Hydraulic fracturing as a global cascade in networked systems

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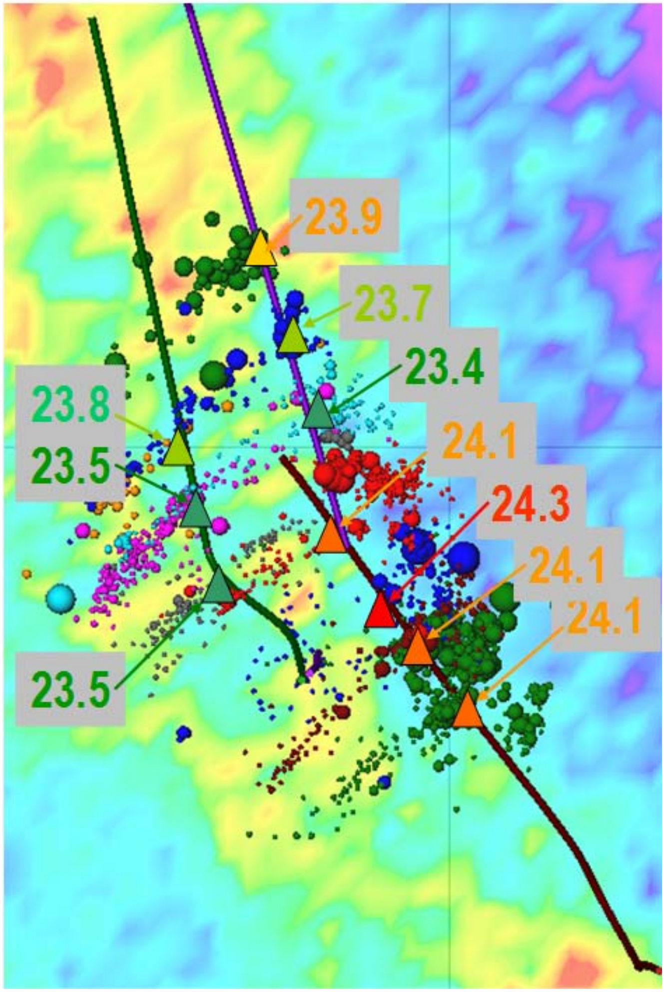
Empirical observations



From Maxwell et al., 2011

⬆ Brittleness ⬇ ISIP

⬆ Brittleness ⬆ Fracture length

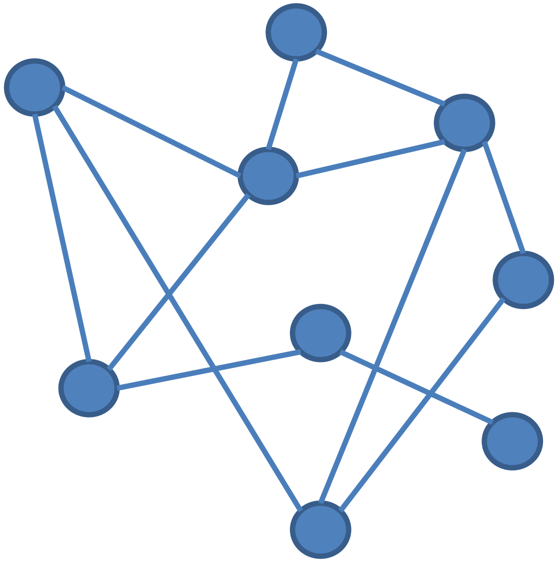
⬆ Brittleness ⬇ Moment density

Outline

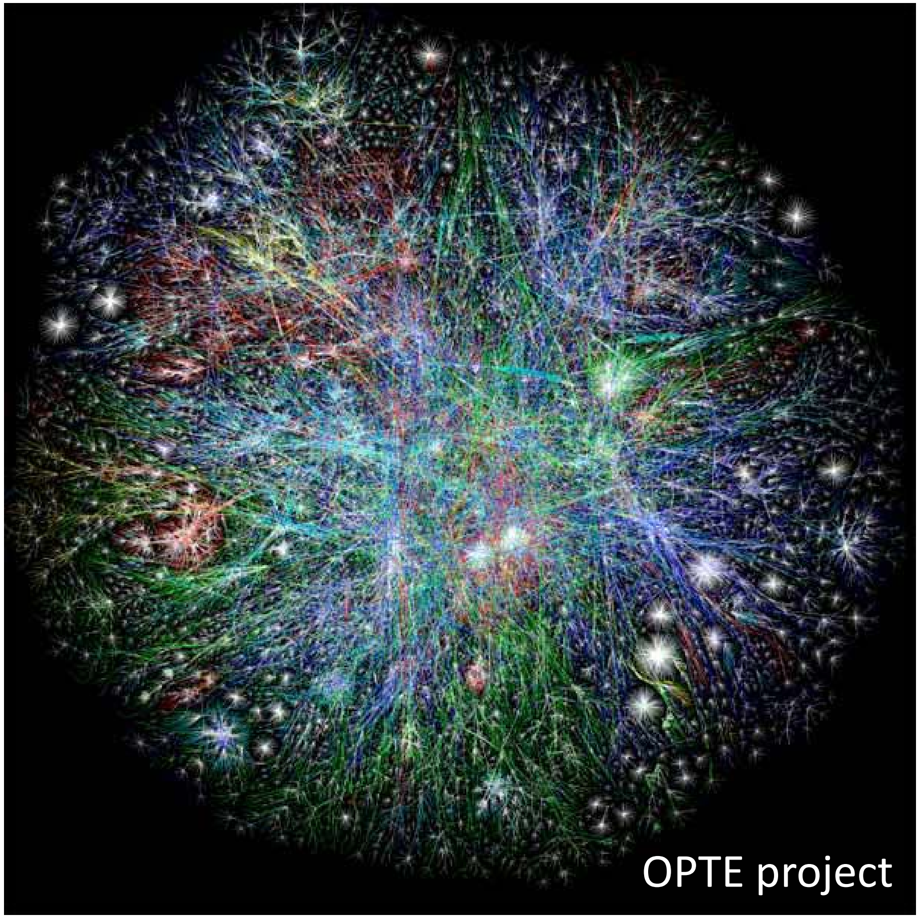
- Introduction to networks
- Model specification
  - Spreading model
  - Rock model
- Results

Networks

- Collection of points or nodes, connected by lines or edges
  - Purely theoretical objects
  - Useful representation
    - Complex systems
    - Systems with interacting components

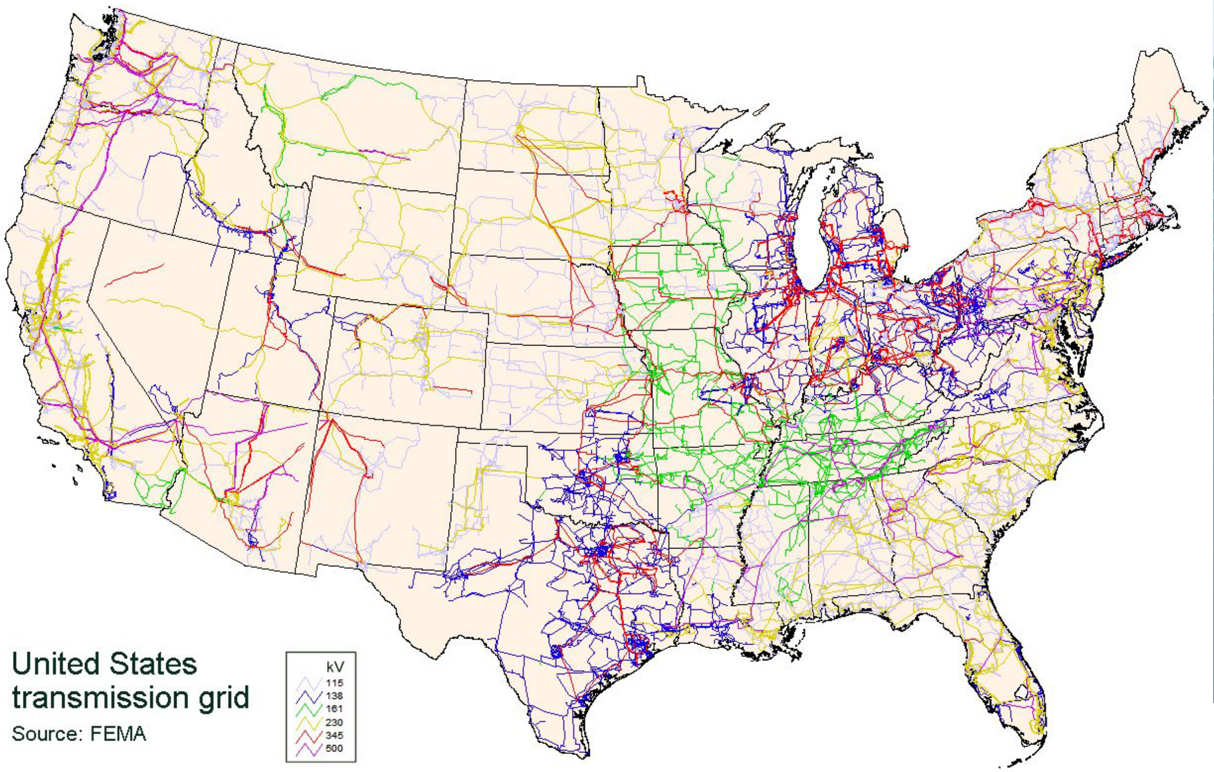


Network examples

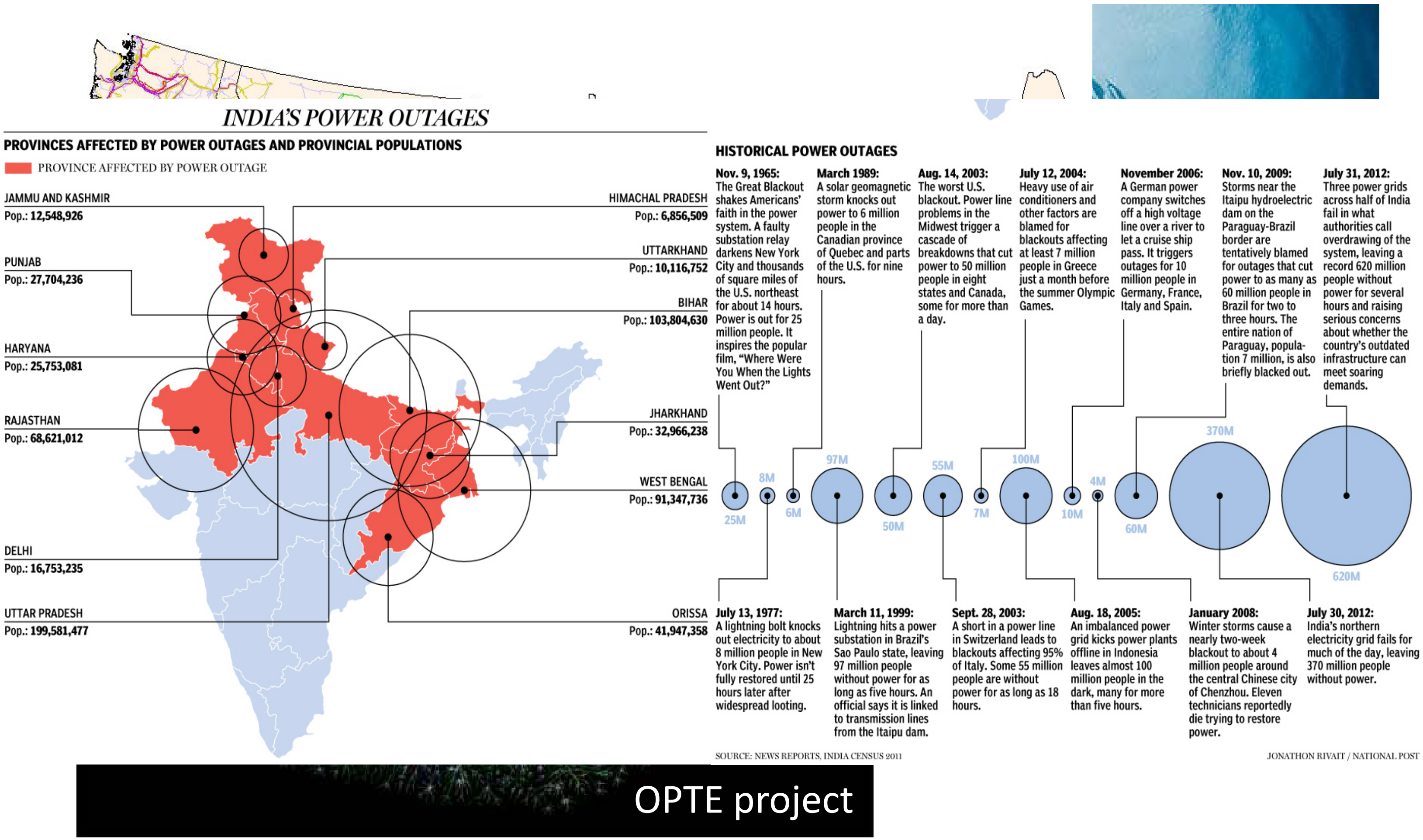


Network examples

Network examples



Network examples



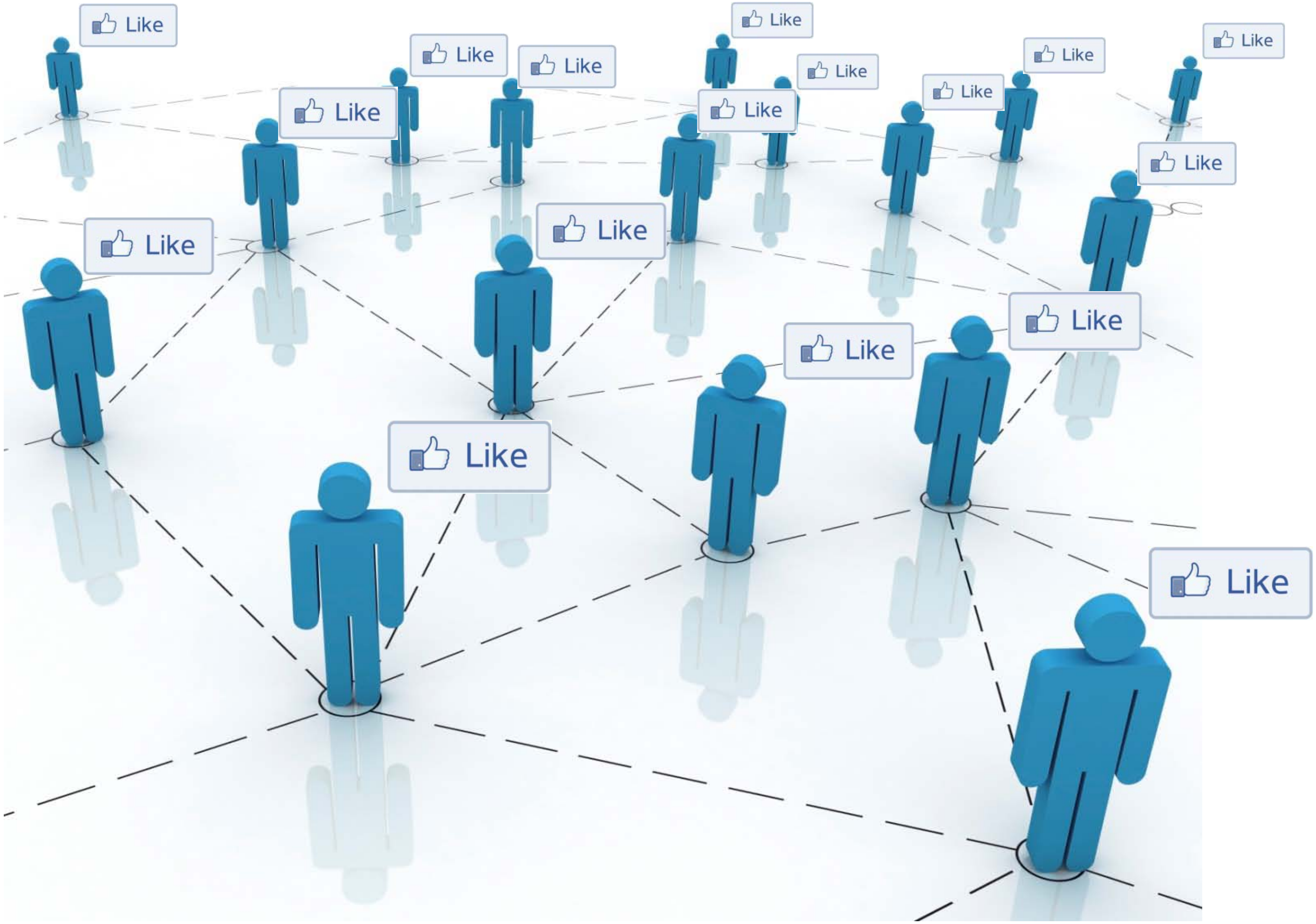
Motivating ideas

- In networked systems, the interactions between component parts are just as important as the parts themselves in defining the properties of the system (Motter and Albert, 2012)
  - Introduce non-linearities
- Macroscopic phenomena do not depend on the microscopic details of the process
  - Effective field theories
    - Applicable at some chosen length scale and ignores the substructure and degrees of freedom at shorter distances
  - Discard the complex fluid flow and fracture mechanics in modeling the dynamic response of hydraulic fracturing

Spreading model (Watts, 2002)

- Binary decision process
  - Each agent decides between two alternative actions
  - Decisions are based solely on the actions of other members in the population

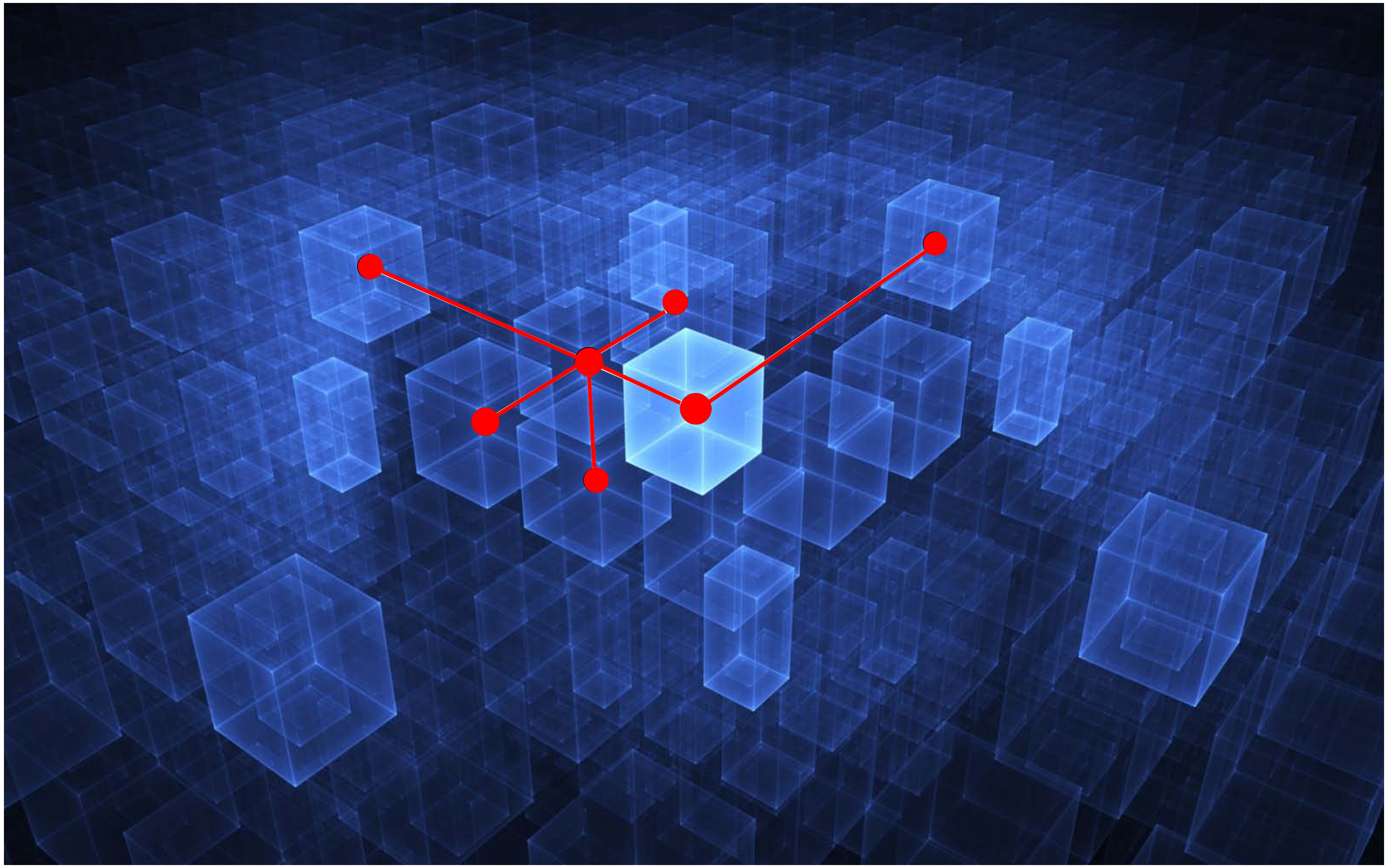
What movie should I watch?



Model specification

- Model parameters for each agent
  - Two possible states of 0 or 1
  - Threshold defined on the unit interval
  - Degree (range of connections)
- Dynamic modeling
  - Initiate with seed nodes
  - An individual agent observes the states of its connected neighbors
    - Adopts state 1 if threshold is reached
    - Remains in state 0 if threshold is not reached
  - Iterate

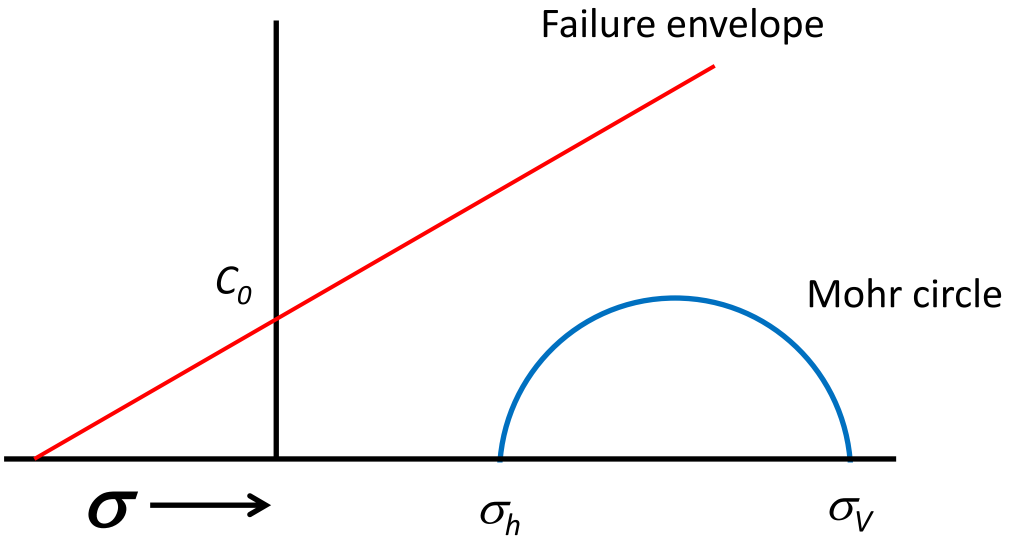
Rock network



Threshold

- Failure occurs when Mohr circle touches failure envelope

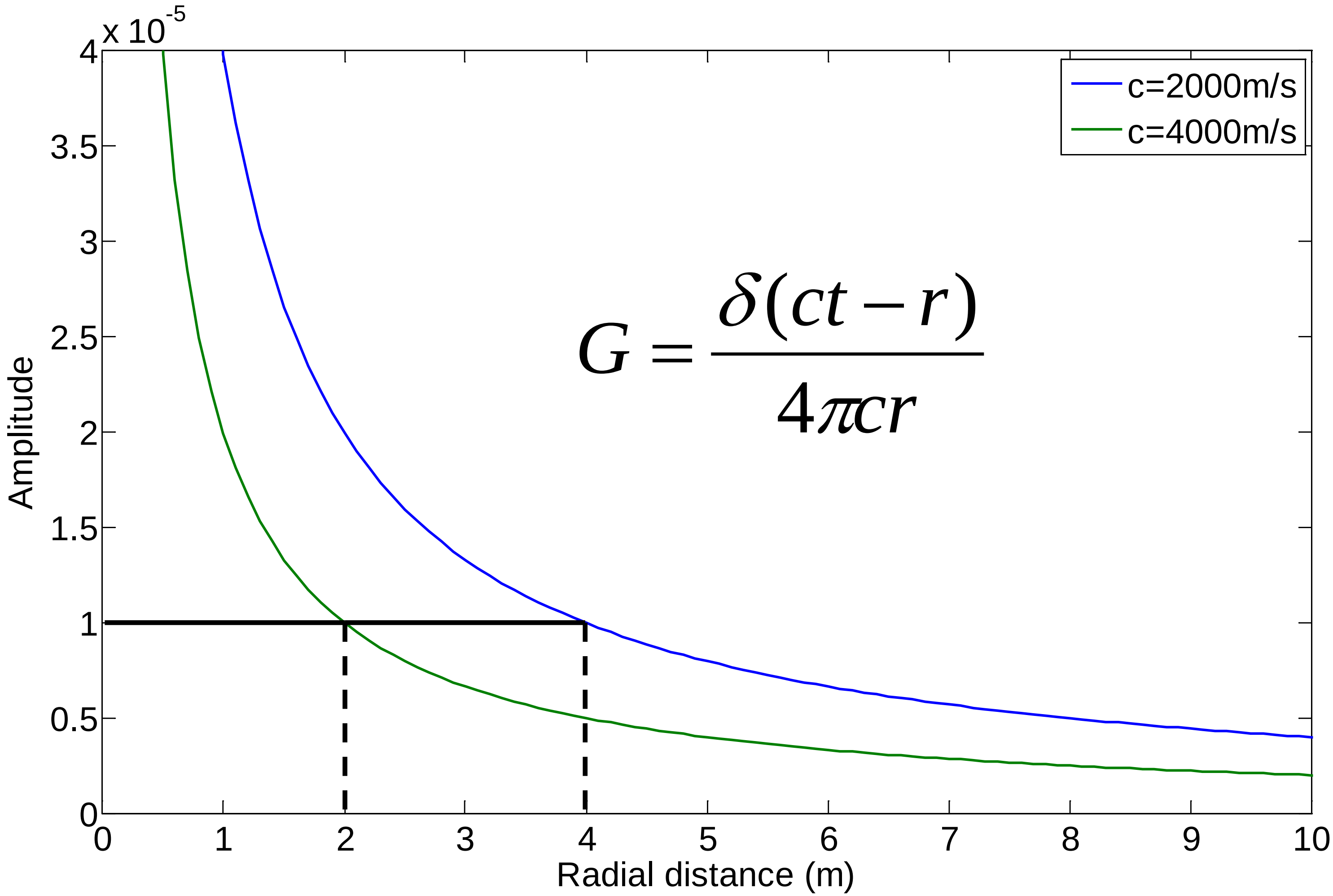
$$\sigma_H = \sigma_h = \frac{\upsilon}{1-\upsilon}\sigma_V$$



Degree

- Consider how information is transferred in an elastic solid
  – Upon the application of a stress, particle motion is excited through strain waves and propagates throughout the medium
  – Information transfer regarding the state of stress
    - Wave mechanics

Wave amplitude

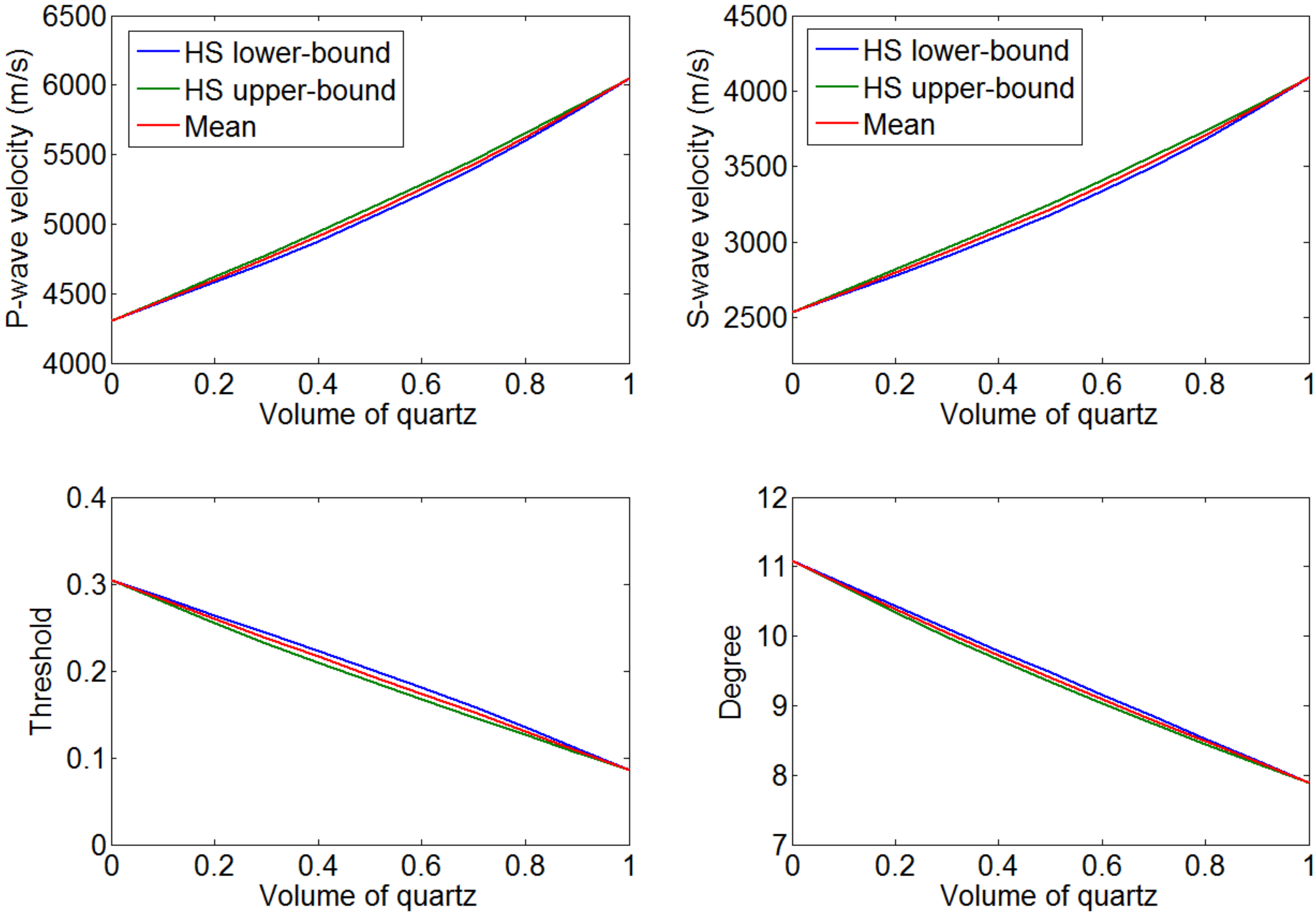


$$G = \frac{\delta(ct - r)}{4\pi c r}$$

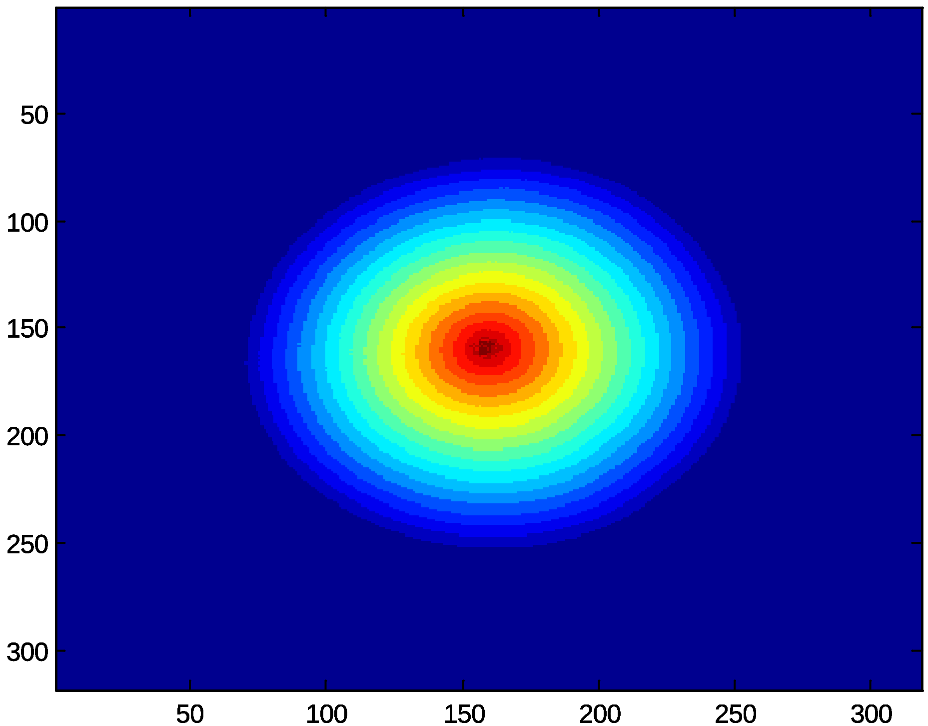
Rock model

- Hashin-Shtrikman (1963) to calculate effective elastic properties of a two phase material
  - Quartz and clay
    - Brittleness correlated to volume of quartz
    - Avoid ill-defined concept of brittleness

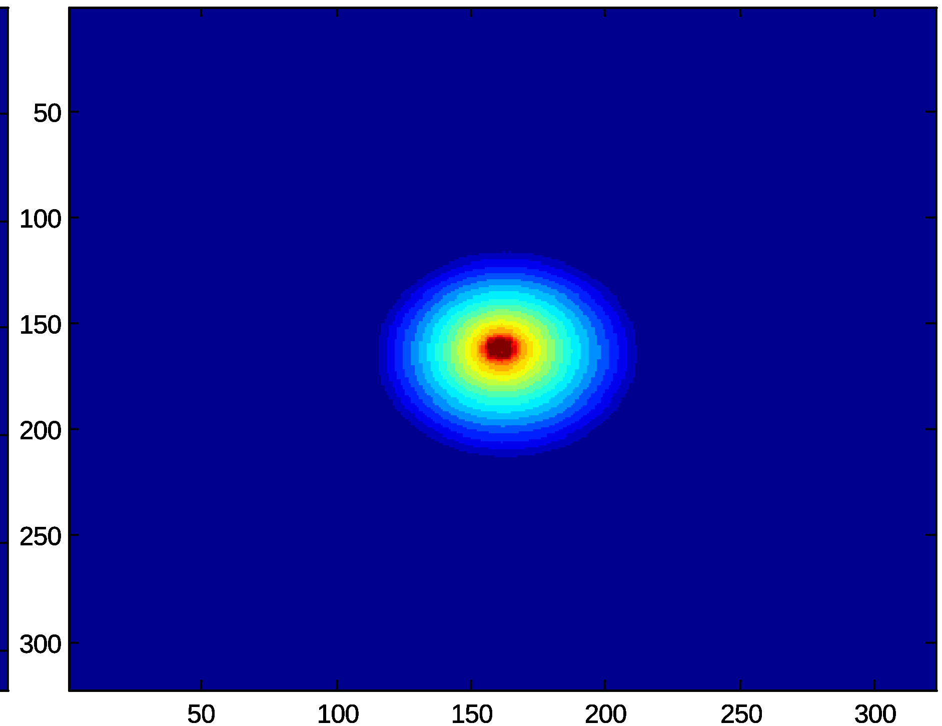
Effective medium properties



2D simulations



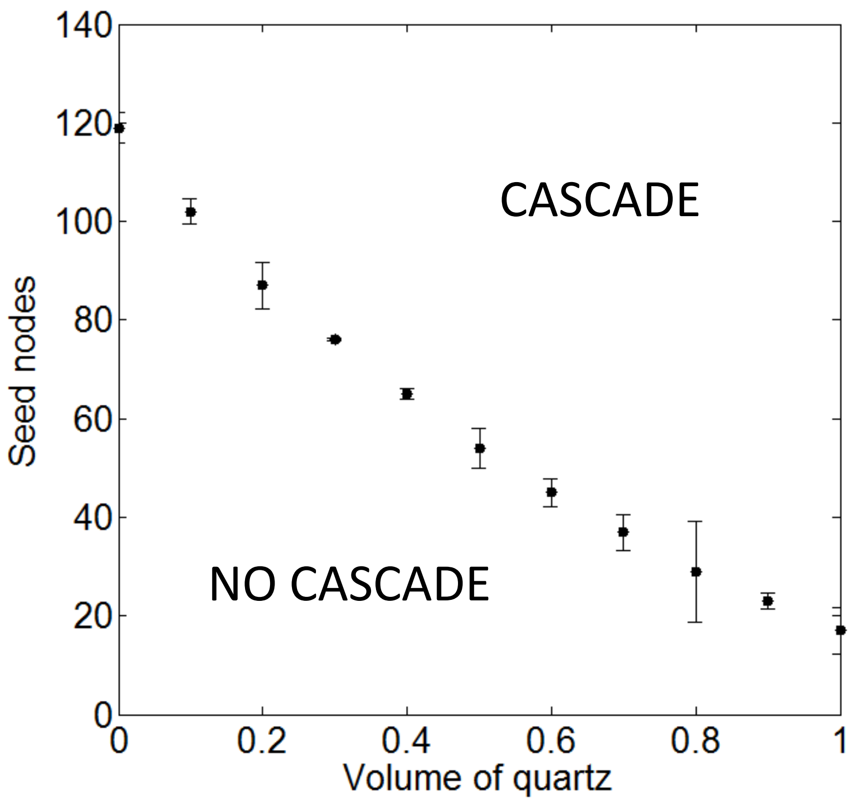
70% quartz



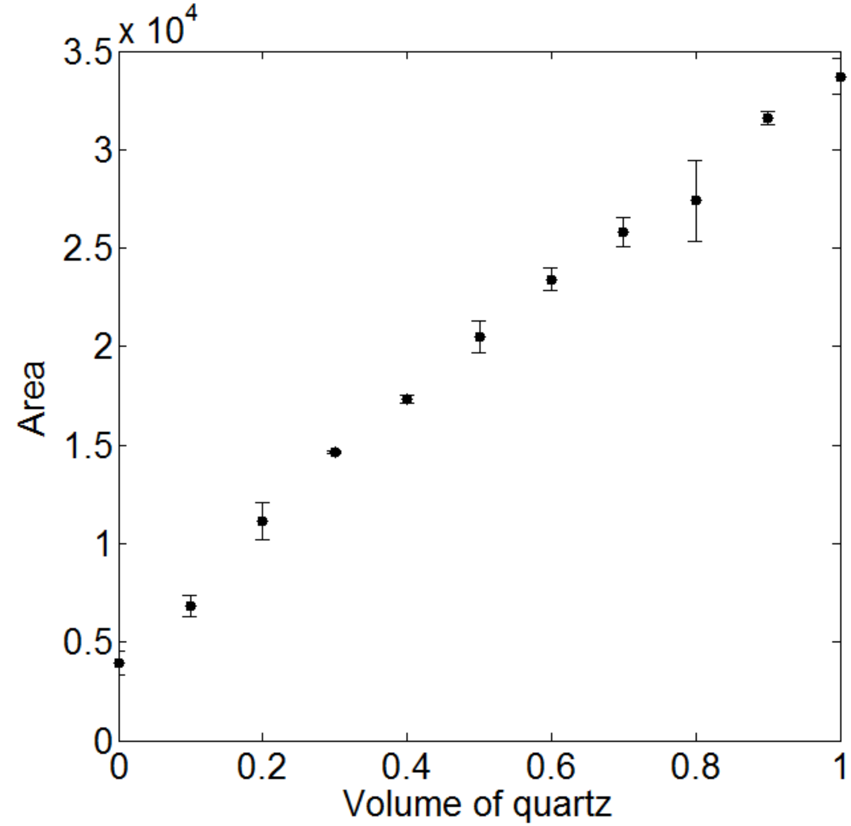
10% quartz

Results

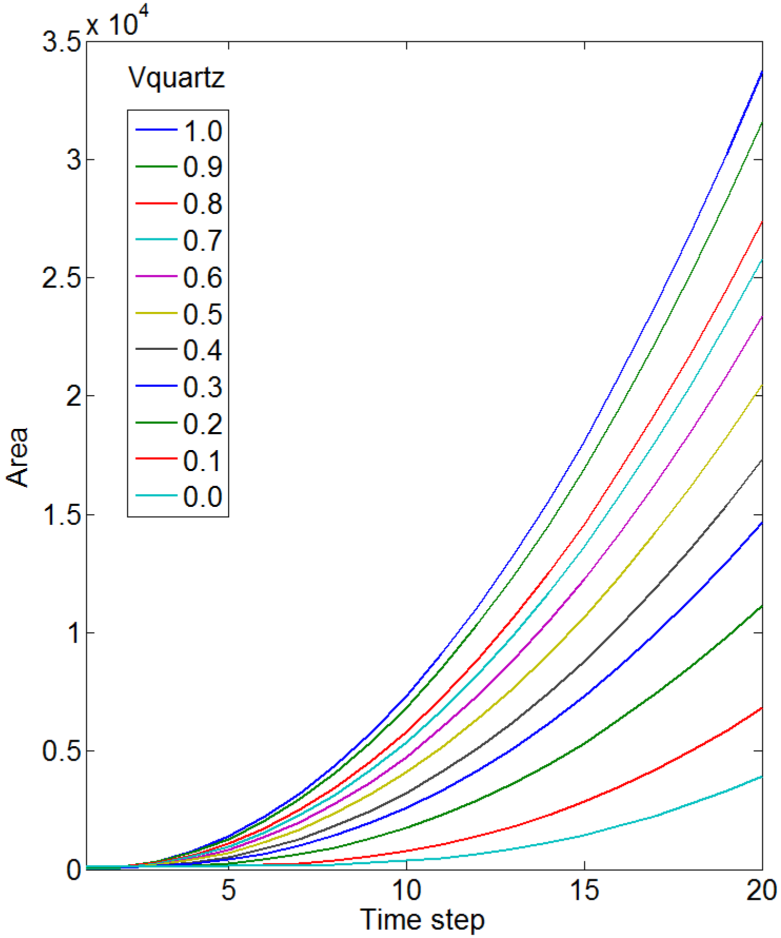
Cascade boundary

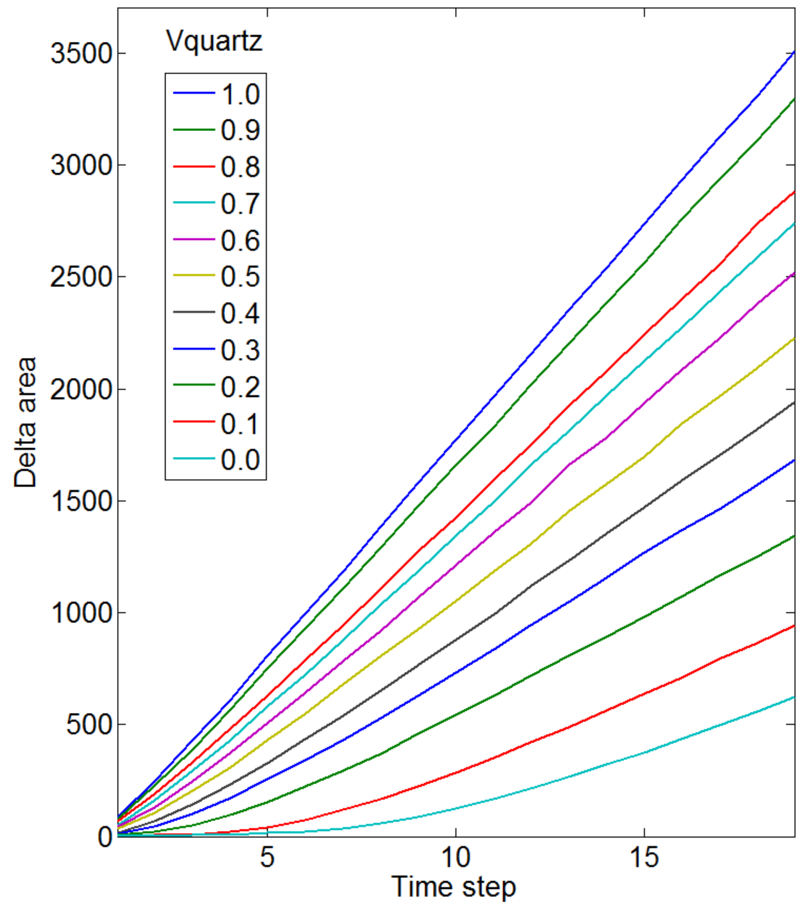


Stimulated area

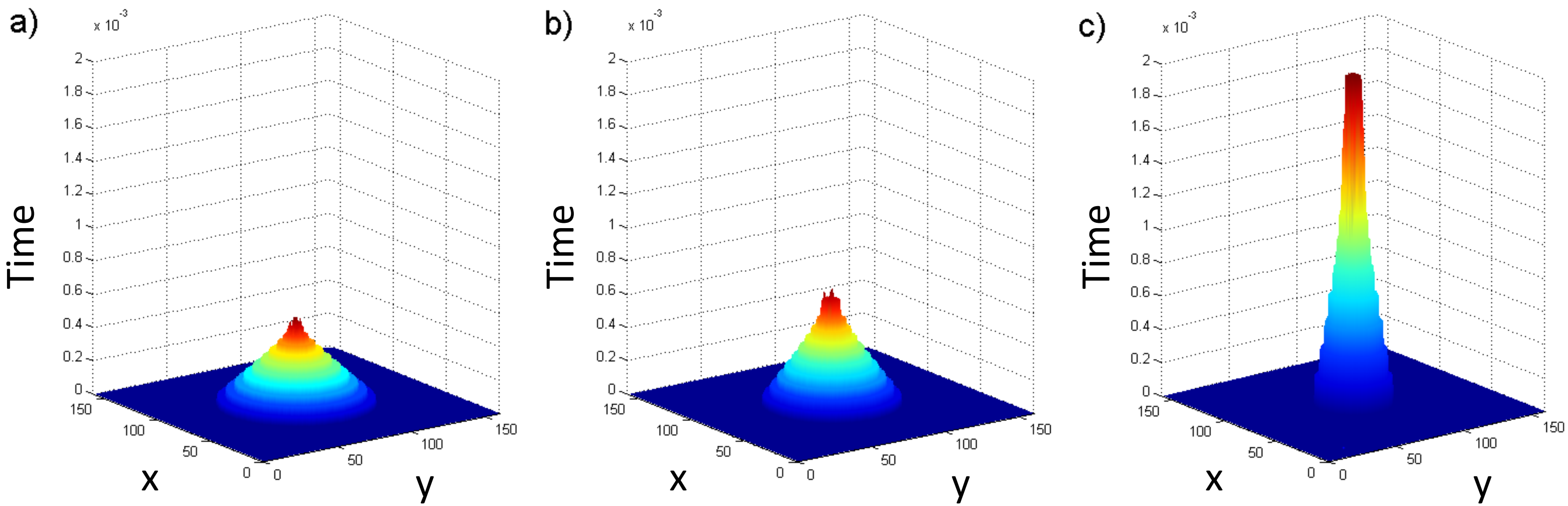


Fracture growth rate





Spatial energy output



70% quartz

40% quartz

10% quartz

Conclusions

- Presented a model for hydraulic fracture propagation
- Caution: Simplifications result in a lack of rigor in understanding the phenomenon at a fundamental level
- Provides an alternative view of the problem

Acknowledgements

- Jeff Grossman for his insights
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