Employing NMR To Quantify Porosity Changes and Surface Relaxivity due to Mineral Alteration for CCUS Carbon Mineralization Applications

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Summary

Carbon mineralization is considered the most stable method for long-term geological carbon storage, whereby CO_2 is transformed into carbonate minerals, mitigating leakage concerns. Carbon mineralization is favored in mafic and ultramafic rocks (Mg- and Fe-rich silicates) such as basalts, peridotites, and dunites due to their high content of reactive minerals (e.g., pyroxene and olivine) that contain divalent cations which efficiently react with CO_2 to form solid carbonates**.** We have spent the past few years exploring how nuclear magnetic resonance (NMR) can be used to quantify natural and engineered changes in pore size distributions and pore surface rexlaxivity as a function of alteration, particularly carbon mineralization, in these mafic and ultramafic rocks. This data is vital to optimizing the carbon mineralization process for carbon capture utilization and storage (CCUS) applications and other sustainable energy practices associated with volcanic rocks including geothermal energy extraction and critical minerals recovery.

Theory / Method / Workflow

We have pursued experiments along two fronts in our attempt to employ NMR to characterize carbon mineralization potential in these mafic/ultramafic rocks. Firstly, low-field NMR measurements on pre- and post-reacted samples are utilized to observe changes in T_2-derived pore size distribution within plugs subjected to thermal fracturing and reactive CO_2 transport core flood experiments. Secondly, the T_2 distributions of a large suite of Newberry Volcano basalt samples from various depths have been recorded and integrated with other petrophysical data. Depending on the depth, the basalts have been subjected to various amounts of gases (including CO2) and aqueous fluid in situ, resulting in varied hydrothermal alteration outcomes, including extensive clay and carbonate precipitation. This study provides a natural laboratory for studying the interplay between pore structures, mineralogy and alterations. In addition to the T_2 data, mosaic SEM-based and BET-based partial pore size distributions were also recorded on these samples. This data allowed the T_2 relaxation time to be calibrated to pore size and the surface relaxivity of each sample derived. Corelating this surface relaxivity to alteration of the pores from exposure to gas and aqueous fluids has given important insight into how carbon mineralization can effect pore surface chemistry.

Results, Observations, Conclusions

A highly reactive ultramafic dunite sample was exposed to CO_2-laden brine in a core-flood apparatus with overburden at reservoir pressure and temperature. Following the flow experiment, the sample was saturated with inert fluid and post flow T_2 distribution was recorded. This distribution was then compared with that of a twin sample that had not undergone CO_2 flow experiment. Figure 1 compares the T_2 distributions of these two samples. The pore volume of the sample which had undergone CO_2 brine flow was reduced by nearly twenty percent as compared to its twin. This reduction in pore volume can be attributed to carbon mineralization within the sample's microfracture system, which also can blocks access to matrix pores (smaller peak).

Figure 2 shows the T_2 distribution of two different basalt core samples, one fresh sample and one altered by exposure to gases and in situ water. Each sample was saturated with decane prior to the NMR measurement. In addition to the T_2 distributions, partial SEM pore size distributions are also shown. These SEM distributions were employed to calibrate the T_2 relaxation time with pore radius and derive a surface relaxivity constant for each basalt sample. Clearly there is a correlation between surface relaxivity with fresh vs altered samples. The large pores in the altered basalt that contain authigenic calcite and clay mineral growth show enhanced relaxation compared to the NMR responses observed in the fresh sample (smaller pores, fractures etc.). This enhanced relaxation is manifested by larger surface relaxivity values. The featured example has been repeated on multiple samples.

Novel/Additive Information

The results display the use of NMR in determining CO_2-minerlization trapping potential as a function of sample properties, including mineralogy and petrophysical properties. NMR core analysis can be a valuable tool in assessing the feasibility of wells for carbon sequestration and storage and for shedding insights into the pore systems of volcanic rocks.

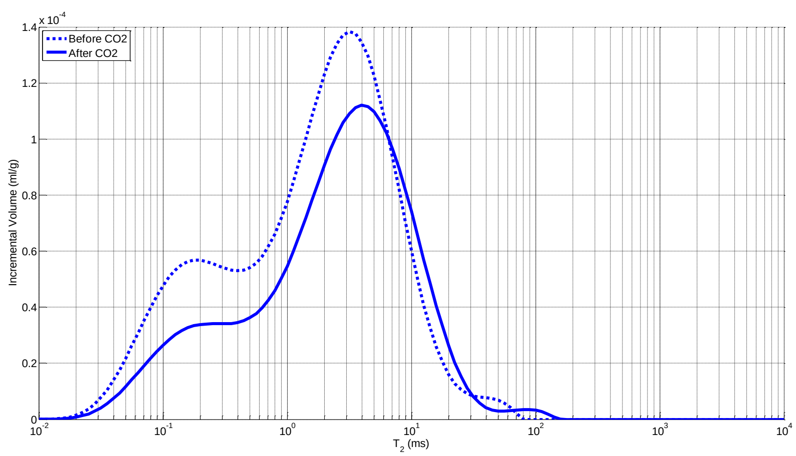

Figure 1

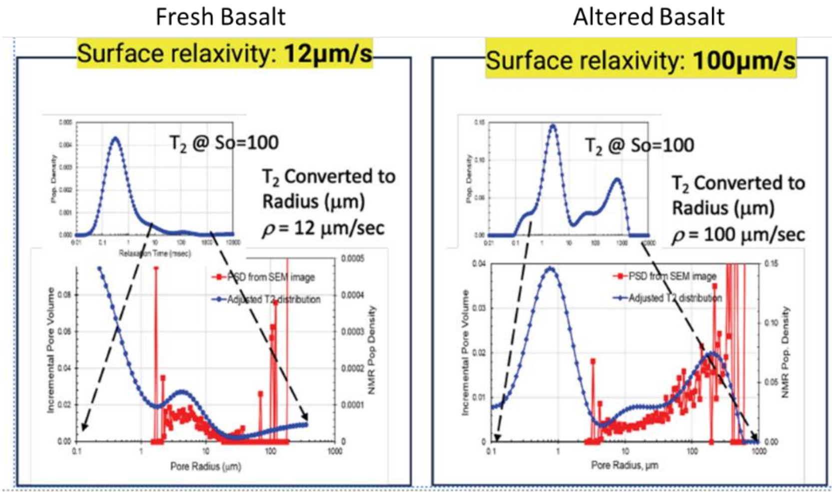
Fresh Basalt
Surface relaxivity: 12μm/s
T2 @ So=100
T2 Converted to Radius (μm)
ρ = 12 μm/sec
PSD from SEM image
Adjusted T2 distribution
Incremental Pore Volume
NMR Pop Density
Pore Radius (μm)
Altered Basalt
Surface relaxivity: 100μm/s
T2 @ So=100
T2 Converted to Radius (μm)
ρ = 100 μm/sec
PSD from SEM image
Adjusted T2 distribution
Incremental Pore Volume
NMR Pop. Density
Pore Radius, μm

Figure 2