The Effect of Atmospheric CO₂ on the Chemical Weathering of Silicate Minerals as Measured by Cation Flux in the Vadose Zone

Jacob Smith, jws3@clemson.edu; Prof. Scott Brame, brames@clemson.edu,
Dept. of EEES, Clemson University

Abstract

The mildly acidic nature of rainwater, a result of atmospheric CO₂ concentrations, is a driving force responsible for the chemical weathering of continental silicate minerals. The release and transport of dissolved ions within the soil is a consequence of the weathering process. This includes cations such as Ca²⁺ and Mg²⁺ capable of precipitating carbonate minerals in the oceans. Thus, over geologic time scales, the weathering process facilitates the flux of CO₂ from the atmosphere to the lithosphere.

To observe the effect of atmospheric CO₂ concentration on weathering, three test areas measuring 4 feet by 8 feet each were established. Two of the areas were enclosed by plastic structures, and one was left uncovered as a control. In the enclosed areas, CO₂ concentrations were held near 800 ppm in one and 2,000 ppm in the other. In the enclosed chambers, ambient air was bubbled through water in reservoirs until the CO₂ concentration reached equilibrium. The CO₂, equilibrated water was then applied to the soil to simulate rainfall. Custom-built suction lysimeters were installed at depths of 2, 4, and 8 feet in each test area to collect pore water samples during the experiment.

Major cation and dissolved silica concentrations from pore water samples are reported. Soil moisture and temperature were also monitored. Initial soil analysis indicated K⁺ and Ca²⁺ were enriched over Na⁺ and Mg²⁺ which is consistent with feldspar mineralogy.

Background: The Carbonate-Silicate Geochemical Cycle

As continental silicate minerals react with the acidic equilibrium products of CO₂ (i.e., H₂CO₃ and HCO₃⁻), alkali cations are preferentially released from the mineral structure. When carbonate minerals precipitate from certain ions, and are stored via geological processes, CO₂ is transferred from the atmosphere to the lithosphere (Berner, 2004).

By Henry’s Law, the concentration of CO₂ equilibrium products is proportional to the partial pressure; if CO₂ concentration increases, so must the equilibrium products. Therefore, chemical weathering is proposed as a negative feedback control on the concentration of atmospheric CO₂ (Berner, 2004). Some authors hypothesize that changes in weathering rates may have influenced past climate trends. For example, it has been proposed that cooling during the Paleogene was influenced by the Himalayan uplift followed by weathering and sequestration of CO₂ (Drever & Zobrist, 1992; Berner et al., 1983).

Methods

- To enclose the soil area, two PVC structures were constructed measuring 4 feet by 6 feet and covered with a sheet plastic.

- **Suction lysimeters** were installed at 2, 4, and 8 feet depths at each of the three sample areas to retrieve pore water.

- To collect a sample: 25ml 1g vacuum is applied from a hand pump to draw pore water into the porous cup. Next, a valve releases 20psi of compressed air to drive the sample from the porous cup to the surface.

- **Controlling CO₂ concentration:** In area A, a CO₂ meter with a programmable relay switch was used. The relay was programmed to open at concentrations above 2,000 ppm and wired to a CO₂ tank with a solenoid valve regulator. This setup allowed CO₂ to flow into the enclosure only when concentration was below 2,000 ppm.

- The theoretical pH of distilled water in equilibrium with sample area A was calculated to be 5.2.

- **Irrigation:** In the enclosed chambers, ambient air was bubbled through 5gal water reservoir until reaching equilibrium. A total of 3in was applied per area per week.

- **Pore water samples** were collected at each sample area during the course of the experiment. Temperature, soil moisture, and CO₂ flux were also monitored.

Results

- **Fig. 5 Cation concentration (ppm) at each depth, for each sample area, over time**

- **Fig. 6 Cation concentration (ppm) at each depth, for each sample area, measured at two periods**

Conclusions

- Increase in pore water concentrations over time at area A (highest CO₂ levels) is consistent with hypothesis.

- Initial condition concentrations of K⁺ and Ca²⁺ were higher than Na⁺. An steady increase in Na⁺ with time infers increased weathering of silicate minerals such as albite.

- Results imply concentrations of cations in surface and groundwater would increase with atmospheric CO₂.

References


Acknowledgments

Dr. Shannon Allain, Clemson University Agricultural Service Laboratory
Dr. Larry Mauk, Hydrogeology, Clemson University
Carbon cycle for this project provided from Tempsat.com