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Statement of Research

Inspiration

As the price of commodities began their fall from grace in 2014, it became apparent to the natural resource sector that you cannot effectively be a cowboy and an engineer at the same time. Before then, energy companies were jumping on the opportunity to horizontally drill and hydraulically fracture unconventional shales, which seemed to endlessly supply oil and gas. It simply did not matter that conventional metrics of rock and elastic properties could not predictively improve hydrocarbon extraction (e.g, 1). Mining companies could leave behind waste piles containing a half percent precious and/or base metals (e.g, 2; 3), as the grades of their processed slurry was still economic. With the fall in the price of natural resources, the "drill baby drill" mentality became unsustainable. In many ways, this has been a large benefit for the science, as it was not financially responsible to use a "guess and check" approach with extraction. Geology, geophysics, and rock physics have became even more important. A good quality subsurface model will drastically reduce costs, increase recoverable volume, limit fluid migration to the environment, and create a better understanding for the next extraction site.

As a geoscientist, one of our fundamental responsibilities to the public is to create models where we understand the subsurface. Our job is to create a balance between effective quality and minimum cost. Understanding what is beneath our feet is not just important for gold and oil, but a wide range of purposes. In civil engineering, projects such as bridges, tunnels, or construction cannot begin without a an understanding of the ground. Without models, we cannot manage groundwater or monitor the location and possible spread of contamination. There are also countless scientific reasons to model geology. For example, why does the subduction of the Pacific Plate on the west coast of North America change to a strike slip fault, and how will this impact earthquakes, especially the ominous future "big one"? Modelling the thickness and extent of tsunami deposits from ancient events may help us predict how future disasters will behave. Geologists have even modelled the thickness and patterns of soils; the extent of the last glaciation has a huge role in where we grow food today. By no means is this an exhaustive list.

While digging and drilling to create models can be effective, this is very expensive. Preferentially, we choose non invasive methods to base our models. This includes surveying seismic, electromagnetic, resistivity, or gravitational properties, as well as traditional field observations. Part of model calibration involves the collection of rock samples in order to measure their physical properties. In order to model a buried lithology without touching it, we need to know how it will respond to induced effects in a controlled laboratory setting first. That's where my research fits in.

Problem Statement and Research Questions

To create a model, many are interested in rock properties: lithological information like mineralogy, porosity, density, and permeability. In non invasive surveys, rock properties are impossible to measure directly. For example, when we set up a seismic survey at the surface, we can measure elastic properties: wave velocity, and intrinsic seismic attenuation (how waves lose energy as they propagate). Our role here is to convert elastic information to rock properties for the region being modelled. A good model will collected rock samples from the area being modelled. These samples will be analyzed in a laboratory to measure rock and elastic properties, in order to understand the relationships at play for local rocks.

There are two research topics here to address:

1)The scientific community does not have accurate measurements for seismic attenuation at the frequency range used in exploration surveys (approximately 0.1 to 100 Hz). Currently, most measure attenuation on rock plugs in a laboratory using ultrasonic transducers. A wave is propagated through a sample, and its amplitude decay is measured. For this method, the wave must be at ultrasonic frequencies which is five orders of magnitude different than field measurements. Unfortunately, research has shown that the intrinsic attenuation mechanisms observed in the MegaHertz or kiloHertz range (e.g. Biot flow, squirt flow) are not relevant to the frequencies used in seismic surveys (4). We also know that intrinsic attenuation is a function of temperature, pressure, fluid content, seismic frequency, and possibly other factors. As we do not understand frequency attenuation mechanisms as a function of pressure or frequency, even if attenuation is measured in a seismic exploration survey, we cannot convert this measurable information to meaningful lithological information in our models. Consider Dasgupta and Clark (1998), where a region was defined in a seismic profile. The authors could not clearly prove if it was sedimentary, igneous, or metamorphic based off their attenuation tomographic section (5).

2) Measuring rock properties requires cutting samples into ideal shapes. This is not always possible for rare or precious rocks. One way around this is to use numerical models. Models will be composed of pixels or bins; it seems particularly realistic to create a model where each pixel is representative of a physical space in a real samples. For hand samples, this can be achieved with computed tomography (CT) scanning, which geologists have been using for 25 years to understand their samples without cutting them open. CT scanning has been effective for results of a generally qualitative nature. This includes rock fabric, presence of a fracture network, and mineralogy. Many have been trying to get quantitative rock properties such as porosity, density, and wave velocity. To date, the current "segmentation based" methodology has achieved reasonable results for density and porosity of samples that are less than half a centimetre in size. Elastic properties have not yet been modelled effectively using CT for hand samples (6). If this modelling can be done accurately, and on large samples, this will ideally be faster and cheaper than laboratory testing. This also does not involve damaging rocks and allows them to be saved, and even shared on the internet.

Current Research

To measure low frequency wave attenuation, we will be using the "sub resonance" method, where a stress is applied to a sample, and its corresponding strain is measured. The lag between the stress and strain can be used to calculate its intrinsic elastic nature (7) Our pressure vessel has been set up, and rock cores have been prepared. Testing will begin shortly.

We have also been pioneering a new methodology to effectively estimate rock and elastic properties quantitatively for rocks that have been CT scanned. The "targeted" or "segmentation-less" method has been used to predictively estimate rock and elastic properties of simple quartz sandstones. We have done this for centimetric sized core, and millimetric sized fragments, similar to the cuttings found on drillbits. As it is not possible to measure rock properties of cuttings directly, the properties of many cuttings were compared to a measured core where the fragments were sourced. For both core and cuttings, results have been independently compared to laboratory measurements and found to be within 5 percent accuracy.

Future Opportunities

The success targeted CT scanning opens up huge opportunities. First, it is becoming routine to CT scan core from certain drilling projects. Hopefully one day each scan can instantly be associated with rock and elastic properties. Second, millimetre sized cuttings are abundant on any sight that drills. If we can estimate the properties of formations at depth using only cuttings, we can add much more information to our models, and cut back the amount of core drilled. We are currently expanding our work to include other types of rocks including carbonates, fine grained siliciclastics, and rocks from outer space.

This method must be calibrated with more samples where both CT scans and laboratory measurements are available. Targeted CT must also be calibrated with more complex rocks. This means rocks that contain many minerals, as well as igneous and metamorphic rocks. This can be a simple project for a student, for example, calibrate the method with a pure mineral sample. It can also be a more complex project, such as incorporating multimineralic rocks like granite, or a sample consisting of a range of rock types such as in a core.

Measurements of low frequency attenuation has proven to be straightforward. Our team has focused so far on simple rocks. Ideally, I would like to see that we proceed with rocks that are considerably more realistic of a depositional system. For example, we have measured attenuation on Indiana limestone as a representative carbonate. In order to use attenuation to understand a carbonate system, it would be valuable to begin measuring grainstones, packstones, boundstones, and so on from a single area. These are all complex rocks, and it would be naive to pretend they can all be called "limestone".

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