6. Weathering and Soil-Forming Processes

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Weathering of rocks and minerals is one of the most important processes operating at the surface of the earth. On a microscopic scale, mineral weathering reactions occur at the interface between solids and solutions. On a grander scale, weathering is a process which operates at the interface between the earth's endogenic and exogenic cycles. The earth's internal forces determine the distribution of rocks, minerals, chemical elements, and relief in time and space. The exogenic system then transforms rock-forming minerals and their constituent elements into residual and secondary solids and dissolved products, and redistributes them physically, chemically, and biologically. These interfacial interactions between the lithosphere, hydrosphere, atmosphere, and biosphere profoundly alter both the surface of the solid earth and the chemistry of its fluid envelopes.

Weathering also influences a variety of human activities. Of particular interest here are mineral transformations during weathering which form soil minerals, releasing both beneficial (nutrient; e.g., K, Mg, and Ca) and detrimental (e.g., Al) elements into terrestrial ecosystems and subsurface and surface waters. In addition, primary and secondary minerals exhibit a range of abilities to ameliorate adverse anthropogenic impacts on our environment. Primary rock materials, for instance, have widely differing abilities to buffer atmospherically deposited acidity and thereby determine the sensitivity of a landscape to acid precipitation. Weathered rocks and soils also have different capacities to store water and therefore buffer the sensitivity of regions to flash floods. Finally, weathering profiles have a wide range of susceptibilities to erosion,
thereby linking chemical processes of weathering and soil formation with the long-term geomorphic evolution of regional landscapes.

The purpose of this chapter is to summarize recent research on the chemical weathering of rocks and minerals in selected watersheds at Coweeta. Because of the importance of mineral weathering in supplying inorganic nutrients to the dissolved load of streams, and the possible importance of soil minerals in supplying inorganic nutrients to the forest biota, this chapter emphasizes the chemistry of mineral weathering processes, and the rates at which these processes of weathering and soil formation proceed. The bedrock geology and tectonic setting of the Coweeta Basin and their relationships to geomorphic evolution are summarized elsewhere (Chapter 5), as are some of the major physical processes of landscape modification (Chapter 7).

The Weathered Regolith of Coweeta

The weathering profiles of the Coweeta Basin consist of two major subdivisions, soil and saprolite. The uppermost 30 cm of the weathering profiles are true, biologically active soils, mostly Ultisols and Inceptisols. Most soils are residual and occur over large areas of moderate slopes. Inceptisols occur in restricted areas of steep slopes, on colluvial parent materials occurring as valley fill, and in fluvial valley bottom sediments. The main difference is that the Inceptisols are developed on parent material which has been transported (by mass movement on steep slopes, or by fluvial processes in valley bottoms), thereby resetting the soil in terms of horizon development. The Ultisols form on a physically untransported, and therefore geomorphically older, substrate. This results in preservation of better developed horizon differentiation. The chemical and mineral properties of the Ultisols and Inceptisols at Coweeta are very similar; the major distinction between them is in soil morphology.

Beneath the soil at Coweeta is a considerable thickness of saprolite. Saprolite was defined by Becker (1895) as "thoroughly decomposed, earthy, but untransported rock." Over the years the term has come to mean a residual subsoil (regolith) developed on crystalline rocks in which some or all of the primary rock-forming minerals have been transformed in situ to weathering products. In saprolite, the spatial distribution of weathering products often mimics the distribution of parent minerals (that is, parent minerals are replaced by pseudomorphs consisting of weathering products), resulting in the preservation of parent rock textures, fabrics, and structures in the saprolite. Furthermore, because of the pseudomorphous nature of the mineral weathering reactions, a unit volume of crystalline parent rock weathers to a unit volume of saprolite (isovolumetric weathering; Millot and Bonifas 1955). In general, mass is lost in the form of dissolved element removal by subsurface solutions, while volume is preserved, in part by hydration of parent minerals and formation of secondary minerals with more poorly crystallized and/or more open structures. Therefore, the bulk density of saprolite is considerably lower than that of fresh parent rock. At Coweeta, for instance, a typical value for the bulk density of fresh bedrock is around 2.8 g/cm³, compared with 1.6 g/cm³ for a typical saprolite (Berry, unpublished data). Thus, around 40% of the mass of a unit volume of rock is removed without changing the bulk volume, so the saprolite may have a void ratio (a rough estimate of porosity) of 40%, compared with
negligible porosity in the fresh bedrock. This profound change in physical properties during isovolumetric weathering of rock to saprolite gives rise to saprolite’s unique hydrologic and geomorphic behavior. The blanket of saprolite on the surface of the landscape, with its enormous volume of pore space, is generally believed to be a primary source of base flow and, to a considerable degree storm flow as well, at Coweeta (Hewlett 1961; Hewlett and Hibbert 1963, 1966) as in the rest of the southern Blue Ridge (Winner 1977). From a geomorphic standpoint, the distinction between rock and saprolite is equally important; porous, friable, unconsolidated saprolite is much more vulnerable to erosion by fluvial processes and landslides (Grant 1983 and Chapter 7) than is fresh bedrock.

Volumetrically, the saprolite portion of the weathering profile dominates over the soil. Although bedrock exposures as exfoliation surfaces, cliffs, and stream exposures are not uncommon at Coweeta, most of the landscape is covered by at least some soil and saprolite. Saprolite is thickest at drainage divides between watersheds, where 6 to 23 m of weathering profile was encountered by drilling before reaching fresh bedrock (Berry unpublished). Of this weathering profile, the true soil (A and B horizons) usually comprises no more than 70 cm; the remainder is “C” horizon material (saprolite). On the slopes between drainage divides, erosion and mass wasting keep saprolite thinner than on divides (Berry unpublished). Swank and Douglass (1975) report an overall average weathering profile thickness (depth to bedrock) of about 6 m. Of this total thickness, perhaps 5% is true (A and B horizon) soil—the remaining 95% is saprolite. This average thickness is used in many of the calculations discussed below.

The Stoichiometry of Major Mineral-Weathering Reactions

Two major lithostratigraphic units occur in the Coweeta Basin, the Tallulah Falls Formation and the Coweeta Group. Descriptions and major features of their origin and distribution are discussed by Hatcher (Chapter 5). From a chemical weathering perspective, the most important feature of the bedrock is its mineralogical composition. Five rock-forming minerals make up the bulk of bedrock in the Coweeta Basin. These are: quartz, biotite and muscovite micas, plagioclase feldspar, and almandine garnet. Of the five major minerals, quartz and muscovite mica are so stable in the weathering environment that they are not likely to contribute significantly to dissolved and botanical mineral nutrient budgets (e.g., Goldich 1938). The three remaining rock-forming minerals are both weatherable, and present in sufficient abundance to significantly influence dissolved mineral nutrient budgets. The remainder of this discussion is concerned with the stoichiometries (that is, the amount of each element released per unit amount of reaction) for the weathering reactions of these three minerals.

Biotite Mica

Biotite mica is an aluminosilicate mineral containing potassium, magnesium, and iron in a sheet structure. General aspects of biotite mica structure and weathering are summarized by Velbel (1984a). Weathering of biotite mica at Coweeta has been studied by
Velbel (1984b, 1985c), who found that the major weathering product of biotite in the saprolite of Coweeta is hydrobiotite, which consists of a regular alternation of 1.0 nm mica layers with 1.4 nm vermiculite or “pedogenic chlorite” layers. The more extensive weathering of biotite in the soil continues to transform biotite layers into vermiculite and pedogenic chlorite. Electron probe microanalysis (EPMA) of fresh biotites and their weathering products (Velbel 1984b, 1985c) have suggested that biotite weathering at Coweeta, as in most natural weathering environments, occurs by a “simple transformation” (Fanning and Keramidas 1977). In this transformation, the primary sheet silicate lattice is conserved; compositional change during weathering is due largely to removal and partial replacement of interlayer potassium by small amounts of calcium and sodium, accompanied by minor loss of magnesium from the octahedral layer. The combined EPMA and mineralogical data suggest the following weathering reaction for the formation of the 1.4 nm layers of hydrobiotite and pedogenic chlorite:

\[
\begin{align*}
K_{25}Na_{02}(Mg_{1.2}Fe^{II}_{1.5}Al_{0.5})(Al_{1.5}Si_{2.5})O_{10}(OH)_2 + 0.19O_2 + 0.078H^+ + 0.31H_2O + \\
0.016Ca^{2+} + 0.04Na^+ + 0.35Al(OH)_{2\text{aq}} & \rightarrow \\
K_{25}Na_{06}Ca_{01}(Mg_{1.1}Fe^{II}_{1.5}Fe^{III}_{0.5})(Al_{1.5}Si_{2.5})O_{10}(OH)_2 - 1.33Al(OH)_2 + 0.6K^+ + 0.1Mg^{2+}
\end{align*}
\]

The weathering of biotite to hydrobiotite and pedogenic chlorite releases a significant proportion of the potassium and some of the magnesium present in the parent mineral, and results in the removal of a small amount of calcium and sodium from the ambient soil- or groundwater.

Almandine Garnet

The garnets are a compositionally complex group of silicate minerals in which silica tetrahedra are linked with octahedrally coordinated aluminum, chromium, or iron (rather than with other silica tetrahedra), with calcium, magnesium, iron, and manganese located in the interstices within the linked tetrahedral-octahedral structure. The almandine variety consists mainly of iron and aluminum silicate, although minor amounts of the other elements are usually present. Little is known about the weathering of the garnet group minerals, largely because of their extreme compositional complexity combined with the fact that garnet does not occur abundantly in most shallow crustal rocks.

Garnet weathering at Coweeta and the related pertinent literature have been studied by Velbel (1984a,b,c). Almandine garnet at Coweeta weathers by congruent breakdown of the parent crystal lattice, localized reprecipitation of most of the iron (as goethite) and some of the aluminum (as gibbsite), and removal of the remaining constituents in solution. The stoichiometry of the almandine garnet weathering reaction at Coweeta based on EPMA and mineralogical data is:

\[
\begin{align*}
Ca_2Mg_5Mn^{2+}_{0.7}Fe^{II}_{1.2}Al_2Si_2O_{12} + 0.625O_2 + 2.5H^+ + 8.35H_2O \rightarrow \\
2FeOOH_{\text{goethite}} + 0.1Fe(OH)_{2\text{aq}} + Al(OH)_{2\text{gibbsite}} + \\
Al(OH)_{2\text{aq}} + 3H_2SiO_4_{\text{aq}} + 0.5Mg^{2+} + 0.2Ca^{2+} + 0.2MnO_2_{\text{at}}
\end{align*}
\]

The weathering of almandine garnet contributes significant quantities of silica, calcium, and magnesium to the soil and streams.
Plagioclase Feldspar

The feldspar minerals consist of aluminosilicates of potassium, calcium, and sodium, in which tetrahedra of silica and alumina are linked with one another in three dimensions, giving rise to a framework structure with the alkali and alkaline earth elements in the interstices. The two major compositional groups are the potassium feldspars, and a continuous solid-solution series between endmember calcium and sodium feldspars known as the plagioclase feldspars. The feldspars are the most abundant single mineral group in the earth's crust, and have therefore received considerable attention from geochemists interested in mineral weathering. Much of the recent literature on feldspar weathering is reviewed by Velbel (1984a, 1986b).

The transformation of the predominantly sodic plagioclase feldspars of Coweeta to their clay-mineral weathering products has been studied by Velbel (1982, 1983, 1984b, 1985c). The weathering of plagioclase feldspar at Coweeta is a two-stage process. The first stage is complete congruent dissolution of the parent feldspar, during which the constituents of the feldspar are released to the solution in the same ratios in which they occur in the fresh parent mineral. The general stoichiometry of this stage of the reaction can be written:

$$Ca_{(1-x)}Na_{(x-2)}Al_{(1+x)}Si_{(3-x)}O_{(8)} + (6-2x)H_2O + (2+2x)H^+ \rightarrow xCa^{2+} + (1-x)Na^+ + (3-x)H_2SiO_4_{(aq)} + (1+x)Al(OH)_2_{(aq)}$$

where $x = 0.25$ for rocks of the Coweeta Group and $x = 0.32$ for rocks of the Tallulah Falls Formation (determined by EPMA).

The second stage of the plagioclase weathering reaction is the precipitation of some of the dissolved constituents (released by the dissolution of the feldspar in the first stage of the reaction) as clay-minerals, which may occur either very close to the original site of dissolution (forming clay-mineral pseudomorphs after the feldspar) or after transport (as clay-mineral fracture-linings) some microns to millimeters or more from the original site of dissolution (Velbel 1982, 1983, 1984b, 1985c). The clay-mineral products of plagioclase feldspar weathering in the soils and saprolites of Coweeta are gibbsite and kaolinite, which precipitate by reactions:

$$Al(OH)^+_{(2aq)} + H_2O \rightarrow Al(OH)_3_{(gel/min)} + H^+$$

and

$$2Al(OH)^+_{(2aq)} + 2H_2SiO_4_{(aq)} \rightarrow Al_2Si_2O_5(OH)_4 + 2H^+ + 3H_2O$$

The presence of these cation-depleted clay minerals in the saprolites of Coweeta could indicate either prolonged weathering (that is, that the weathering profile of Coweeta is extremely old), or very intense weathering over a shorter time period, with the relative depletion of alkali and alkaline earth cations due to extreme rapid flushing of water through the porous and permeable weathering profile (see the discussion above on the hydrologic properties of saprolite). Given the extremely high rainfall and the occurrence of primary rock-forming minerals in the soils and saprolite of Coweeta, it appears
that the kaolinite–gibbsite mineralogy of the soils and saprolites is due more to the intensity of weathering at Coweeta than to the antiquity of the weathering profile. As is discussed below, present day rates of mineral and chemical weathering of Coweeta rocks could produce the observed thickness of saprolite in several hundred thousand years, suggesting that the Coweeta landscape is much younger than many kaolinitic–gibbsitic landscapes beneath 10 to 60-million-year-old peneplains. Other clay minerals form in incipiently weathered bedrock below the saprolite and in outcrops, but as is shown elsewhere in this chapter, these weathering microenvironments involve minimal quantities of the subsurface water, and therefore do not contribute measurably to the dissolved load of surface or subsurface waters.

Geochemical Mass Balance of Small Watersheds

Most streamflow at Coweeta is fed by subsurface water percolating through the soil and saprolite (e.g., Hewlett and Hibbert 1966); as a consequence, only the weathering reactions which take place within the soil and saprolite influence the composition of streamwaters leaving Coweeta watersheds. This can be seen in the close correspondence between the geochemical character of the streamwaters and the clay mineralogy of the weathering profiles (Velbel 1982, 1984b, 1985a,c). The amount of water percolating into and through fractures in the bedrock is extremely small relative to the amount flowing through the saprolite, and mineral–water interactions taking place within these small bedrock fractures leave no detectable imprint on the geochemistry of Coweeta waters. Because only mineral transformations taking place within the soil and saprolite influence the measured output fluxes via Coweeta streams, only these reactions need to be considered in geochemical modelling of input-output budgets in small watersheds.

Geochemical mass balance studies (also known as input-output budgets) invoke a simple conservation-of-mass principle, the principle that “some of it plus the rest of it equals all of it.” Put another way, if the flux of any element leaving a watershed (e.g., via streams), and the flux of that element into the watershed (e.g., via atmospheric precipitation) are known, the difference between the two can be calculated. This difference must be due to the sum of all reactions and transformations involving that element which took place within the watershed. Pioneering mass balance studies on weathering profiles and/or small watersheds include those of Garrels (1967; Garrels and Mackenzie 1967), and Cleaves and Bricker and their coworkers (Cleaves et al. 1970, 1974). Geochemical mass balance studies are widely recognized as the most reliable means of estimating mineral weathering rates in nature (Clayton 1979). The mathematical basis for watershed mass balance studies is developed and discussed by Velbel (1986a).

Early geochemical mass-balance studies placed primary emphasis on inorganic weathering. Cleaves et al. (1970), however, recognized that weathering reactions in a forested watershed produce larger quantities of mineral nutrients (especially calcium and potassium) than are observed in streams and that these excess quantities are probably taken up by the forest biota. Likens et al. (1977) also recognized that weathering products derived from the breakdown of soil minerals leave the weathering profile both via the dissolved load of streams and via biomass uptake, and that estimates of weather-
ing rates (i.e., mineral breakdown rates) based only on stream fluxes might be as much as a factor of two lower than the actual value which includes biotic uptake.

Velbel (1984b, 1985b) developed a geochemical mass balance model for forested watersheds at Coweeta which extends previous models in two ways. First, mineral compositions in this study were determined empirically, and compositional data were combined with micromorphological data to arrive at the mineral weathering reactions described above. This is in contrast to many of the earlier studies, in which mineral compositions were assumed to be nearly ideal (essentially, estimated from geological occurrence and standard mineralogy texts). Secondly, botanical uptake of three major mineral nutrients (potassium, calcium, and magnesium) is explicitly included in the mass balance expressions, which permits direct estimates of biomass uptake.

Mineralogical and petrographic (micromorphological) data constrain the mineral weathering reaction stoichiometries described above. Combining these with previously published hydrogeochemical data (Hewlett 1961; Hewlett and Hibbert 1963, 1966; Swank and Douglass 1977; Velbel 1982, 1984b, 1985a), reveals that four transformations influence elemental budgets in the watersheds; the weathering of the three major weatherable rock-forming minerals (biotite mica, almandine garnet, and plagioclase feldspar), and the uptake of mineral nutrients by the forest biota. The stoichiometries of these reactions (that is, the amount of each element released per unit amount of reaction) are known for minerals (from the data and references discussed above) and can be approximated for biomass (using the data of Day, as reported in Birn et al. 1981), but the rates of the four reactions are not known. However, the input and output fluxes (mass of each major element per unit time) are known, as is the difference, which is the rate of total change of element abundance in the watershed per unit time. The difference between output and input fluxes for each element is due to the sum of the four transformations taking place within the watershed; we can therefore write a mass balance expression for each element, which has the following form:

\[ \sum_{j=1}^{n} a_j \beta_{cj} = \Delta m_c \]

where \( \beta_{cj} \) is the stoichiometric coefficient of element \( c \) in reaction \( j \) (known from mineralogical studies or published botanical compositions), \( \Delta m_c \) is the net flux of element \( c \) from the watershed (stream output minus precipitation input), and \( a_j \) is the number of moles of weathering reaction \( j \) occurring per unit area of watershed per unit time (the rate of the transformation, which is unknown). \( \varphi \) is the number of phases involved (i.e., transformations taking place); in this case, \( \varphi = 4 \). Each mass balance equation is an equation in \( \varphi \) unknowns; therefore \( n = \varphi \) such mass balance equations are required to solve for the desired number of unknowns (\( \varphi \)). There are four unknowns in Coweeta watersheds, and therefore mass balance equations for four elements are needed. Fortunately, stoichiometric coefficients and net fluxes are known for sodium, magnesium, potassium, and calcium, so a system of four equations in four unknowns can be constructed, constrained, and solved for rates of mineral weathering and botanical uptake. Rates of clay-mineral formation can be incorporated by adding additional terms to the equations if we add an equal number of mass balance equations for addi-
tional elements, such as silica. Rates of mineral weathering and mineral nutrient supply to the terrestrial biota have been calculated by this method (Velbel 1984b,c, 1985b) and rates of weathering profile development and geochemical denudation of the landscape have been calculated from these results (Velbel 1984b, 1985b).

Rates of Mineral Weathering

In previous studies weathering rates were calculated for individual minerals in seven control (unmanipulated) watersheds of the Coweeta Basin, including WS 27 (Velbel 1984b, 1985b). Using volumetric estimates of mineral abundance (based on petrographic data), estimates of mineral grain size and geometry, and the average thickness of the weathering profile, the results of the WS 27 mass balance calculations (in moles of reaction/ha of watershed/yr) were transformed into moles/m² of mineral surface/sec, the units in which laboratory experimental rate data are often reported. The results for rates of garnet and plagioclase weathering are no more than approximately one order of magnitude slower than rates determined in laboratory experiments under similar hydrogeochemical conditions. Rates of biotite mica weathering are considerably different, due in part to the fact that a reasonably similar set of laboratory experimental data does not yet exist.

The similarity of field and laboratory rates of plagioclase and almandine weathering is quite good in geochemical terms; the two major sources of the remaining discrepancy are (a) the character of artificially treated mineral surfaces in laboratory experiments, which renders them more reactive than their natural counterparts (e.g., Holdren and Berner 1979) and/or (b) difficulties in estimating the reactive mineral surface area in natural systems. The second is probably a major problem (Velbel 1986b) although the method of estimating mineral surface area in this study gives results which compare favorably with laboratory data and other recent mass balance studies (Paçes 1983; Siegel 1984). Several orders of magnitude of error are associated with the surface area estimate, so the favorable correspondence between field and laboratory rates in this and other mass balance studies may be somewhat fortuitous. Nevertheless, the relatively good accord between field and laboratory kinetic results is encouraging, and suggests that (1) the two aforementioned sources of error may not be large, and (2) refinement of laboratory kinetic data and field mineral surface area determinations should rank high among future research priorities.

The same mass balance calculations which provide the basis for the above discussion also provide quantitative estimates of mineral nutrient uptake by the forest biota. However, the integration of these results with ongoing ecological studies is only beginning, and no conclusions can be safely drawn at present regarding the possible ecological significance of the model results. Assessment of this aspect of the weathering processes and their rates is currently underway.

Chemical Weathering Rates, Rates of Saproliite Formation, and the Geomorphic Evolution of the Southern Blue Ridge Landscape

Geochemical export via the dissolved load of streams is used in various ways to estimate rates of weathering profile development and chemical preparation of the landscape for erosion. In saprolitic landscapes, chemical weathering is isovolumetric, and
involves no change in the volume of landforms or landscapes (Cleaves and Costa 1979; Costa and Cleaves 1984); it is therefore inappropriate to speak of “chemical denudation” of saprolitic landscapes. The rate of saprolite formation does, however, determine the rate at which rock is made susceptible to physical erosion, and is therefore a significant factor in the geomorphic development of saprolitic landscapes.

Berry (1977) calculated geochemical weathering rates using total dissolved solids (TDS) in streams as the measure of chemical mass export from the watersheds of Coweeta, and determined that a rate of landscape lowering of between 0.4 and 1.0 cm/1000 yrs would be in balance with the observed rate of chemical export of TDS. Two difficulties exist with the use of TDS as the measure of chemical weathering; first, the possible transfer of elements out of the minerals into compartments other than stream export (e.g., uptake and accumulation by biomass; Likens et al. 1977) is not allowed for, and, second, TDS includes mass from sources other than weathering in the landscape (e.g., atmospheric input). The geochemical mass balance approach allows for the incorporation of both nonweathering inputs and nonstream outputs from the mineral compartment; it is (partly) for this reason that mass balance models are considered the most reliable method for the determination of natural weathering rates (Clayton 1979).

The geochemical mass balance results of Velbel (1984b, 1985b) permit estimation of the volume of rock transformed into saprolite per unit area of watershed per unit time. The rate of saprolite formation from fresh bedrock in WS 27 is around 3.8 cm/1000 yrs. This value is very close to the long-term average denudation rate of 4 cm/1000 yrs estimated by Hack (1980) for the southern Appalachians based on a variety of independent means. These rates suggest that, in geologic time, the landscape of the southern Blue Ridge is in dynamic equilibrium, in which all components of the landscape and the rates of all geomorphic processes are essentially in steady state. In the (geologically) short term, however, erosion at the top of the weathering profile is much more sporadic and discontinuous than chemical weathering at the base of the weathering profile. In order for dynamic equilibrium to exist in the short term, sediment export rates from watersheds should equal 600 kg/ha/yr (assuming a soil bulk density of 1.5 g/cm³). Normal erosion rates at Coweeta (as measured at weirs) range from about 30 kg/ha/yr for undisturbed forested watersheds to around 255 kg/ha/yr for a watershed clearcut and replanted with grasses (Monk 1975). This “normal” erosion load is therefore only about 5 to 45% of that required to maintain dynamic equilibrium (steady state with respect to chemical weathering). If long-term dynamic equilibrium is to be maintained, some 50 to 95% of the short-term physical erosion must occur as high-magnitude, low-frequency events (e.g., severe storms, landslides, debris avalanches), giving rise to brief episodes of abnormally high physical erosion not represented by “normal” sediment export loads. These findings are in excellent accord with the findings of Grant (1983, and Chapter 7) regarding the importance of debris avalanches in the geomorphic evolution of the Coweeta landscape.

**Summary**

1. Most weathering profiles of the Coweeta Hydrologic Laboratory comprise thin (to ~30 cm) A and B horizons atop substantial thicknesses (ave. ~6 m) of saprolite.
2. Extensive isovolumetric weathering of rock to saprolite results in the landscape being covered by a porous, permeable blanket of weathered material which supplies streamflow as water drains slowly from it, and which is vulnerable to erosion by fluvial processes and landslides.

3. Rock weathering to saprolite occurs primarily via weathering of three major rock-forming minerals: biotite mica, almandine garnet, and plagioclase feldspar. Furthermore, each of these mineral weathering reactions contributes to mineral nutrient budgets of the terrestrial ecosystems and watersheds of Coweeta. Biotite mica weathering releases significant quantities of potassium; magnesium comes from both biotite mica and almandine garnet; and calcium is derived from both plagioclase feldspar and almandine.

4. Geochemical mass-balance calculations permit quantification of mineral weathering rates and rates of geomorphically significant saprolitization. Mineral weathering rates determined for Coweeta WS 27 compare favorably with mineral weathering rates determined in laboratory experiments under similar hydrogeochemical conditions. One major source of uncertainty in this comparison of field with laboratory rates is the difficulty in estimating reactive surface area of the minerals in natural systems. Provided that future research resolves this difficulty, it should become practical to use carefully constrained laboratory experiments to estimate rates of elemental transfer in natural weathering systems.

5. Transformation of bedrock to saprolite (saprolitization) presently prepares the landscape for erosion at a rate equal to the long-term average denudation rate for the southern Appalachians (4 cm/1000 yrs), suggesting that dynamic equilibrium of the landscape prevails in the long term. In the (geologically) short term, erosion at the top of the profile is much more sporadic. Present rates of erosion by normal fluvial processes suggest that high-magnitude, low-frequency geomorphic events accomplish most of the short-term erosion required to maintain long-term geomorphic equilibrium of the southern Blue Ridge landscape.