Mechanism of Clast Weathering: A Study of Quartzite Cobbles

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ABSTRACT

The object of this study is to understand weathering of quartzite cobbles and to evaluate the potential for correlating river terraces. Two modes of weathering were discovered: grain alteration of feldspar and dissolution of intergranular contacts. Interstitial clay formed along grain contacts appear to play the major role in weathering. Point count data show that qualitative weathering categories are related to increased interstitial clay content.
Key words: terrace cobbles, quartzite clast weathering, correlation techniques.

INTRODUCTION

During the summer of 1997, the Keck Geology Consortium sponsored undergraduate research. Geomorphology projects were supported by 3 advisors in the Ridge and Valley of Virginia. Mapping and correlating terraces along the Maury, James, and South Rivers was a major objective accomplished during the field work. The ultimate goal is to establish age constraints for the terraces in order to calculate river incision rates.

Mapping and correlation of river terraces involved examination of aerial photographs and topographic maps. Terraces identified on maps and aerial photographs were confirmed by field reconnaissance. Elevations above modern river levels were used as a first approximation of correlating river terraces. Unfortunately, some of the terraces were not easily correlated. Uncertain strath contact and uncertain sediment thickness led to imprecise terrace elevations. Other correlation methods being studied involve soil weathering. Preliminary findings have shown an increase in A and B horizon thickness and increased clay accumulation in the B horizon as the soil matures (Dodoye-Alali, 1998; Elliott, 1998). Mature soils yields more clay than immature soils due to leaching of minerals in the upper horizons and depositing the leached materials in the lower horizons of the terrace. Another possibility of correlating terraces is to examine weathered clasts deposited on terraces.

In order to deal with correlation problems of alluvial fan deposits, Whittecar (1992) developed a classification system for weathered quartzite cobbles to assign the relative ages of alluvial fans in the Appalachian Mountains. The classification system is divided into five categories based upon the texture and hardness of the cobble (Table 1). This classification system can be applied to the terraces in this study.

The purpose of this project is to investigate weathering of quartzite cobbles deposited into alluvial terraces and to evaluate an alternative method of correlating terraces. By determining the key mechanism controlling cobble disintegrations, more accurate correlations of terraces might be possible. It is possible that a relationship between cobble weathering and soil development can be established.

CATEGORY	DESCRIPTION
1	**well indurated, very resistant; no oxidation rind visible**
2	**well indurated, very resistant, oxidation rind present (>2 mm thick) or internal oxidation apparent**
3	**breaks into chunks when struck by hammer but chunks not crushable by hand**
4	**removable from outcrop, crushable by hand; disintegrates into individual grains when struck by hammer**
5	**cannot be removed intact form outcrop; sliceable with shovel**

Table 1. F# classification system (from Whittecar, 1992).

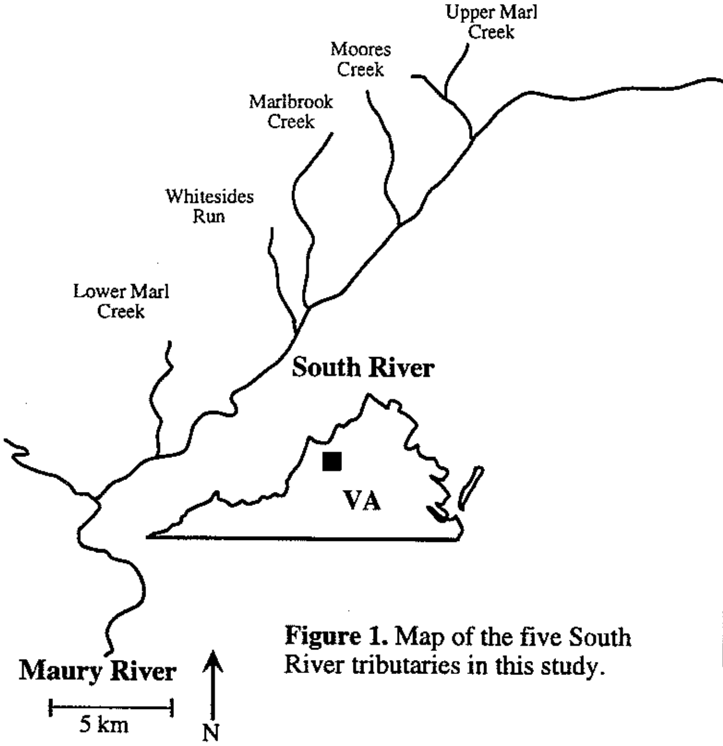

Figure 1. Map of the five South River tributaries in this study.

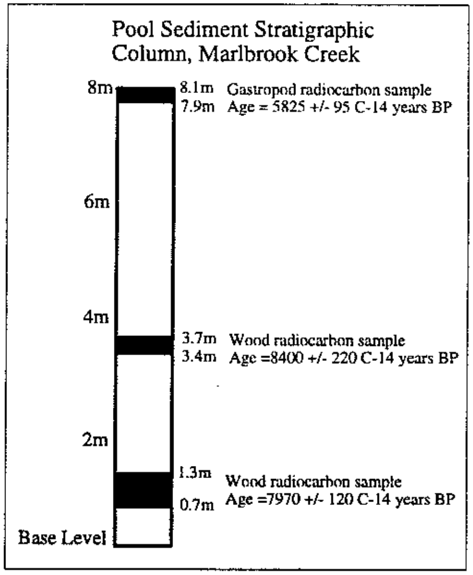

Figure 2. Radiocarbon dates and locations of samples within the stratigraphic column.

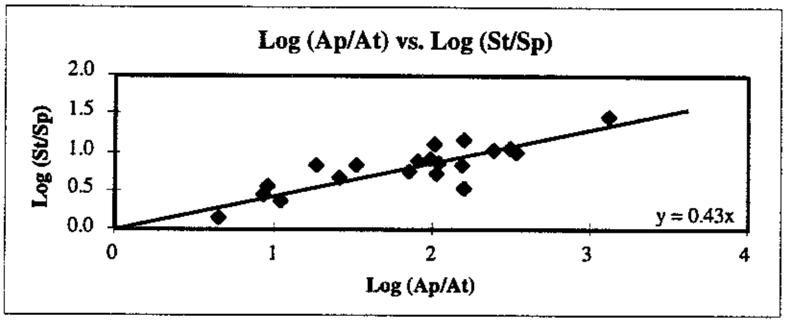

Figure 3. Log-log plot of the principle stream drainage area (Ap) to tributary drainage area (At) ratio against tributary gradient (St) to principle stream gradient (Sp) ratio (after Seidl and Dietrich, 1992).

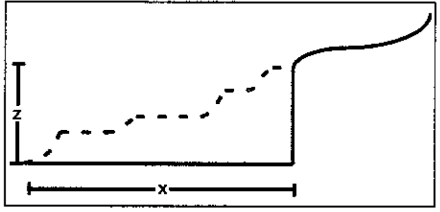

Figure 4. Schematic drawing of a bedrock stream dominated by knickpoints. X represents the overall longitudinal migration distance. Z represents the overall height.

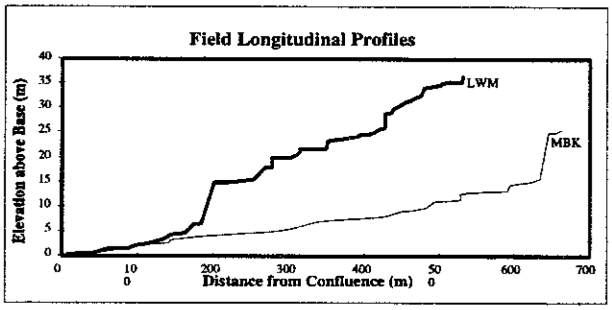

Figure 5. Longitudinal profiles of Lower Marl and Marlbrook Creeks obtained from field surveys.

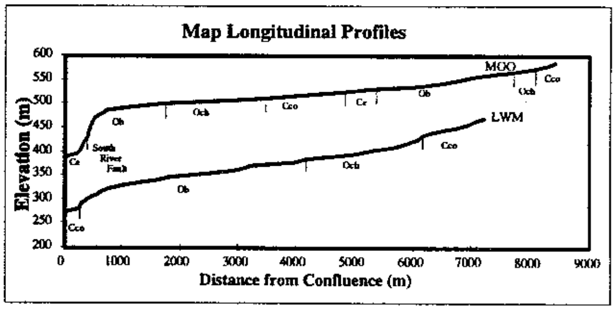

Figure 6. Longitudinal profiles of Moores and Lower Marl Creeks obtained by topographic map analysis. Profiles contain bedrock contacts (Ce = Elbrook, Ob = Beekmantown, Och = Chepultepec, Cco = Conococheague).

SAMPLING AND ANALYTICAL TECHNIQUES

Samples were collected from 11 different terraces along the Maury, James, and South River. Most samples were collected from easily accessible exposures near the surface in the A horizon. Three samples were collected from a clay pit and one sample from a soil pit that were deep in the B horizon. Ten random cobbles at each sample site were broken open to determine an average F# and clast weathering rind thickness.

Petrographic analysis was the most informative analytical technique used. Thin section billets were cut from 13 samples; F5 cobbles required impregnation to prevent disintegration of the cobble during cutting. Selected samples were chosen in order to examine unique features, such as skolithos tubes, weathering rinds, fractures, etc. Basic petrographic studies involved identification of minerals, textural characteristics, and distribution of clay particles. Point counts were conducted to estimate the percentages of key minerals. A count of 200 grains per slide was selected as a reasonable precision (~plus or minus 2-3%), without spending a disproportionate amount of time. Since most of the percentages occurred between 1-10%, an increase in precision produced by using a higher point count would be negligible.

Scanning electron microscope with energy dispersive X-ray was utilized to look for feldspars, clay particles, and/or key textural features; unfortunately, none could be found with the exception of a single feldspar grain (Fig. 1). The only useful information obtained was qualitative chemical analyses. In addition to the ubiquitous silicon, most sampled points yielded varying amounts of Al, K, and Fe. Obviously, most of the silicon is attributable to quartz. Al and K are probably related to feldspars and/or clays, while the Fe detected is from iron oxides (clearly visible in some hand samples).

Figure 1. Feldspar grain seen with a scanning electron microscope. Note cleavage face and dissolution scars.

PETROGRAPHIC OBSERVATIONS

The major mineral constituent of the cobbles is quartz with undulatory extinction (Fig. 2A). Dust rims can be identified in some quartz crystals, indicating the boundaries of the original sand grain (Fig. 3). However, most of the quartz grains were monocrystalline, and dust rim could not be seen. A few polycrystalline quartz grains also occur. Unusual strain patterns were found in some of the quartz grains. Although some of these strain textures resembled microcline twinning and perthitic texture (Fig. 2B), these grains are clearly quartz based upon the uniaxial positive optical sign, lack of cleavage, and absence of weathering material. These strain patterns are the products of intense strain acting on the quartz grains (Scholle, 1979)

Heavy minerals, consisting of zircon, tourmaline, and rutile, were also present in most samples. Such grains appeared fresh and unaltered. These minerals are quite common in quartz sandstones since they are so resistant to mechanical and chemical attack (Pettijohn *et al.*, 1973).

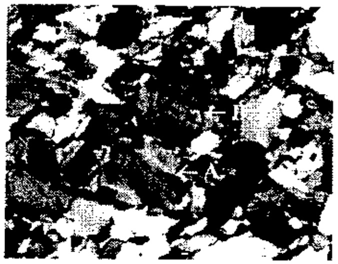

Figure 2. Characteristic quartz textures. A-displays differential birefringence of undulatory quarts. B-quartz showing pseudo grid iron twin deformation texture.

Surprisingly large percentages of potassium feldspar were observed in some samples (Fig. 4). These percentages ranged from 0-6.5% (Table 2). The K-feldspar grains have grid iron twinning and can be distinguished by the presence of a biaxial negative optical sign, good cleavage, and presence of weathered materials. The condition of the feldspars ranged from fresh to partially altered to heavily altered. Partially altered K-feldspars showed minute clay flakes along cleavages. The more weathered K-feldspars displayed a "dusty" appearance. Few heavily altered clay grains retained the cleavage and twinning patterns of fresh feldspars, but an optical sign could not be found and weathering materials appear to have completely replaced the original grain (Fig. 5).

Figure 3. Quartz with dust rim. Prominent dust rim in upper right shows boundary with quartz overgrowth and sand grain. Subdue dust rim can be shown in lower left.

Three types of weathering materials were found to exist in the cobbles: large clay grains, iron oxides, and interstitial clay particles. The large clay grains have probably been formed from the weathering of feldspars (Selley, 1988). This inference is based on relict grains showing textural characteristics of twinning and cleavage similar to feldspars (Fig. 5). These grains are interpreted to be "ghosts"of clay replaced feldspars. Grains containing both iron oxide and clay, replacement has totally destroyed the original mineral and texture. Patches of iron oxides were seen in thin sections and were included into the clay grain percentages, as iron oxides are nearly always associated with clays.

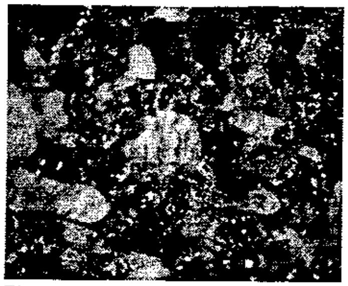

Figure 4. Feldspar grains showing cleavage in reflected light.

The second form of weathered materials is the interstitial clays. Interstitial clay overwhelmingly occurs between quartz crystal boundaries, this type of clay can also be found along fractures (Fig. 6 and 7). There is an increase in the interstitial clays with the F#s. Interstitial clays in F1 cobbles are thin and light, compared to the thick, dark interstitial clays present in F5 cobbles. This type of weathering material comprises up to 21.6% of a F5 cobble (Table 2).

DISCUSSION

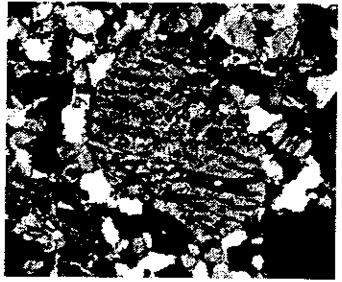

Figure 5. Modestly altered K-feldspars. Note "relict" twin lamellae.

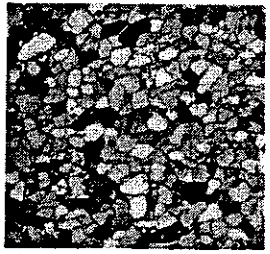

Figure 6. Clay grains and interstitial clay particles seen in thin section with partially crossed polars.

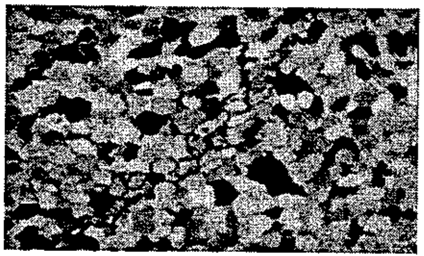

Figure 7. Clay localized along fractured cobble seen in thin section with partially crossed polars.

The two distinctive clay textures suggest two different modes of weathering: grain alteration and dissolution/clay growth between grain boundaries. Grain alteration is a weathering process involving feldspar replacement. This is the most reasonable explanation, since the entire range of feldspar alteration is observed. Feldspar is the only abundant mineral likely to be replaced by clay. A visual inspection of total feldspar + clay grains shows two types of cobbles: feldspar + clay grain bearing and nearly pure quartzite. When the feldspar + clay grain cobbles have high clay grain percentages, there is a low feldspars percentage and vice versa, that is the feldspar + clay grain abundance is constant. This is strong evidence that feldspars are indeed changing to clay grains. Reflected light binocular microscope examination of some rock surfaces, shows pits with clay residue, probably feldspars that have corroded to clays. These pits are almost certainly the same large clay grains observed in thin section.

The other mode of weathering is probably dissolution between crystal boundaries, which involves replacement of silica cement with interstitial clays. Thin section analysis show clay particles occurring almost entirely at crystal edges and fractures. These grains were originally cemented together with a silica cement, but crystal contacts most likely provided the only zone of weakness in the cobble's interior fabric. Subtle gaps in the intercrystalline cement fabric allowed fluids to migrate inwards. Weathering starts as dissolution at crystal contacts, providing a pathway for fluid flow, followed by clay precipitation.

Point count data show a relationship between average interstitial clay percentage and cobble F#. As the F# increases, so do the average interstitial clay percentage. The average interstitial clay percentage is most useful given the variability of clay content in equal F# clasts. By using average values, chance of section variability will be minimized. Dissolution of cement weakens the cobble by breaking down the interlocking crystal patterns. Weak clay minerals replacing strong silica cement, during the dissolution process, weakens the cobble causing a loss of cohesion. Alteration of feldspars do not appear to have any correlation with F# and overall disintegration of the quartzite cobbles because the individual feldspars appear to be largely isolated and contribute little strength to the overall clast.

CONCLUSION

Quartzite cobbles are effected by a two modes of weathering. Interstitial clay precipitation at crystal contacts and feldspar grain alteration appear to be the dominant weathering processes. Precipitation of interstitial clays is the most significant process destroying the cohesion of the cobble, accounting the change from F1 cobbles to F5 cobbles.

The increase in clay content is similar to the findings in the soil weathering studies by Dodoye-Alali and Elliot. Soil clay content increases with age (Dodoye-Alali, 1998; Elliott, 1998). Analysis of interstitial clays in thin section could be developed as a technique for assigning relative ages. With additional studies of quartzite clasts, it may be possible to establish a quantitative relationship between terrace age and clay percentages. This could be a useful technique to determine the relative ages of deposits where correlation based on soil profiles is not feasible.

Sample	Location	Elev. AMRL (ft)	Ave. F#	Feldspar %	Clay grains %	Interstitial clay %	Total clay %	Feldspars % + clay grain %
6A	river bed	0	1	1.6	5.2	0.5	5.7	6.8
7A	St. Mary	20	1	6.5	1.6	0	1.6	7.1
1C	clay pit	**	2	2.6	4.4	6.0	10.4	7.0
4A	Rail Road	60	2	0	1.0	6.2	7.2	1.0
5A	Rail Road	60	2	1.4	5.0	1.4	6.4	6.4
10A	St. Mary overpass	20	2	0.4	0.9	2.2	3.1	1.3
2A	trailer lot	70	3	0.9	0.5	8.6	9.1	1.4
3A	Rail Road	60	3	3.8	4.2	13.8	18.0	8.0
1B	clay pit	**	4	0.8	6.7	2.5	9.2	7.5
9A	Cherry Orchard	180	4	0	4.0	13.0	17.0	4.0
8A	landfill	**	5	0	7.8	13.8	21.6	7.8
11A	Carrie's pit	270	5	0.5	0	4.3*	4.3	0.5
1A	clay pit	**	5	0	3.8	16.5	20.3	3.8

Table 2. Data sheet.
*clays localized around fracture
**data not yet available

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REFERENCES CITED

Dodoye-Alali, Bala A., 1998, (title not available at this time), *in* Eleventh Keck Research Symposium in Geology Proceedings: (place, publisher, volume, and page numbers not available at this time).

Elliott, Carrie, 1998, (title not available at this time), *in* Eleventh Keck Research Symposium in Geology Proceedings: (place, publisher, volume, and page numbers not available at this time).

Pettijohn, F. J., Potter, Paul E., and Siever, Raymond, 1972, Sand and Sandstone: New York, Springer-Verlag, 618 p. [text book on sediments]

Schoole, Peter A., 1979, A Color Illustrated Guild to Constituents, Textures, Cement, and Porosities of Sandstones and Associated Rocks: Tulsa, OK, The American Association of Petroleum Geologist, Memoir 28, 201 p. {book of petrographic pictures of grains]

Selley, Richard C., 1988, Applied Sedimentology: London, Academic Press, 446 p. [text book on sedimentation]

Whittecar, Richard G., and Duffy, Debra F., 1992, Geomorphology and stratigraphy of late Cenozoic alluvial fans, Augusta county, Virginia, *in* Whittecar, Richard G., ed., Alluvial Fans and Boulder Streams of the Blue Ridge Mountains, West-Central Virginia: Norfolk, VA, Southeastern Friends of the Pleistocene, p. 79-112. [article in a field trip guidebook]

Terrace correlation from soil study along the Maury River, Virginia

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INTRODUCTION

The Appalachian Mountains are interesting not only for their Late Paleozoic folds and thrusts, but also for the geologic processes since then that have drastically altered the topography. Rapid downcutting, inverted topography, knickpoints, and terraces are among the terms being used to describe this continuously changing area. This region of the North America is surprisingly not as "stable" and "passive" as originally thought.

The area for this study is central Virginia's Great Valley. The Blue Ridge to the east is comprised mainly of Precambrian crystalline rocks, but is flanked on the west side with flatirons of Cambrian sandstone. The Great Valley is underlain by Cambrian and Ordovician carbonates and shales. To the west, the Valley and Ridge is composed of folded and thrusted Paleozoic sedimentary rocks; immediately west of the study area, the ridges are capped with Silurian sandstones whereas the valleys are underlain by Cambrian through Devonian shales and carbonates.

The purposes of this study are to map terraces along the Maury River in the Lexington area, and to attempt to correlate them. How fast the rivers are cutting into the bedrock is also of interest; there is a possibility that this is happening more rapidly that previously thought. This specific project entails establishing a soil chronosequence to show how the terraces soils change with elevation (or time) at one location. I also examined terraces at different locations to see if there is variabilityof different terrace levels along the river.

Even though soils cannot be used to get exact ages of landforms, they may be used for relative dating of terraces. Soil development depends on many variables, including mineral composition, particle sizes, compaction, and lithology of the underlying bedrock. The relative age of a terrace can be determined by looking at its elevation above the river and the soils there. Within the soils, thickness of the zone of accumulation (the B horizon) the color, and clay mineralogy can be examined. The longer a surface has been exposed, the thicker the soil's B horizon should be. An older terrace should have more clay accumulation, and more iron oxides, noted by the increase in hue. This is a general statement, however, and is not always the case.

FIELD AREA

The Maury River travels roughly 63 km south from Goshen Pass to the James River at Glasgow, Virginia. It travels through Silurian sandstone at Goshen Pass, but then makes its way over a series of dolomites, limestones and shaly limestones. The lower few kilometers are over shale. One set of terraces was picked to conduct a chronosequence. A chronosequence is a soil study in one area, keeping all variables except time constant: "...because all factors but one are 'ineffective' in the landscape, the influence of the one variable factor is revealed. Sequences of soils can [then] be sought..." (Boul, 1973). The location of the chronosequence is Rockbridge Baths, approximately 25 km upstream of Lexington. To compare the variability along the Maury, five other terraces were picked downstream in Lexington, Buena Vista, and Buffalo Forge (Fig. 1).

METHODS

On aerial photographs terraces can be identified as flat areas along the sides of river valleys. Broad areas outlined by contour lines on topographic maps also indicate terraces. Most of the soil pits were dug by backhoe; at one site (Bee's terrace) soil samples were acquired by auger, and at VMI Pit and Hill terraces, the soils were previously exposed. After the pits were dug, soils were described in the field using Soil Conservation Service nomenclature as in Birkeland (1974). Different horizons were designated by noting color or structural differences. Some horizons were split into two or three subhorizons based on the previously mentioned characteristics. Samples of each section were taken in a horizontal line across the face of the wall to maintain consistency within the horizon. If the section was thin and ungulatory, its pattern was followed, so as to sample within the same type of soil. When there was a unique section within a designated area, ie. manganese accumulation in the floodplain, then this was measured and sampled separately, but included within the designated subhorizon. Complete descriptions of color, texture, and clayskins were made. The pH was determined to help interpret the soils, but the data plots were scattered and did not reveal useful information.