Carbon exchange dynamics and mineral weathering in a temperate forested watershed (Northern Michigan): links between forest ecosystems and groundwaters

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Our research team is determining the fate of organic carbon produced in temperate forests, which may constitute a major sink for anthropogenic CO_2. Importantly, studies of carbon allocation in forests under enhanced and ambient CO_2 growth conditions show that above and below ground carbon storage, as well as root and microbial respiration, all increase at elevated PCO_2 (e.g. Zak *et al.*, 1993). A portion of this additional organic carbon is rapidly recycled via respiration to the atmosphere. However, an unknown amount of organic carbon may be transported from the soil zone to the regional groundwater system for longer term storage. Past investigations have demonstrated important links between carbon transport and carbonate mineral weathering under open and closed system conditions (e.g. Rightmire and Hanshaw, 1973, Reardon *et al.*, 1979). As an extension of these classic studies, we are investigating how increased carbon fixation and processing in forest stands and soils may affect the overall carbon budget in groundwaters and the rate of carbon processing at the watershed scale.

Hydrogeochemical and ecological framework

Our multidisciplinary approach integrates experimental and natural system measurements on a catchment within the Cheboygan watershed in Northern Michigan. Here, forests are established on relatively permeable glacial drift deposits which host regional aquifer systems. These relatively recent glacial deposits are dominantly quartz, but contain variable amounts of reactive minerals such as calcite, dolomite, K-feldspar and plagioclase. Streams and rivers, largely groundwater fed, drain the upland morainal systems and feed into several large lakes along the topographic gradient, utlimately discharging into Lake Huron, one of the Great Lakes. There are two well studied forest stands (one aspen, one sugar maple) and an elevated CO_2 open-top chamber experiment located within the confines of the catchment. The experimental chambers contain aspens and sugar maples which are being grown under controlled conditions of CO_2- and N-fertilization. Soil mineralogic and water chemistry profiles

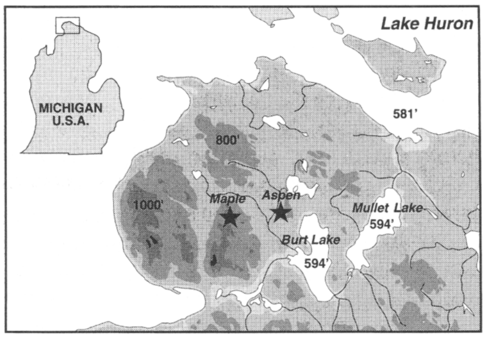

FIG. 1. Schematic view of catchment in the Cheboygan watershed, in Northern Michigan, USA The approximate elevations of glacial moraines and lakes (Burt Lake, Mullet Lake, and Lake Huron) are shown as are the locations of the natural forest sites (stars).

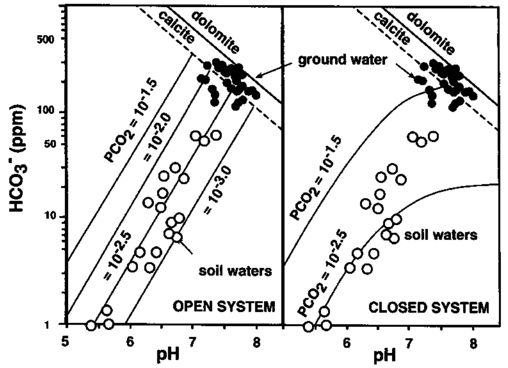

FIG. 2. Schematic of the equilibration of pure water with calcite and/or dolomite at 10°C (after Deines and Langmuir, 1974). Theoretically determined open system and closed system pathways are compared with soil water and groundwater compositions from profiles in the Cheboygan watershed.

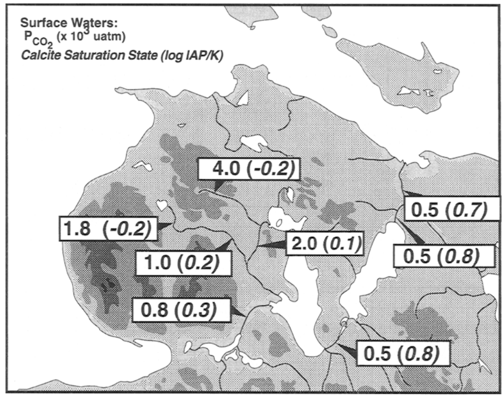

FIG. 3. Areal distribution of carbonate geochemical parameters in surface waters of the study catchment. Values for CO_2 partial pressure (μatm × 10^3) and calcite saturation index (log IAP/K) are given along the flow path from upland morainal systems to the lowland lakes and streams which discharge into Lake Huron.

have been determined in the open-top chamber experimental mesocosms and in the two natural forest stands (sugar maple upland forest, aspen lowland forest) (see Fig. 1).

Initial project results

As we are in the early phases of the project, results at this time focus on hydrologic and geochemical characterization of soil waters, surface waters and groundwaters as well as characterization of soil profiles and glacial drift (e.g. mineralogy, carbon content, permeability, etc.) for the study area. Soil waters exhibit large vertical chemical variations, generally grading from dilute, dissolved organic carbon-rich solutions in the upper 20 cm into mineralized solutions chemically similar to regional groundwaters by 4 m depth. Mass balance among dissolved carbon species suggests that dissolved organic carbon (DOC) originating from reactions in the upper rooted zone is transformed to inorganic carbon (DIC) via respiration and coupled mineral solubilization reactions. Dissolved silica and aluminum increase rapidly in soil waters suggesting that aluminosilicates, as well as carbonates, are dissolving as DOC (especially organic acid anions) is transformed to DIC.

The significant solute acquisition and carbon transformation evident in soil water profiles suggest that organic processes in the upper soil horizons are closely linked to mineral dissolution (DIC transport) and, in turn, to the overall rate of solute transport to unconfined glacial drift aquifers. The general evolution path is shown in Fig. 2 which depicts the carbonate system composition of soil waters and groundwaters from the catchment.

To a first general approximation, the soil water/ground water system in this region can be considered open to CO_2 and equilibrated with a CO_2 partial pressure of about 6,000 μatm. The soil waters range in their DOC content from a high of 3–4 mM within the upper 20 cm to about 0.6 mM in deepest soil water zones sampled (about 2 m). The continued respiration of this DOC, with associated dissolution of carbonates encountered as soil moisture migrates to the water table, completes the compositional evolution of the water. Geochemical and isotopic budget for water and solute sources will be assessed. Analyses are underway to determine how these systematics vary between the two natural forest sites and with the behaviour of the elevated and ambient CO_2 open-top chamber tree growth experiments.

Implications and continuing studies

The surface water system provides an interesting integrator of seasonal changes in weathering reactions. Surface waters within upland ecosystems are generally similar in their CO_2 partial pressures and calcite saturation states to regional groundwaters they are fed by. The lowland lakes and streams, in contrast, have much lower CO_2 partial pressures and remain significantly supersaturated with respect to calcite (see Fig. 3).