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On the Hydrodynamics of Crystal Clustering

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Introduction

The mechanical strength of a magma can depend on the fromation of crystal clusters. However, how and when these clusters form is still not well understood. We use numerical simulations and Voronoi tesselations to explore the role of cluster formation under settling and open system mixing conditions of a basaltic melt with 1, 9, and 20 percent particles.

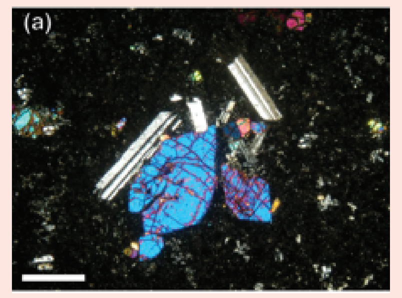


Image Modified from Nicoli et al., 2018

Nicoli, G., Holness, M., Neufeld, J., Farr, R., (2015), Microstructural evidence for crystallization regimes in mafic intrusions: a case study from the Little Minch Sill Complex, Scotland. *Contributions to Mineralogy and Petrology* **173**. (DOI:10.1007/s00410-018-1525-7).

Model and Model Parameters

We use four numerical models of particles settling in a viscous fluid. Three are Open System Models (OSM) where fluid is intruding at the base of the domain and the fourth is a Settling only Model (SM).

Domain and resident fluid
- size = 2.56 m x 1.28 m
- viscosity = 0.2 Pas
- MgO = 10.76%
- temperature = 1290˚

Intruding Fluid
- velocity = 0.023 m/s
- viscosity = 0.2 Pas
- MgO = 12.94%
- temperature = 1340˚

Particles
- diameter = 0.004 m
- density = 3.3 g/cm^3

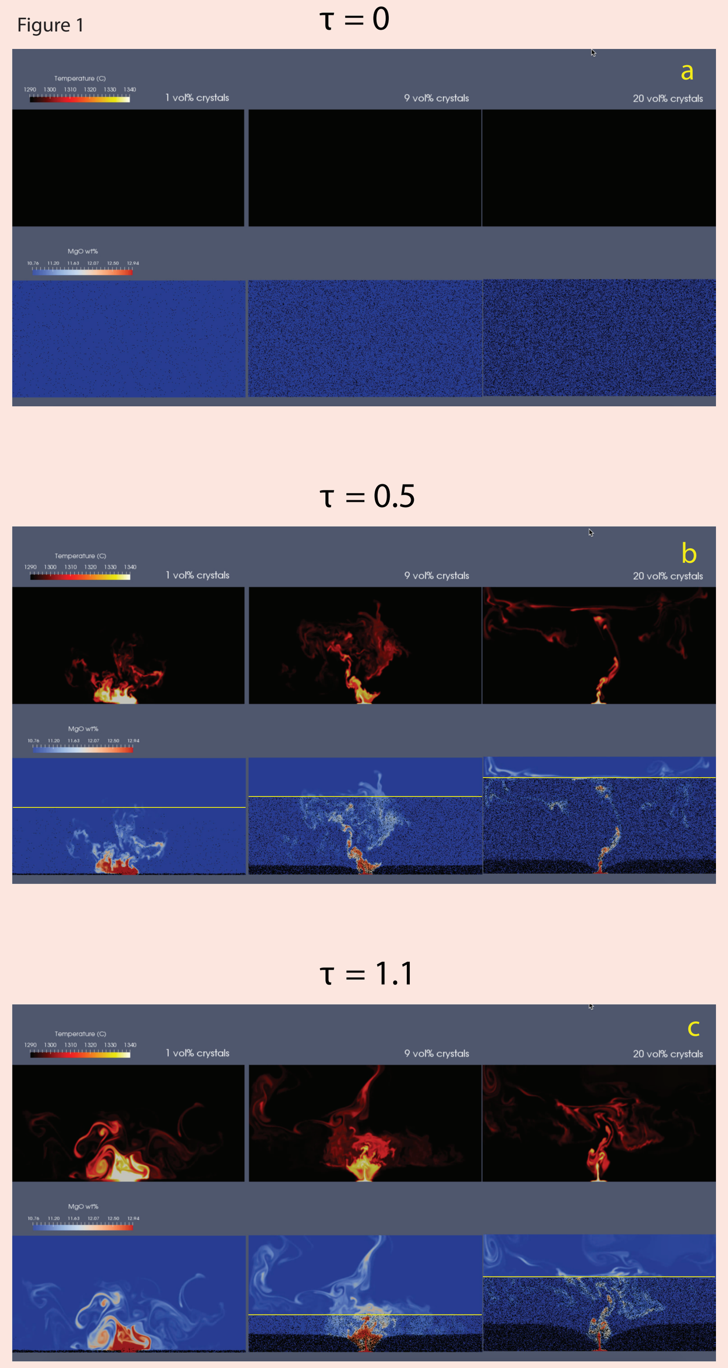
Solid Volume Fraction
- OSM = 0.01, 0.09, 0.2
- SM = 0.09

Figure 1 (right) shows the three OSM simulations. The timesteps depicted are the three timesteps used in later analyses. Each timestep is shown as a dimensionless number, where

$$\tau = \frac{t}{t^*}.$$

Here t is time and t* is the time it takes a single particle to settle the domain height under laminar Stokes condtions. The yellow horizontal bar in figures b and c shows the particle settling front.

Figure 1



Clustering in a Settling System

There are two ways clustering can be initiated in the simulations: 1) clustering from settling, and 2) clustering from open system mixing. In settling systems we can see clusters froming from synneusis, where the particle wake reduces drag on following particles. The ability for settling particles to develop a strong attractive wake depends on the Galileo number, Ga:

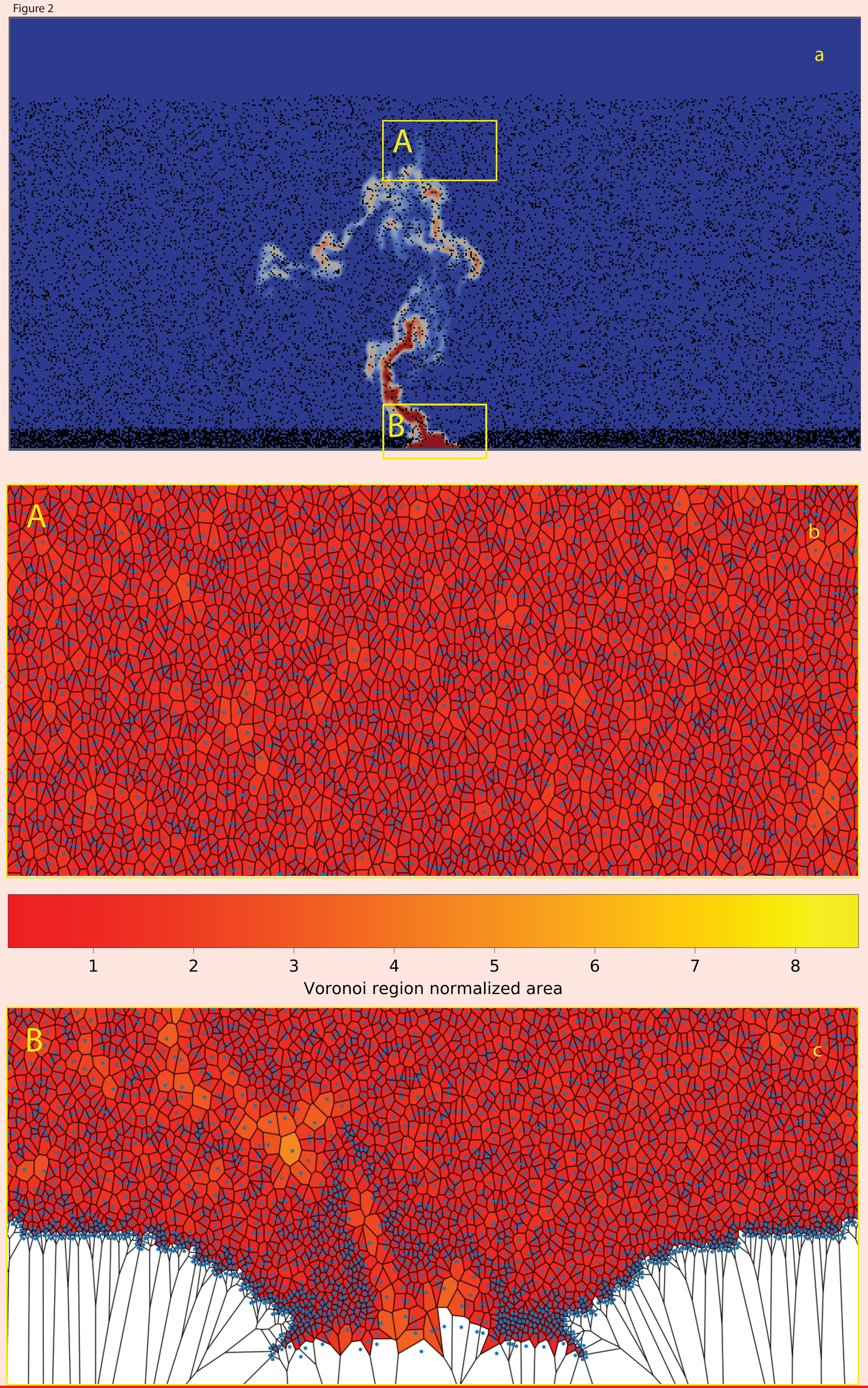
$$Ga = \frac{U_g d}{\eta} \qquad U_g = [(\frac{\rho_p}{\rho_f} - 1)\ gd]^{\frac{1}{2}}$$

Here d is the particle diameter, η is the kinematic viscosity, g is gravity, and ρ_p and ρ_f are the particle and fluid density respectively. The onset of clustering in dilute settling systems is associated with Galileo numbers above 120.

Voronoi Tesselations

We use Voronoi tesselations to determine the particle distribution of the 4 numerical models. Each particle is within its own Voronoi polygon, where the size of the polygon is determined by the distance between particle centers of the particle and its nearest neighbors. The aspect ratio and orientation of the polygon can be used to obtain fabric information. Comparing the polygon size to the mean polygon size of a random distribution provides information on the particle distribution.

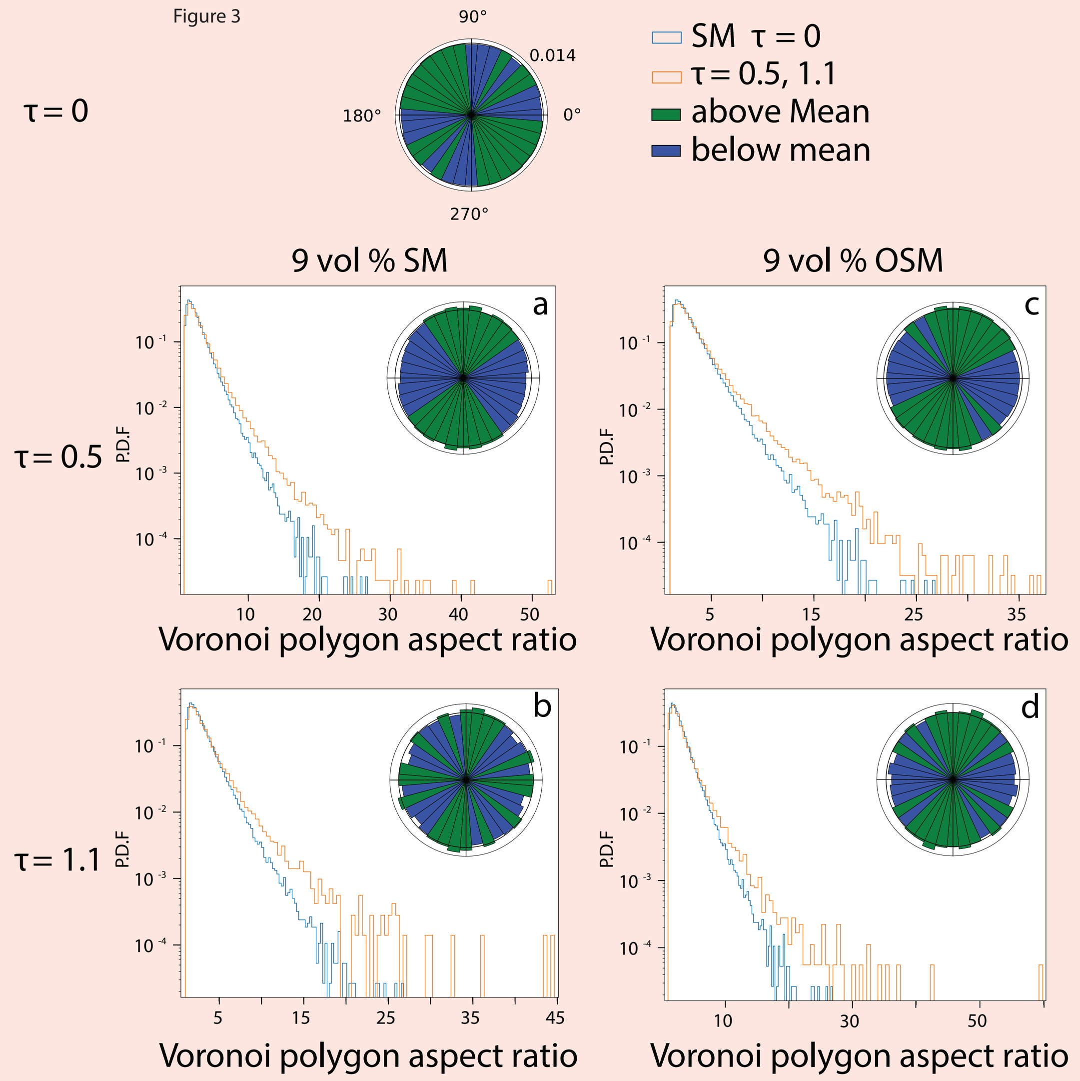
Figure 2



Voronoi Aspect Ratio and Orientation

The aspect ratio of the Voronoi polygon along with orientation of the polygon's long axis can tell us about the kinematics of clustering in the system. Horizontally oriented aspect ratios indicate a vertical clustering of particles possibly formed by synneusis. However our results show near vertical to randomly oriented polygons, indicating little to no clustering by synneusis.

Figure 3

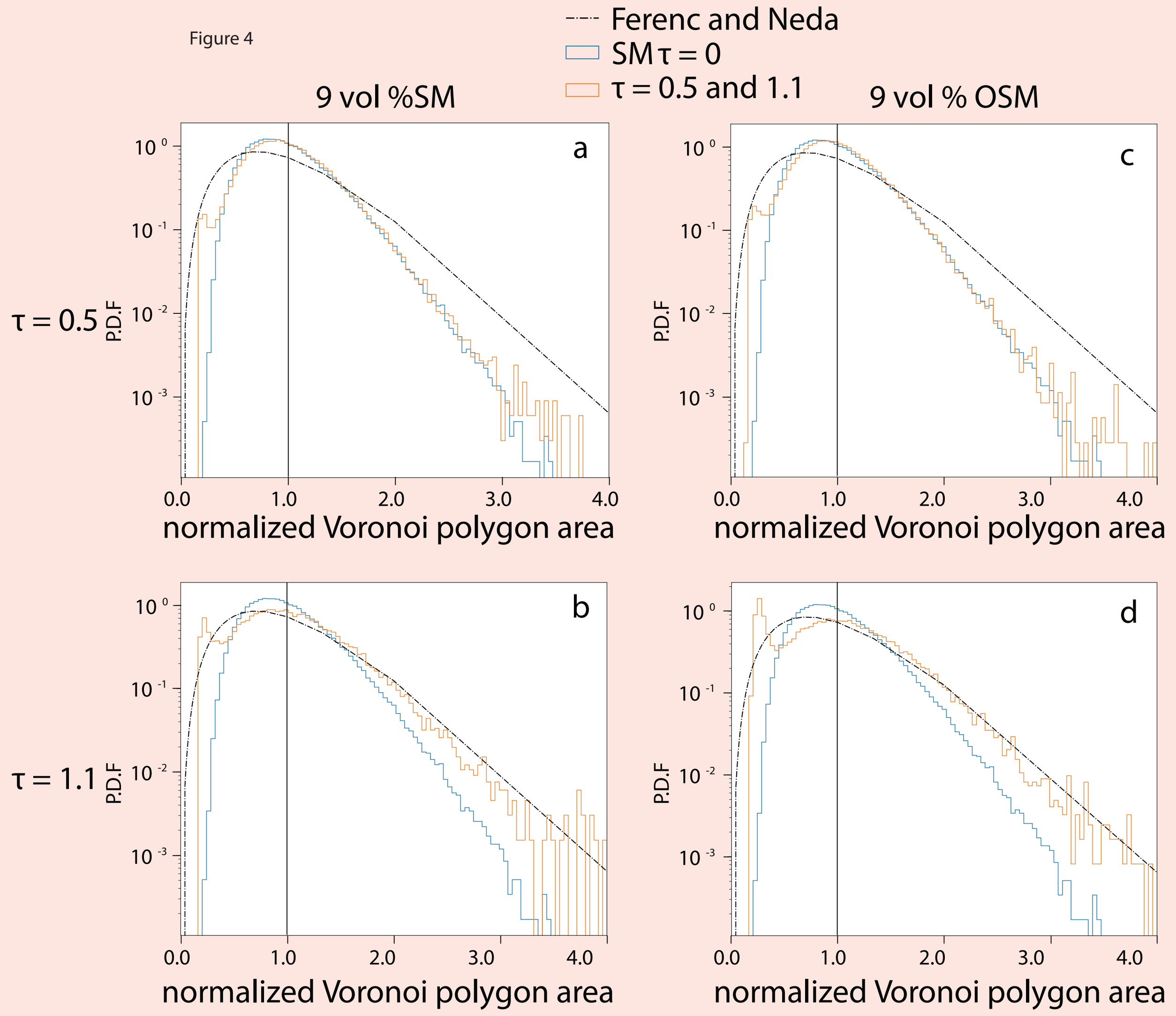


Polygon Area

The area of the Voronoi polygon is a measure of the spacing between particles and their nearest neighbors. The black curve (fig. 4) from Ferenc and Neda (2007) shows an idealized random distribution of particles.

Looking at the histograms in figure 4 b and d indicates that clusters are just as likely to be found as individual particles. Samples that have abundant crystal clusters are likely from a disaggregated crystal mush.

Figure 4



Ferenc, J.-S. and Neda, Z., (2007), On the size distribution of Poisson Voronoi cells. *Physica A: Statistical Mechanics and its Applications* **385**, 518-526. (DOI:10.1016/j.physa.2007.07.063).

Acknowledgements

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