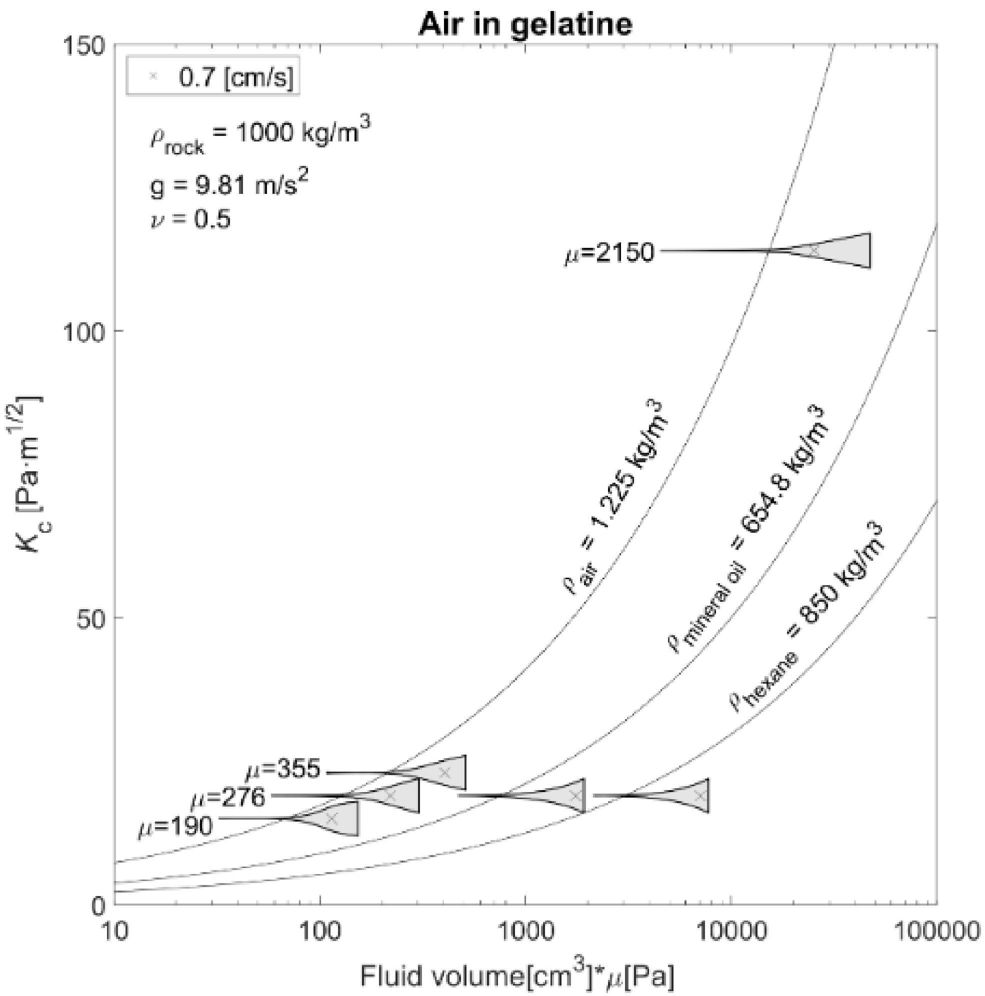
$$V_{min} = \frac{(1-\nu)}{16\mu}\left(\frac{9\pi^4 K_{IC}^8}{\Delta\gamma^5}\right)^{1/3}$$

$$V_c = \frac{(1-\nu)}{10.\dot{6}\mu}\left(\frac{9\pi^4 K_{IC}^8}{\Delta\gamma^5}\right)^{1/3}$$

Reasons why this estimate is 'conservative'



Comparing to experimental data



Formula matches critical volume data from gelatine experiments of Heimpel and Olson (1994)

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Comparing to hydrofracturing data

- K_{IC} lab = 1-3
- K_{IC} field veins = 8-25

- Around scale of mine injection experiments [a]

  (1-15m^3)

- Typical 'hydrofrac' job per well [b]

  (5600-21500 m^3)

Using K_{IC} from field our equation provides critical volumes of:

- 2.5-55m^3

a) Max:
2m^3 Warpinski et al. [1982].
15.6m^3 Jeffrey et al. [2009]
9.24m^3 Zimmermann et al. [2019]

b) https://www.americangeosciences.org/critical-issues/faq/how-much-water-does-typical-hydraulically-fractured-well-require

Conclusions

- Introduced scale independent volumetric limits on stability of fluids inside fractures.
- The limit matches well with critical volumes observed in gelatine experiments.
- More research to constrain this tipping point is required, the problem remains poorly quantified.

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