CORPUS PUBLISHERS

Environmental Sciences and Ecology: Current Research (ESECR)

ISSN: 2833-0811

Volume 6 Issue 1, 2025

Article Information
Received date : February 25, 2025
Published date: March 10, 2025

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Keywords: Climate change, Temperature, CO_2, Peridotites

DOI: 10.54026/ESECR/10109

Review Article

Carbon Dioxide Capture in Rocks Of The Oceanic Floor

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Abstract

To explain each of the processes involved. Starting with carbon sequestration from the processing of carbon dioxide from the atmosphere, its management and optimal conditions, mineral carbonation of ocean floor rocks, and the conditions of oceanic ridges. To outline a proposal that allows the process of carbon dioxide capture and carbonation by injection into ocean floor rocks to be sustainable.

Introduction

Carbon dioxide (CO_2) is a greenhouse gas that has been increasing its concentration in the atmosphere exponentially since the beginning of the industrial era (18th century) (nasaclimate.nasa.gov n.d.). Today the concentration of this gas in dry air is 422 ppm (nasaclimate.nasa.gov, September 2024). The ocean floor is generated from the separation of two oceanic crusts, these divergent tectonic plate boundaries are called ridges. As this separation occurs, resulting fractures provide a larger contact surface. The ocean floor is the superficial part of the oceanic crust, which is composed of a sequence of basaltic rocks rich in iron and magnesium minerals. Peridotites are abundant rocks in these regions, composed mainly of olivine (up to 90% of these rocks), clinopyroxene and orthopyroxene (Tarbuck et al. 2005). Mineral carbonation is a chemical alteration process that consists of ionic replacement of phases (elements or compounds) between minerals, in this case by affinity carbon, together with Mg and water, replace ferromagnesian elements in the mineral structure, thus creating carbonates (CO_3). In this case, carbonation of peridotites is a naturally occurring process in the ocean (Peuble et al. 2018). Cabonation of peridotites requires constant fluid interaction with the rock through porosity. Increases in rock volume of approximately 44% have been found due to this process (Kelemen et al., 2011).

Methodology

The present text is a compilation of the most outstanding information of different articles and experiments that have as common point, the treatment of Carbon (C). Then, a series of comparisons between different methodologies is made, each one focused on the processes proposed in the model of carbon capture in peridotites.

Carbon sequestration from atmospheric CO_2

Direct carbon capture in industries is a process by which carbon dioxide is collected from a point source preventing its release into the atmosphere. This collection from a power plant or factory can be done through 3 processes. Pre-combustion: where hydrogen and carbon dioxide are separated from the natural gas to use the hydrogen as fuel. This method is used in petrochemical industries. After combustion: the exhaust gases produced by combustion are cooled and compressed to separate the CO_2 from the other gases. “Oxygen-combustion” capture: combustion is carried out in an oxygen atmosphere instead of free air in order to have a higher concentration of CO_2 and make it easier to capture. Unfortunately, these capture technologies are still very expensive and the process becomes complicated due to the large amount of energy required for their use. Once the CO_2 has been condensed, it can be handled in different ways to bring it to different states for storage. In the case of CO_2 for injection in peridotites, it is necessary that it is in a supercritical state (in liquid phase at 31°C, 74 bar). To achieve this behavior, CO_2 undergoes a hydration and compression process.

Experimentation on peridotitic rocks

In the experimentation of Peuble et al. 2018 a percolated dunite sample with a CO_2-rich acidic fluid at 160°C was compared with a naturally carbonated Meso-Atlantic Ridge sample, the experiment was monitored for 8 days. The experimentations of Noort et al. 2013 were performed in different methodologies, in the first one peridotite cores were dissolved in acidic solutions at temperatures of 50 -80°C, under semi-open conditions at atmospheric pressure. The second experiment was carried out in a pressurized autoclave at 10 MPa using CO_2 at a temperature range of 60-150°C, also in semi-open system conditions. The last experiment was in a closed dissolution-precipitation system using vessels with cold-seal technology, in a temperature range of 60 - 200°C and CO_2 pressures up to 70 MPa. The experimentation took 1200 hours (50 days). In the experiment of Andreani et al. 2009 a comparison of two identical experiments is made where water saturated in CO_2 was injected at constant flow through cylindrical samples of dunite (peridotite variety) of 9 mm in diameter (D) and 18 mm long (L), at a pressure of 12 MPa and a temperature of 160°C. The radial and axial sample confining pressure was 110% of the total injection pressure.

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Reactions observed in the olivine alteration process (not balanced)

$$MgSiO_4 + 2CO_2 \Rightarrow 2MgCO_3 + SiO_2$$

$$MgSiO_4 + CO_2 + 2H_2O \Rightarrow Mg_3Si_2O_5(OH)_4 + MgCO_3$$

$$CO_2 + H_2O \Rightarrow H_2CO_3 \Rightarrow H + HCO_3$$

$$Mg_2SiO_4 + 4H \Rightarrow 3Mg + SiO_2 + 2H_2O$$

$$Mg + HCO_3 \Rightarrow MgCO_3 + H$$

Results

Starting with the results of the Peuble et al. 2018 experiment; on the permeability side of the sample, a decrease in permeability of 80% and an impoverishment in Ca and Mg was observed due to the dissolution of olivine that was lodged in the form of carbonates between the cracks of the sample. The minerals observed between the cracks are mainly magnesite and serpentine formed at approximately the same time. The above on the part of the experimental rock. On the other hand, the control sample first went through a serpentinization process, which allowed more olivine replacement by carbonates than fluid accommodation in the cracks, with Mg being the dominant mineral in the carbonate structures.

The results of multiple experiments in the article by Noort et al. 2013 mostly observed changes in the color of the sample due to pH and temperature variables, which regulate the dissolution rate. Exhumation of serpentine veins was observed at a rate proportional to olivine dissolution. It was observed that the mass also varies with time, depending on the duration of the experiment there was a decrease or an increase, together with the conditions to which the rock was subjected. While some samples decreased in mass within the first 13 days, others increased in mass within the first 5 days, depending on the temperature, pressure, porosity, and pH of the sample. Regardless of mass, all showed an increase in volume, with special attention to the salinity variable in the fluid having a direct relationship with the ratio of mass to volume increase.

The third experimental methodology compared in this paper obtains through two different experiments, similar changes in the permeability of the rock (decrease in porosity), also observed the release of major elements (Si, Mg, Ca) in the system due to the dissolution of olivine, recovering Mg in the form of carbonates in the walls (microfractures) of olivine. In the first sample, magnetite and siderite-forming alteration was observed as the olivine dissolved. The oxidation of the olivine iron to magnetite is highlighted by the resulting H_2 production in these CO_2-rich systems. The second sample had higher Ca-rich magnesite growth, which means higher carbonate production. In general, it was observed that the flow rate of the CO_2-rich liquid is important at the moment of contact with the rock since it affects the penetration of the fluid into the micropores. In the same way, it was concluded that the carbonation rate is a function of porosity, injection range and injection distance.

Discussions

In general, it is notable that carbonation results in an increase in rock volume. In turn, the optimization of carbonation depends on the knowledge of the conditions under which it is sought, from the pH of the fluid (prior to CO_2 saturation), the composition, porosity, geometry and degree of alteration of the rock, the type of flow around the rock where the CO_2-rich fluid is present, the pressure and the temperature.

All the experiments compared consider different conditions of the test system, however, despite the differences between models, the results are consistent with each other, being able to estimate the ranges where carbonation can be modeled in an optimal way, as well as to modify it according to the characteristics of the model to which it is desired to apply.

These tests were performed in controlled environments and do not consider variations that occur in a real context, the results are still limited and have not gone beyond the analysis of the effects of carbonation for a few days. There is a lack of evidence of the behavior that the rock may have once the saturation limit, no porosity or complete replacement has been reached. The quantitative evaluations of the experiments are extrapolable to nature up to a certain time of CO_2 injection.

The benefits of carbon capture in peridotites

Carbonation of peridotites is an optimal model that does not require multiple structural and geological studies when compared to the model of carbon sequestration in sedimentary rocks of the continental crust. Likewise, the risk of CO_2 returning to the atmosphere is much lower than in the aforementioned alternative (no CO_2 destabilization was found in the experiments at the different temperatures at which they worked). The area available for the application of this method can be extrapolated to ridge regions near continental crust.

Potential in the Mexican territory

As the creation of the ocean floor occurs, by having a thermal contrast, an irregular texture with high contact surface potential is achieved. Likewise, by not having the same displacement rate, cracks (faults and fractures) are created that reach tens of meters deep (Weinberger, 2018) and increase the contact surface. Through observations of satellite images, regions with greater potential are distinguished near the continental borders of the Mexican territory (145 km from the continent) on the Pacific Ocean side from Jalisco to Guerrero.

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