Cracking the Elastic Geobarometry Puzzle in Diamond–Olivine Inclusions

A Numerical Investigation into Udachnaya Kimberlite's Low-Inclusion-Pressure

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Abstract

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

1 Background

What is Geobarometry?

- Chemical (conventional): Requires two minerals, assumes equilibrium.
- Elastic: Needs just one inclusion, based on stress – more versatile!

Why does it Matter?

- Reveals Earth's deep history
- Used in diamond exploration & mantle reconstruction

The Puzzle:

- Udachnaya diamonds show anomalously low residual pressures (< 0.5 GPa).
- Elastic geobarometry alone cannot explain this.

Could brittle fracture be responsible for this discrepancy?

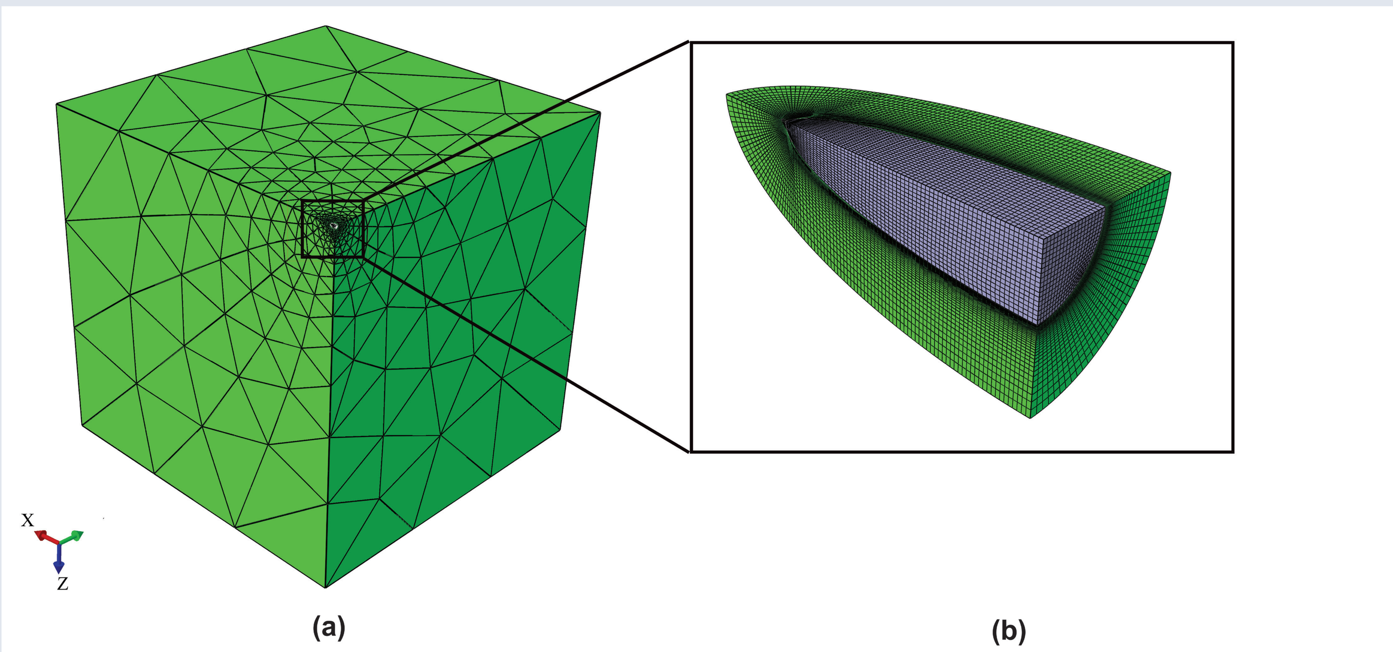
2 Research Objectives & Questions

Objectives:

To evaluate if brittle fractures can explain the observed pressure anomaly through advanced numerical simulations.

Key Questions:

- How much pressure can brittle fractures relax under inclusion-induced stress?
- Can numerical methods (XFEM, PFM) simulate this behavior accurately?



(3D host–inclusion model. Only 1/8th is simulated by exploiting symmetry)

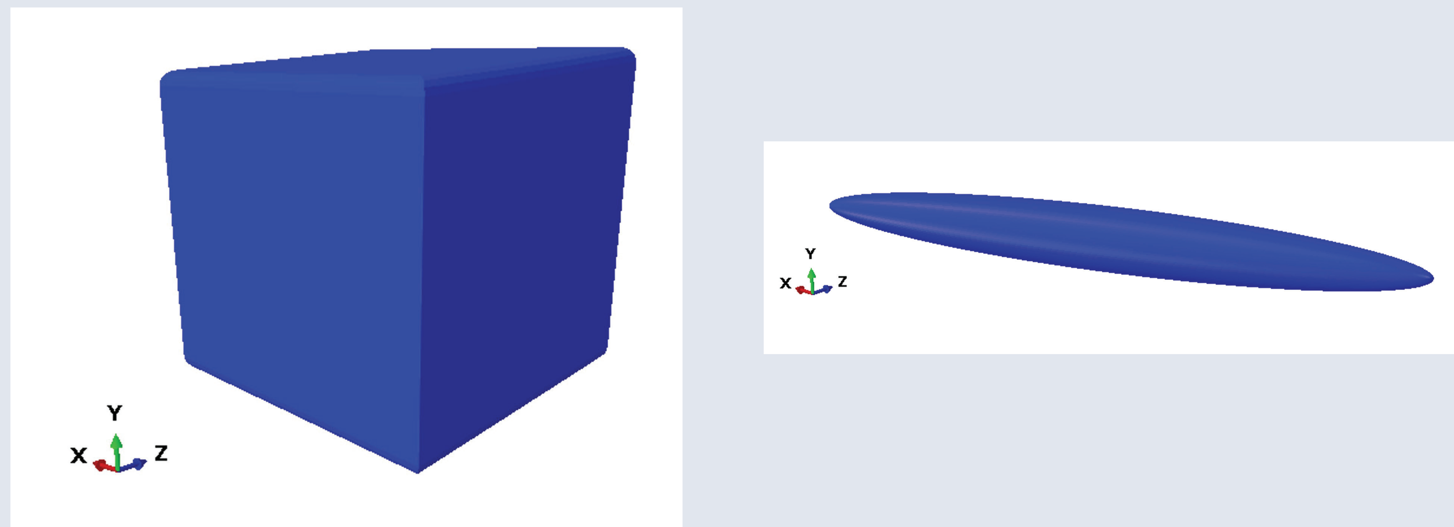
3 Methods & Modelling Approach

1. Extended Finite Element Method (XFEM):

Captures crack initiation and propagation without predefining crack paths.

2. Phase-Field Method (PFM)

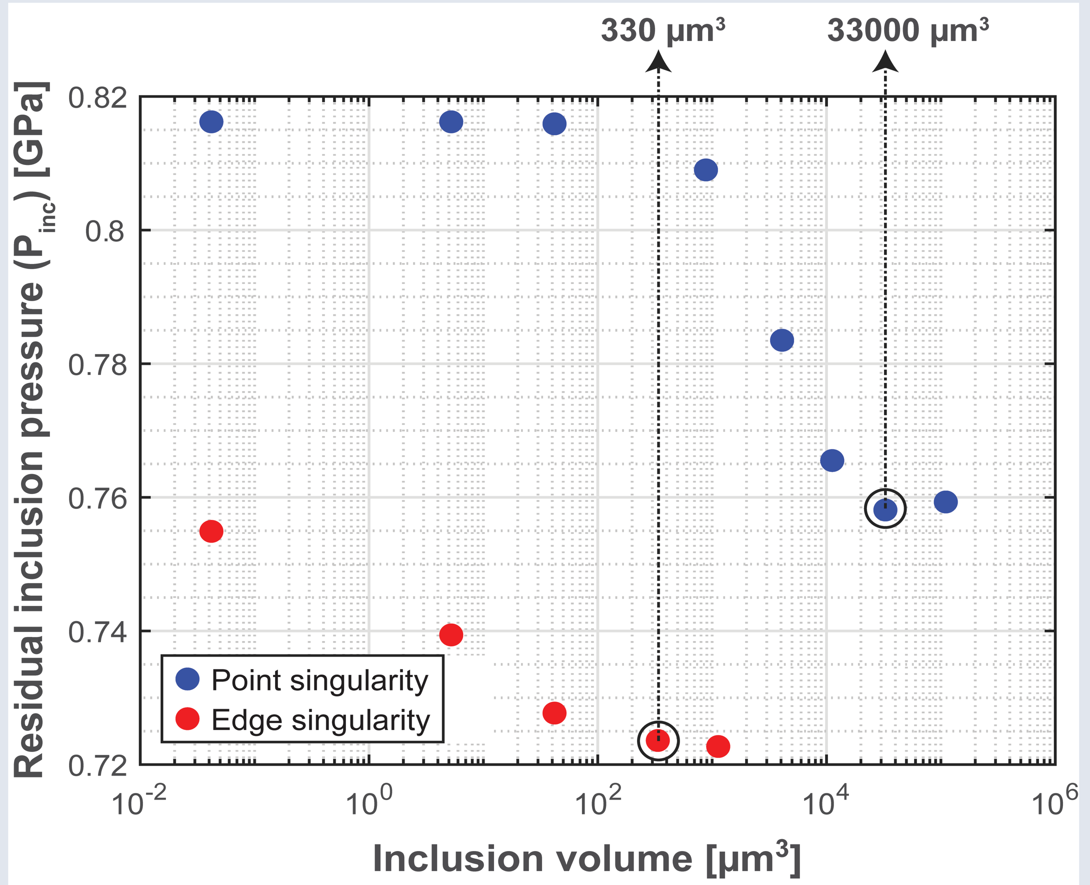
Models the fracture evolution by minimizing the system's total energy.



(Investigated inclusion singularities: edge (left) and point (right))

4 Results & Discussions

Does inclusion size matter? Does singularity type matter?

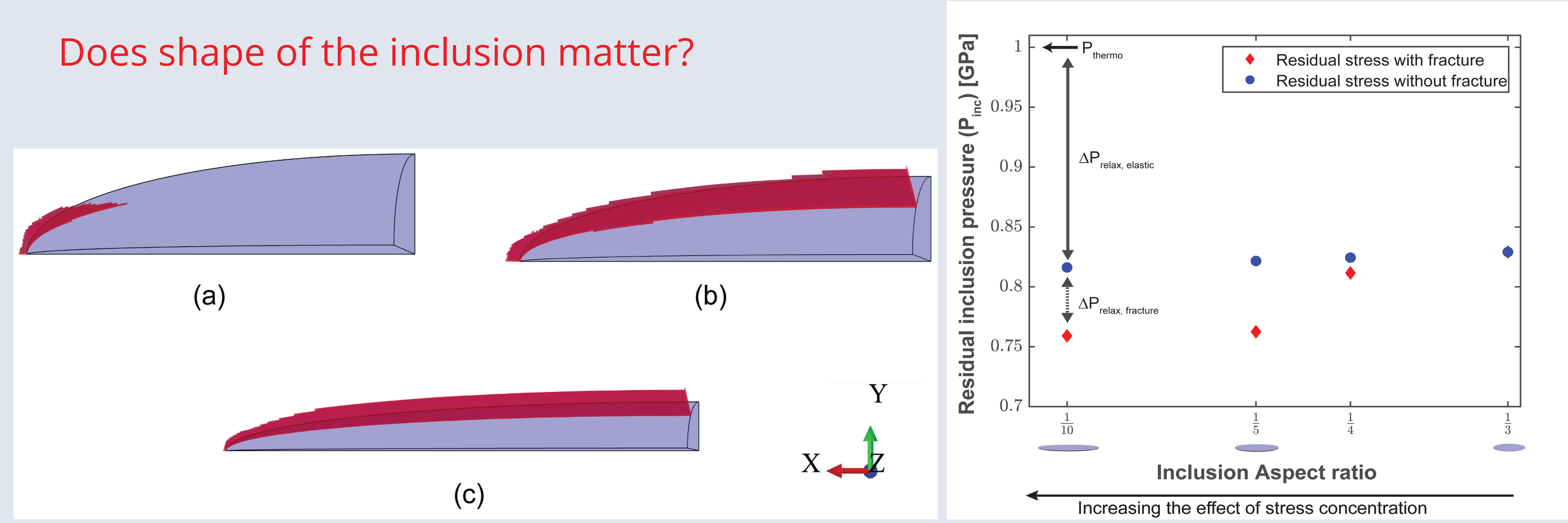


At 330µm³, the edge singularity is already fully fractured — the point singularity hasn't even started!

(Residual pressure for two singularities at varying inclusion volumes)

- While larger inclusions enhance relaxation, this effect **plateaus**; beyond a certain size, further increases yield minimal additional relaxation.
- Edge singularity relaxes **2-3%** more pressure than point singularities, despite much earlier damage initiation due to high stress concentration effect**.**

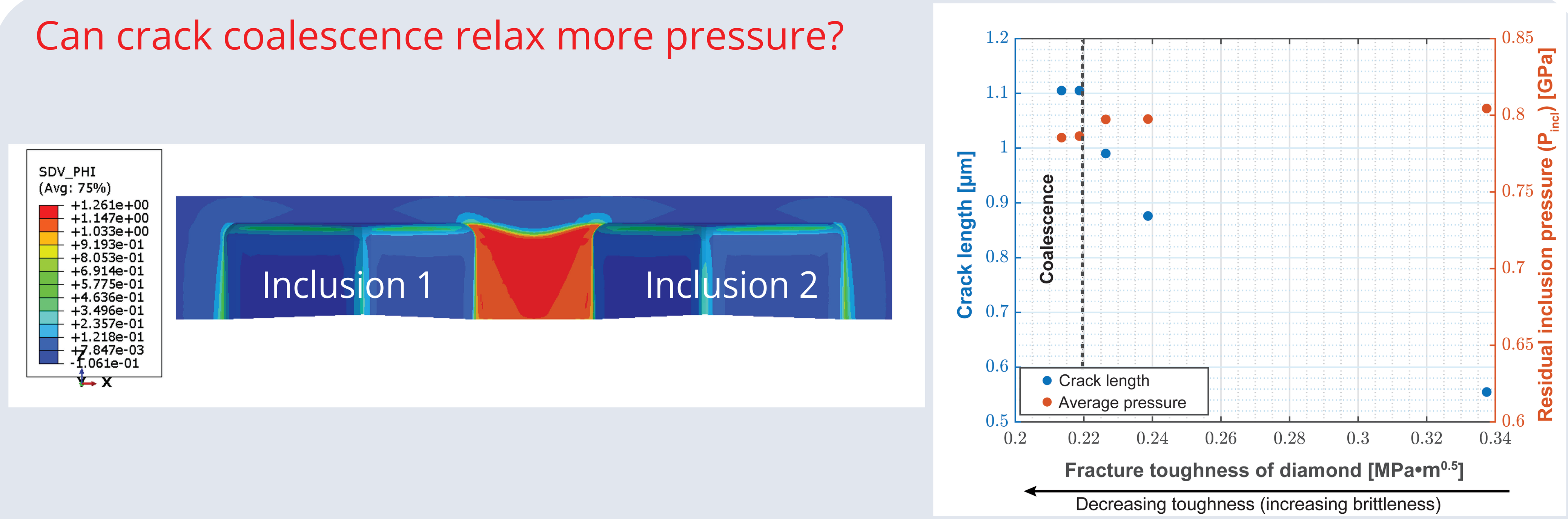
Does shape of the inclusion matter?



(Left: Fracture propagation (red) in diamond hosts for over-pressurized inclusions at aspect ratios: (a) 4:1:1, (b) 5:1:1, (c) 10:1:1; Right: Residual pressure vs aspect ratio of inclusion)

- Sharpness of the inclusion matters initially, but once fractures open and propagate, their impact becomes **negligible**.

Can crack coalescence relax more pressure?



(Phase-field simulations show crack coalescence and host weakening (left), with longer cracks yet lower residual pressure at reduced fracture toughness (right).

- Interaction between cracks **amplifies** propagation but not relaxation significantly.

5 Conclusions

- Edge singularities trigger earlier damage than points; size enhances relaxation but both effects plateau after fracture grows.
- Crack Coalescence: Cracks merge rapidly between inclusions but cause only minor extra pressure drop.
- Even combining singularities, size, and coalescence, residual pressures only fall **to ~0.7 GPa**.
- **Bottom Line: Brittle fractures alone can't explain low inclusion pressures in Udachnaya.**

Future Work: Effect of anisotropy, fluid interactions, and complex inclusion shapes should be investigated.