# Increasing the productivity of unconventional gas reservoirs via graded proppant injection (GPI)

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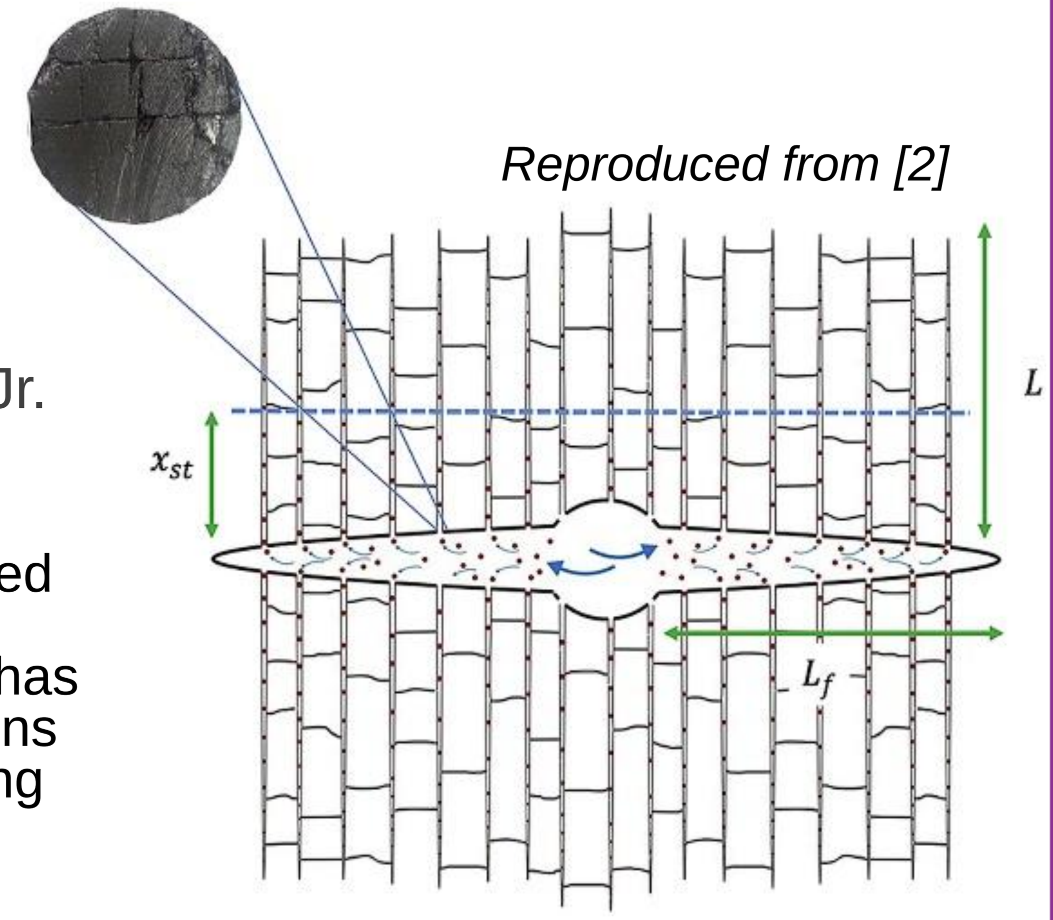
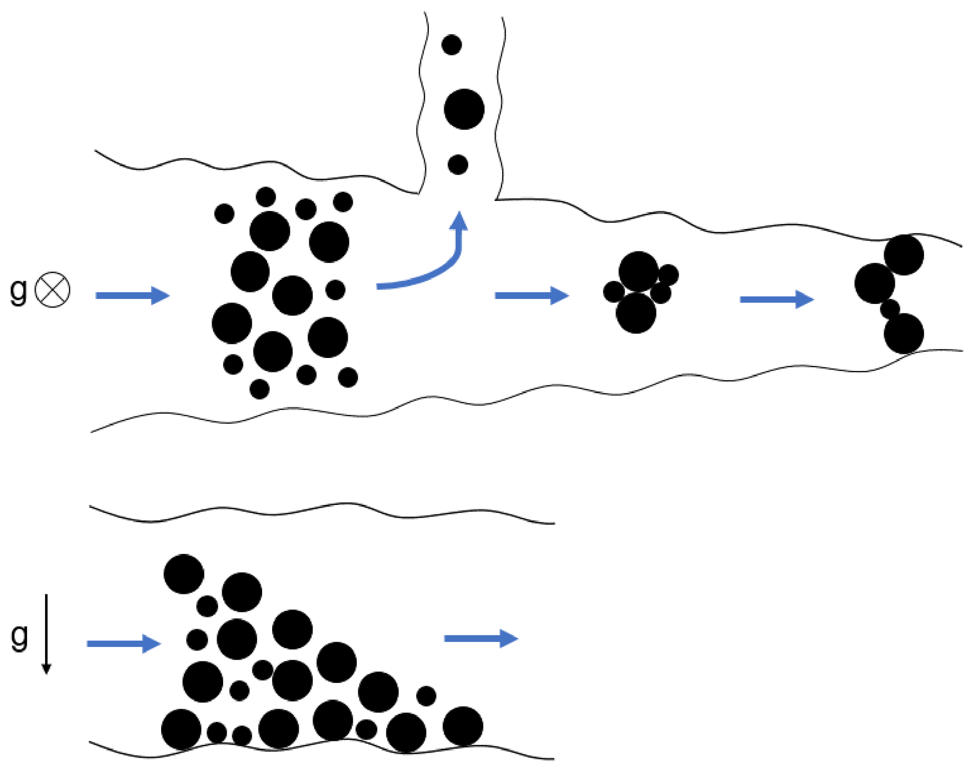



## Introduction

In order to convert Queensland's low-permeability natural gas contingent resources to reserves, enhancement of well productivity is required. GPI was recently proposed as a novel method for increasing the stimulated reservoir volume, whereby micron-sized solid particles (micro-proppants) suspended in a hydraulic fracturing fluid are sequentially injected in order of size into a hydraulically fractured reservoir, facilitating deeper penetration compared to mono-sized particles [1]. Preliminary modelling has demonstrated a three-fold increase in reservoir permeability following drawdown under the assumption of optimal proppant placement [2]. However, improved predictions of what will happen to particles as they travel into the hydraulically fractured network are required to assess the validity of GPI and facilitate adjustment of injection sizing and scheduling to optimise particle placement. The fracture network is modelled in two different ways:

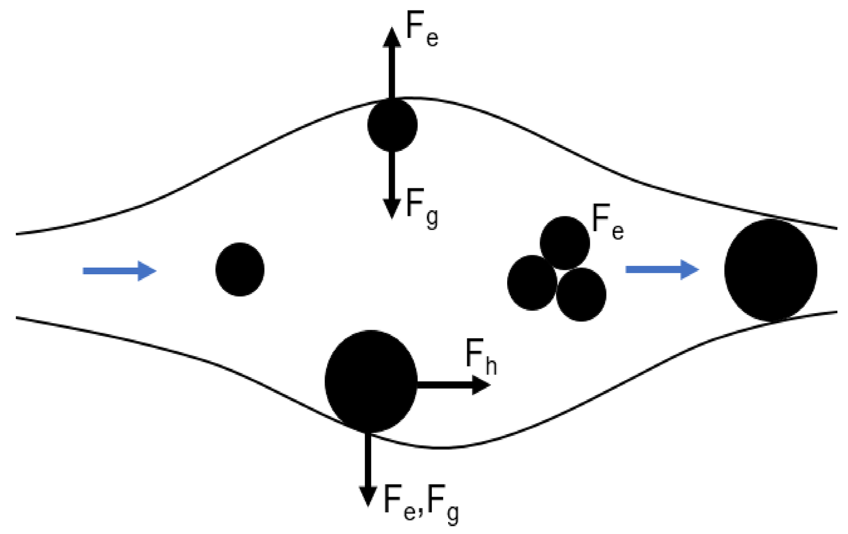
## 1. Main hydraulic fracture

Proppant first flows through the main fracture channel extending from the wellbore. A number of inhibiting mechanisms prevent proppant from being delivered far into the fracture network, including: sedimentation; agglomeration; bridging; leak-off into cleats; and retardation of small particles due to size segregation. However, knowledge of particle behaviour when the particle size approaches that of a leak-off cleat is lacking, as is size segregation in three-dimensional, inertial flows. Both electrostatics and non-Newtonian rheology (shear-thinning and viscoelasticity) are lacking in nearly all three-dimensional models, such that they are not representative of the physics present in a real-world fracture.




## 2. Cleat system

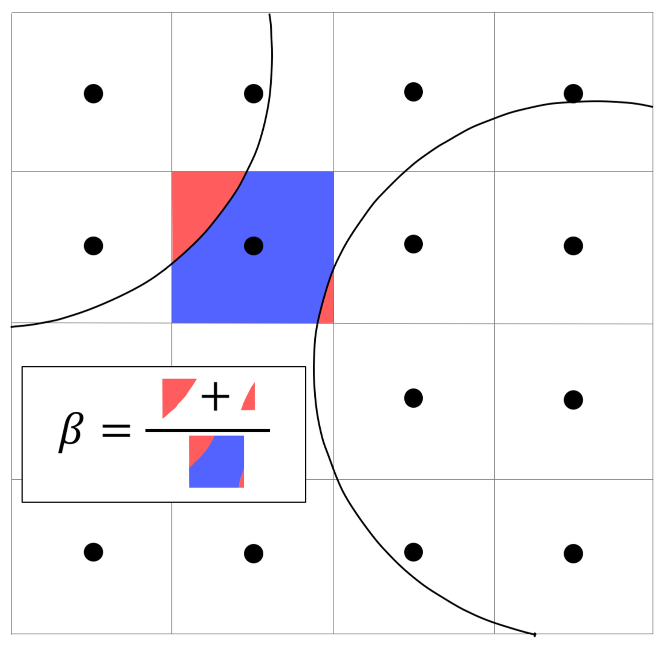
The complex network of interconnected natural cleats is akin to a porous medium, in which size exclusion and attachment to the coal surface reduce particle penetration depth. Electrostatics contribute a net attractive force, $F_e$, while detachment is caused by hydrodynamic forces imparted by the fracturing fluid, $F_h$, which is a strong function of the fluid velocity and rheology. Large-scale models for porous media filtration have the potential to effectively model non-linear particle penetration far into the complex natural cleat system, yet matching these models to real-world reservoirs requires tuning using data obtained from experimental core-flood tests. However, incorporating and controlling the pertinent attachment physics and fluid rheology is costly and time consuming.




## Modelling approach

A fully coupled lattice Boltzmann method (LBM) and discrete element method (DEM) solver is employed to model the fluid and solid phases respectively. The partially saturated method (PSM) for solid object coupling,

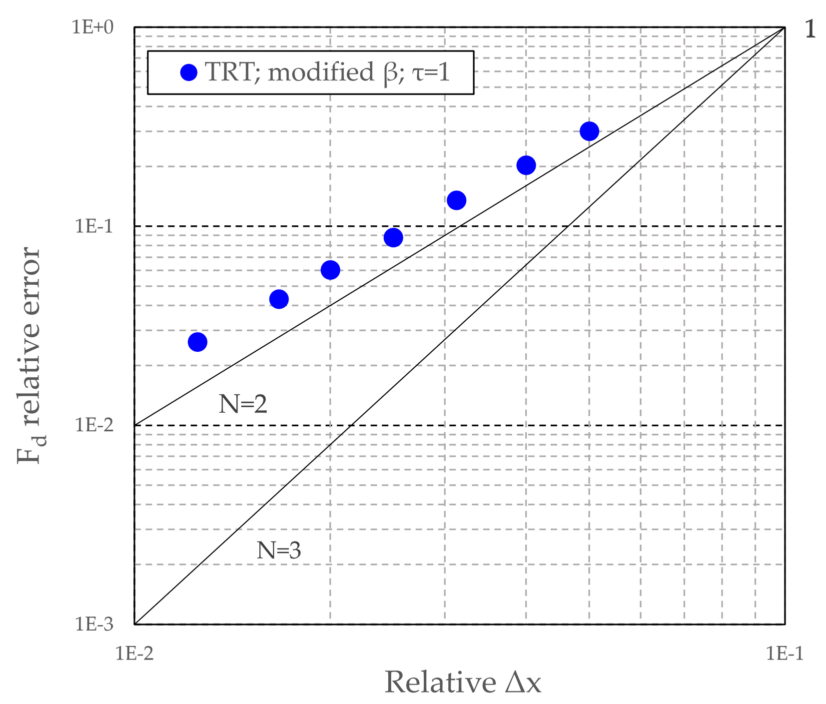
$$f_i(\boldsymbol{x} + \boldsymbol{c}_i \Delta t, t + \Delta t) = f_i(\boldsymbol{x}, t) + (1 - \beta)\Omega_i(\boldsymbol{x}, t) + \beta \Omega_i^S,$$

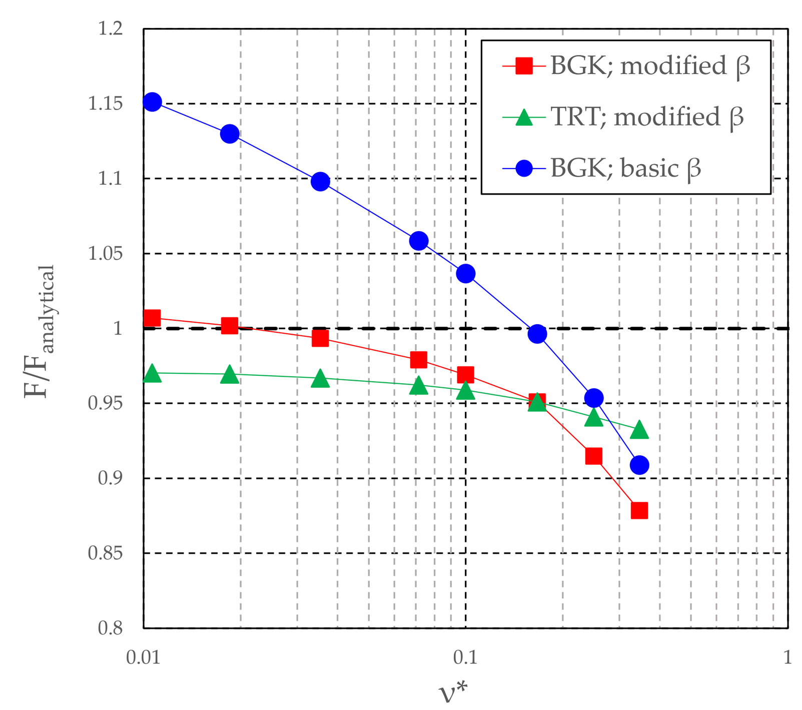



incorporates an additional solid collision operator, $\Omega_i^S$, and solid weighting function, $\beta$, into the discretised lattice Boltzmann equation The PSM fully recovers fluid-particle hydrodynamics, and as such efficiently captures the physics of individual particles at the spatial scale of a coal cleat.

## Model validation

Sphere settling between two parallel plates in the Stokes regime: 2nd order convergence; significantly reduced viscosity dependence.



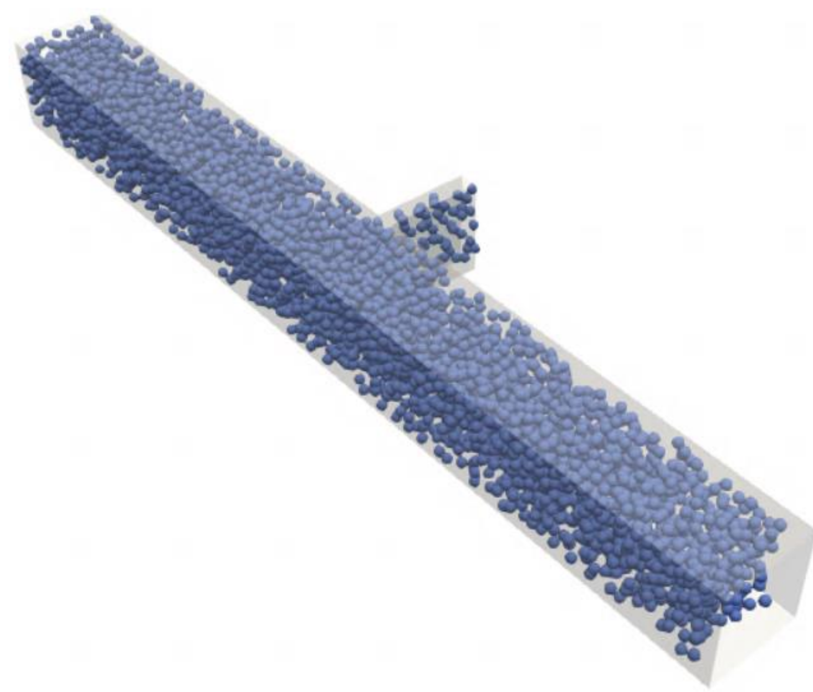



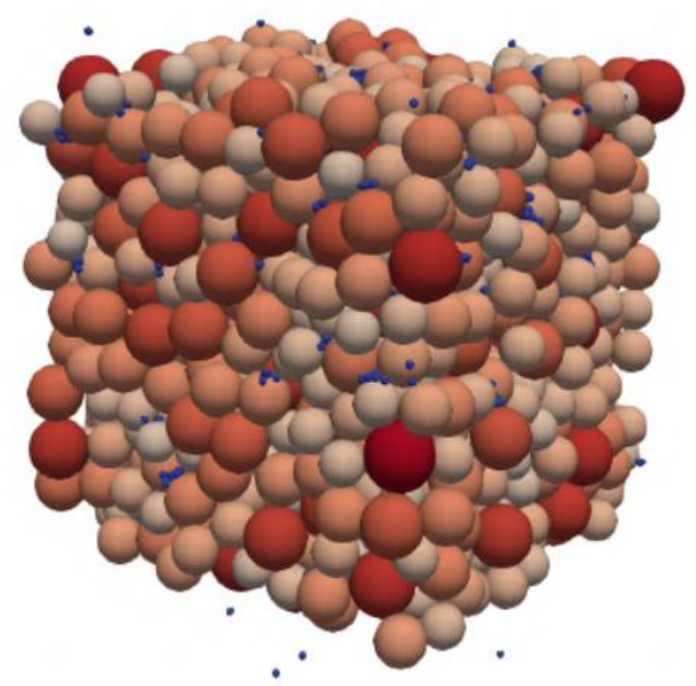

Reproduction of the Segre Silberberg effect gives confidence in the modelling of inertial flows.

## Preliminary results

Particle size affects leak-off into horizontal and vertical cleats, while leak-off into vertical cleats is proportional to particle density.

A repeatable method has been developed for obtaining porous media retention data with variable physics.





## Acknowledgements

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## References

[1] A. Khanna *et al.* (2013), *Stimulation of the natural fracture system by graded proppant injection.*
[2] A. Keshavarz *et al.* (2016), *Productivity enhancement by stimulation of natural fractures around a hydraulic fracture using micro-sized proppant placement.*