1. PRF# 57123DNI8
2. Project Title: The effect of a liquid phase in a granular system on force distribution during deformation
3. PI: Jacqueline E. Reber, Department of Geological and Atmospheric Sciences, Iowa State University

Geological systems are often complex and contain more than one material phase. Phases that are fluid-like and solid-like can co-exist, leading to a complex deformation behavior. Here, we investigate the stress distribution in such a two-phase system where one phase is solid and the other a viscous fluid. These systems are important geologically – for example as petroleum fluids in reservoir rocks – but have only had limited experimental attention. Understanding the stress distribution will provide insights into the mechanisms of how such systems deform and fail, which has a large economic impact on the effective extraction of natural resources. In order to explore such behavior we perform physical experiments on a photoelastic granular material with a viscous pore fluid. Physical models have several important advantages over other approaches: (1) the photoelastic grains provide quantifiable visual evidence of the stress distribution during deformation, (2) the experiments do not prescribe a priori whether the system is continuous or frictional, and (3) higher resolution can be achieved in comparison to numerical approaches.
The stress distribution in a granular medium is only uniform in cases of perfect packing. As soon as the material shows disorder, the stress distribution is no longer uniform and force chains develop. Force chains form when individual particles form bridges supporting stresses across the compressional direction. The photoelastic nature of the experiment material allows for a direct observation of these force chains under polarized light. The fringes developing in the photoelastic material correspond to the strain in the deformed object. The color and brightness of each fringe can be correlated to a specific strain that is constant along an individual fringe. Grains that are experiencing deformation appear bright (Figure 1) while unstrained grains appear black.

So far, we have conducted two different types of experiments. In the first type we deform a photoelastic granular system in the absence of the liquid phase. In these experiments we observe the formation of force chains spanning the entire width of the experiment. The force chains are supported by the rigid walls of the experimental chamber (Figure 1A). During deformation the force chains break and rearrange randomly. Experiments performed with a mixture of grains and fluid show a significantly different pattern in the force distribution (Figure 1B). Only particles close to the shear plane are strained and therefore bright. These first sets of experiments illustrate that the presence of a fluid phase has a significant impact on the force distribution in the system. The fluid phase is able to absorb part of the stress which leads to a termination of force chains without reaching a ridging wall of the experiment.

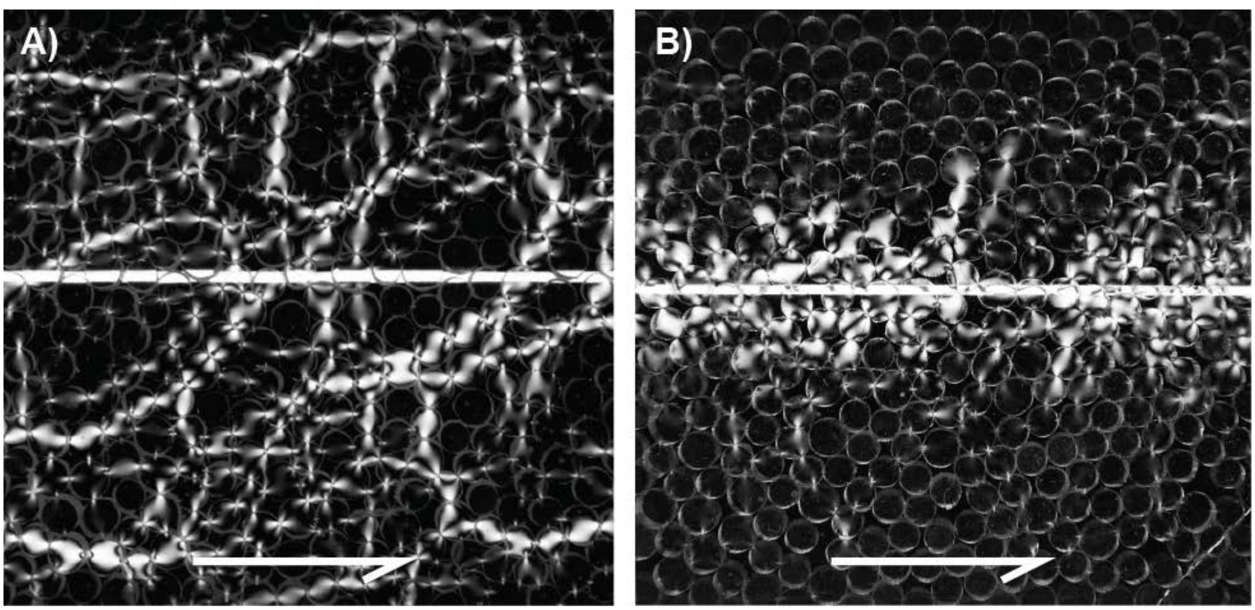

Figure 1: A) Dry granular experiment. The brightness of the individual particles correlates with the amount of force supported by the particle. Lines of bright particles form load bearing force chains while other particles are undeformed and therefore black. B) Experiment with a viscous fluid in the pore space. Only particles close to the shear plane experience any deformation. White horizontal line illustrates the shear plane and arrows the shear direction.

All experiments are conducted on a simple shear table with a discrete velocity jump. This leads to localized shear deformation in the middle of the table. We illuminate the experiment from below and take pictures of the experimental surface at constant intervals. Each experiment contains approximately 900 beads, which are placed on the experimental table as a single layer. We use two different bead sizes to ensure that the system does not experience perfect packing. For experiments with a fluid phase we fill all the pore spaces with a linear viscous silicone oil.

To quantify the force chains we are in the process of adapting a Matlab code published by Puckett and Daniels (2013). This code allows for an automated detection of the force chains (Figure 2) and a simultaneous calculation of the force magnitude experienced by each grain. For an accurate force calculation we match the number of fringes to a known force (Figure 3). In a next step we will compare the orientation and connectivity of the force chains in both types of experiments. One of the obstacles we had to overcome before we were able to automate the analysis of the force was how to get pictures of the experiments where the grain boundaries can be identified at the same time as the force chains are visible.

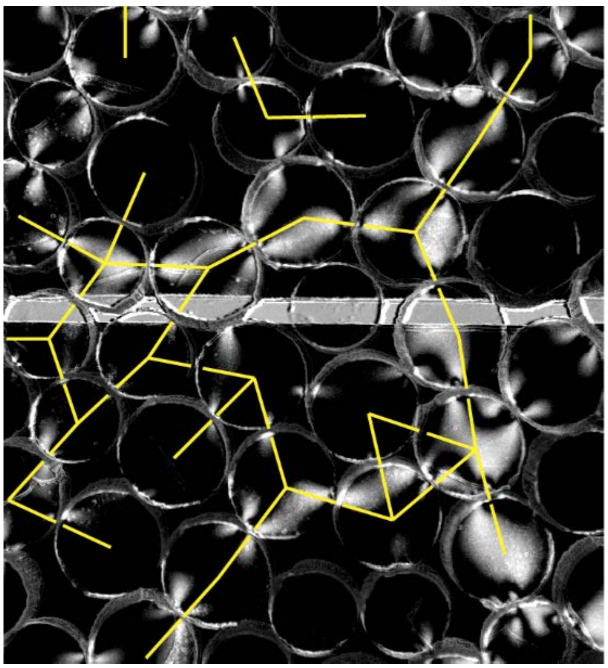

Figure 2: Photograph of dry granular experiment. Yellow lines indicate automatically detected force chains.

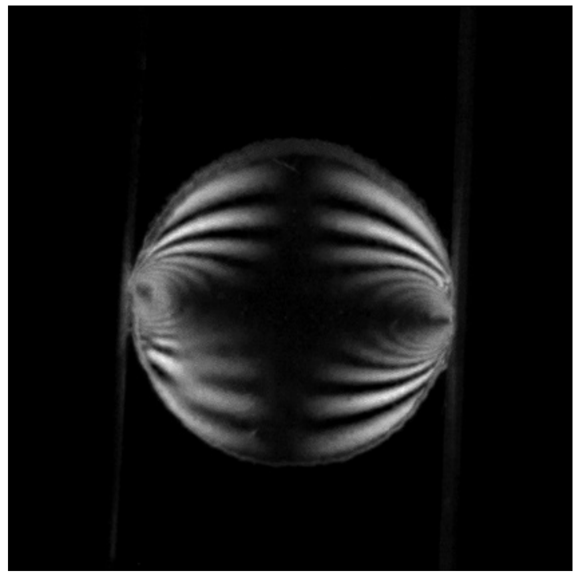

Figure 3: Fringe pattern in a grain. A force of 2N is applied from left and right.

For this fall (2018) we have experiments planned where we will systematically change the ratio between the granular and viscous phases. During the spring 2019 semester we will start cementing some of the grains to determine the impact of the cement versus the fluid phase on the stress distribution.

This grant is currently supporting graduate student Christopher Ladd by paying for tuition, salary, and conference participation. Chris is in his third semester as a Masters student at Iowa State University. Chris has presented his preliminary findings at the North-Central GSA meeting in April 2018 in Ames, IA. This was his first experience at a professional meeting and he presented a poster with the title ‘Force distribution in a two-phase system during simple shear’. Furthermore, he will present his research at the AGU fall meeting in December in Washington, D.C.

The project supported by this grant has become a corner stone of the lab activities in the PI’s structure lab. Besides providing funding for a graduate student it is also used for teaching. The experimental setup used in this project is used in a lab section on stress in the structural geology class (GEOL 356) taught by the PI. Furthermore, the structural geology class from Macalester College, MN, has visited in spring to run some experiments with photoelastic grains to gain an intuitive understanding of force distribution in granular materials. They will return later this fall to repeat the experiments. The PI has presented some of the teaching material during the biannual Structural Geology and Tectonics Forum in January 2018, Phoenix, AZ.