12.21: *A Generalized Model to Describe the Elastic Stiffness Tensor for Complex Strains*

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ABSTRACT

We develop a three-step framework to model the anisotropic elastic properties of a mechanically compacted mudrock based on the full strain tensor. We model the microstructure as an effective medium representative of locally aligned domains of clay grains and porosity with isolated quartz. Then we predict the orientation of these domains due to the application of any strain field. Finally, the previous two steps are combined to determine an effective medium model for the entire mudrock that predicts the elastic stiffness matrix. We focus on the relationship of deformation to porosity reduction and grain alignment in mudrocks. Our results show that the application of axial loading leads to the development of elastic anisotropy with stiffnesses increasing more rapidly in the direction perpendicular to the loading (Fig. 1). These stiffness predictions closely match experimental data on a mudrock specimen from Eugene Island – Gulf of Mexico (Fig. 1). We further apply our three-step framework to predict elastic stiffnesses in a salt basin based on the full strain tensor predicted by an evolutionary poromechanical model. This coupling allows us to predict elastic stiffnesses and anisotropy due to sediment deposition and non-uniaxial salt loading (Fig. 2). Accurate estimation from elastic stiffnesses of mudrocks can help improve pressure prediction, seismic imaging in complex geologic environments, and prospect evaluation.

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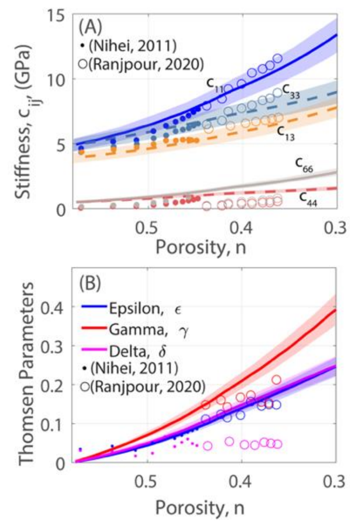

Fig 1: Prediction of elastic (A) stiffnesses and (B) anisotropy as a function of porosity for a mudrock undergoing uniaxial compaction using the three-step framework. Comparison with measured data.

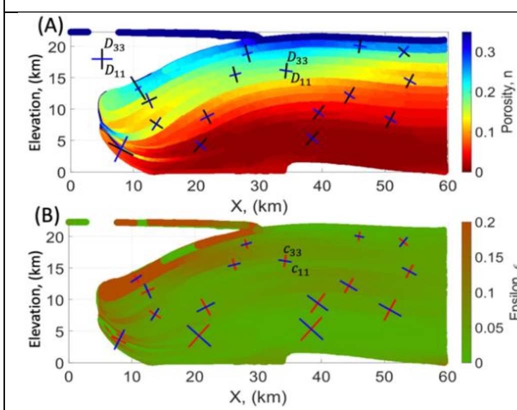

Fig 2: (A) Porosity in salt basin predicted by poromechanical model and (B) Thomsen's epsilon predicted by the three-step framework coupled with the full strain tensor from the poromechanical model.

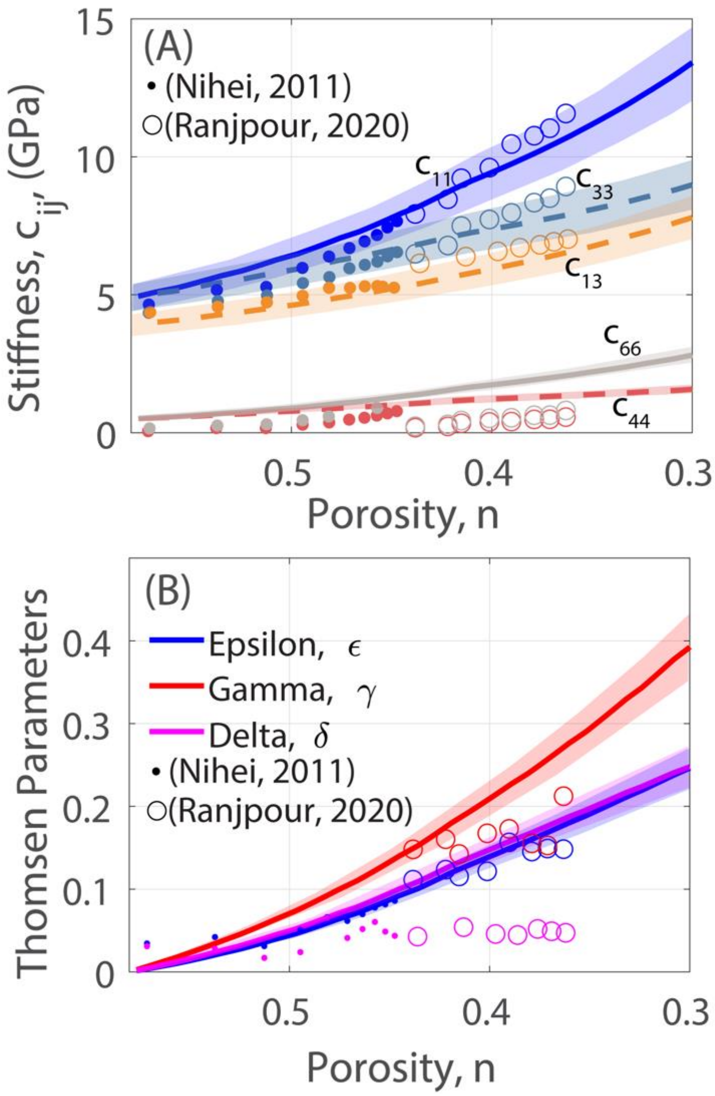

Fig. 1: Prediction of elastic (A) stiffnesses and (B) anisotropy as a function of porosity for a mudrock undergoing uniaxial compaction using the three-step framework. Each elastic stiffness needed to describe a transverse isotropic (TI) medium is overlain by experimental data from Nihei (2011) (dots) and Ranjpour (2020) (open circles). Shading represents 10% error of the model results. Compressional elastic stiffnesses and seismic anisotropy agree with experimental results. Shear elastic stiffnesses are overpredicted compared to both sets of experimental data.

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Nihei, Kurt T., et al. "Phased array compaction cell for measurement of the transversely isotropic elastic properties of compacting sediments." *Geophysics* 76.3 (2011): WA113-WA123.

Ranjpour, Deniz. *Stiffness and Anisotropy Characterization of Mechanically-Compressed Cohesive Soils Using Directional Wave Propagation*. Diss. Tufts University, 2020.

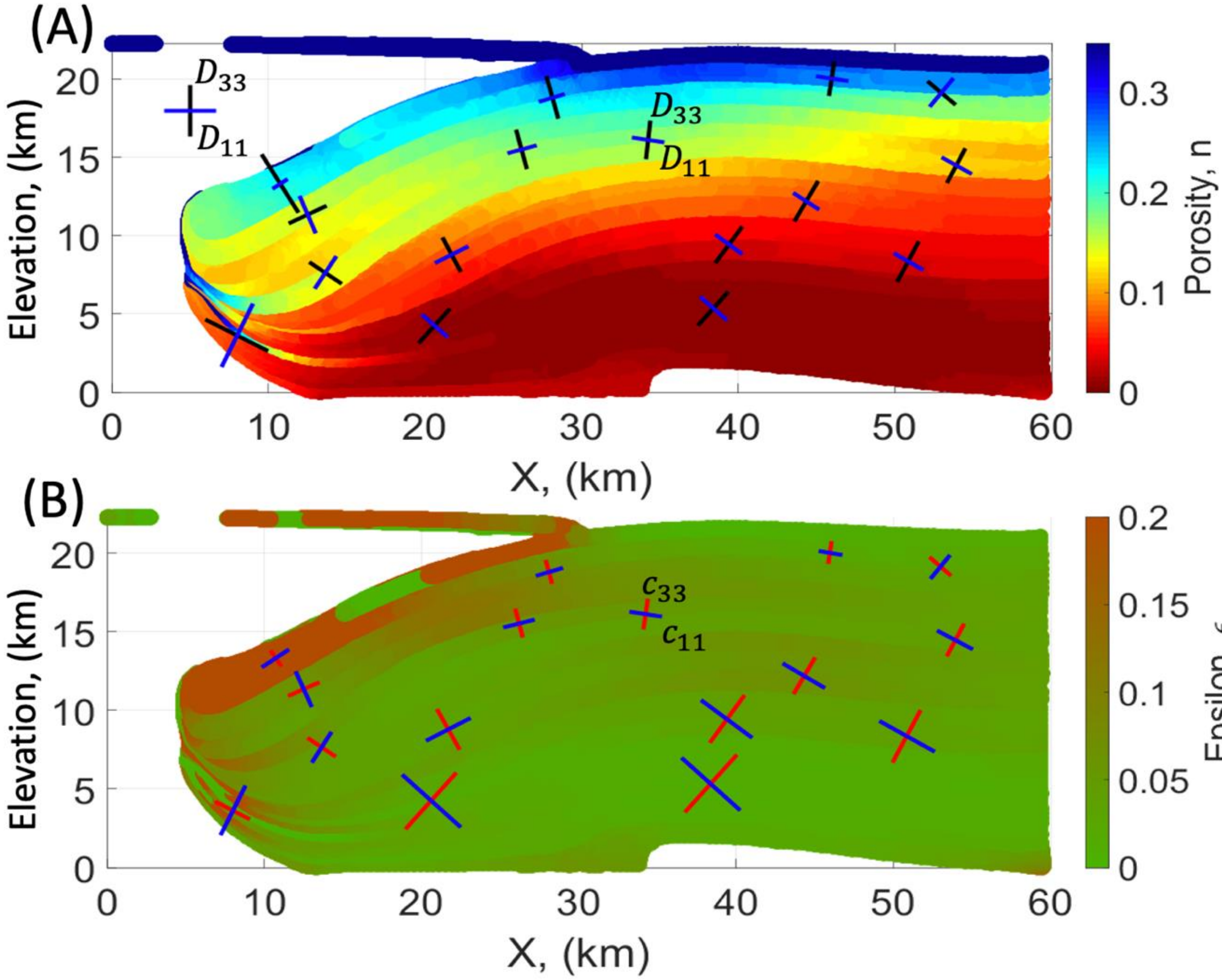

Fig. 2: (A) Color contours of porosity in salt basin predicted by poromechanical model and bars illustrating the orientation and relative magnitude of the maximum, D_{11}(blue), and minimum, D_{33}(black) principal strain. (B) Color contours of Thomsen's epsilon predicted by the three-step framework coupled with the full strain tensor from the poromechanical model and bars illustrating the orientation and relative magnitude of the maximum, c_{11} (blue), and minimum, c_{33}, (red) elastic stiffness.

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