Estimation of Permeability with Seismic "I really did mean to say permeability not porosity"

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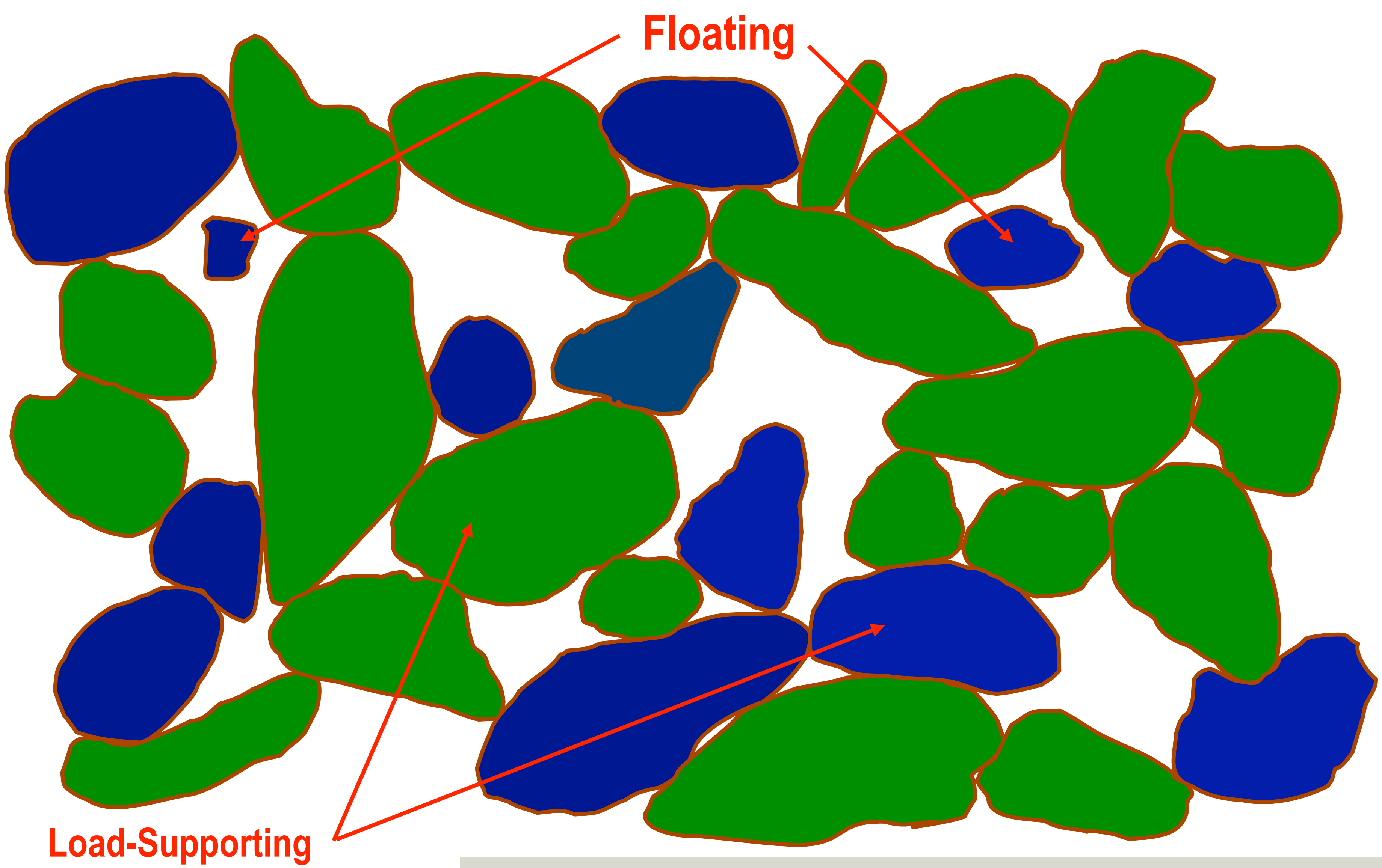
Outline

- rock physics model
- supporting measurements (log and core)
- numerical rock assembly model
- model based seismic inversion & practical detectability
- conclusions

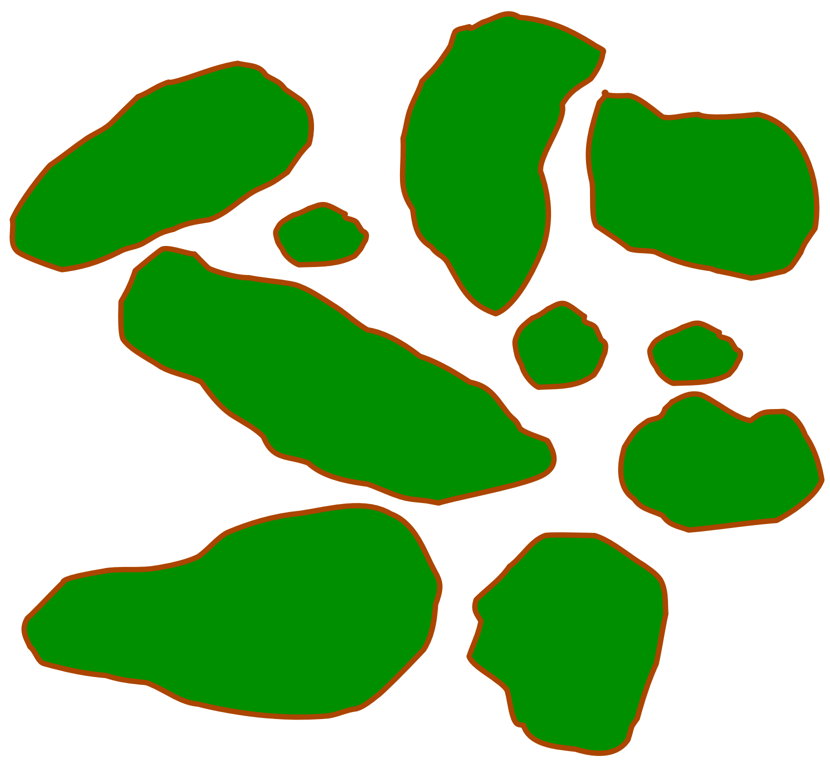
Floating grain model - the link of deposition physics to grain scale properties, permeability



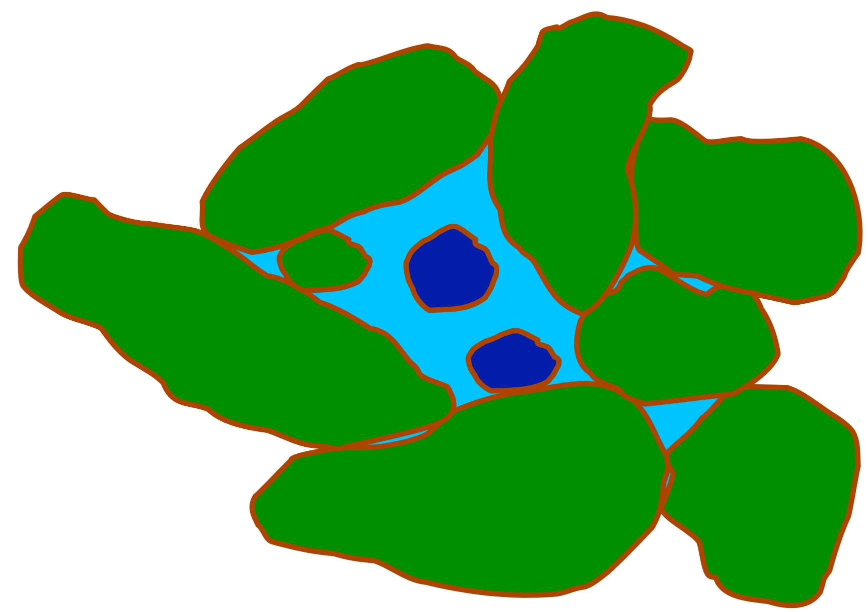
Abundance of potential floating grains in the system is due to two factors
- overall abundance of silt/mud-sized particles (related to nature of clastic input and system-scale proximal vs distal position)
- local variation due to depositional processes (e.g. rapid fallout vs traction)

Capture ratio is another key concept

At a constant Effective Stress - For every 3 small grains, 1 becomes part of matrix and 2 will float



Bimodal grain sizes (big and small)

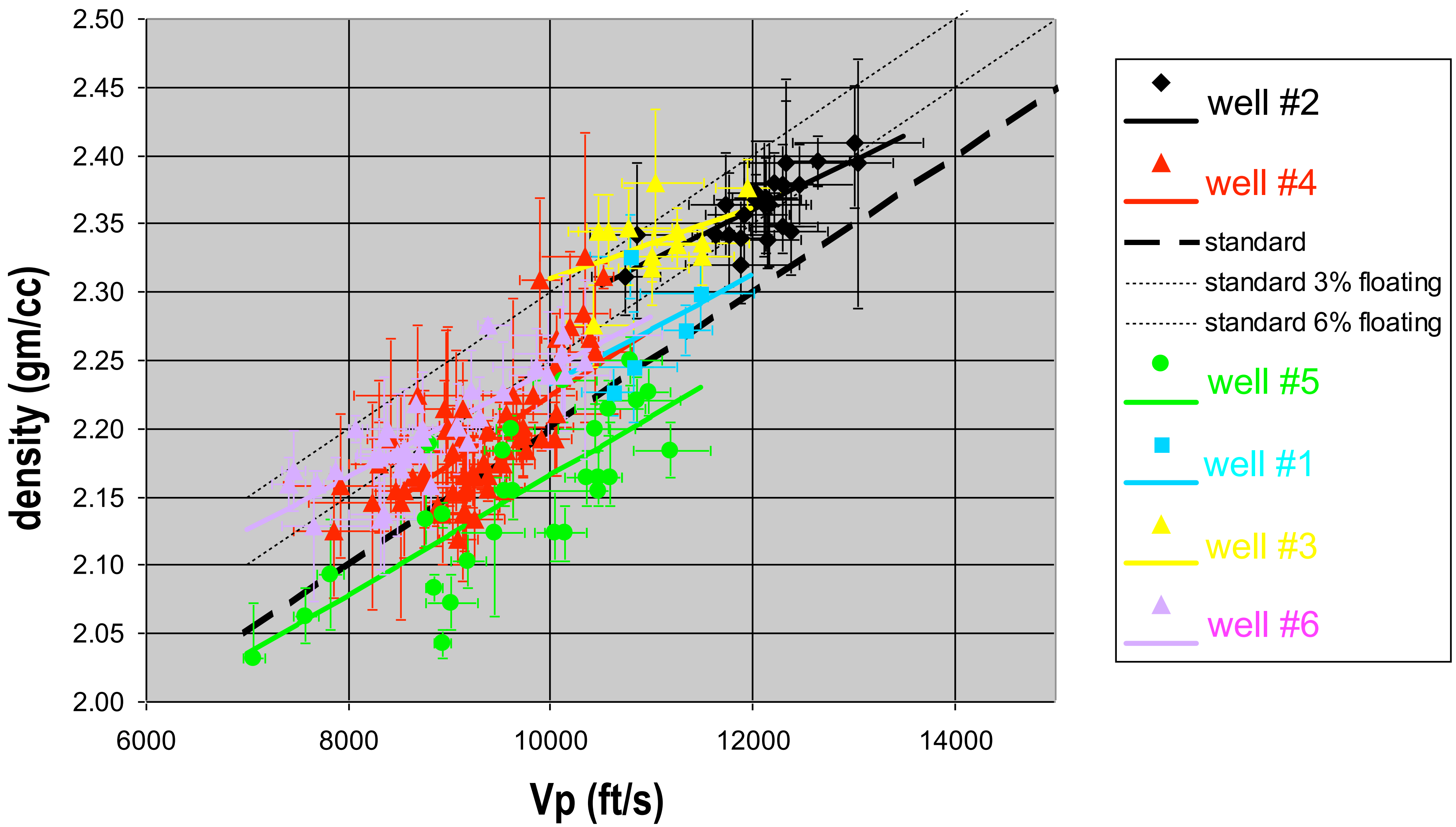


porosity (%) = -1.5*float(%) + B
(B is a constant for a particular constant Pe)

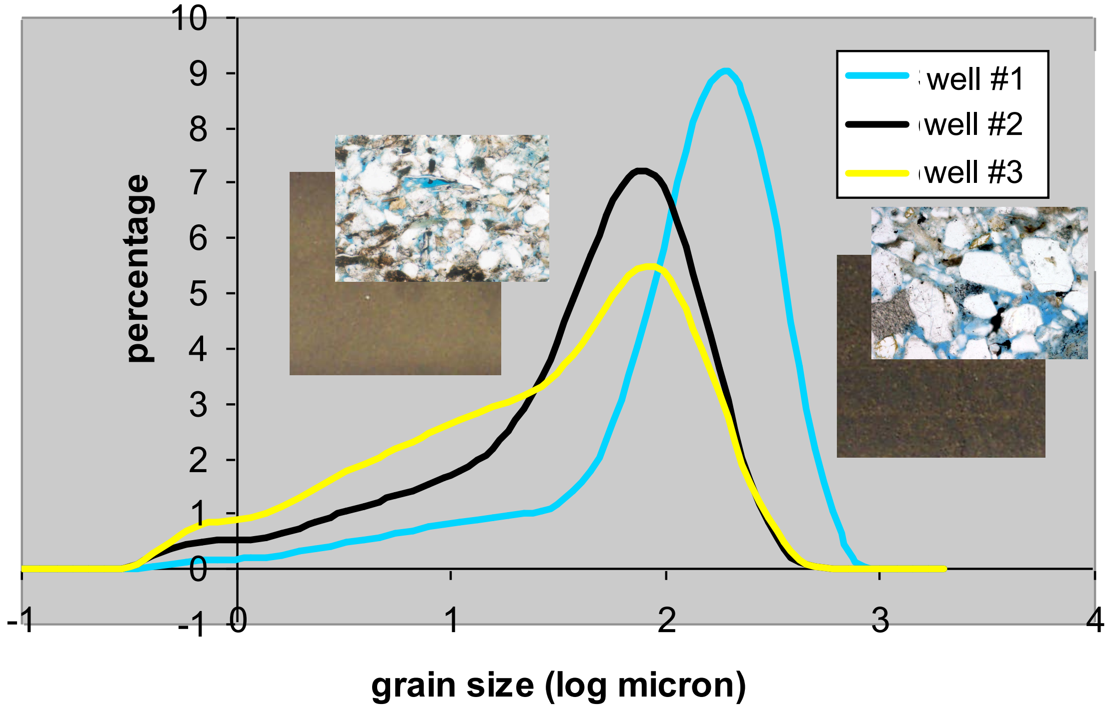
Capture Ratio = 1 – (1/1.5) = 33%
ie 1/3 of small grains are captured in to the load bearing matrix of the rock. The capture ratio will depend on the geometries of the original grains.

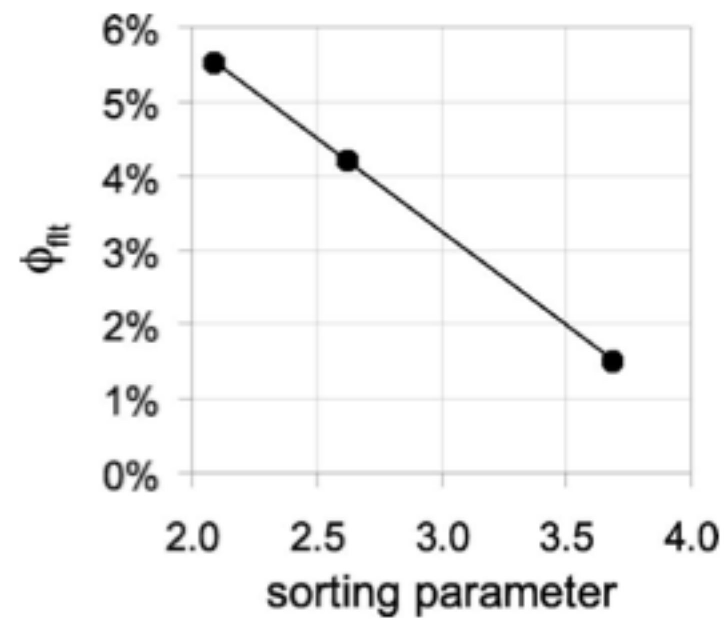
porosity in % = -1.54 * float in % - 88% * (1 – exp(- Pe / 800 psi)) + 110% +- 0.2%

Petrophysical evidence for the floating grain model



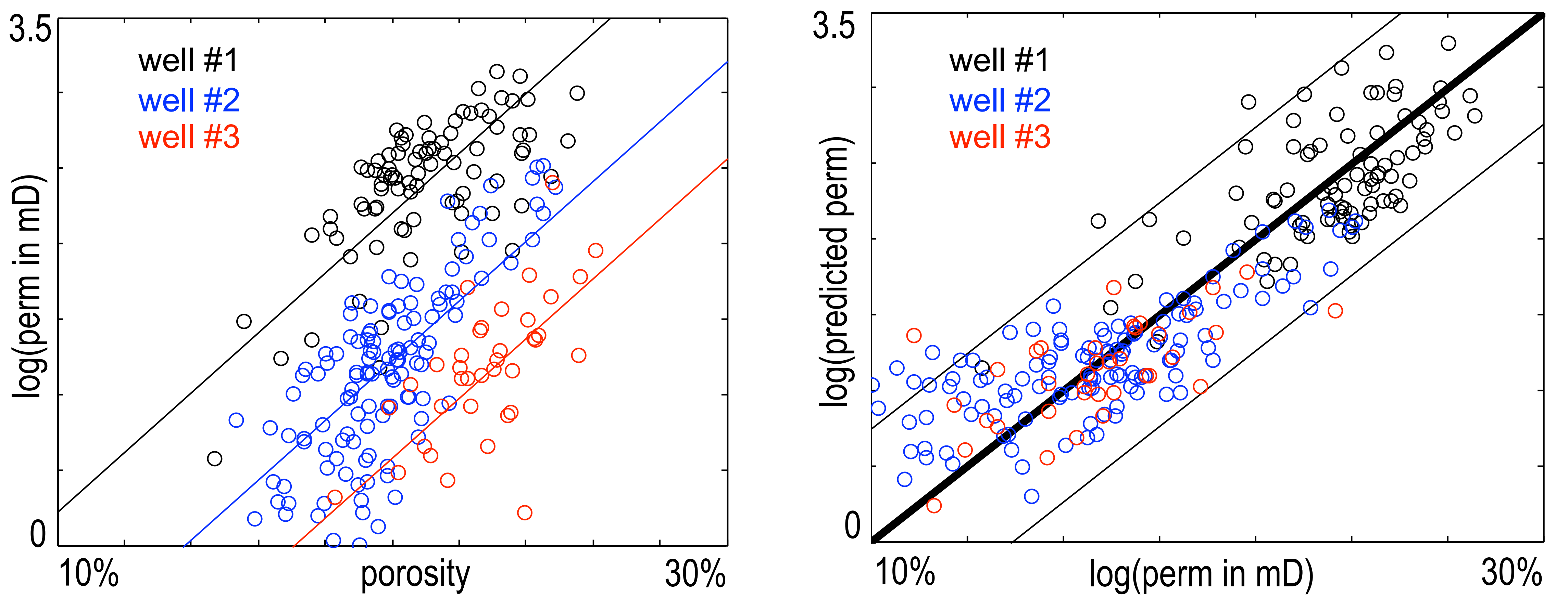
Relationship between size distribution and floating grain fraction





	mean	stddev	%floating
well #1	2.03	0.55	0%
well #2	1.58	0.60	3%
well #3	1.42	0.68	5%

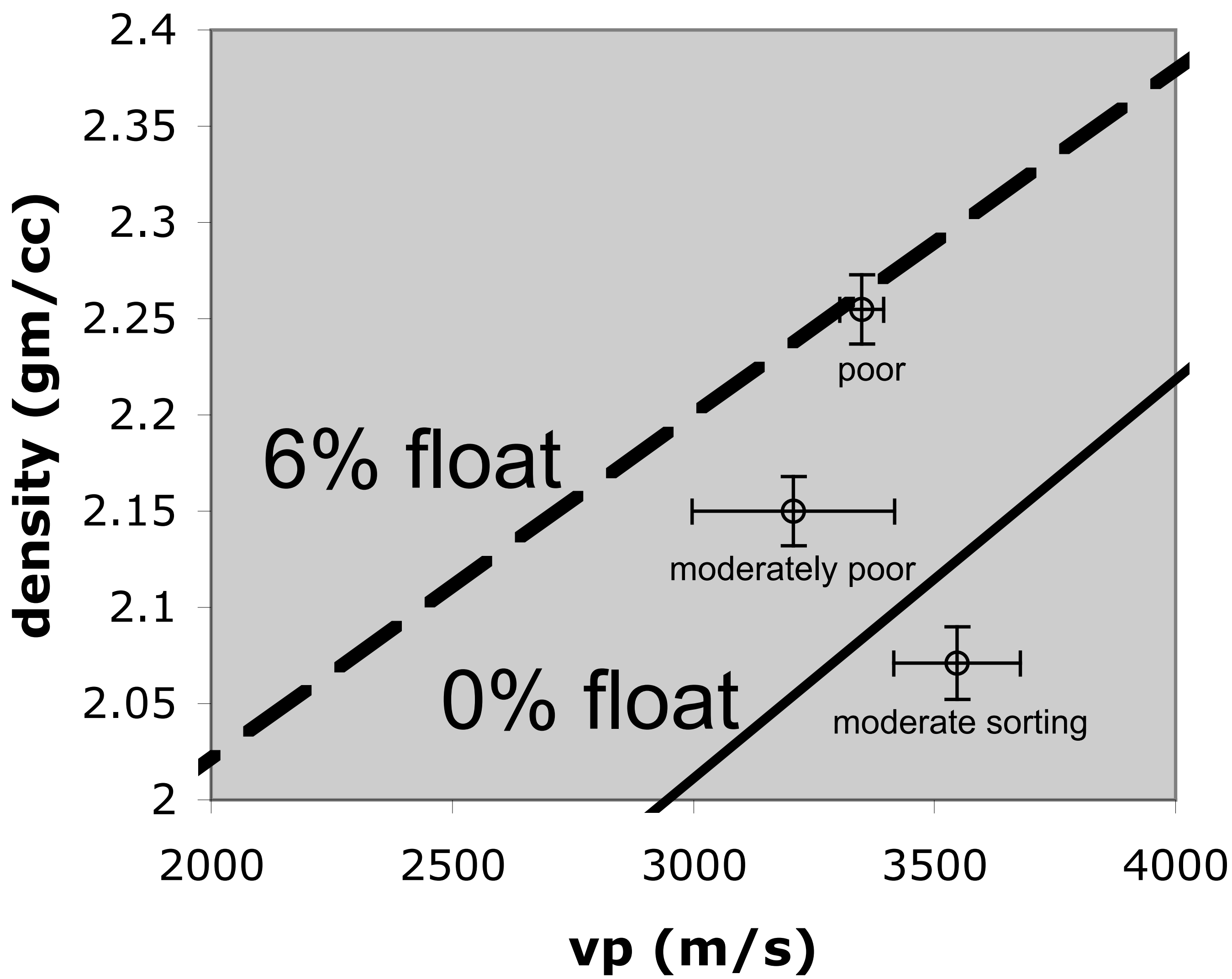
Good regression found between the permeability, porosity, and floating grains



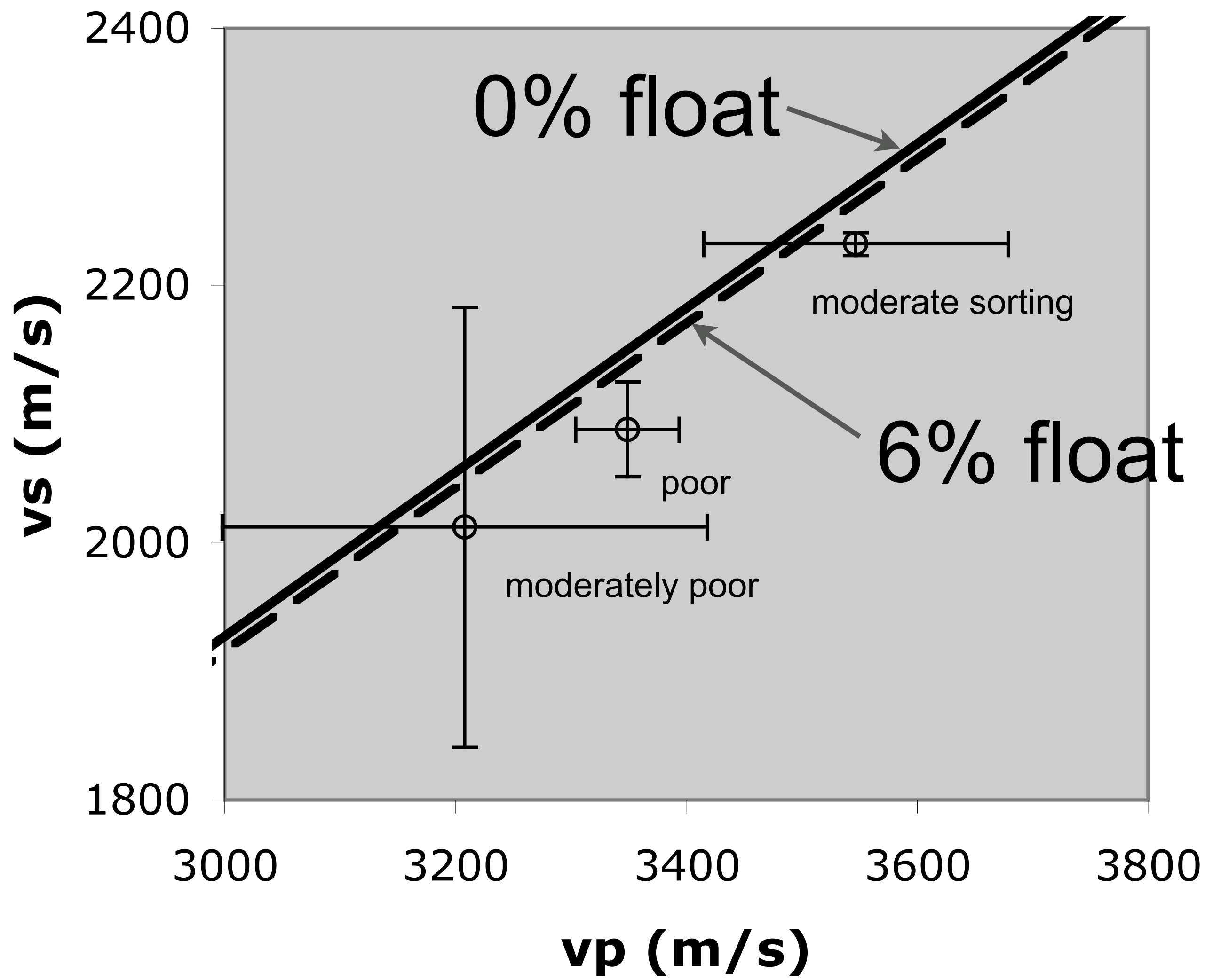
log(perm in mD) = 0.198 * porosity in % - 0.325 * floating in % - 1.76   + - 0.37

x / 2.3

Acoustic resonance measurements on well #2 core confirm trend seen in logs

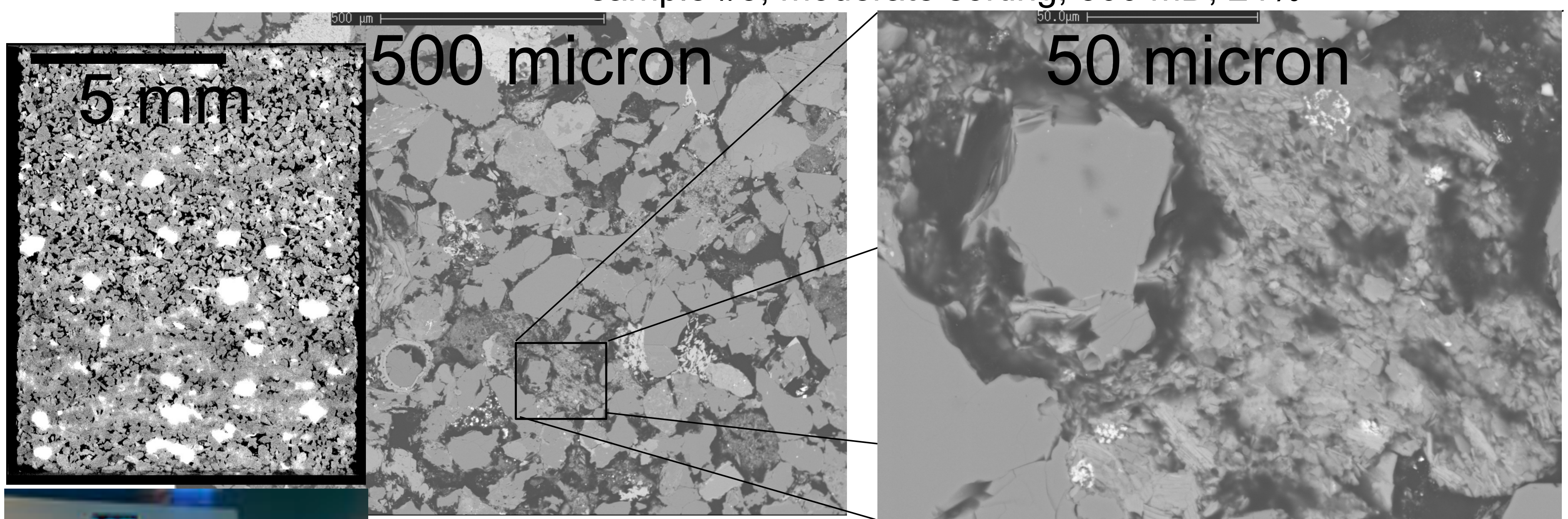


No change in shear velocity as seen on logs and predicted by theory

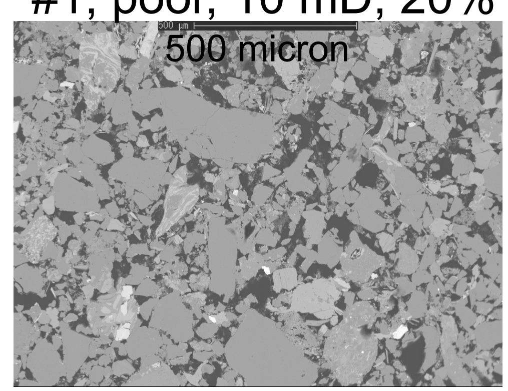


Floating grains seen in CAT scan and SEM of well #2

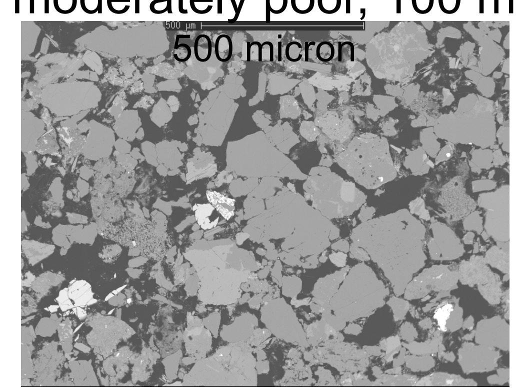
sample #3, moderate sorting, 300 mD, 24%



#1, poor, 10 mD, 20%



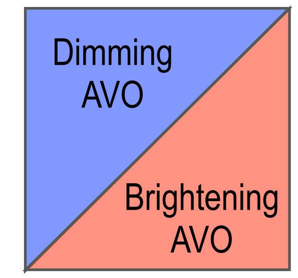
#2, moderately poor, 100 mD, 22%



Guide to AVO interpretation

Increasing NG
0% to 100%

Brine to Oil

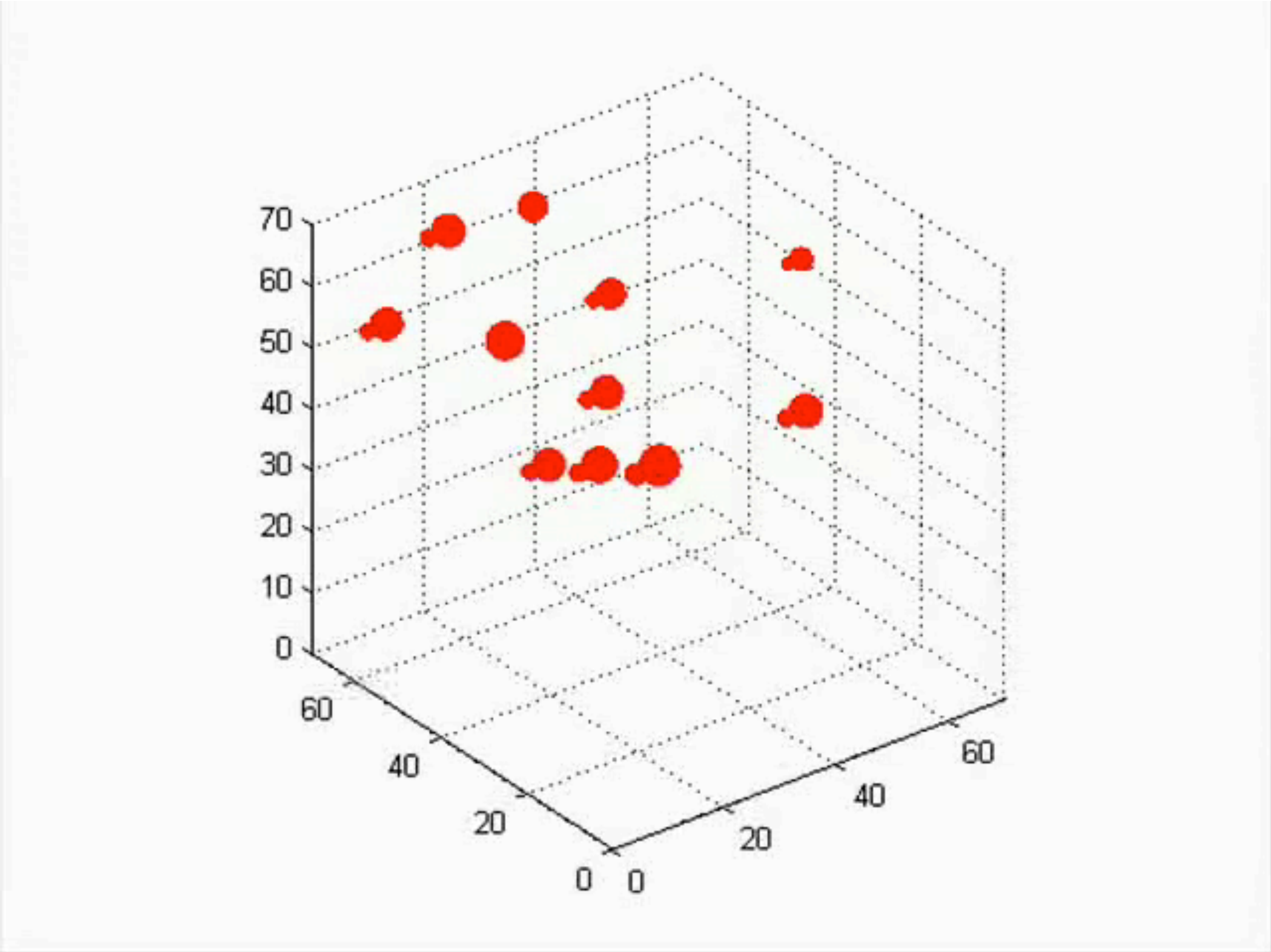


Decreasing Float
6% to 0%
Increasing perm
1 mD to 1000 mD

Decreasing
Effective Stress
1000 psi

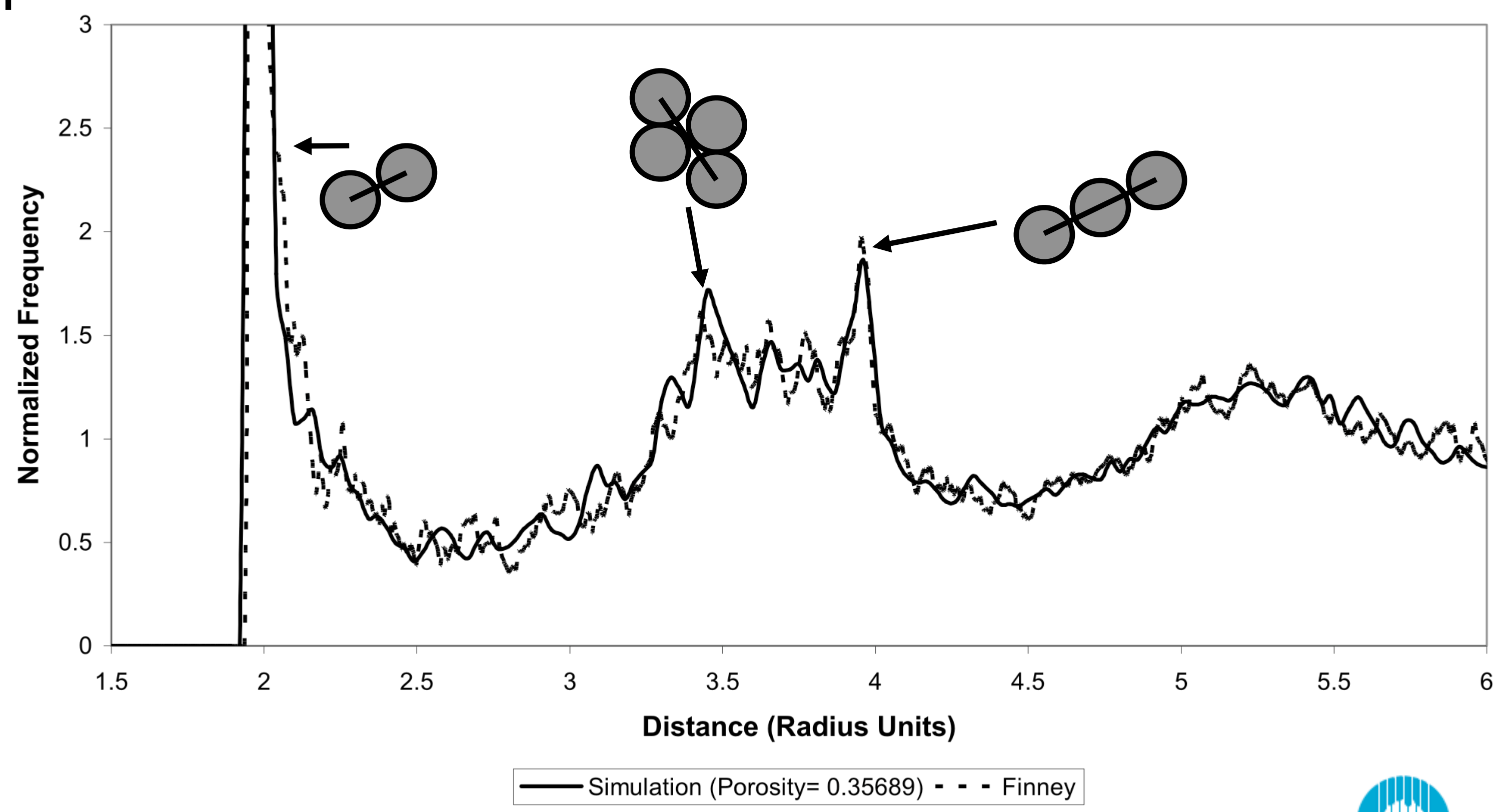
Numerical rocks give important understanding of floating grain model

- Create sphere packings (two size) representative of unconsolidated sediment through “cooperative rearrangement” algorithm
- Quantify the number of loose grains in packings
- Understand capture fraction

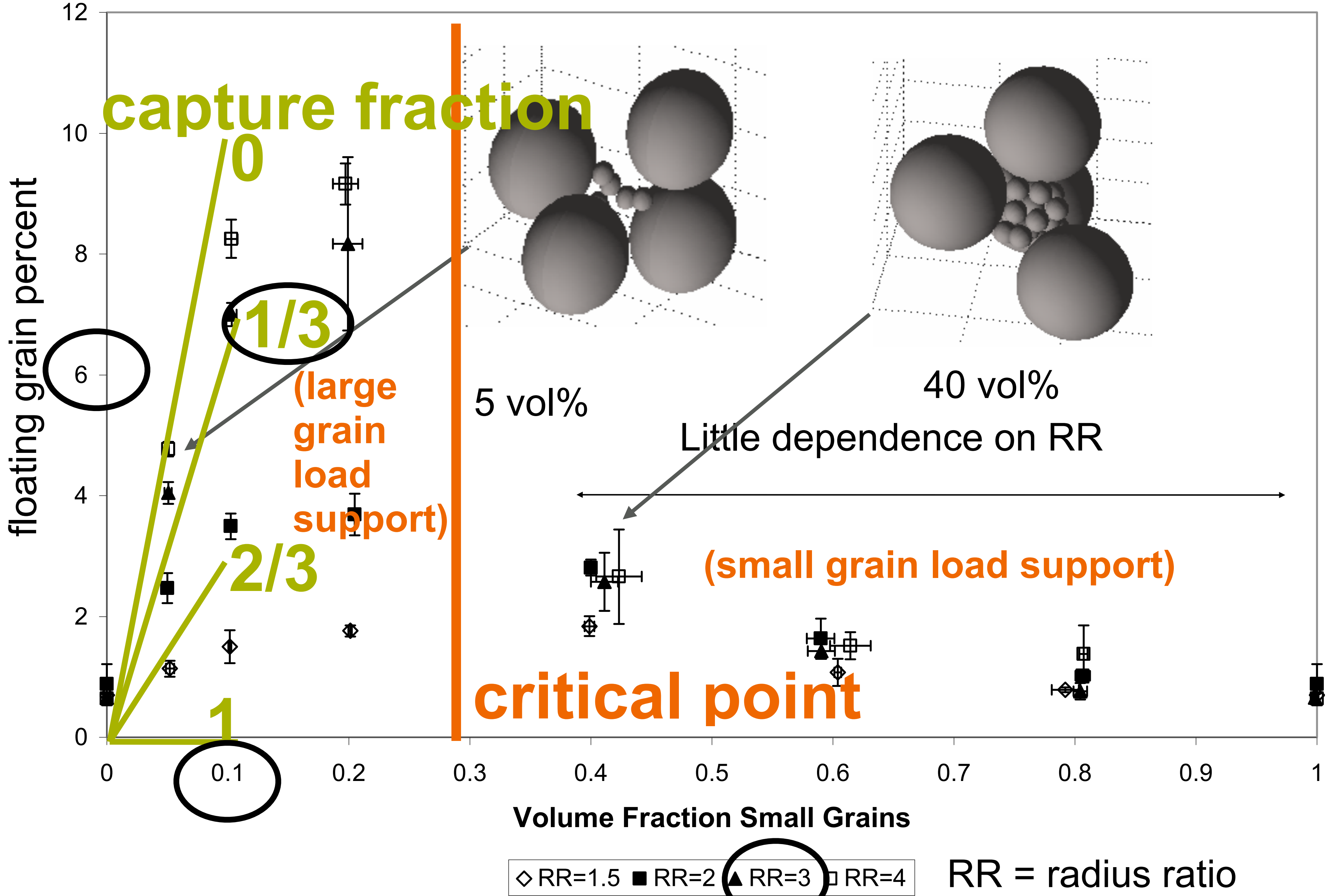


Mono-dispersed packing validation

- Single grain size
- Comparison with Finney packing
- Quality checks:
  - Porosity
    - 36.3% Finney v. 36.2% simulation
  - Percent of loose grains
    - 1.8% Finney v. 1.6% simulation
  - Radial distribution function

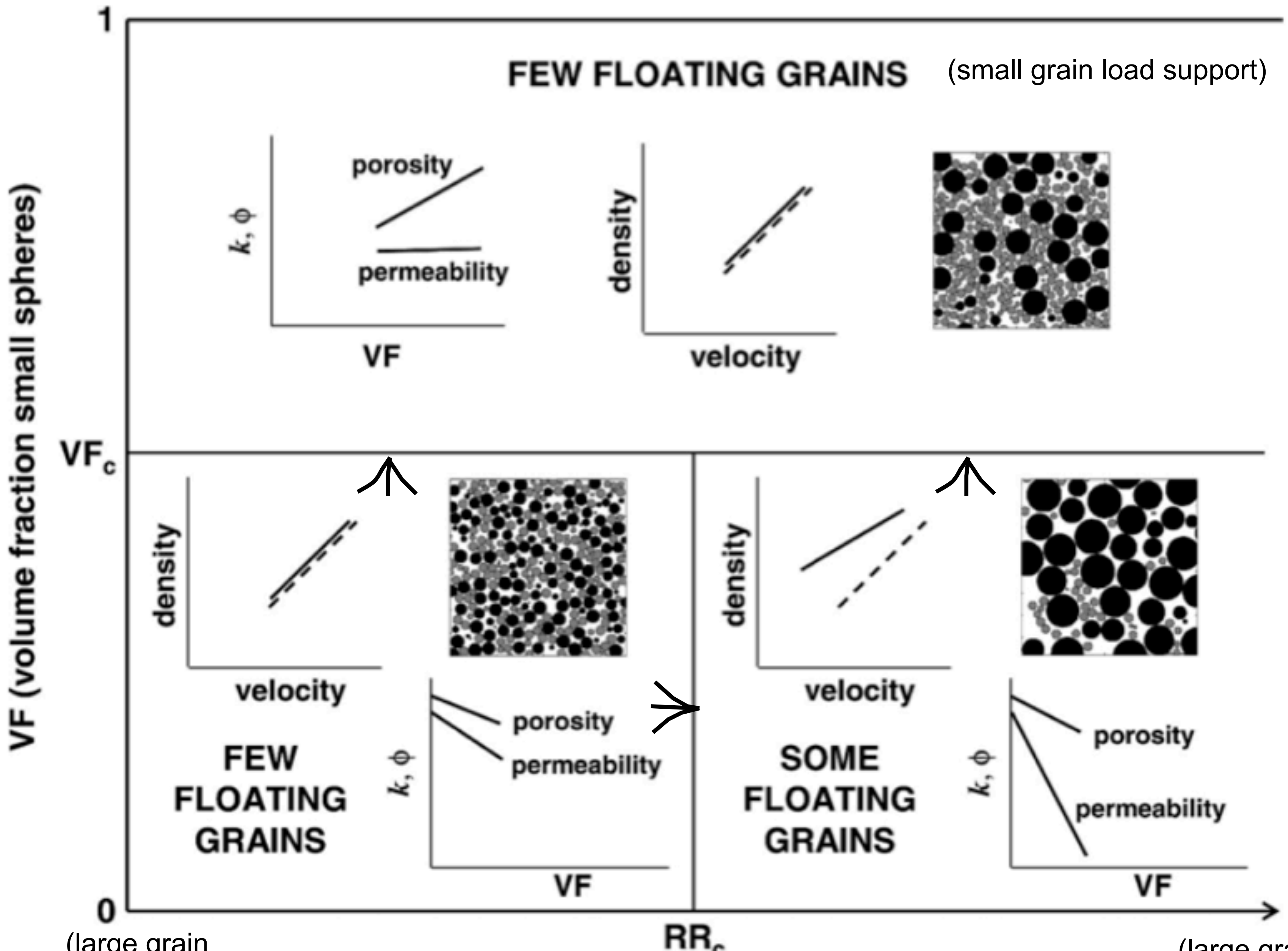


Floating grain fraction & capture ratio demonstrated



“Thermodynamics of random packing”, Physics Today (June 2007)

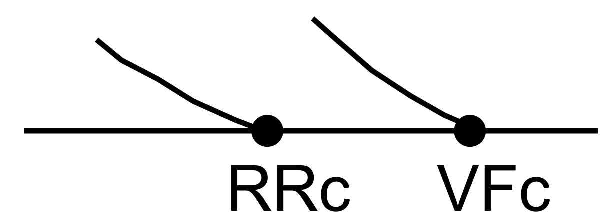
Phase diagram for random packing of binary mixture of spheres



(large grain load support, small grains part of matrix)

(large grain load support, small grains float)

note: volume fraction dominates over radius ratio critical point



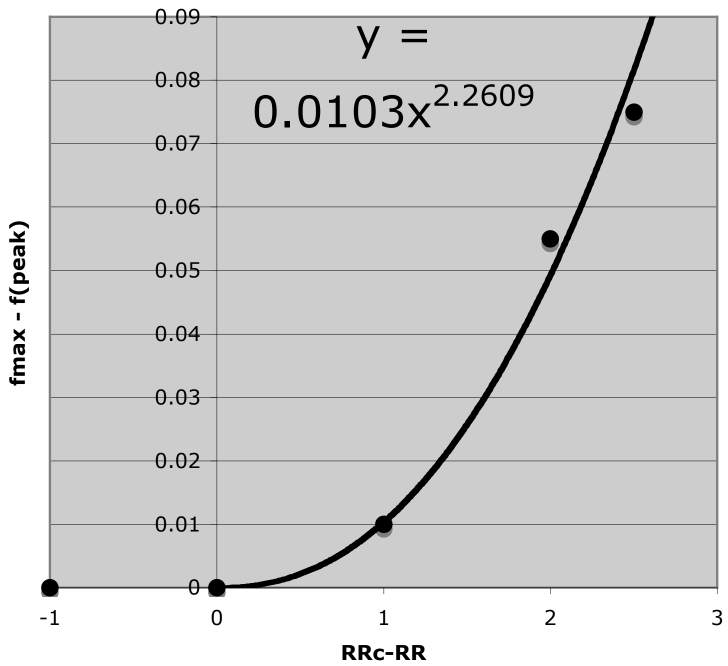
$Rc \approx 4$

$VFc \approx 0.45$

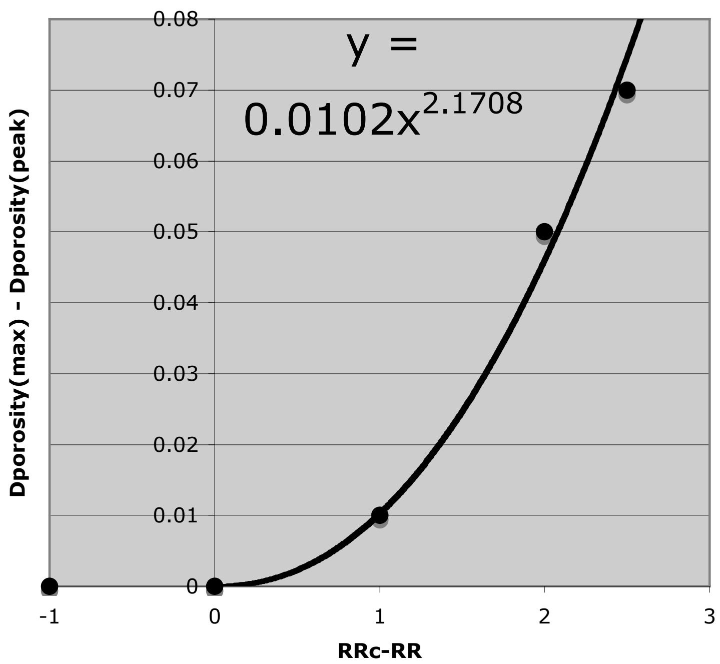
"Statistical mechanics of dense granular media", Coniglio et al., J. Cond. Matter **17**, S2557 (2005).

Critical scaling for radius ratio critical point (RRc)

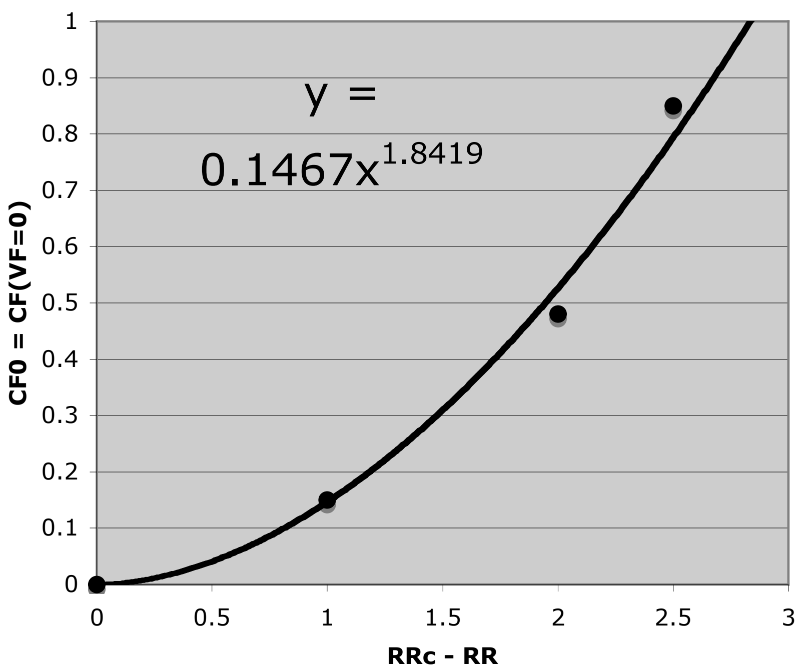
peak floating fraction



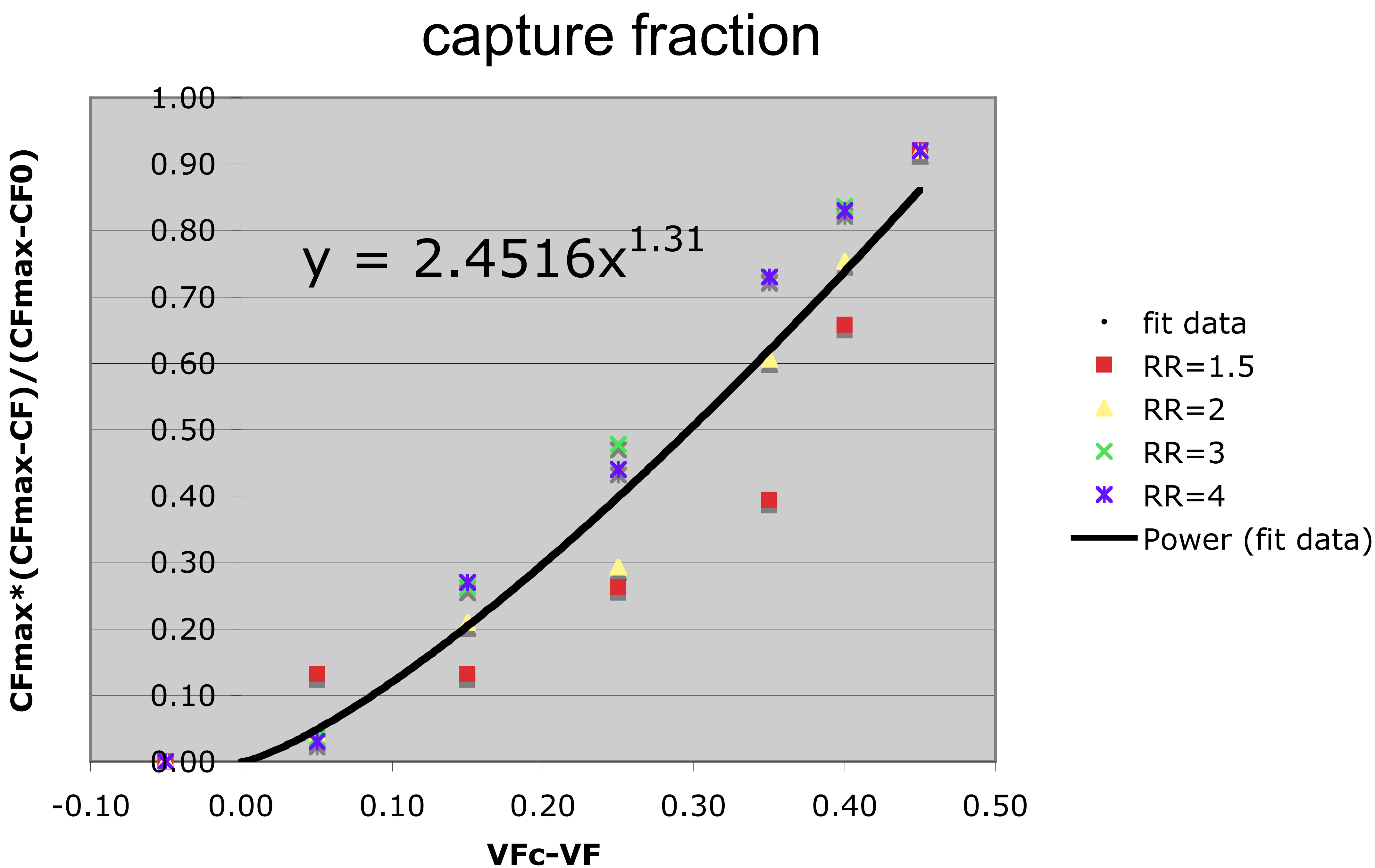
peak decrease in porosity



capture fraction @ volume fraction = 0

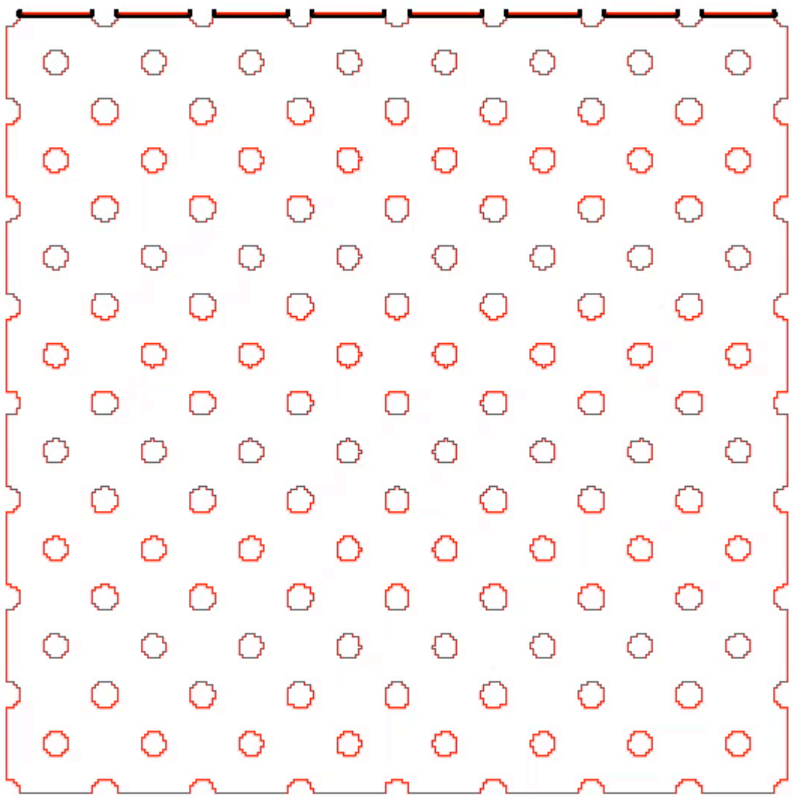


Critical scaling for volume fraction critical point (VFc)

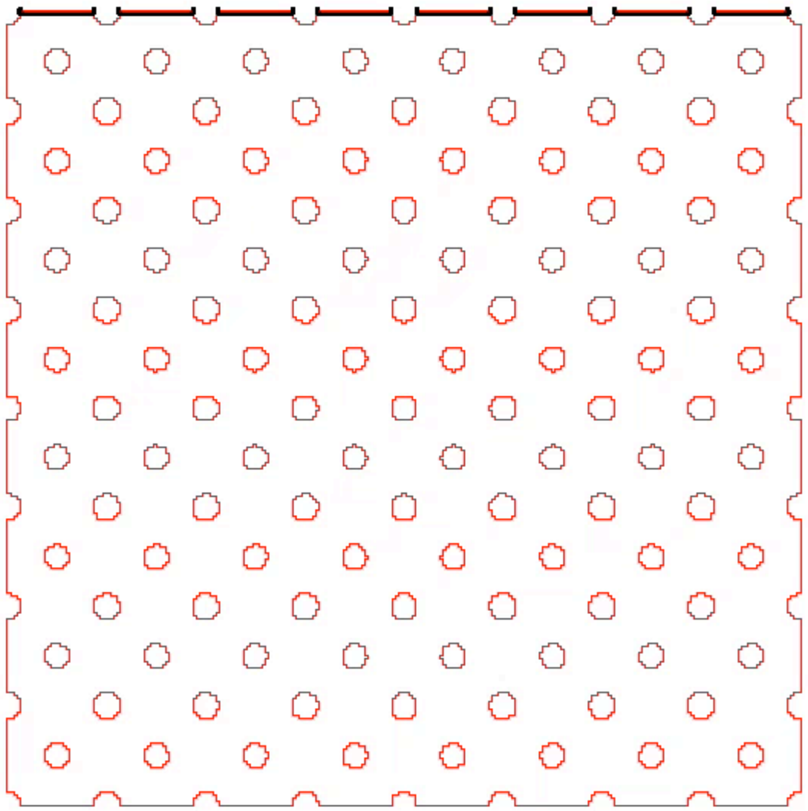


Permeability can be simulated given 3D rock matrix from CAT

small capillary pressure



large capillary pressure



Implementation of floating grain model in DELIVERY

$$v_p^2(\phi_{flt},\lambda)=\frac{K_g}{\rho_g(1-\phi)+\rho_f\phi}\left(\frac{3(1-\nu)}{(1+\nu)}(1-(\phi+\phi_{flt})/\phi_0)^\lambda+\frac{(1-(1-(\phi+\phi_{flt})/\phi_0)^\lambda)^2}{\phi(K_g/K_f-1)+1-(1-(\phi+\phi_{flt})/\phi_0)^\lambda}\right)$$

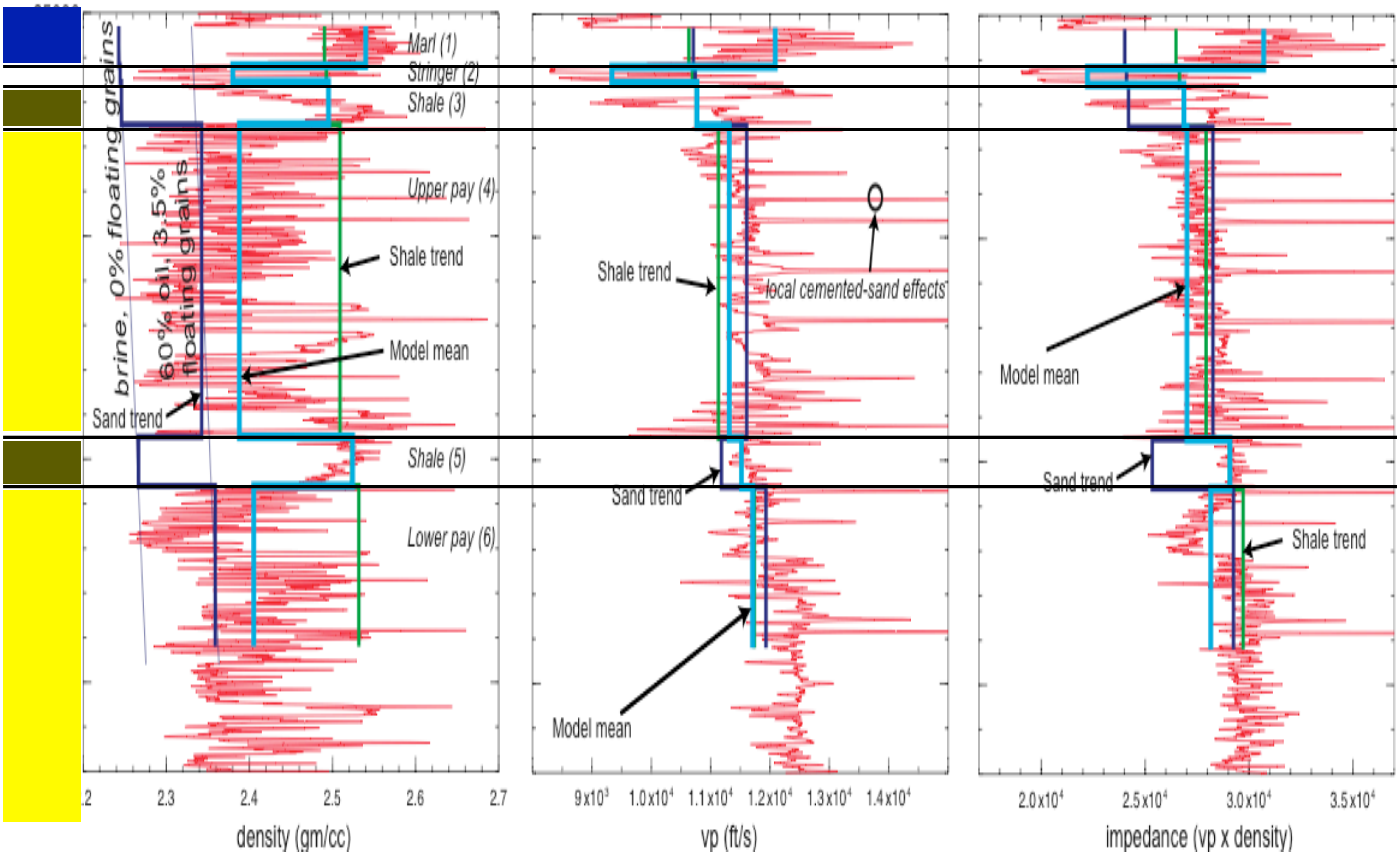
- $\phi = A_\phi + B_\phi\, v_p + C_\phi \phi_{flt} + \varepsilon_\phi$
  - *(from numerical inversion of above, using clusters)*
- $v_p = A_p + B_p d + C_p\, LFIV + D_p\, \phi_{flt} + \varepsilon_p$
  - *(inverted from this regression, direct from log data and clusters)*

    $\phi = A' + B'd + C'\phi_{flt} + \varepsilon_\phi$, *with* $d \leftarrow (1-\exp(-\sigma_{eff}/P_0))$

    $C=-1/(1-f_c)$, f_c *is 'capture fraction'*
- $V_s = A_s + B_s\, v_p + \varepsilon_s$

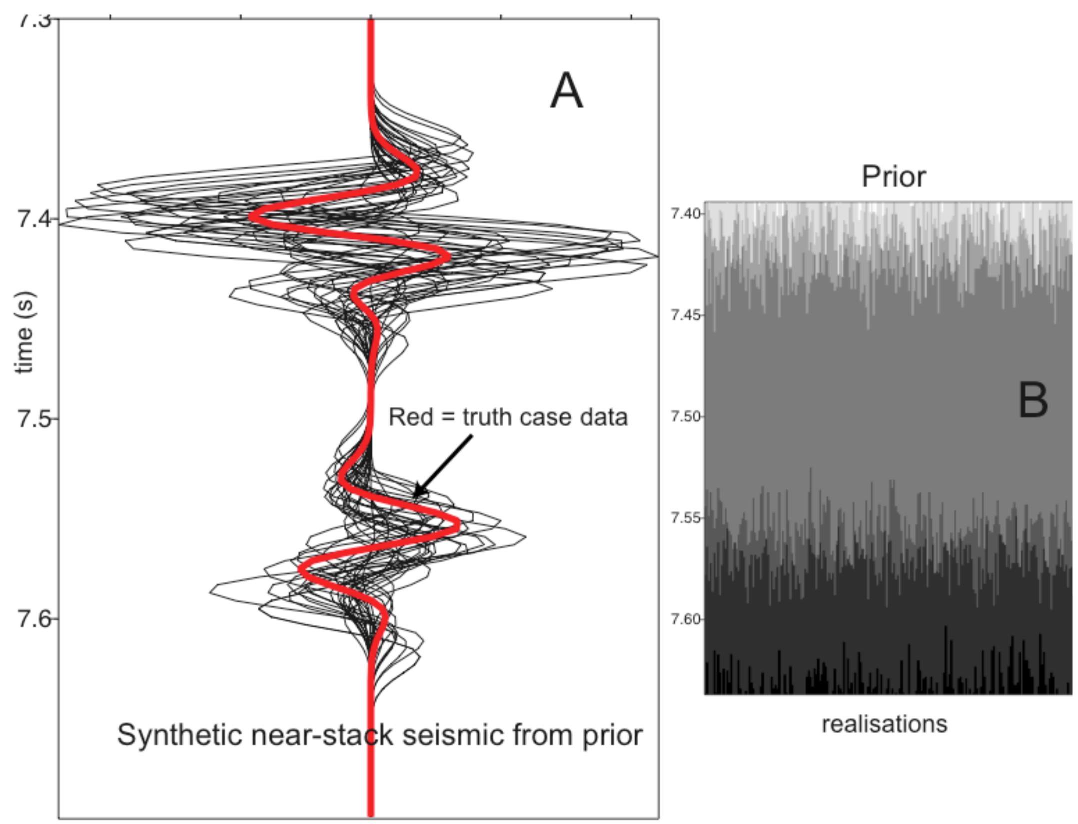
  - *direct from log data*

Layer based model derived from blocking for well #2

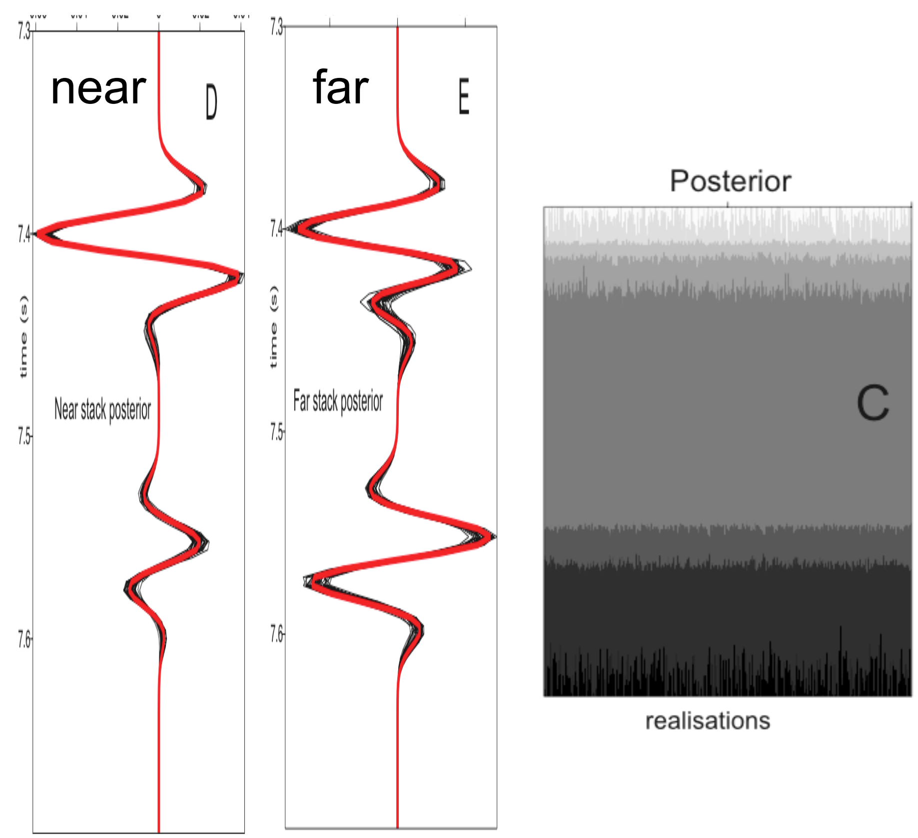


Multiple stack inversion Bayesian inversion is used

before inversion, ignore seismic

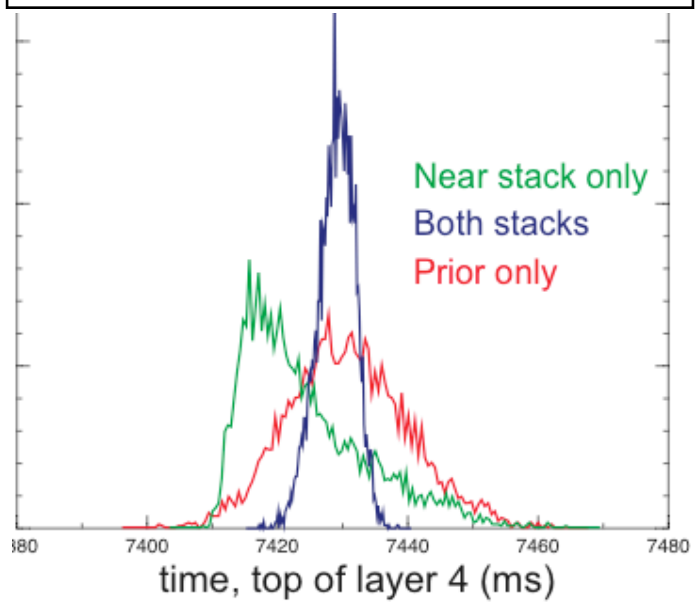


after inversion, honour seismic to within noise level

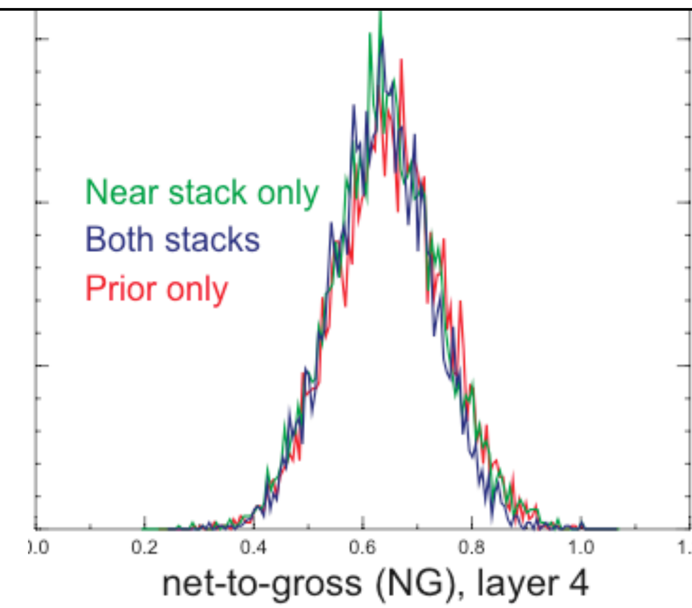


Floating grain fraction and porosity are determined by seismic

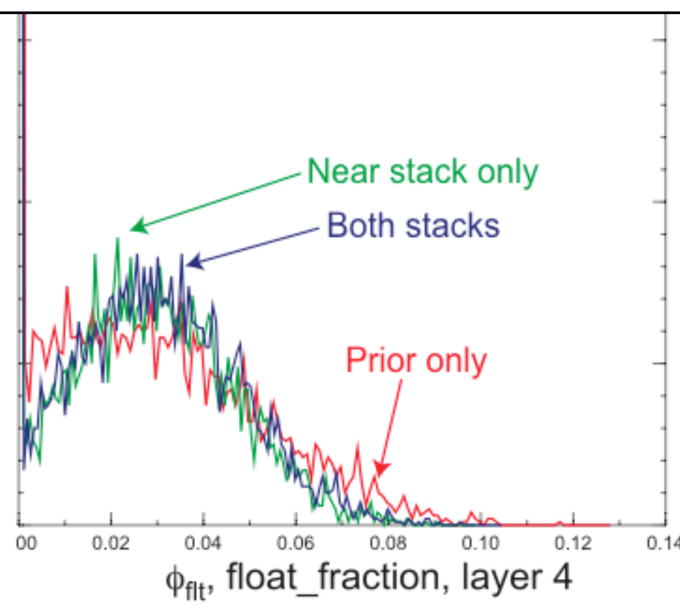
time of layer boundary - seismic determines

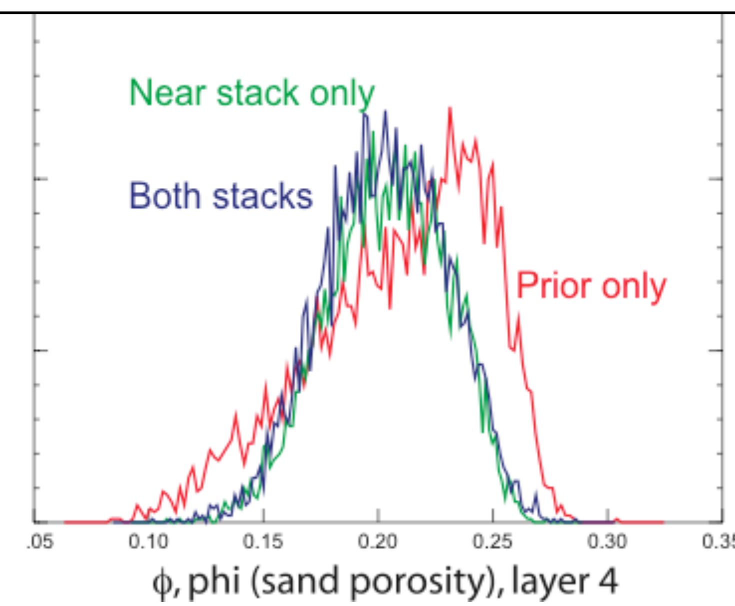


N/G - seismic does not determine



float fraction & porosity - seismic determines ==> permeability





CSIRO. Estimation of Permeability with Seismic "I really did mean to say permeability not porosity"

Conclusions

- floating grain model:
  - explains well log measurements
  - relates seismic to the sorting and the permeability
  - strong link between the microscopic picture and the mesoscopic effective media model
- support given by:
  - standard core measurements (laser grain size, permeability)
  - acoustical core measurements
  - CAT scan & SEM of core
  - numerical rock assembly modelling showing critical behaviour
- practical application shown to be feasible
  - deployed in stochastic model based inversion
  - applied to case of deepwater turbidite
  - porosity and floating grain percentage determined by seismic, **therefore permeability**

Acknowledgments

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"A model for variation of velocity versus density trends in porous sedimentary rocks", Demartini & Glinsky, J. Appl. Phys. **100**, 014910 (2006).
"Critical grain-size parameters for predicting framework and floating grains in sediments", Bryant et al., J. Sedimentary Research **79**, 817 (2009).
"Detection of reservoir quality using Bayesian seismic inversion", Gunning & Glinsky, Geophysics **72**, R37 (2007).