CHEMICAL WEATHERING IN HETEROGENEOUS BEDROCK

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ABSTRACT

Chemical weathering is a natural process that disintegrates rock and supplies solutes and nutrients for plant uptake and the hydrologic cycle. The extent of chemical weathering is commonly assessed using a geochemical mass balance model (Brimhall & Dietrich, 1986). The mass balance model depends on selecting unweathered parent material to compare element mobility. This study compares two 21m deep rotosonic drill cores and outcrop samples to characterize parent material and evaluate bedrock variability. These data are used to select appropriate immobile elements for mass balance calculations. Drill cores were sampled both on ridges and toe slope within in a 9-hectare, first-order watershed located in a forested nature preserve in the Piedmont coastal plain of southeastern Pennsylvania. Preliminary data from drill cores suggest that the bedrock has variable concentrations of zirconium, one of the most common immobile elements for geochemical mass balance calculations. This study explores several options for assigning unweathered parent material to assess chemical weathering in heterogeneous bedrock.

INTRODUCTION

Atmospheric carbon dioxide emissions are drastically above pre-civilization levels (Petit, et.al, 1999), and most of the current carbon dioxide emissions are the result of land use changes and the combustion of fossil fuels (Amundson, 2001). The reservoir of organic carbon stored in soil can rapidly respire as atmospheric carbon dioxide unless the soil carbon is tightly associated with mineral surface (sorbed, Kleber, et.al, 2007). Understanding the processes that generate mineral surface area is a first step to understanding a soil's potential to sequester carbon. Mineral surface area is initially produced by physical weathering but substantially modified by chemical weathering, which acts to 1) dissolve and break down primary minerals and 2) create secondary clay minerals and oxide coatings which contain orders of magnitude more surface area than primary minerals.

Carbon is commonly sequestered in soil profiles in the form of organic carbon and carbonate mineral species. The ability of a soil to sequester carbon is therefore a function of the movement and availability of ions capable of complexing with carbon-bearing species. It is therefore critical to understand the physiochemical processes operative at the air/water/rock interface of the Critical Zone. Elemental mobility, and therefore the ability to sequester carbon, is a function of bedrock composition and the nature of physical and chemical weathering processes. The primary objective of this investigation is to document the nature and rate of elemental redistribution between unweathered parent material and the developing soil profile in the Christina River Basin Critical Zone Observatory.

PROCESS

To gain a complete picture of the deep chemical weathering profile we will assess elemental composition changes in two 21-meter drill cores in a 900 hectare, first-order watershed in the Christina River Basin Critical Zone Observatory in southeast Pennsylvania. The mass balance model is used to assess mass and volume changes of elements in unweathered parent material to weathered soil. To apply the mass balance model to a system, one must assume that 1) the soil being measured was formed on the parent material being measured, 2) that the elemental concentrations of the parent material were homogeneous prior to weathering, 3) that immobile elements remain stable and unweathered, and 4) that there are no physical losses from the system (Brimhall & Dietrich, 1987) or that the system is in landscape equilibrium (Riebe et.al, 2004). The present work is to test these assumptions to assess the applicability of the mass balance model to this bedrock system.

Soil Profile

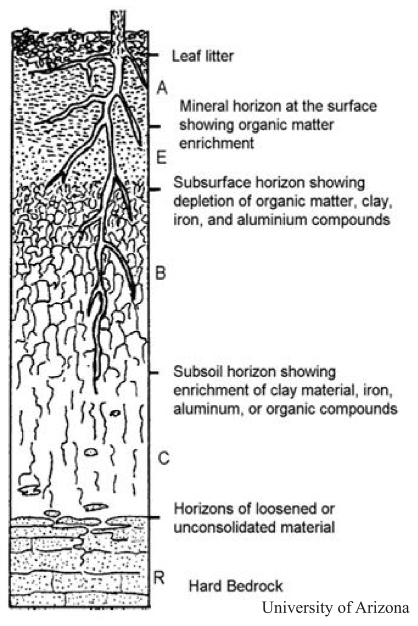
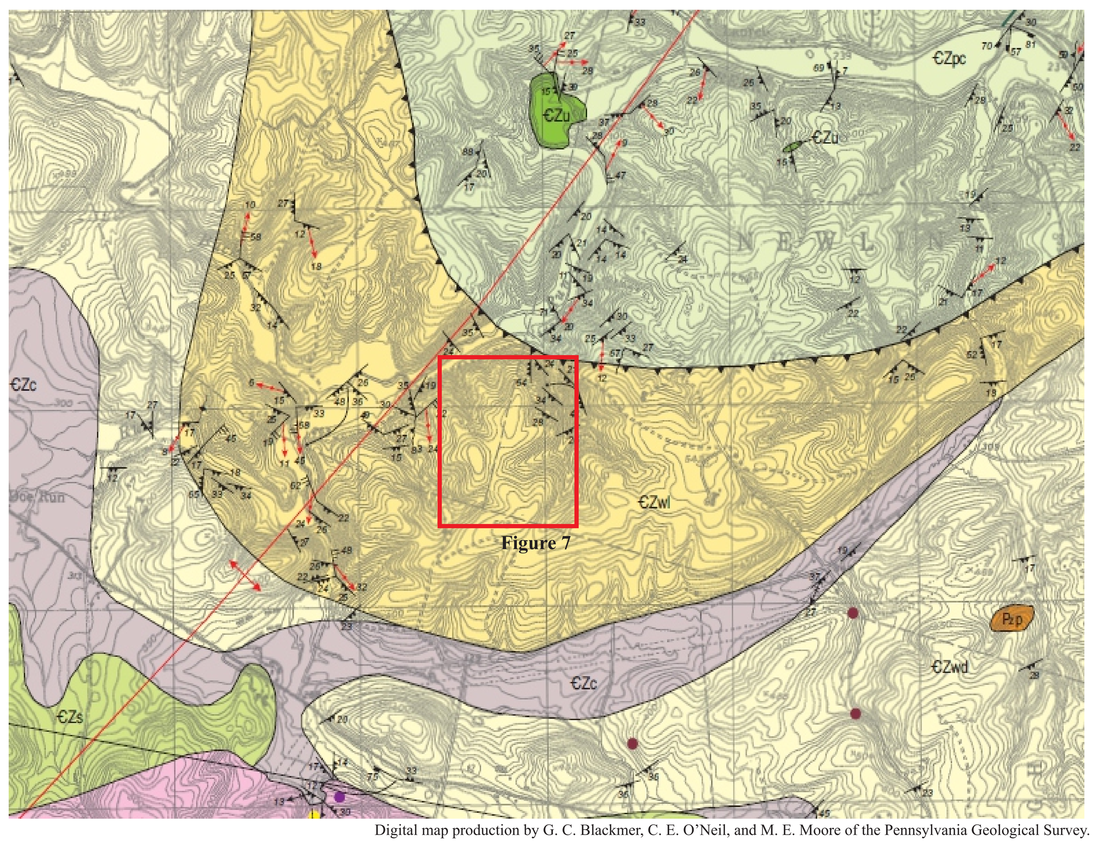


Figure 6: The top portion (O) is the organic horizon consisting of fresh or undecomposed organic material like leaf litter. Below is the A-horizon, which is enriched in organic matter. In some soils, a lighter E-horizon develops from leaching, followed by the B-horizon, a zone of accumulation. This layer is where the weathered products or mobile elements accumulate from the above processes. At the base of this soil profile is weathered parent material directly above the bedrock.

Regional Geology



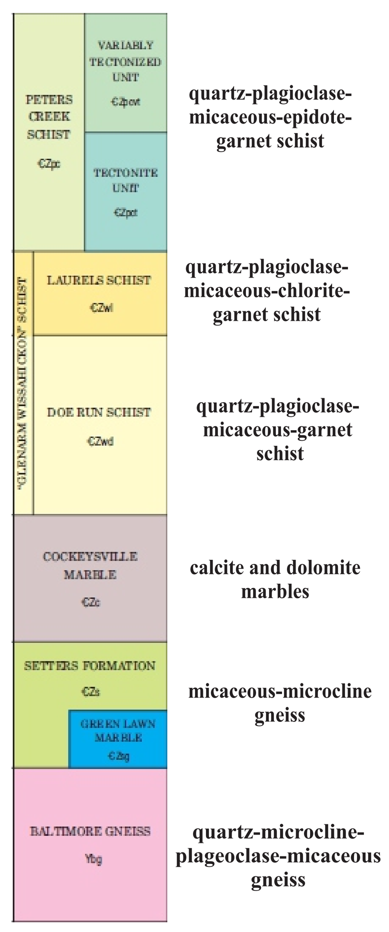


Figure 7: The geology of the Christina River Basin Critical Zone Observatory. Both wells are located within the Laurel Schist, which consists of a quartz-plagioclase-micaceous-chlorite-garnet schist.

BEDROCK GEOCHEMISTRY

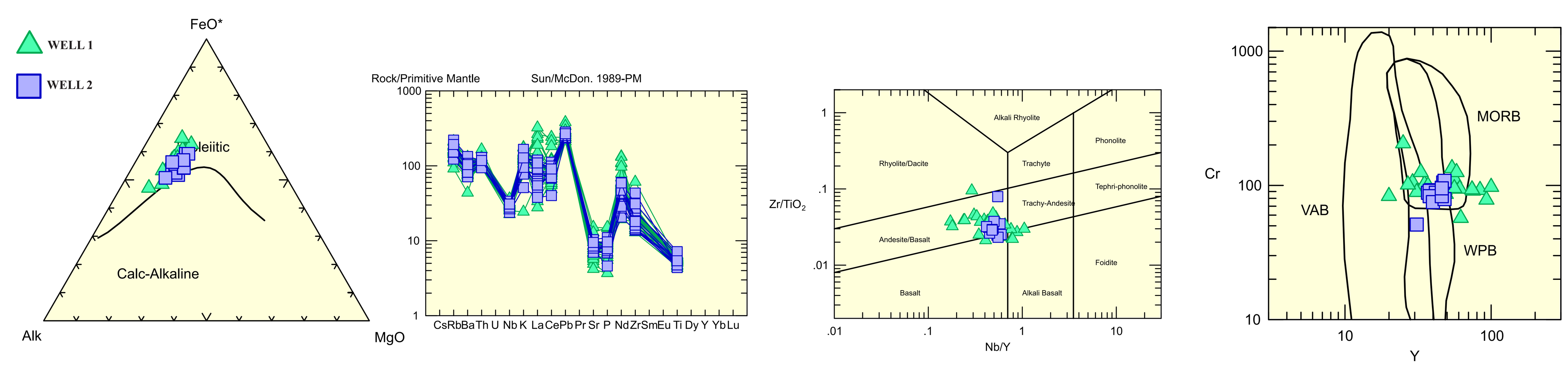


Figure 8: Geochemical analyses of drill core samples below the 3 meter level, which assumed to represent initial bedrock composition. Note the strong degree of overlap between the two wells, suggesting that the bedrock is relatively homogeneous throughout the study area. The more heterogeneous nature of Well 1 might be the result of heterogeneous bedrock or a higher sampling density. The bedrock in each well consists of the Laurel Schist, which is a quartz-plagioclase-mica-chlorite-garnet schist of probable andesitic to basaltic andesite protolith.

DATA COLLECTION

The samples were collected by Beth Wenell in southeast Pennsylvania at the Christina River Basin Critical Zone Observatory. There were two 21-meter drill cores taken in a 900 hectare, first order watershed as highlighted in figure 5. These cores were then sorted and labeled by depth, well, and grain size (<2mm and >2mm) before being sent to the lab.

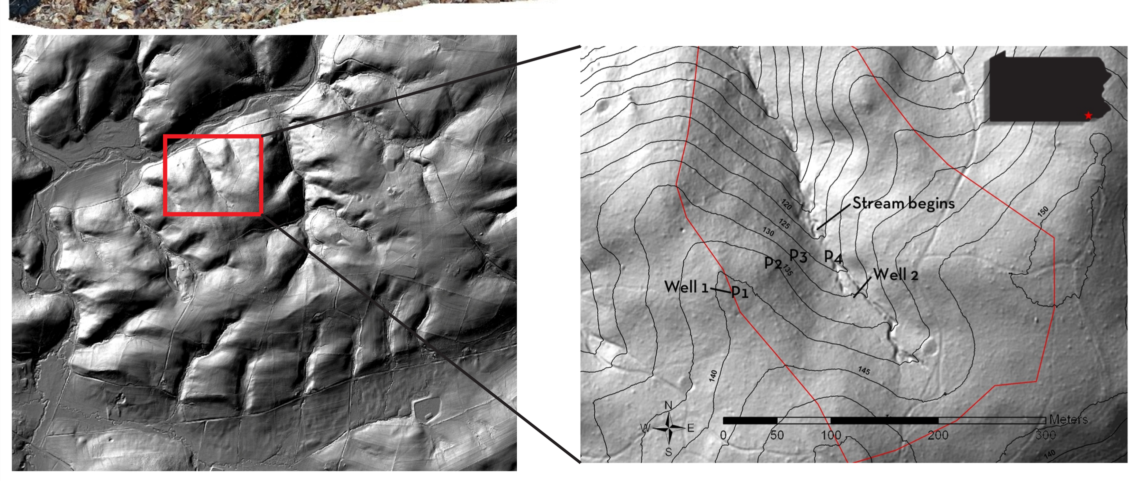


Figure 5: The watershed area of focus is located in the Christina River Basin Critical Zone Observatory in southeast Pennsylvania. Four areas were sampled along a slope at the summit, shoulder, backslope, and gully.

Figure 1 and 2: A track-mounted rotosonic drill was necessary to access roadless areas and minimize environmental impact.

Figure 3: Core drilling yielded a variety of materials, ranging from disaggregated fine sand in the upper portion of the well to fresh bedrock in the lower portion of the well. Note foliated fragments of schist within Well 2.

Figure 4: Note the progression of color within the soil horizon with increasing depth, suggesting a depth-controllled compositional change.

DATA ANALYSIS

Drill core samples were separated into fine (<2 mm) and coarse (>2 mm) fractions. Samples were pulverized using tungsten carbide, and major and trace element geochemistry was conducted via sequential X-Ray Flourescence (XRF) spectrometry at the University of Wisconsin-Eau Claire. Compositional data is presented as a function of depth for selected elements. Elements were selected on the basis of observed mobility.

Well 1

Well 2

RESULTS

Three observations are immediately apparent within the geochemical data:

- Fine and coarse grained fractions in each well are geochemically distinct,
- The two wells display different geochemical profiles,
- The soil profile is much more well developed within the coarser grained fraction

These observations are interpreted to indicate:

- The fine grain fraction contains abundant clay, which itself is the product of extensive weathering and elemental mobility, and is also homogenized by the drilling process, so large compositional shifts are less evident
- The different geochemical profiles in the wells suggest that geographic position or initial bedrock composition may control the nature of the vertical geochemical profile. Geochemical analysis of bedrock material suggests that the two wells are within similar bedrock, so the geographic position may be the determinant function. Note that Well 1, which as a higher topographic position, has a more well developed soil profile. This may be a function of differences in fluid flux or gravity-driven mass transport.
- The coarse grained fraction contains a higher percentage of unaltered and partially weathered parent material, so vertical geochemical variations are much more pronounced, resulting in well-developed zones of leaching and accumulation.

CONCLUSION

To understand the ability of soil to sequester carbon, it is important to fully understand weathering processes involved in the critical zone. This study examines soil of the Christina River Basin Critical Zone Observatory by analyzing elemental mobility through the transition between unweathered bedrock and well-developed soil horizons. Geochemical data was derived from a range of samples divided by both depth and size. Elemental mobility seems to be a function of initial bedrock homogeneity, grain size, topographic location and fluid infiltration rates. Analysis of elemental mobility is a fundamental first step in evaluation of the assumptions necessary to apply the geochemical balance model comparing mobile elements to immobile elements such as zirconium.

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