Micro-structural characterization of Green River shale from GSA inversion
Malleswar Yenugu and Tao Jiang, University of Houston

SUMMARY
A detailed knowledge of microstructure properties helps us to understand the pore connectivity, fluid mobility, which is critical in successful characterization of unconventional shale reservoirs. We used GSA (Generalized Singular Approximation) method to determine the microstructure such as pore/crack shape, and their connectivity for the Green River shale outcrop samples. The optimized anisotropic microstructure properties can be obtained from solving an inverse problem of GSA modeling, by minimizing the objective function, which is defined as the difference of anisotropic P and S velocities between ultrasonic measurements and the GSA calculation.

INTRODUCTION
One of the major challenges to characterize the shale reservoirs is to get the microstructure information i.e. the clay platelet orientation, the type, density, shape and connectivity of the inclusions. These are directly linked to three physical parameters: porosity, aspect ratio and friability with the assumption that the pore/cracks are gas filled and have ellipsoidal shape.

The problem of calculating the effective stiffness tensor is a many body problem, which can be solved, in general case, only approximately (Chesnokov et al. 1995). The majority of the methods of effective medium theory is based on the Eshelby (1957) solution, which finds the strain field in an individual ellipsoidal inclusion embedded in a homogeneous matrix with other elastic properties, caused by a stress or strain field applied at infinity. In the effective medium theory, it is assumed that the inclusions (mineral grains, pores and cracks) have an ellipsoidal shape. Hornby et al. (1994) used biconnected clay matrix cracks in isotropic clay matrix and rotated them in accordance with the distribution function of the clay platelet orientation. Then, silt-sized minerals were inserted resulting the anisotropic clay-cracks material.

Figure 1: SEM image of a shale microstructure
We used GSA method to compute the effective elastic constants of cracked anisotropic media for arbitrary crack concentration and aspect ratio. We consider that clay forms a matrix containing grains of different minerals, pores and cracks with different shape and orientation as inclusions. This consideration is in line with the microstructure seen in SEM (Scanning Electron Microscope) image shown in Figure 1.

Figure 2: Workflow for GSA method
GSA (Shermongor, 1977) uses the singular part of Green's function to get the analytic solution. GSA is a powerful effective medium modeling method for porous media. It gives the effective properties of the whole medium provided the components of the rock (i.e. matrix and inclusions). The advantages of GSA over other EMT (Effective Medium Theory) models are: GSA can handle large volume of inclusions, it takes into account the effect of the connection of pores, it works for arbitrary ellipsoidal inclusion with any aspect ratios, it assumes that the elastic properties are anisotropic for both matrix and inclusions.

GSA modeling for the Green River shale is carried out using the mineral composition measured by FTIR, the elastic constants and densities taken from published literature. The velocities calculated and measured from ultrasonic are plotted for the three plugs and shown in the Figure 4. The difference between the velocities is due to only the mineral matrix is considered.

Figure 3: Schematic of GSA method for microstructural characterization

Figure 4: GSA modeling for pure mineral composite

Figure 5: Comparison of experimental and calculated velocities after inversion

CONCLUSIONS
GSA method is used for microstructural characterization of Green River shale samples. One of the major advantages of GSA over other methods is that we can estimate the connectivity between pores/cracks (friability). The inversion results show that the pores have spherical shape and are well connected. The reason for the difference in the velocities between calculated and measured in the lab is due to changes in the pressure and temperature conditions while measuring the elastic moduli of the minerals. The elastic moduli of each mineral are considered from the published literature, so the conditions may not be the same for each mineral, which contributes to the mis-match between the inversion and ultrasonic results.