

## **FLUVIAL GEOCHEMISTRY OF SELECTED TRIBUTARY WATERSHEDS IN THE ENOREE RIVER BASIN, NORTHWESTERN SOUTH CAROLINA**

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### **ABSTRACT**

A major question facing the study of fluvial geochemistry is the nature of the relationship between weathering processes and the chemical composition of stream water. Although numerous studies have focused on either very small watersheds or very large river basins, few studies have examined the chemical composition of intermediate (10-1000 km<sup>2</sup>) watersheds, particularly in the humid subtropical climate of the southeastern Piedmont region in the southeastern United States.

To better understand the fluvial geochemistry of piedmont streams in a subtropical climate, the chemical composition was determined for 115 sample localities on nine tributary watersheds of the Enoree River basin, South Carolina, that drain igneous and high-grade metamorphic rocks. The samples were collected during the summer drought conditions of 1999 and 2000. Silicate-weathering diagrams show that kaolinite and gibbsite are the main weathering products, but that smectite may be present in the regolith. Mineral stability diagrams indicate that the chemical compositions of streams in seven of the nine watersheds are in equilibrium with kaolinite, whereas streams in two of the watersheds are in equilibrium with smectite. Two of the most likely factors that control the difference in stream chemistry are rock type and contact time. Contact time appears to be more important, although confirmation would require a better understanding of the distribution of mafic rock types in the Enoree River basin. Comparison of the results from the Enoree River to the chemical composition of rivers in the Orinoco River basin that drain similar rocks suggests that chemical composition of river water is sensitive to variation in climate.

### **INTRODUCTION**

Studies of fluvial geochemistry in the past have focused on large river systems such as the Amazon (Stallard and Edmund, 1987), Siberian rivers (Huh and others, 1998 a,b, Huh and Edmond, 1999), the Fraser (Cameron and others, 1995), the Seine (Roy and others, 1999), and the Huanghe (Zang, 1990). Many of these rivers, such as the Amazon, are notable for the pristine condition of the watersheds. Significant among these rivers is the Orinoco River basin draining the Guayana Shield in South America. The Orinoco is similar to the Enoree River basin in that it drains only igneous and high-grade metamorphic rocks. Other large river systems, such as the Seine, have chemical compositions that are significantly modified by human activity and drain primarily carbonate rocks. Other studies have focused on the relationship between mineral weathering and stream chemistry in small watersheds under very controlled conditions. The two best examples are the studies of Coweeta (e.g., Velbel, 1985), and Hubbard Brook (e.g., Likens and others, 1977).

Relatively few of the larger river systems that drain into the Atlantic Ocean have been the subject of detailed geochemical study. Our goal is to understand the processes that control the fluvial geochemistry of rivers draining the

Piedmont of South Carolina. The watersheds of the coastal region of South Carolina have received some attention (Gardner, 1981), but rivers in the upstate have been ignored. In this paper, we report the results of a study of nine tributary watersheds of the Enoree River: Upper Enoree River, Beaverdam Creek, Mountain Creek, Brushy Creek, Rocky Creek, Gilder Creek, Durbin Creek, Indian Creek, and Kings Creek. The Enoree River basin is entirely within the crystalline terrane of the Piedmont Province, which is characterized by high-grade metamorphic rocks, granites, gabbros, and occasional diabase dikes. The nine watersheds were sampled at a variety of locations to include streams of different order, drainage area, land cover and rock type.

This paper focuses on characterizing the chemical composition of stream water in those watersheds. The results are compared to those of the Orinoco River basin that drains the Guayana Shield (Edmond and others, 1995). Like the bedrock in the Enoree River basin, the Guayana Shield is characterized by a complete absence of sedimentary rocks other than a quartzitic platform cover. The primary difference between the two basins is climate, which is humid tropical in South America, and soils, which are lateritic oxisols. The results indicate that the chemical

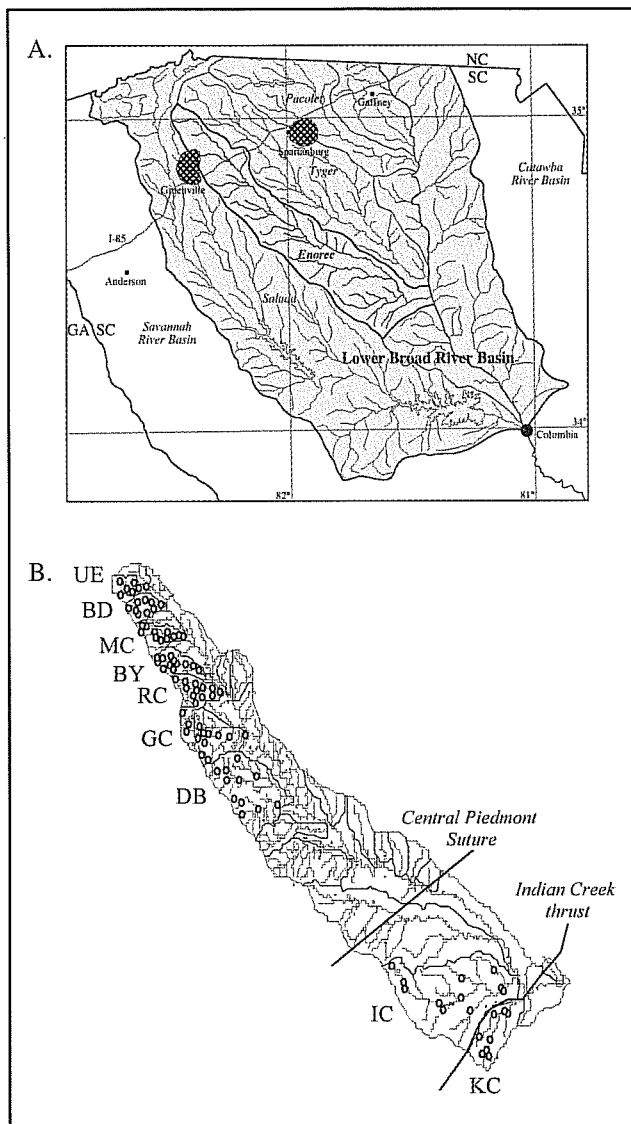


Figure 1. Maps of the Enoree River basin. A) The Enoree River basin in the context of the Lower Broad River basin. B) Sample localities within the Enoree River basin. The approximate positions of both the Indian Creek thrust (Lawrence and Corbett, 1999) and the Central Piedmont suture (Dennis, 1995) are shown on the map. The Inner Piedmont is to the northwest of the boundary and the Charlotte belt is to the southeast of the boundary. The location of the boundary is controversial.

composition of the Enoree tributaries reflect weathering under subtropical conditions. In general, it appears that the chemical compositions of the streams are in equilibrium with the weathering products.

## REGIONAL SETTING

The Enoree River basin is a sixth-order basin (Strahler, 1952) that covers 1893 km<sup>2</sup>. Hierarchically, the Enoree River basin is part of the Lower Broad River basin that includes the Enoree, Pacolet, Tyger and Saluda basins as well as several smaller, unnamed basins on the east side of

the Broad River (Figure 1). The Lower Broad River basin, in turn, is part of the Santee River basin, one of the watersheds in the National Water Quality Assessment (NAQWA) program of the United States Geological Survey. The Enoree River basin is elongate and asymmetrical, with the larger tributary watersheds on the southwest side of the basin.

The Enoree River basin drains both the Inner Piedmont and the Charlotte belt. The geology of most of the basin is summarized on the Greenville 1°x2° quadrangle (Nelson and others, 1998) and the Spartanburg 30' x 60' quadrangle (Boland, 1997). Although the Indian Creek and Kings Creek watersheds are not located in the above maps, Lawrence and Corbett (1999) have mapped part of the area. On their maps, all the watersheds except Kings Creek drain rocks of the Inner Piedmont. Only Kings Creek drains rocks of the Charlotte belt.

The Inner Piedmont in the Enoree River Basin consists of Paleozoic metamorphic and igneous rocks (Nelson and others, 1998). Metamorphic rock types include granite gneiss, biotite granite gneiss, sillimanite-mica schist, biotite sillimanite schist, muscovite garnet schist, gondite, and amphibolite. Igneous rock types include Paleozoic granite intrusions and rare Jurassic diabase dikes. The geologic maps and field observations suggest that the rocks in the Durbin Creek watershed are more biotite-rich than rocks in the watersheds to the northwest.

The controversial position of the Central Piedmont suture, which separates the Inner Piedmont from the Charlotte belt, is located somewhere in the southeastern portion of the Enoree River basin. On the maps of the Spartanburg 30'x60' quadrangle by Boland (1997) and Dennis (1995), the Central Piedmont suture is located northwest of the Indian Creek watershed. Lawrence and Corbett (1999), however, suggested that the Indian Creek thrust that separates the Indian Creek watershed from the Kings Creek watershed is the boundary between the Inner Piedmont and the Charlotte belt. Most of the Indian Creek watershed is located in the Newberry NW and Joanna quadrangles. The Newberry NW quadrangle has not been mapped, so the geology of the northern Indian Creek watershed is unknown. The Joanna quadrangle (Niewendorp, 1995) shows biotite gneiss and amphibolite as the primary rock types, with scattered small gabbros and metagabbros.

The Kings Creek tributary watershed is entirely within the Charlotte belt. The rocks include both metamorphosed and younger, unmetamorphosed igneous rocks. Rocks in the Kings Creek tributary watershed include the Newberry granite, biotite gneisses, amphibolites, and scattered blocks of garnet metagabbro and metadiorite (Lawrence and Corbett, 1999).

The denudation regime of the Enoree River basin is best described as transport limited (e.g., Stallard and Edmond, 1987). With the exception of Paris Mountain in the northern part of the basin, slopes normally are gentle

and bedrock is not generally exposed at the surface except at shoals in the streams. The soils in the Enoree River basin uplands are primarily ultisols. Small flood plains are typically covered with entisols and inceptisols. The ultisols are typically kaolinitic, whereas the entisols and inceptisols are poorly developed flood plain deposits. In the southern third of the basin, upland alfisols are more common in forested areas, although ultisols still are the dominant soil type. Kaolinite and gibbsite are the typical clay minerals in the soils, although smectites may be present in the alfisols. Full descriptions of the soils in the Enoree River basin, along with associated climate information, can be found in county soil surveys produced by the U.S.D.A. Soil Conservation Service (Camp and others, 1960; Camp, 1960; Camp and others, 1975; Camp, 1975).

Typically, the soils have poorly developed A and B horizons that lie on top of thick saprolites. The saprolites may be relict in the sense that they formed separately from the soil, and the soil horizon may have developed on the saprolite rather than on bedrock (Gardner, 1992). This hypothesis, however, is controversial, and the relationships among weathering, saprolite development and river chemistry remain poorly understood.

Climate in the Enoree River basin is subtropical (Camp and others, 1960; Camp, 1960; Camp and others, 1975; Camp, 1975), averaging daily high temperatures of 22° C and daily lows of 11° C. Rainfall averages 120 cm per year with a rainy winter and dry late summer and fall. During the period of this study, the area has been in drought conditions with record low streamflow (Figure 2).

## METHODS

Grab samples were collected at 115 localities in the watersheds during the summers of 1999 and 2000 (Appendix, Figure 1). No attempt was made to sample specific hydrologic events; most samples were collected during base-flow periods associated with drought conditions (Figure 2). Samples were collected once per week for seven weeks at each locality in order to assess variability in composition over time. Samples were collected in precleaned HDPE bottles that were precontaminated with river water by rinsing three times prior to collection. Dissolved oxygen, conductivity, pH, and temperature were measured in the field at the time of sampling.

In the laboratory, samples were filtered through a 0.45- $\mu$ m membrane filter, using nitrogen-gas positive-pressure apparatus. One filtered aliquot was preserved with 2 ml of concentrated HNO<sub>3</sub> for cation analysis, and one filtered aliquot was left unpreserved for anion analysis. The filtered aliquots were stored in a refrigerator at ~4°C until chemical analysis. Cation concentrations (Na, K, Ca, Mg, Si, Al, Mn, Fe) were measured with a Varian ICP-AES. In general, the concentrations of aluminum were often below the detection limit of 0.125 mg/L. Iron and manganese concentrations were generally above the respective detection limits of 0.050 and 0.012 mg/L and are not discussed in the paper. Anion

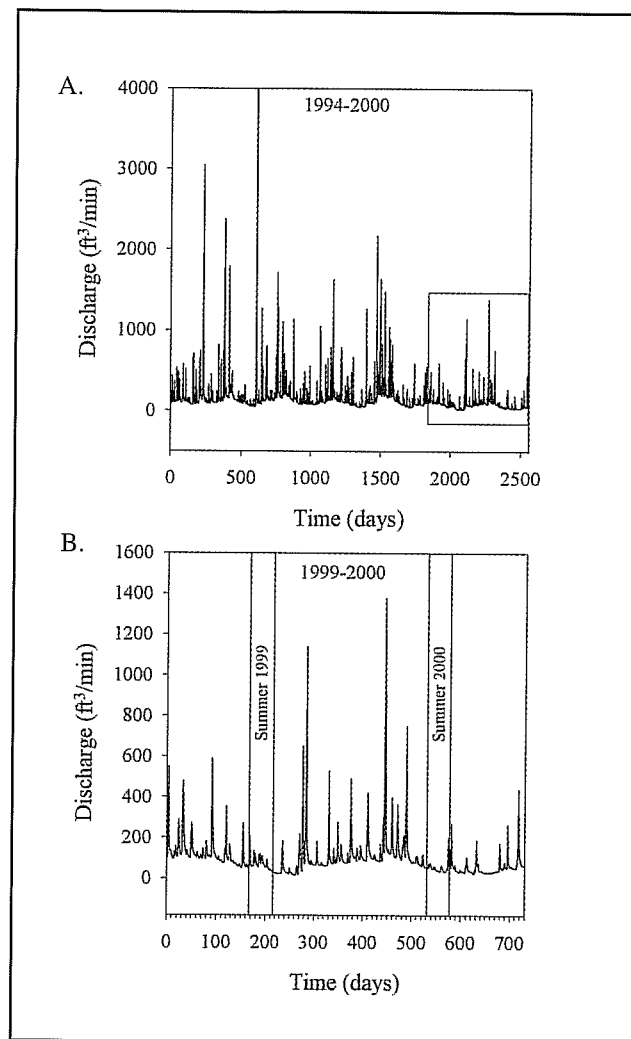


Figure 2. Hydrographs for the U.S.G.S. gaging station on the Enoree River at Pelham, South Carolina. A) Hydrograph for the period 1/1/1994 to 12/31/2000. The Enoree River basin has been in drought conditions during the past two summers, as indicated by lower base flow with fewer and smaller storm events. The boxed area corresponds to the hydrograph in B. B) Hydrograph for the period 1/1/1999 to 12/31/2000. Weekly sampling events during the summers of 1999 and 2000 occurred during low-flow conditions with few storm events. Storm flows lasted only a few hours, so most sampling events occurred during base flow.

concentrations (fluoride, chloride, bromide, nitrate, nitrite, phosphate, and sulfate) concentrations were determined by a Dionex 120 ion chromatograph. Alkalinity was measured by the low-alkalinity titration method (Eaton and others, 1995) in the summer of 1999 and the Gran titration method (Gran, 1952) during the summer of 2000. The two methods of alkalinity titration give essentially the same results, although the Gran titration is slightly more accurate at very low alkalinities. All alkalinity was assumed to be in the form of bicarbonate given the pH of the samples and their very low phosphate concentrations (<0.50 mg/L).

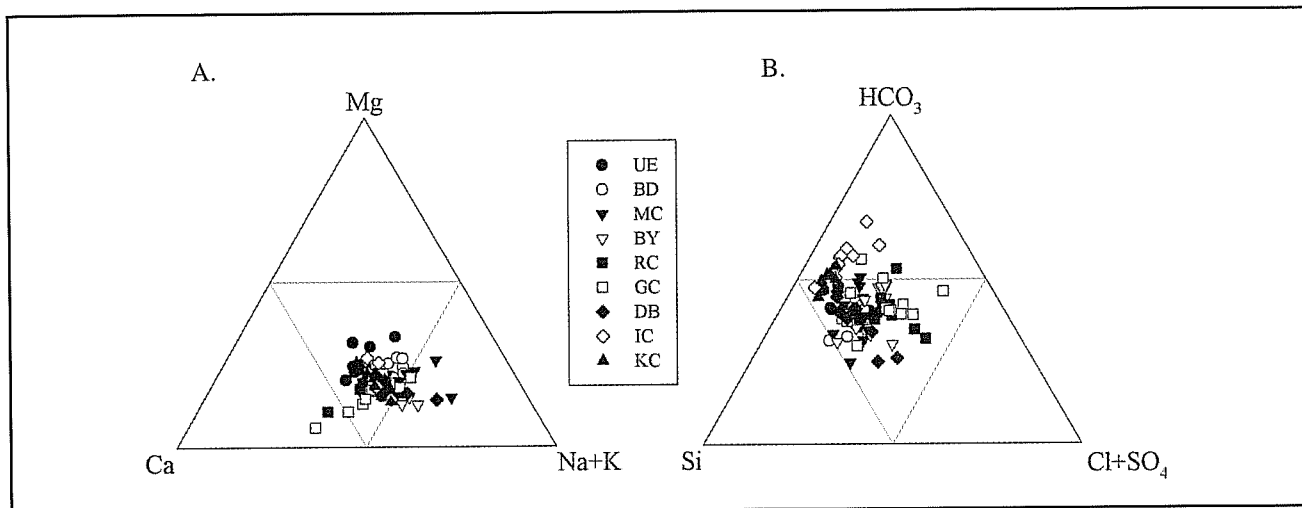


Figure 3. Ternary diagrams based on microequivalent ratios. A) Cation ternary diagram. Samples are typically mixed cation, although samples from Indian Creek, Kings Creek, and Upper Enoree River, on average, have proportionally more calcium and magnesium than the other watersheds. The low proportion of calcium and magnesium reflects the lack of carbonates in the Enoree River basin. Calcium and magnesium sources include amphiboles and biotite from amphibolites and pyroxenes and calcium plagioclase from gabbroic intrusions and diabase dikes. River waters from the humid tropical Orinoco River basin that drain the Guayana Shield would plot from near the Na+K apex to approximately 50% Na+K. B) Anion ternary diagram. Alkalinity, in the form of bicarbonate, is entirely from the weathering of silicate minerals, as indicated by the high proportion of silicon compared to rivers draining carbonate bedrock. The primary source of chloride and sulfate is rainwater, although some sulfate may be derived from the oxidation of sulfide minerals and other anthropogenic sources.

The quality of the analyses was assessed by the charge-balance method of Freeze and Cherry (1979). The majority of the samples have charge-balance errors of less than  $\pm 10\%$ . Samples with errors greater than 10% typically are the result of poor alkalinity data. Nitrate can be a significant proportion of the negative charge in these streams, and therefore it was included in the charge balance. The charge balances are reasonable, given the dilute nature of the streams analyzed.

The cation concentrations should be corrected for atmospheric input (e.g., Stallard and Edmond, 1983). Three optional methods exist for the correction of atmospheric input. In the method of Garrels and McKenzie (1967), stream water is corrected for atmospheric input by subtracting the composition of the rainwater from the stream water. Stallard and Edmond (1983) corrected for cyclic salt input by assuming all chloride was from rainwater and subtracted it from sodium ( $Na^* = Na - Cl$ ). Moulton and others (2000) employed a more elegant method that uses the cation to chloride ratio of precipitation as a function to calculate the stream water concentration. We corrected for precipitation by using the method of Stallard and Edmond (1983) because the Moulton and others (2000) method would require a detailed record of recent local precipitation chemistry. The 1979 through 1986 records of the U.S.G.S. National Atmospheric Deposition Program for the Clemson Hydrologic Station show an average Na to Cl ratio of 1.03, very close to the assumed ratio of 1.0 for the Stallard and Edmond method. The Clemson data, however, are not recent

and show a poor charge balance. The poor charge balance may be because of the very low concentrations of cations other than sodium. This would make the application of the Moulton and others (2000) method suspect when applied to our data, and, as a result, we have chosen to correct for cyclic salts, by using the method of Stallard and Edmond (1983). The method was developed for the pristine conditions found in the Amazon study area, but the tributary watersheds in this study may have sources of chloride other than precipitation, such as septic tank discharge and fertilizer runoff. Known sources of chloride other than rainfall exist at eight sites in the Upper Enoree River and Durbin Creek tributary watersheds. These samples are excluded from discussion in this paper.

## RESULTS

All the data are discussed as averages of the seven sampling events per locality. Nearly all of the samples were collected during base flow, and no discharge data are available for the tributary streams. Hence, the average compositions are not discharge weighted. The results are summarized in Appendix. Aluminum concentrations are averaged by using the detection limit as the concentration for samples below the detection limit. In such cases, the average represents a maximum, and thus the concentration is preceded by a "<."

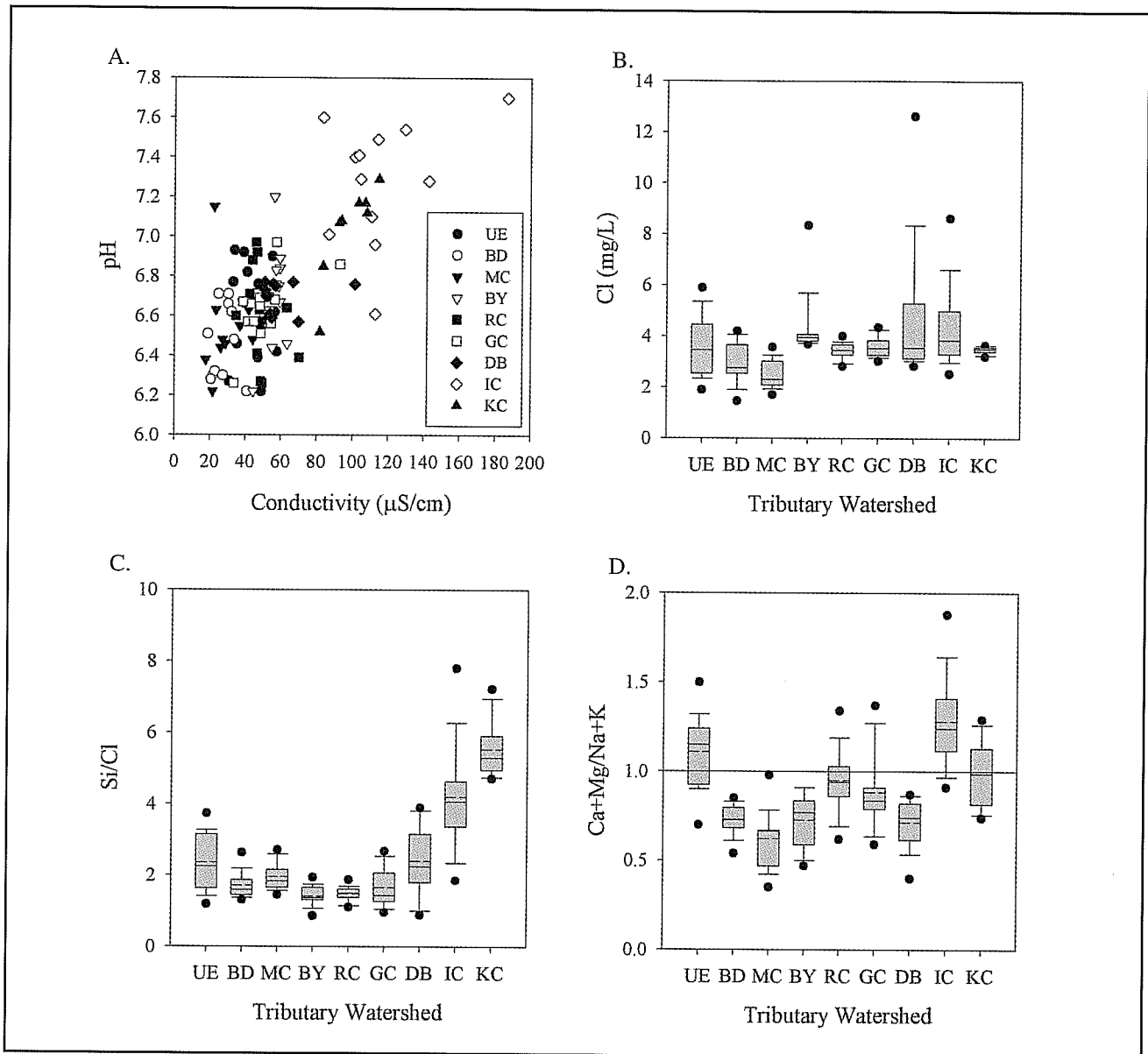


Figure 4. Descriptive geochemistry. A) pH increases with conductivity and samples from the Indian Creek and Kings Creek watersheds have the highest of both. B) Similarity in chloride concentrations between the two watersheds suggests rainwater as the primary source. Outliers in Brushy Creek (BY) and Durbin Creek (DB) reflect urban contributions. C) The silicon to chloride ratio is highest for samples from Indian Creek and Kings Creek watersheds, and this ratio reflects the higher concentrations of silicon in those watersheds. D) The ratio of Ca+Mg to Na+K roughly corresponds to a mafic to felsic ratio. The ratios are highest in the upper Enoree River, Indian Creek and Kings Creek watersheds, and they reflect the presence of mafic rocks.

### Chemical composition

The chemical compositions of the stream water from the nine watersheds are mixed cation-bicarbonate (Figure 3). On the cation ternary plot, the samples plot in the center of the diagram (Figure 3A). The lack of sedimentary rocks means that all the cations are derived from the weathering of silicate minerals or are from cyclic salts. The primary source of sodium and potassium would be feldspars,

although biotite would be an additional source of potassium. The primary sources of calcium and magnesium would be biotite and amphibole for the felsic gneisses and granites. In the gabbros and amphibolites, amphiboles, pyroxenes, and Ca-feldspar would be the major sources of calcium and magnesium. The lack of any real trend in the diagram suggests that all the streams contain a mixture of rocks.

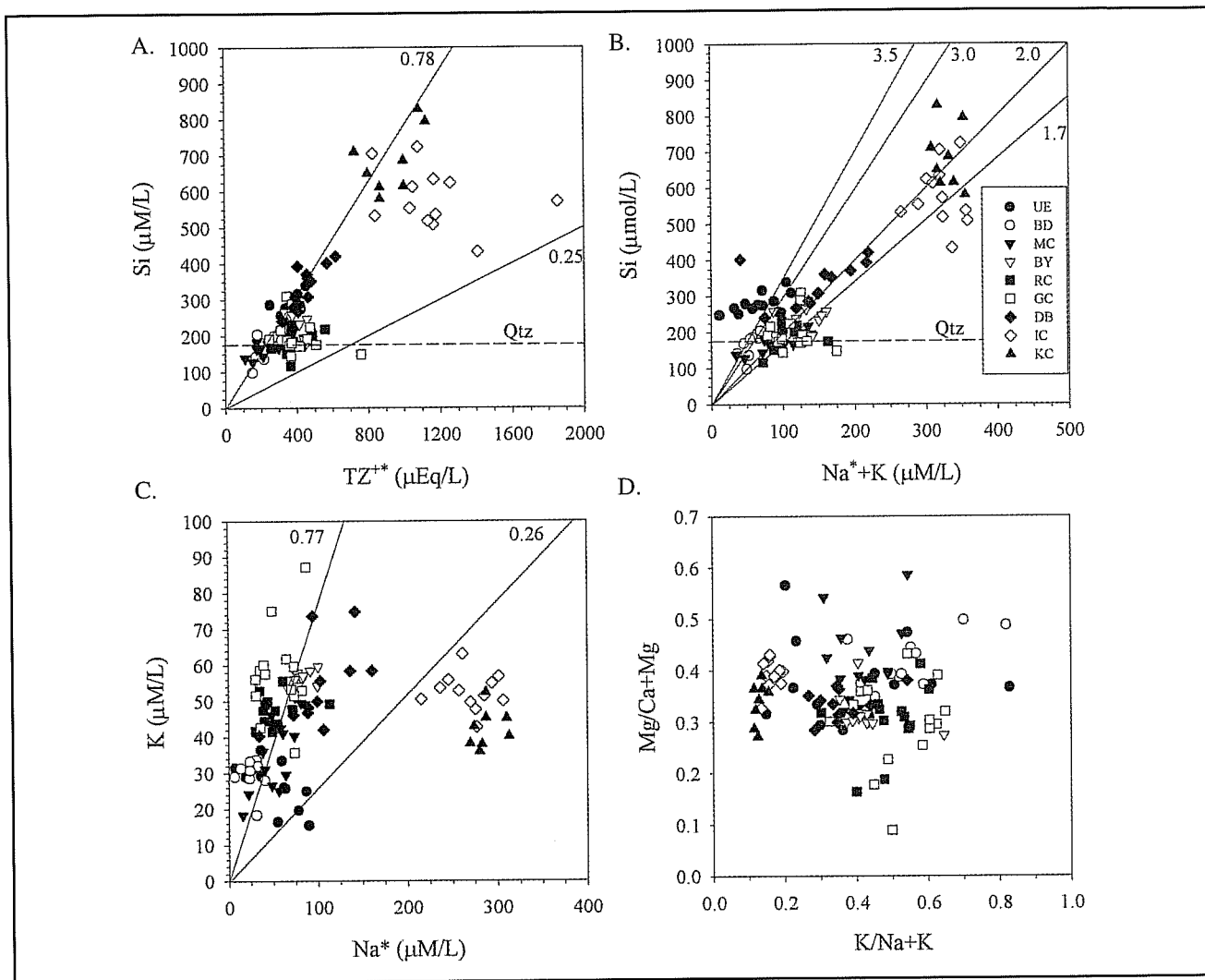


Figure 5. Silicate-weathering diagrams. Symbols are the same for all graphs and are shown in B. A) The ratio of dissolved silica to  $TZ^{**}$ , where  $TZ^{**} = (Na+K+2Mg+2Ca) - (Cl-2SO)$ . Weathering of the average shield rock to kaolinite yields a ratio of 0.78 and weathering of the average shale yields a ratio of 0.25 (Huh and Edmond, 1999). Dashed line in both A and B is quartz saturation (Rimstidt, 1997). B) The ratio of dissolved silica to  $Na^{*}+K$  ( $Na^{*} = Na - Cl$ ). Weathering of the average shield rock to kaolinite yields a ratio of 3.5 (Huh and Edmond, 1999). The ratios associated with the weathering of typical silicate minerals are the following: Na-feldspar to beidellite, 1.7; Na feldspar and K feldspar to kaolinite, 2; K-feldspar to illite and Na-feldspar to gibbsite, 3; beidellite to kaolinite, 4 (Huh and others, 1998a). C) The ratio of K to Na. Weathering of granite yields a ratio of 0.77 and weathering of a tholeiite yields a ratio of 0.26 (Huh and others, 1998b). D) The ratio of  $Mg/(Mg+Ca)$  to  $K/(K+Na)$ . Complete weathering of amphibolites and granites should show a typical igneous differentiation trend (see text for details). Samples from the Enoree River basin do not vary systematically.

Samples with higher proportions of calcium and magnesium probably drain areas with greater proportions of amphibolites. The anion ternary plot shows that Indian Creek and Kings Creek samples plot along the silicon-bicarbonate axis, whereas the other streams have larger proportions of chloride and sulfate (Figure 3B). The source of bicarbonate is from the weathering of silicate minerals because the region lacks carbonate rocks. Theoretically, because the Enoree River basin lacks evaporites, all the samples should lie on the silicon-bicarbonate axis. The shift towards the chloride and sulfate apex is therefore problematic. One source of chloride and sulfate is cyclic salts in rainfall. Additional

sources of sulfate are acid rain and the oxidation of pyrite. Rainfall in Greenville has an average pH of 4.5, and sulfate is a major component (Shaver and others, 2001). Pyrite is an accessory mineral in the rocks of the region and would be an additional source of sulfur. An additional possible source of sulfate for a total of four localities in Rocky Creek and Gilder Creek is industrial discharge. The difference of Indian Creek and Kings Creek from other tributaries is a function of the difference in the concentration of silicon and bicarbonate, because chloride and sulfate concentrations stay about the same in all the tributaries (e.g., Figure 4B).

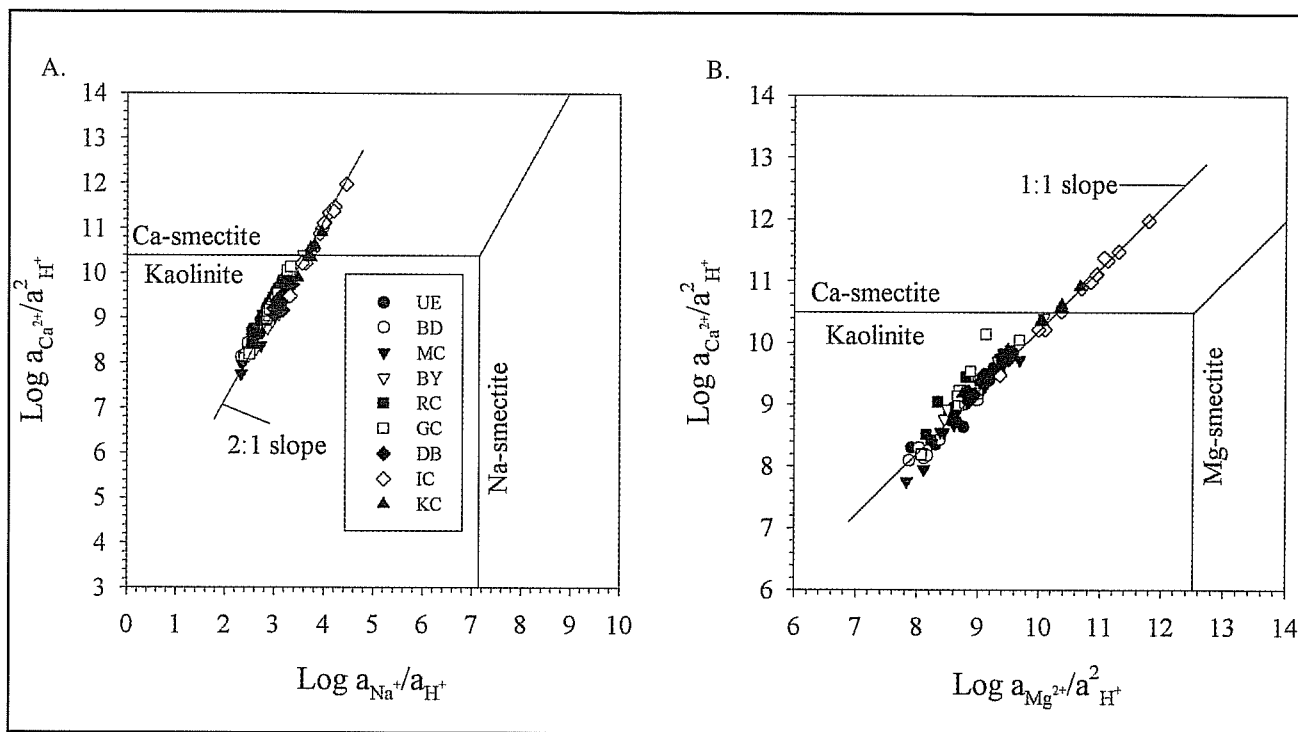


Figure 6. Mineral stability plots for data from the Enoree River tributaries. Stream samples from Indian Creek and Kings Creek watersheds plot in the smectite field, whereas all other samples plot in the kaolinite field. The assumed activity of dissolved silicon is  $10^{-3.7}$  for both diagrams. A) Data plotted on the stability diagram for the system  $\text{CaO-Na}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$  at 1 atmosphere and  $25^\circ\text{C}$ . B) Data plotted on the stability diagram for the system  $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$  at 1 atmosphere and  $25^\circ\text{C}$ .

Conductivity and pH are typical for streams draining siliciclastic rocks (Figure 4A). The stream waters are dilute, with all conductivities less than 200  $\mu\text{S}/\text{cm}$  and the majority less than 80  $\mu\text{S}/\text{cm}$ . The pH of stream water is circumneutral, ranging from 6.3 to 7.7. The majority of the samples have a pH around 6.6. In general, the conductivity and pH of samples from the Kings Creek and Indian Creek watersheds are higher than from the other watersheds.

In contrast, chloride concentrations do not vary in a similar pattern and show little variation among the watersheds (Figure 4B). Assuming that most of the chloride is from rainfall, then the ratio of Si to Cl would not change if weathering reactions were held constant and the concentrations only were increased by evapotranspiration. Evapotranspiration concentrates biologically nonessential solutes in the ground-water by removing water from the system. Therefore, both silicon and chloride concentrations would increase and similar Si to Cl ratios would be observed in all watersheds if only evapotranspiration were causing the increase in concentration. The ratios of Si to Cl in Indian Creek and Kings Creek, however, are higher than in the rest of the watersheds. This suggests that the variation in Si concentration is the result of changes in mineral solubility associated with changes in bedrock composition and/or weathering intensity (Figure 4C).

The ratio of the concentrations of Ca+Mg to Na+K is a rough indicator of lithologic variability. The caveat to this

is that rainfall may be an important source of sodium to the system. Uncorrected data show that the ratio is highest in the Upper Enoree, Indian Creek, and Kings Creek watersheds (Figure 4D). Amphibolites have been observed in the Upper Enoree tributary watershed, and amphibolites are found in the Weeping Mary gneiss in the Kings Creek watershed (Lawrence and Corbett, 1999). The Shelton amphibolite is the largest mafic unit located in the Kings Creek watershed (Lawrence and Corbett, 1999). Additionally, there are small blocks of garnet metagabbro and metadiorite in the Kings Creek watershed (Lawrence, personal communication). Weathering of calcium and magnesium rich minerals in the amphibolites, metagabbros, and metadiorites may account for the slightly higher Ca+Mg to Na+K ratios in the Kings Creek watershed. In Iceland, streams draining basalts have similar pH, but they have a Ca+Mg to Na+K ratio of less than 0.5 (Moulton and others, 2000). Small streams draining only amphibolites in the Buck Creek watershed in North Carolina also have similar pH, but they have much lower conductivities and a much higher ratio of Ca+Mg to Na+K (Ramaley and Andersen, 1998). In the Orinoco River basin, the Carapo River, which drains amphibolites, has a Ca+Mg to Na+K ratio of 0.7 (Edmond and others, 1995). As a result, the Ca+Mg to Na+K ratio can be quite variable for streams draining similar rock types.

## Silicate weathering

Various plots can be used to assess the silicate weathering processes that occur in the bedrock to produce secondary minerals. Two common methods used are comparison of river water chemical composition with stoichiometric ratios of weathering reactions (silicate weathering diagrams of Huh et al, 1998a, 1998b; Huh and Edmond, 1999) and with thermodynamic mineral stability diagrams (e.g., Norton, 1974; Miller and Drever, 1977). Other methods include modeling of the total amount of minerals dissolved by simultaneous equations (e.g., Finley and Drever, 1997). These models, however, require far more detailed information of the distribution and elemental composition of minerals, stream discharges and biotic uptake than are available for this study, and typically they are used in studies of small, well-characterized watersheds. In contrast, the silicate weathering diagrams are more useful for larger watersheds.

The silicate weathering diagrams are useful indicators of weathering processes in a watershed (e.g., Huh et al, 1998b). The weathering of aluminosilicate minerals releases soluble cations and dissolved silica. The ratio of dissolved silica to soluble cations changes as weathering intensity increases. Thus, the  $\text{Si}/\text{TZ}^{+*}$  and  $\text{Si}/(\text{Na}^{*}+\text{K})$  ratios are useful to understand the extent of weathering. In these ratios,  $\text{TZ}^{+*}=(\text{Na}+\text{K}+2\text{Ca}+2\text{Mg})-(\text{Cl}+2\text{SO}_4)$  and is the total cation charge in  $\mu\text{Eq/L}$ , and  $\text{Na}^{*}=\text{Na}-\text{Cl}$  in  $\mu\text{M/L}$ . Subtracting chloride and sulfate corrects for cyclic salt and evaporite contribution. Certainly, one issue associated with silicate regions in the northern hemisphere is the contribution of sulfate by acid rain. The sulfate concentration is generally low, however, and with few exceptions has relatively little impact on the trends observed in the data.

As some examples, the weathering of Na-feldspar to beidellite gives a  $\text{Si}/(\text{Na}^{*}+\text{K})$  ratio of 1.7, whereas the same mineral weathering to kaolinite gives a ratio of 2, and to gibbsite gives a ratio of 3. The average shield rock weathering to kaolinite gives a  $\text{Si}/\text{TZ}^{+*}$  ratio of 0.78. For the tributaries of the Enoree River, many of the samples plot near the stoichiometric ratios for the weathering of feldspar or shield rocks to either gibbsite or kaolinite (between 1.7 and 3.5 or higher), indicating nearly complete leaching of the soluble cations (Fig. 5 A, B). The  $\text{TZ}^{+*}$  for Indian Creek and Kings Creek samples is very high. Although these watersheds drain igneous and metamorphic rocks, the  $\text{TZ}^{+*}$  is five times greater than for rivers draining shield rocks in the Orinoco River basin and is similar to Amazon tributaries draining sedimentary rocks of marine origin (Stallard and Edmond, 1983; Edmond and others, 1995). The ratio of K to  $\text{Na}^{*}$  indicates that the tributaries, particularly Indian Creek and Kings Creek, are sodic, which is to be expected because Na-feldspar is common in metamorphic rocks and it is more soluble than K-feldspar (Figure 5C). The abundance of biotite gneiss in the Enoree River basin is the likely cause of the relatively high

concentration of potassium. Biotite tends to be quite soluble and weathers rapidly to kaolinite, and can be the most significant source releasing both potassium and magnesium into solution (Kretzschmar and others, 1997; Murphy and others, 1998). The nearly complete leaching is consistent with the mineralogy of the soils in the region. Some samples from Gilder Creek, Brushy Creek, Rocky Creek, Mountain Creek, and Indian Creek watersheds have ratios near to or greater than 1.7, suggesting the presence of smectites such as Na-bidellite (Figure 5B). Huh and Edmond (1999) call this “superficial” weathering, where some cations and silicon remain behind in secondary clay and are not released into solution.

The plot of the molar ratio of  $\text{Mg}/(\text{Mg}+\text{Ca})$  versus  $\text{K}/(\text{K}+\text{Na}^{*})$  theoretically should display a conventional igneous differentiation trend (e.g., Edmond and others, 1995). In the Orinoco basin draining the Guayana Shield, rivers draining granites and amphibolites show such a trend ranging from a high alkali ratio and low alkaline earth ratio (granite) to a low alkali and high alkaline earth ratio (amphibolites). The results from the Enoree River tributaries are equivocal in that they do not form a well-defined trend, but they do drain granites, granitic gneisses, and amphibolites. The ratio of  $\text{K}/(\text{K}+\text{Na}^{*})$  varies considerably, whereas there is much less variation in the ratio of  $\text{Mg}/(\text{Mg}+\text{Ca})$ .

Nearly all of the samples are saturated or oversaturated with respect to quartz, but undersaturated with respect to amorphous silica, which has a solubility of over 1900  $\mu\text{mol/L}$  (Figure 5A, B; Rimstidt, 1997; Gunnarsson and Arnorsson, 2000). Only a few samples from Mountain Creek, Beaverdam Creek, Gilder Creek, and Rocky Creek are undersaturated with respect to quartz. The dissolved-silicon concentration of 400 to 850  $\mu\text{M/L}$  in streams from the Indian Creek and Kings Creek tributary watersheds are extraordinarily high, on the same or higher order as those observed in the Luquillo Mountains of Puerto Rico (White and others, 1998). The average concentrations are two to three times higher than the average world stream (Davis, 1964), four to five times higher than in the Amazon headwaters (Stallard and Edmond, 1987), and higher than the major rivers in the world (Gaillardet and others, 1999).

Mineral stability diagrams based on thermodynamic data are useful for understanding the relationships of water composition and minerals produced by weathering. Diagrams for the systems  $\text{Na}_2\text{O}-\text{CaO}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$  and  $\text{MgO}-\text{CaO}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$  were constructed from the data of Norton (1974). Activities were calculated with the Debye-Huckel or extended Debye-Huckel equation at one atmosphere of pressure and 25° C. Parameters for the equations were taken from Drever (1988). Plots of sample compositions on the mineral stability diagrams indicate that samples from the Upper Enoree River, Beaverdam Creek, Mountain Creek, Brushy Creek, Rocky Creek, Gilder Creek, and Durbin Creek watersheds plot in the kaolinite field (Figure 6). Samples from the Indian Creek and Kings Creek



watersheds plot in the Ca-smectite field (Figure 6). For comparison, samples from the Orinoco River basin draining the Guayana Shield all plot in the kaolinite field (Edmond and others, 1995). The results from the mineral stability diagram are consistent with the distribution of soil mineral composition (Camp, 1960, 1975; Camp and others, 1960, 1975). If amphibolites and the gabbro/metagabbro bodies are controlling the chemical composition of the streams, then these results are also consistent with the results obtained by Bluth and Kump (1994) for rivers draining basalts in the Hawaiian Islands, Columbia River Plateau region, and southwestern Iceland. For Indian Creek, the problem is that gabbros are a minor component of the bedrock, and it is not clear that the distribution of amphibolites are any different from elsewhere in the Enoree River basin. The results from the mineral stability diagram for the Enoree River samples, however, appear to conflict with the silicate-weathering diagrams, in which Si to Na<sup>+</sup>+K ratios of less than 1.7 (Fig. 5 B) indicate that smectite is forming in a number of samples from watersheds other than Indian Creek and Kings Creek.

The assumption behind the mineral stability diagrams is that aluminum is immobile. The work of Gardner (1992) has called this assumption into question on the basis of bulk density and chemical analyses of the saprolite, which suggest that aluminum is lost from the saprolite. If aluminum ions were mobile throughout the system, however, and were discharged into the streams, the ratio of silicon to aluminum would be similar to the loss ratio of 4:1 (Gardner, 1992). For the tributaries of the Enoree River, the ratio of silicon to aluminum ranges from 25:1 to more than 200:1 (Appendix), similar to the results from other river systems examined by Gardner (1992). This suggests that if aluminum is mobile, it is precipitated as a solid phase somewhere along the groundwater flow path.

## DISCUSSION

The nature of the relationship between weathering processes and the dissolved chemical composition of river water is a major problem of fluvial geochemistry. The chemical composition of rivers is controlled by complex relationships among rock type, climate, relief, vegetation, and time (Drever, 1988). A comparison of the Enoree River basin with that of the Orinoco River basin draining the Guayana Shield is useful because the bedrock is similar in composition, whereas the climate is subtropical rather than humid tropical. This comparison allows a test of the hypothesis that the geochemical composition of river water is a function of weathering intensity.

The Guayana Shield, like the Piedmont of South Carolina, has been subjected to long-term weathering that has resulted in the formation of a thick regolith. The regolith of the Guayana Shield is completely weathered and characterized by lateritic oxisols consisting of iron oxides, gibbsite, and kaolinite (Edmonds and others, 1995). The regolith of the Guayana Shield is considered to be relict,

and all primary minerals have been dissolved. In contrast, the regolith of the South Carolina Piedmont is characterized by ultisols overlying a partially weathered saprolite that contains primary minerals. Detailed examinations of saprolite in the Piedmont of North Carolina show that kaolinite, halloysite, gibbsite, and amorphous aluminosilicates are formed directly during the weathering of granitic gneiss (Buol and Weed, 1991; Kretzschmar and others, 1997), suggesting intense weathering. Smectite, vermiculite, and smectite-vermiculite are formed during the weathering of gabbro and metagabbro (Buol and Weed, 1991). Thus, although the Guayana Shield and the Piedmont of South Carolina both are highly weathered, the climate difference between the two regions results in the presence of primary minerals and cation-rich clay as weathering products in the Piedmont saprolite, in addition to iron oxides, gibbsite, and kaolinite.

Rivers draining the Guayana Shield and streams of the Enoree River basin both have mixed cation-bicarbonate water (Edmond and others, 1995). The primary chemical differences between river water from the Guayana Shield and stream water from the Enoree River basin are as follows. River water from the Guayana Shield plots nearer the Na+K apex on the cation ternary diagram than stream water from the Enoree River basin, and the ratio of Si to Na<sup>+</sup>+K and TZ<sup>+</sup> in river water from the Guayana Shield both indicate complete leaching of cations, with the result that gibbsite and kaolinite are the weathering products. The differences in water chemistry suggest differences between weathering in humid tropical environments and subtropical environments. The presence of primary minerals in the saprolite of the Enoree River basin results in a greater concentration of calcium and magnesium in the water of its streams than in water from the tributaries of the Orinoco River that drain the Guayana Shield. Weathering is less intense in the subtropical Enoree River basin than in the tropical Orinoco River basin. Consequently, the Si to cation ratios (Si/TZ<sup>+</sup> and Si/Na<sup>+</sup>+K) in stream water from the Enoree River basin suggest that some cations have not been leached and that smectites occur as weathering products. Kaolin and gibbsite, however, remain the dominant secondary minerals in water from streams of the Enoree River basin. If smectites are associated with mafic rock types (e.g., Buol and Weed, 1991), then the indication of smectite as a weathering product in the Enoree River basin likely results from the ubiquitous presence of amphibolites.

The difference in the chemical composition of Indian Creek and Kings Creek from the tributaries to the northwest is more problematic. Both Indian Creek and Kings Creek have higher total dissolved solids, and samples of river water from both those creeks plot in the smectite field of the mineral stability diagrams, consistent with maps of the soil distribution. Samples from the other seven watersheds plot in the kaolinite field, even during low flow. Geologic maps of the region show insignificant mafic rocks. The Indian Creek watershed contains small, volumetrically insignificant

gabbros and metagabbros (Niewendorp, 1995). Amphibolites are more abundant in the Kings Creek watershed than in the other watersheds (Lawrence and Corbett, 1999). Mafic rocks are not abundant in the tributaries of the Enoree River basin. The overall paucity of mafic rocks in streams of the Enoree River basin suggests that contact time may be an important factor in controlling the chemical composition of those streams. Collecting of the base-flow samples during drought conditions would enhance the importance of contact time. Rice and Bricker (1995) showed that the chemical composition of river water varies seasonally and that during summer base-flow conditions, processes occurring below the regolith-bedrock interface control the chemical composition. Two studies have found that river water samples will plot in the smectite field of mineral stability diagrams when ground-water discharge dominates but will plot in the kaolinite field when spring runoff dominates (Miller and Drever, 1977; Bluth and Kump, 1994). Bluth and Kump suggested that, if stoichiometric weathering were the primary control of river chemistry, then cation-activity ratios should vary more than is observed. Their observations and those of Bluth and Kump (1994), Drever (1988), and Miller and Drever (1977) suggest that other processes, such as cation exchange and kinetics of dissolution, can also exert important controls over river chemistry.

All of the above discussion assumes that aluminum is immobile within the regolith. Gardner (1992) suggested that aluminum actually is mobile in the regolith. The ratio of silicon to aluminum in our rivers, like the results from Gardner (1992), far exceeds the 4:1 ratio predicted by the chemical composition of saprolite. Thus, the results from our study do not confirm the mobility of aluminum. Aluminum, however, is transported primarily in colloidal form in rivers, and it may be rapidly lost from the river system. A full test of the aluminum mobility hypothesis would require analysis of ground-water to determine if aluminum is mobile beyond the soil horizon, and if mobile, where the aluminum is precipitated.

## CONCLUSIONS

The tributaries of the Enoree River basin drain igneous and high-grade rocks weathered in a subtropical basin. The chemical composition of the stream waters suggests that kaolinite and gibbsite are the dominant secondary weathering products, but that smectites may be present throughout the basin. Mineral stability diagrams indicate that smectites are most likely to be abundant in the Indian Creek and Kings Creek watersheds, although, if the presence of mafic rocks determines the secondary weathering products, these watersheds are not much different from the other seven watersheds.

The comparison of the Enoree River basin to the rivers of the Orinoco River basin draining the Guayana Shield is useful because the main difference is climate. The suggested presence of smectites in the Enoree River basin may reflect

weathering in a subtropical environment versus a humid tropical environment. This conclusion is consistent with the presence of ultisols overlying a saprolite in the Enoree River basin rather than the deeply weathered lateritic oxisols of the tropics.

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## Appendix

Sample	pH	Conductivity	Na	K	Ca	Mg	Cl	SO4	HCO3	Si	Al
Location		( $\mu$ S/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)

**Upper Enoree River**

UE03	6.92	39.01	2.98	1.31	3.13	0.75	2.49	2.56	13.30	7.22	<0.176
UE04	6.69	77.39	3.61	1.38	5.47	1.77	16.46	1.69	12.03	7.81	<0.162
UE05	6.76	47.20	3.96	0.61	4.72	1.32	2.93	0.80	24.71	9.54	<0.125
UE07	6.39	46.94	3.02	0.64	3.62	1.85	2.72	0.82	17.40	8.90	<0.242
UE08	6.27	30.88	3.03	1.02	2.26	0.57	2.50	0.46	12.40	8.05	<0.126
UE09	6.68	47.21	3.11	1.23	3.73	1.31	4.56	1.66	16.50	7.08	<0.133
UE10	6.62	56.51	3.30	1.31	4.27	1.44	5.89	1.34	17.86	6.99	<0.125
UE11	6.42	57.47	3.68	1.68	5.29	1.45	3.69	4.79	17.23	5.90	<0.208
UE12	6.46	35.21	3.50	0.77	2.16	1.70	2.65	1.90	14.88	7.18	<0.143
UE13	6.93	33.88	2.69	1.01	2.60	0.79	1.90	0.86	14.90	5.26	<0.132
UE14	6.82	41.06	3.07	1.14	3.26	1.28	3.46	1.17	15.29	7.78	<0.185
UE15	6.71	45.33	3.37	1.14	3.79	1.37	4.53	1.32	16.25	7.87	<0.156
UE16	6.58	51.76	3.38	1.43	4.40	1.58	3.96	2.33	14.68	7.73	<0.227
UE17	6.90	55.20	3.43	1.32	4.28	1.41	5.35	1.36	18.56	7.53	<0.133
UE18	6.22	48.80	3.34	1.22	3.32	1.81	4.21	3.04	15.27	7.50	<0.239
UE19	6.77	33.10	3.51	0.98	3.12	1.10	2.34	1.10	17.22	8.70	<0.284

**Beaverdam Creek**

BD01	6.66	30.33	2.93	1.32	2.50	0.96	3.41	1.38	12.35	5.16	<0.125
BD02	6.51	18.83	1.66	0.72	1.07	0.56	1.46	1.69	6.61	2.78	<0.125
BD03	6.71	30.42	3.42	1.32	2.51	0.99	4.20	1.32	10.03	5.50	<0.125
BD04	6.71	24.80	2.19	1.12	1.81	0.88	2.55	1.04	11.56	3.84	<0.125
BD05	6.48	33.67	3.32	1.26	2.46	0.97	3.96	1.18	11.67	5.58	<0.125
BD06	6.30	21.70	1.79	1.14	1.36	0.78	2.53	0.90	7.54	4.02	<0.125
BD07	6.32	22.86	1.96	1.23	1.37	0.83	2.55	0.90	7.45	4.77	<0.125
BD08	6.62	32.14	2.41	1.30	2.32	0.84	2.89	1.52	9.99	5.25	<0.125
BD09	6.30	27.33	2.33	1.21	1.58	0.73	2.75	1.36	7.63	5.14	<0.125
BD10	6.28	20.57	2.35	1.10	1.36	0.50	2.19	0.87	7.71	5.74	<0.125
BD11	6.22	40.74	3.61	1.65	2.86	0.93	3.75	2.04	10.16	5.32	<0.125

**Mountain Creek**

MC02	6.63	41.86	3.27	1.66	2.40	0.90	2.99	2.16	12.78	4.71	<0.125
MC03	6.67	38.33	3.17	1.61	2.30	0.89	2.73	2.10	12.72	4.77	<0.125
MC04	6.55	36.99	3.11	1.58	2.28	0.86	2.18	1.81	14.66	4.72	<0.125
MC06	7.15	22.27	1.96	0.95	1.10	0.59	2.24	1.59	8.09	3.61	<0.125
MC07	6.44	25.95	2.14	1.41	1.93	0.78	1.96	1.40	11.09	5.03	<0.125
MC08	6.57	45.98	3.95	1.94	2.96	0.94	3.22	2.52	15.05	5.34	<0.125
MC10	6.38	17.60	1.71	0.72	0.62	0.53	2.09	1.54	4.30	3.90	<0.125
MC11	6.53	48.98	4.29	1.92	3.39	0.97	3.58	2.11	16.55	6.10	<0.125
MC12	6.46	28.73	3.51	1.16	1.13	0.51	3.15	1.43	7.50	4.57	<0.125
MC13	6.22	21.65	2.40	0.98	0.84	0.61	1.71	1.07	6.90	4.63	<0.125
MC14	6.48	44.02	3.68	2.00	2.93	0.86	3.02	1.51	16.81	5.60	<0.125

## Appendix (continued)

Sample	pH	Conductivity	Na	K	Ca	Mg	Cl	SO4	HCO3	Si	Al
Location		( $\mu$ S/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
MC15	6.48	27.12	2.38	1.21	1.54	0.73	2.24	1.94	8.22	4.06	<0.125
MC16	6.71	44.65	2.64	1.80	3.12	1.23	2.36	2.15	16.85	5.05	<0.125
MC17	6.63	23.30	2.43	1.04	1.07	0.56	2.05	1.60	7.10	5.15	<0.125

**Brushy Creek**

BY01	6.89	59.43	4.24	2.26	4.60	1.20	3.85	2.99	19.96	5.26	<0.125
BY02	6.84	59.37	4.27	2.27	4.76	1.22	3.85	2.89	20.28	5.34	<0.125
BY03	7.20	56.17	4.24	2.20	4.12	1.16	3.71	2.19	19.04	5.48	<0.125
BY04	6.84	59.10	4.47	2.20	4.24	1.15	3.97	2.20	19.44	5.48	<0.125
BY05	6.76	57.13	4.45	2.22	4.11	1.13	3.95	2.04	18.97	5.38	<0.125
BY06	6.75	58.76	4.58	2.23	4.12	1.14	4.09	1.96	19.41	5.36	<0.125
BY07	6.22	44.26	4.17	1.88	2.44	1.05	3.93	0.95	12.24	6.70	<0.125
BY08	6.67	59.27	4.36	2.19	4.31	1.20	4.08	2.03	19.22	4.95	<0.140
BY09	6.61	49.24	4.73	2.33	2.79	0.72	3.73	0.94	17.99	7.25	<0.150
BY10	6.63	53.41	5.49	2.12	2.78	0.76	5.69	1.28	13.76	7.47	<0.125
BY11	6.44	54.86	4.76	2.19	3.04	0.90	4.99	1.29	17.40	5.32	<0.125
BY12	6.83	57.26	3.98	2.09	4.40	1.12	3.76	2.27	18.74	4.94	<0.132
BY13	6.70	52.83	4.57	2.29	3.67	0.96	3.80	1.49	17.68	6.57	<0.127
BY14	6.46	63.36	6.12	2.18	4.17	0.96	8.35	1.18	13.75	7.28	<0.140
BY15	6.69	54.70	4.88	2.12	3.97	1.26	3.98	2.97	14.84	6.96	<0.130

**Rocky Creek**

RC01	6.97	46.10	3.24	1.95	3.55	0.96	3.45	2.88	13.65	4.71	<0.172
RC02	6.92	46.54	3.18	1.93	3.87	0.95	3.44	3.45	13.27	4.76	<0.148
RC03	6.63	47.99	3.16	1.85	3.99	1.00	3.49	3.27	15.20	4.89	<0.125
RC04	6.71	42.59	3.10	1.74	3.75	1.07	3.36	2.27	15.37	4.91	<0.143
RC05	6.57	47.87	3.40	1.70	3.87	1.12	3.46	2.10	15.31	5.20	<0.125
RC06	6.26	49.57	3.49	1.71	3.33	1.27	3.44	1.57	13.53	6.49	<0.125
RC07	6.27	48.76	3.58	1.85	3.74	0.98	3.67	2.53	13.61	5.91	<0.125
RC08	6.68	45.66	3.21	2.07	3.24	1.12	3.72	1.54	15.86	4.27	<0.130
RC09	6.64	63.23	3.79	2.17	6.01	0.84	3.68	9.11	16.14	5.67	<0.163
RC10	6.39	70.31	4.26	1.87	7.34	0.88	4.01	12.51	16.99	6.14	<0.150
RC11	6.88	43.93	4.57	1.92	3.59	1.02	3.02	2.96	14.23	4.90	<0.136
RC12	6.41	46.77	2.62	1.63	3.44	1.46	2.96	2.27	17.22	3.29	<0.125
RC13	6.60	34.69	2.96	1.63	2.18	0.66	2.83	1.21	10.05	4.65	<0.125

**Gilder Creek**

GC01	6.69	49.14	3.14	2.19	3.50	1.00	3.75	3.02	15.17	5.28	<0.125
GC02	6.97	57.57	3.68	1.40	5.07	1.33	3.04	0.87	25.66	6.31	<0.125
GC03	6.71	47.29	3.21	2.29	3.74	0.95	3.70	3.20	14.50	4.89	<0.125
GC04	6.51	48.71	3.95	2.07	3.74	1.13	3.17	1.51	20.97	8.00	<0.195
GC05	6.66	42.86	3.79	2.02	2.79	0.95	3.24	1.56	16.28	8.71	<0.125
GC06	6.65	48.14	3.40	2.35	3.82	0.93	3.85	3.31	14.41	4.05	<0.133
GC07	6.57	41.43	3.79	2.08	3.19	1.10	3.34	1.76	15.21	8.12	<0.125
GC08	6.26	33.57	3.05	1.67	1.89	0.87	3.43	0.70	7.89	5.38	<0.125

## Appendix (continued)

Sample	pH	Conductivity	Na	K	Ca	Mg	Cl	SO <sub>4</sub>	HCO <sub>3</sub>	Si	Al
Location		( $\mu$ S/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
GC09	6.56	54.43	4.24	2.42	5.12	0.91	4.23	5.12	16.56	5.38	<0.125
GC10	6.69	48.00	3.28	2.94	4.05	1.07	3.31	2.35	19.50	4.83	<0.125
GC11	6.68	56.71	4.36	2.34	6.17	0.81	4.11	6.66	17.02	4.94	<0.125
GC12	6.57	44.71	3.31	2.25	4.05	0.84	3.65	3.37	14.73	5.11	<0.125
GC13	6.86	93.00	4.84	3.41	10.64	0.63	4.36	15.99	31.97	4.17	<0.140
GC14	6.67	38.64	2.83	2.02	2.76	1.08	3.27	2.20	12.86	6.07	<0.125

**Durbin Creek**

DB02	6.77	66.76	5.73	2.28	5.18	1.70	3.13	1.86	28.89	11.82	<0.164
DB07	6.75	56.91	5.10	1.95	4.18	1.27	4.34	1.60	19.42	8.69	<0.166
DB09	6.59	54.76	5.01	1.58	3.01	1.12	6.51	0.59	8.91	6.77	<0.150
DB10	6.73	51.20	5.35	2.29	3.45	1.09	3.42	1.86	20.71	10.43	<0.127
DB11	6.76	55.55	4.38	2.18	3.87	1.34	3.12	1.18	23.38	10.15	<0.123
DB12	6.70	52.47	5.11	2.93	2.36	0.84	2.84	1.69	19.99	11.07	<0.127
DB13	6.57	69.73	6.22	2.88	4.18	1.26	6.25	3.77	19.16	9.92	<0.129
DB14	6.76	101.37	7.24	3.20	6.72	2.33	12.63	3.57	17.98	11.28	<0.130
DB15	6.61	53.68	4.33	1.83	3.89	1.01	3.54	1.88	18.07	8.07	<0.133
DB16	6.73	51.12	4.37	1.89	3.39	0.94	3.57	1.70	16.37	7.91	<0.125
DB17	6.70	51.63	4.10	1.81	3.93	1.10	3.76	1.47	17.25	7.51	<0.165
DB18	6.77	50.93	4.49	1.65	3.49	0.84	3.15	2.29	16.74	8.64	<0.137

**Indian Creek**

IC01	7.28	142.60	9.66	2.01	12.49	5.45	4.78	2.33	78.39	12.18	0.228
IC02	7.70	186.86	11.94	1.87	18.69	7.25	8.64	8.14	91.82	16.06	<0.258
IC04	6.96	112.49	9.45	2.22	9.20	4.18	3.87	2.13	61.21	14.30	<0.160
IC05	7.10	110.57	9.54	1.96	9.63	4.13	3.86	2.47	64.28	15.09	<0.160
IC06	7.40	101.01	8.24	2.47	9.75	3.92	3.45	1.86	58.41	14.58	0.208
IC08	7.54	129.36	9.38	2.18	11.57	4.61	5.75	2.71	68.73	17.55	<0.195
IC10	7.49	114.00	8.26	1.94	10.64	3.84	3.17	2.54	61.95	17.83	<0.205
IC11	7.41	103.40	7.59	2.09	8.93	3.62	3.32	1.54	55.52	15.57	0.232
IC13	7.01	86.76	7.07	1.98	7.19	2.62	3.27	1.29	45.24	14.99	<0.170
IC14	7.60	83.46	8.02	1.67	6.84	2.01	2.54	0.77	43.99	19.84	<0.211
IC15	6.61	112.67	10.14	2.15	8.31	3.82	5.21	1.58	56.78	20.35	<0.147
IC16	7.29	104.38	8.39	2.07	9.03	3.49	3.82	1.76	55.80	17.25	<0.159

**Kings Creek**

KC01	7.17	107.00	8.94	2.05	8.48	2.89	3.61	1.66	54.05	17.28	<0.179
KC02	7.08	93.86	9.37	1.77	6.71	2.13	3.45	2.39	44.54	16.29	0.180
KC03	7.29	114.60	9.49	1.57	9.76	3.41	3.53	1.86	60.66	22.33	<0.178
KC04	7.12	108.10	8.39	1.68	9.34	3.64	3.22	1.68	57.63	23.30	<0.181
KC05	7.07	92.37	8.68	1.48	7.40	2.15	3.36	1.28	46.58	17.20	<0.142
KC06	7.17	103.38	8.88	1.77	8.46	2.95	3.50	1.77	53.72	19.28	<0.133
KC07	6.52	81.74	8.57	1.49	6.06	1.37	3.65	1.02	41.15	19.97	<0.127
KC08	6.85	83.53	8.75	1.40	6.87	1.68	3.56	1.03	41.62	18.27	<0.136

