A proposal for Muon Tomography survey techniques for use in hydraulic fracturing

Key terms: muography, particle physics, geology, snolab, geophysics, tomography, surveying

Muographic imaging uses elementary particles to develop a 3 dimensional density map of a region, similar to an electron microscope or a CAT Scan except at a large scale. Research groups such as CRM, associated with TRIUMF, and the volcanology group DIAPHANE have developed muographic technology for geological surveys, which have wide applications to the natural resources industry. These applications include making hydrofracturing more efficient and environmentally sustainable through the targeting of low density "sweet spots" in shale deposits. The authors design an innovative muographic imaging technology which could be used to image regions surrounding potential hydrofracturing regions. The muon detectors use high precision silicon photomultipliers and SNO+ liquid scintillator which are very flexible to use on top of being environmental, non toxic, and low cost. The retrieved data would be analysed using transmission muography techniques. Prior research indicates a range of precision of ±0.8% for measurements of density (Tanaka, 2015). These detectors will be tested in an experiment to determine the correlation between the number of muons passing through a region and the density of that region. Kuila (2011) extrapolates this density to the weakness of shale in that region; this information can be used to optimize hydrofracturing methods and improve the sustainability of oil drilling.

Scientific Background

An important goal of environmental organizations is making hydrofracturing more efficient. This would involve taking action to reduce usage of toxic fluids as well as surveying locations that would decrease the possibility of damaging seismic activity. Current developments in ground surveying include recent advances in fiber optic geophones (Paulsson et al., n.d.) as well as less traditional imaging techniques. Muography is one such imaging technique, utilizing the scattering properties of subatomic particles called muons in order to develop a 3D density map of a large region. Due to the ability of muons to penetrate deep into the Earth's crust (*Muon Tomography*, n.d.), this sort of technology could be widely applicable to geological engineering due to the depths at which shale deposits are found underground. A company associated with TRIUMF in Vancouver, CRM GeoTomography, has already developed muographic geological surveying technology for use in mines, similar to that which would be used in hydrofacturing (Schouten, 2015). **The proposal herein describes the use of innovative miniaturized muon detectors in finding low density regions of shale, which are optimal for hydrofracturing. Tracking these regions would contribute to the efficiency of hydrofracturing, which would reduce the need for as many hydrofracturing plants and possibly allow a reduction in the amount of potentially toxic fluid used.** In addition to the prior mentioned environmental efficiency, this development would greatly improve existing technology used by multitudes of scientific fields as well as the natural resources industry. This is showcased by volcanology research groups such as DIAPHANE and Saracino et al. have used muography in order to image internal cavaties in volcanos such as Mt. Echia in Naples, citing applications to civil engineering and archaology (Marteau et al., 2017; Saracino et al., 2017). The Pacific Northwest National Laboratory states that muography can be used to image the density of materials underground by sending detectors down underground (ie: in boreholes) (Bauer, 2016).

Principles of Muography

Low density regions found during a muographic survey are attributed to regions of rock containing small scale fractures as well as highly porous regions of shale. Kuila *et al* concluded in 2011 that regions of high microporosity (ie; natural fractures and air/liquid pockets in the rock layer) greatly affected the wavelength of transmitted acoustic signals through shale, indicating weakness in that region (Kuila, Dewhurst, Siggins, & Raven, 2011). This means that it would be possible to correlate such a muographic map with maps generated from traditional seismic techniques, strengthening the certainty of finding weak "sweet spots" in the shale deposit. CRM GeoTomography has developed muographic imaging techniques which do exactly this (Schouten, 2015), except in mines with more room for large detectors, so being able to miniaturize muographic imaging devices would have a great impact on other geological engineering fields.

Apparatus

Muons are most easily detected with scintillation. The scintillator fluid, SNO+ is low cost and environmentally friendly (Quirk, 2008). Since it is liquid it is very flexible to use compared to the traditional plastic scintillators. When a muon passes through the scintillator, the fluid emits radiation which is detected by a silicon photomultiplier (see definition 6) (SiPM) (see figure 1). The detector will measure the number and angle of muons which pass through. The SiPMs used are smaller, lower cost, and lower voltage than traditional photomultiplier tubes. Scintillators will be linked to a cable that can be run back up the hole allowing for retrieval and powering. Wavelength shifting fibers can be used inside the scintillator to make sure the detector picks up all the possible light signals. Highly durable tyvek reflective material will be wrapped around the scintillators so that light does not escape. This design is consistent with traditional designs, but improves cost effectiveness and sensitivity.

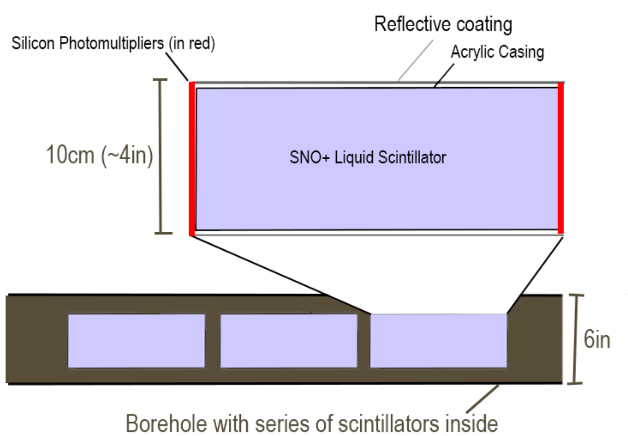

Figure 1. Diagram of scintillator

Experimental Methods

Scintillators would be linked together with a power cable and lowered into one or more boreholes. The scintillators would then continuously collect data over the course of a month or longer.

In order to control for variances in surface muon flux, a scintillator will be set up on site on the surface.

Multiple small neighboring boreholes could also be used in order to widen the angular and spacial resolution of the detectors as is done in most muographic surveys (Procureur, 2017). **The hypothesis of the experiment is that the muon flux in a region of a shale deposit will vary with the density of that region. A higher muon flux means that the region is less dense. This data could be extrapolated according to Kuila (2011) to mean that a less dense region contains weak spots which are optimal for hydrofracturing.**

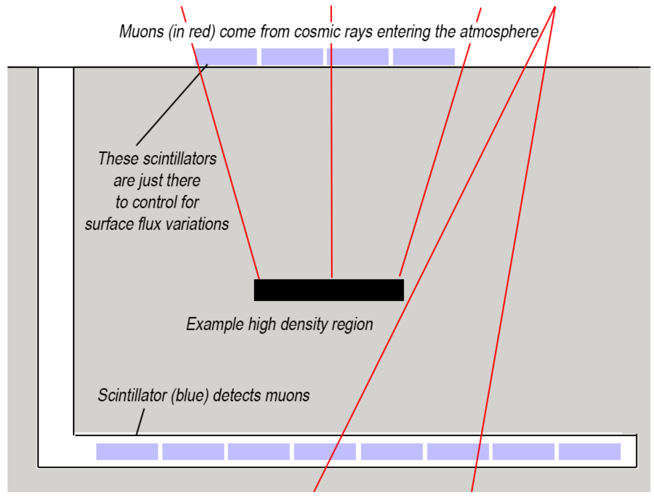

Figure 2. Diagram of scintillator apparatus in borehole.

Analytic Methods

The technique of taking data from a geological survey and producing a 3 dimensional map of a region is called inversion. This process is similar to the construction of a 3d picture from an MRI scan or a CAT scan, except at a much larger scale. The basic principle is that you take many 2 dimensional density maps and layer them on to one another to form a 3 dimensional map through what is called transmission muography (Procureur, 2017). Many programs have been developed to perform such 3D inversions, including that developed by CRM (Schouten, 2015). As an example of the type of uncertainty range we can expect, a research group in Japan mapped the subsurface density with an uncertainty less than or equal to ±0.8% (Tanaka, 2015). This uncertainty was determined through comparison with more traditional survey techniques. Prior geographical surveys of the region (such as seismic or radar surveys) can similarly be used to strengthen the certainty of finding a "sweet spot".

Following data analysis, the boreholes could be used for hydrofracturing, or data could be used to procure new regions to drill. The technology itself could lend itself to many other more sustainable forms of resource collection. In conclusion, more sustainable forms of shale based oil extraction could be discovered until renewable energy is ready to overtake the oil industry altogether.

Definitions

1 Geophone: an instrument for detecting seismic vibrations (compression and shear waves)

2 Muon: a fundamental particle similar to an electron but heavier; they are able to penetrate through materials up to a few kilometers thick

3 Borehole: The hole drilled into the ground in which scintillators are placed or hydrofracturing fluid is pumped.

4 Resolution: The range and precision at which the scintillators can provide accurate data.

5 Muon flux: The amount of muons passing through a surface area per unit of time

6 Photomultiplier: A device which uses the photelectric effect to measure scintillation events.

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