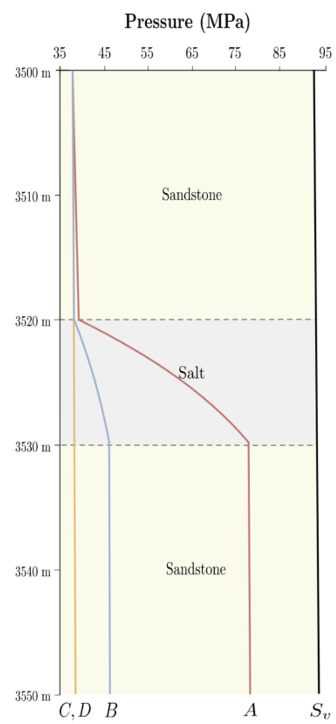
Update on the staffing of the project:
As mentioned in the last report, I have worked an undergraduate student at UT Austin, Preston Durham, on the first of the three proposed research question. We have made good progress and Preston has some novel results detailed below that will lead to a publication. Unfortunately, Preston got an very attractive offer from industry and has decided to take it up rather than to continue his education. Instead, I have recruited Afzal Shabab (University of Hong Kong) as a new graduate student. He has been admitted into our very competitive applied mathematics graduate program and has joined UT Austin in the Fall 2019. Afzal has already begun to make progress on the second research question.

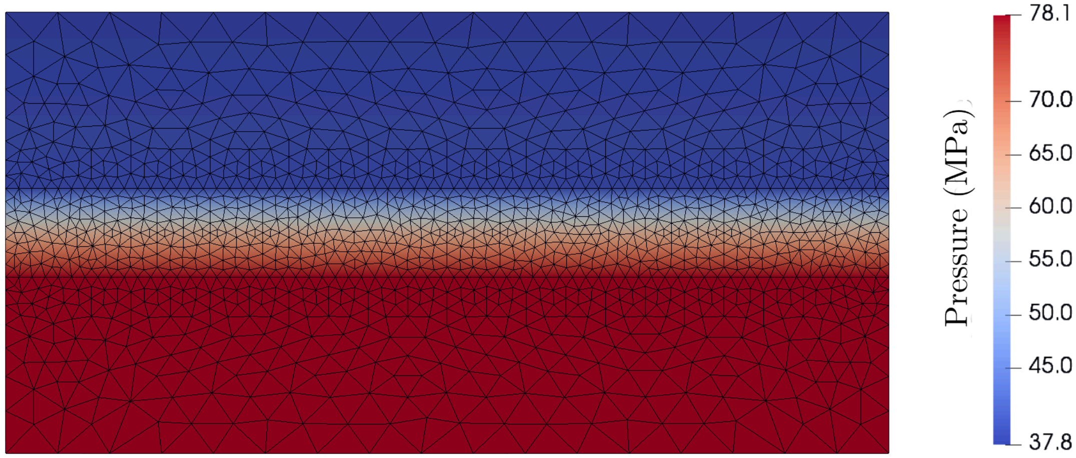
Update on the research questions:
Brine flux through salt (Section 3.1 in the proposal)



My undergraduate student Preston has continued his work on this question throughout his senior year 2018/2019 at UT Austin. In the fall 2018 Preston completed the derivation of the governing equations and their non-dimensionalization. As we began thinking about the nature of the solutions to these governing equations, we realized that the initial problem formulation was not well posed. In section 3.1 of the proposal we planned to study the brine flux due to a fixed pressure gradient across the salt layer. However, it has become clear that pressure in the lower aquifer is set by the compaction of the salt and cannot be specified independently, as shown in the figure to the left. The figure shows instantaneous fluid pressure profiles though the sedimentary layers. The difference between the profiles is due to the viscosity of the salt. The higher the salt viscosity the smaller is the pressure increase.

This result is interesting, because it shows a new pressurization mechanism that has not been discussed in the literature. In the commonly studied elastic setting, the fluid pressure only increases above hydrostatic if the vertical stress increases, i.e., during active *external* loading due to ongoing sedimentation. If the sediments contain a salt (or any other ductile layer such as mud), the fluid pressure is increased above hydrostatic by *internal* loading due the compaction of the soft material. Preston has not investigated the transient evolution of the overpressure, largely due to numerical problem that arise when the permeability ratio between salt and sandstone becomes too extreme as the salt compacts.

Instead Preston spent the spring of 2019 extending his numerical model to three dimensions. He implemented the equations he derived using a Finite Element Toolbox called Fenics. This has allowed him to utilize a large number of inbuilt features from complex gridding to automatic generation of the finite element discretization. An example of a two-dimensional solution for the fluid pressure is shown below. Given that Preston was an undergraduate, he has made significant progress, both in the formulation and in the numerical solution.



Despite this progress and the interesting results, a significant amount of work remains to bring this work to a publication. The PI will complete this work and hopes to submit a manuscript with the undergraduate student as coauthor by the summer 2020. The main work that remains is to study the transient evolution and to switch to a numerical method that allows extreme permeability contrasts. The PI has experience in such methods and is confident that this can be completed with interesting results.

This work has been presented at the annual meeting of the European Geophysical Union in Vienna in the spring of 2019. The undergraduate, Preston Durham, successfully defended his honors thesis, based on this project, graduated, and found immediate employment.

Two-phase percolation in ductile rocks (section 3.2 in proposal)
The new graduate student Afzal has begun working on this problem in the Fall of 2019. This requires combining two extensive bodies of work: First the formulation of two-phase flow in ridged rocks as it is commonly used in petroleum engineering. Second, the formulation of single-phase flow in a ductile matrix, as used above. The PI is currently working through these formulations with the graduate student. After implementing them separately initially, we hope to combine then into a set of equation for two-phase percolation in ductile rocks.

Hence, we have made good progress on achieving the first of the three projects outlined in the proposal. We have begun work on the second project and hope report similarly good progress in the next report. Only once the first two projects are completed we will begin work on the third.

Regards,
Marc Hesse