A tale of two chronosequences: soil development on two flights of terraces on shale and limestone bedrock, James River, VA

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INTRODUCTION

In order to fully understand the geomorphic evolution of the Valley and Ridge region in southern Virginia it is useful to understand the relative age relationships of alluvial terraces. This study constructs two soil chronosequences on the James River spanning from the current floodplain or lowest available terrace to high terrace surfaces 60 meters above the modern river level. To examine the effects of bedrock on alluvial terrace soil formation over time, one of the chronosequence sites is on limestone bedrock, the other on shale providing context on the influence of bedrock on soil formation. In all, five to six terrace levels are examined in two different locations. Virtually no dates have been determined for the terraces along the James River, therefore this chronosequence uses elevation AMRL as an age substitute when comparing the terraces. Complexity of horizonation, clay content and clay films, Bt horizon thickness and soil color are the indicators of relative soil development used in this study.

River Terraces. The morphology of river terraces along the course of a river is not necessarily uniform. Terraces can be preserved with different thicknesses of alluvium over their bedrock surfaces. Terraces on different bedrock types weather and erode in different ways, leaving terraces surfaces of similar ages unlike in morphology and elevation above the modern river.

If terrace surfaces can be dated, then they can be accurately correlated and a rate of river incision over time may be extrapolated. However, there is a lack of easily dateable material in the James River system. The waters of this river and its tributaries in the Valley and Ridge cut through quartzite, sandstone, carbonate and shale bedrock. The river leaves rounded limestone, sandstone, shale, and quartzite cobbles interbedded with sand, silt, and clay behind in its terraces

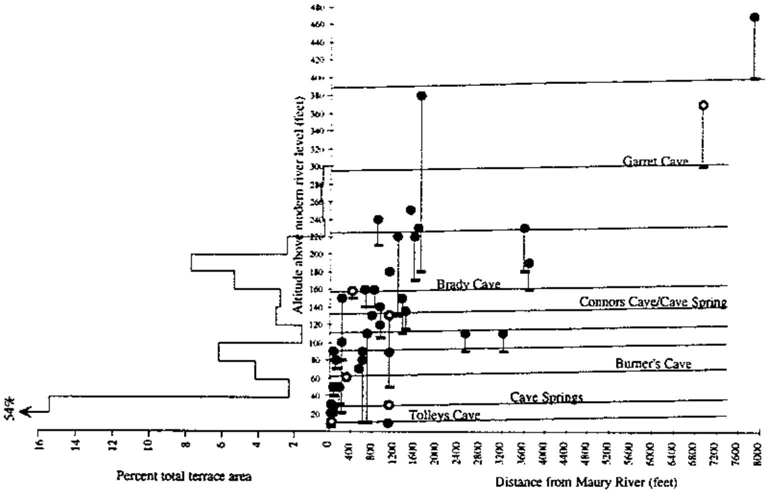
Soil Chronosequences. There are five factors that define the process of soil formation: climate, topography, parent material, vegetation, and time (Jenny, 1941). A soil chronosequence is a series of soils that form in generally the same parent material, climate, vegetation, and topography, but at different times. Pedogenic changes over time can be quantified by compiling a soil chronosequence. Some of the best, and most common circumstances for soil chronosequence studies are nested flights of terraces (Mc Fadden and Knuepfer, 1990), (Bull, 1990).

METHODS

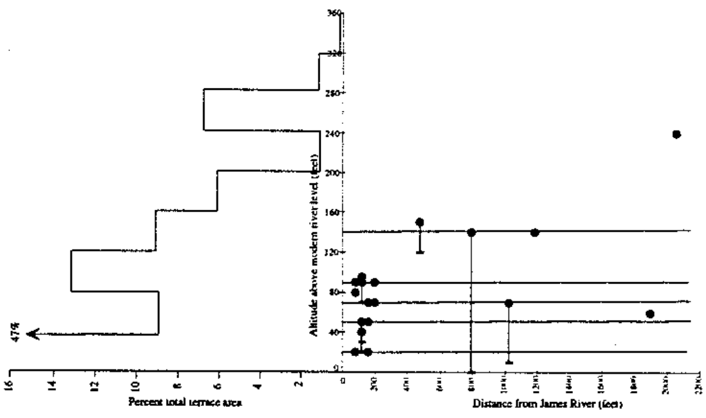
Study area and site descriptions. Reconnaissance field mapping of the fluvial terraces of the James River led to the identification of hundreds of terraces at varied elevations along a stretch from James Gap at the Blue Ridge to Rainbow Gap near the Allegheny Plateau. Once a map of the terraces was established two sites of terrace stands were located for this study, one on a bedrock of limestone, the other on shale.

The limestone site, situated on a meander bend called Oxbow James, is northeast of the town of Bucannan, VA. The site has four terrace surfaces (OT_1, OT_2, OT_3, OT_4) that are fairly continuous and readily identifiable, ranging in elevation from 7.9 to 82.3 meters AMRL. Four pits were dug with a backhoe and pedons were described at the Oxbow site. The floodplain (OT_0) was sampled with an auger hole. Pit locations were on flat treads (2-3 degrees), away from sinkholes and other evidence of terrace degradation from erosion or colluvial deposition. The bedrock underlying the Oxbow terrace material is a limestone/dolomitic limestone member of the Cambrian Elbrook Formation. The Oxbow James terraces exhibits signs of dissolution: sinkholes and undulating topography on the terrace treads. The terrace surfaces are continuous at the lower levels and surfaces are less preserved with increasing elevation.

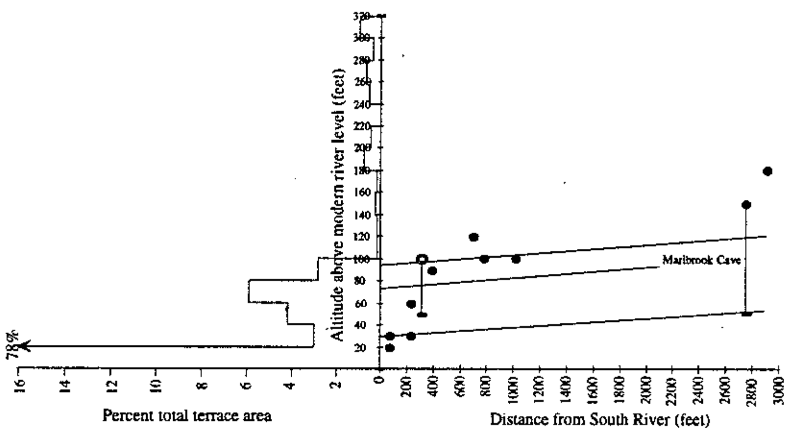
Upriver from the Oxbow site is the Town of Gala, where there are five clear terraces (GT_1, GT_2, GT_3, GT_4, GT_5). Here, the James has a confluence with Mill and Sinking Creeks. The terrace surfaces range in elevation from 4.3 to 64.6 meters AMRL. The floodplain (GT_0) was augered for sampling. Pits were located away from the eroding or colluviated terrace edges and in fairly flat, (2-4 degrees) well-drained areas on the terrace surfaces. The first



A. Cavern and terrace frequency distribution along the Maury River and its tributaries. Caves with horizontal passages at certain altitudes are labeled. and this is assumed to have been the paleo-water table level. Other lines have been drawn at altitudes where there seem to be a greater number of cavern entrances. These lines appear to correlate nicely with terrace distribution on the Maury River.



B. Similar plot of cavern and terrace frequency distribution on the James River. The terraces on the James are very well developed, reflecting greater time periods of relatively little downcutting. The caverns are not abundant at higher altitudes, probably due to having collapsed or filled with products of surface weathering processes. Paleo-water table along the James is seen to be near horizontal.



C. South River cavern and terrace frequency distributions. There are very few well developed caves along the South River, and terraces are very scarce at higher altitudes. The high topographic relief in the area is reflected in the scarcity of both terraces and caves, and in the steepness of the paleo-water table in comparison to that of the James and Maury Rivers seen in **Figs. A and B**

Figure 1. Cavern and terrace distribution along the Maury (A), James (B), and South (C) Rivers. Cavern entrances are represented by a closed or open circle. Caves in which there is a known horizontal passage at a certain altitude are denoted by an open circle, and are labeled. The vertical extent of a cavern is expressed as a fine line connecting a circle with a bar. The paleo-water table lines are based upon individual cave information and the appearance of numerous caves at a particular altitude above modern river level.

terrace pit was hand dug, the second gathered from a roadcut exposure, and the third, fourth and fifth pits were dug by backhoe. The underlying bedrock at Gala is the Brailler formation, a Devonian greenish-gray, hard, and fissile shale.

Field methods. Soils were described according to the conventions of the Soil Survey Staff (1975). The pits were dug to a depth where bedrock was reached, or cobble layers made digging difficult. Once the pits were dug, a fresh surface was cleared to examine soil structure and color. Horizonation was determined first, using direct observations of texture, color, structure and clay films as a guide to determine horizon boundaries. Moist color was determined in the field using the Munsell Soil Color Charts. Soil structure was examined for type, grade, and structure size. The amount, distinctness, and location of clay films on ped faces, pores, and grains in the form of coatings and bridges between grains were recorded for each pit. Samples were taken in each pit from each horizon, additional horizon sub-samples were taken every 20-30 cm.

Lab methods. In the lab, sand, silt and clay fraction percentages were determined by the use of the pipette method adapted from the method of Day (1965). The samples were pretreated for the removal of organic matter, and the sands and silts were separated by wet sieving before the pipette procedure. Particle size analysis was performed on 4-7 samples per pedon depending on the degree of horizonation and depth of the soil pedon observed in the field.

RESULTS

Soil Reddening. Increasing reddening is seen in both the Oxbow and Gala sites from 10YR in the lower terraces and floodplains to 2.5YR on higher terraces (Figure 1). The one exception to this trend is the Gala GT_5 pit, whose soil us reticulately mottled, a sign that it is waterlogged.

Many soil chronosequence studies have shown that soil color is redder in older soils, such as Harden (1982), and Howard et al, (1993). Harden (1982) found that as age increased, reddening or rubification increased significantly. The problems that arise in using reddening as a relative age indicator lay in deciphering the role of climate over time. Warmer climates develop redder soils faster, according to comparative soil chronosequence studies (Harden, 1982). In the Coastal Plain of Virginia, soils become redder as age increases: Pleistocene river terraces are 10YR-7.5YR, while Pliocene and Miocene upland gravel units are 10R (Howard et al., 1993). When trends of an increase of soil reddening over time are seen, a warmer past climate, simply time, or both may be responsible (Birkeland, 1984).

Horizonation. Soils increase in complexity of horizonation over time (Birkeland, 1994). In the Oxbow and Gala chronosequences E horizons of eluviation and Bt horizons of illuviation develop (Figure 2). A Bt horizon is an argillic, or clay-rich horizon that has a greater clay content in its B horizon than the parent material and/or overlying horizons (Birkeland, 1984). In addition, evidence of translocating clays in the form of clay films or coatings on grains, peds, or pores is typical of a Bt horizon. B and Bt thicknesses, as well as pedon thickness increase over time in both chronosequences (Figure 2). A problem in using Bt horizon thickness as an indicator of relative age is that some profiles are truncated due to terrace degradation, and in this study, in most instances the pits were not dug deeply enough to determine the entire thickness of the Bt horizon.

Clay content. A trend of increasing clay content in the Bt horizon versus elevation is seen in the terrace soils (Figure 3). At Oxbow James the lowest terrace, OT_0 has a B horizon clay content of 15%. The top terrace, OT_4 has 63% clay in its Bt horizon. The Gala site has a clay content of 31% in the B horizon of the GT_0 terrace increasing to 56% in the Bt of the GT4 terrace and 47% in the GT_5 terrace's B horizon.

Eolian dust influx, the amount of clay and minerals that weather into clays in the parent material, and soil moisture all play a part in determining how fast a clay rich Bt horizon takes to accumulate (Birkeland, 1984). The rate of dust influx varies from region to region, which is a problem with using increases in clay content for age differentiation. In a climate close in regional proximity to the James River terraces, soils on fluvial and marine terraces in Maryland and Virginia span an age from 30 ka to 1Ma (Markewich et al., 1987). Bt horizons approximately 120 cm thick begin to show up in 60 to 125 ka soils with 22% clay in the Maryland and Virginia Coastal Plain soils.

DISCUSSION

Steady State Condition. Many of the soil forming processes are said to reach a steady state of formation. Curves for results of soil development are steep initially and afterward flatten, indicating that changes level out over time (Birkeland, 1984). The time required to reach a steady state will vary with the particular soil properties of the parent material and erosion (Birkeland, 1984). A horizons are the first to reach the steady state before B horizons. Only when a property has reached a steady state can a state of equilibrium be said to have been reached (Birkeland, 1984).

There has been some amount of debate about the length of time it takes soil properties such as clay content, organic content, and chemical content such as iron and aluminum to reach a steady state. Some curves have not shown flattening after 10^6 years (Birkeland, 1986). The physical properties of soils of the Maryland and Virginia Coastal Plains and Piedmont continue to change over time (Markewich et al., 1987).

No steady state plateaus appear on the graphs of clay content, B horizon thickness, and color in this study. The GT_5 terrace stands out as an anomaly, with color and clay content lower than expected. However the reticulated mottling and texture of the profile indicate that there are particular circumstances that account for these differences on this terrace.

The Shenandoah River basin to the North. Terrace weathering characteristics identified from geomorphic studies in the Shenandoah river basin are different than those of the James River. High, T5 terraces (elevation 25 meters AMRL) on the Shenandoah drainage basin are considerably lower than the high terraces of the James River in this study (60 meters AMRL) (Bell, 1986). The top, T5 terrace is comparable in elevation to the OT2 and GT2 terrace elevations on the James River in this study. The Oxbow and Gala soil colors for the highest terraces are still much redder than those of comparable elevation AMRL in the Shenandoah drainage. The Shenandoah's T5 terrace is only 10YR 6/7, not nearly as red as the higher terraces (5YR) in the James Basin. These discrepancies are indicators of differences in the rate of stream incision and terrace generation for the two areas.

CONCLUSIONS

In general, both locations of James River terraces show with increasing elevation: 1) an increased level of horizonation, 2) an increase in soil reddening, 3) a significant increase in percent clay, 4) increased B horizon and solum thickness, and 5) a relative increase in clast weathering.

Soil chronosequences suggest that the soils have not yet reached a steady state of equilibrium. The terraces are redder and more clay rich, and the development of the soils does not begin to taper off as they progress in elevation above the modern stream channel.

This study lays preliminary groundwork on terrace soils in the James River Basin. This chronosequence is a first step in understanding the relationships between soil development, bedrock type, and terrace elevations in the region. As more work is done terrace ages will be more constrained. The ages of the soils in the context of their elevations and relative development will be useful in unraveling the complex tale of landscape evolution in the Valley and Ridge.

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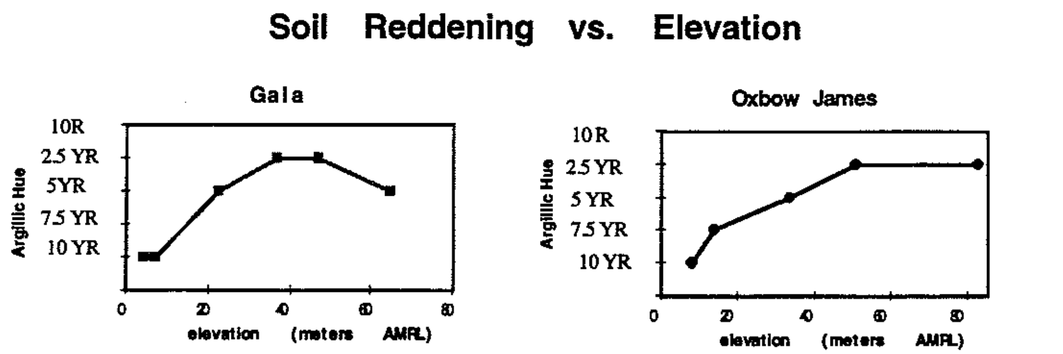

Figure 1: Soil reddening versus elevation for Gala and Oxbow locations. The color was measured in the B or Bt (argillic) horizon.

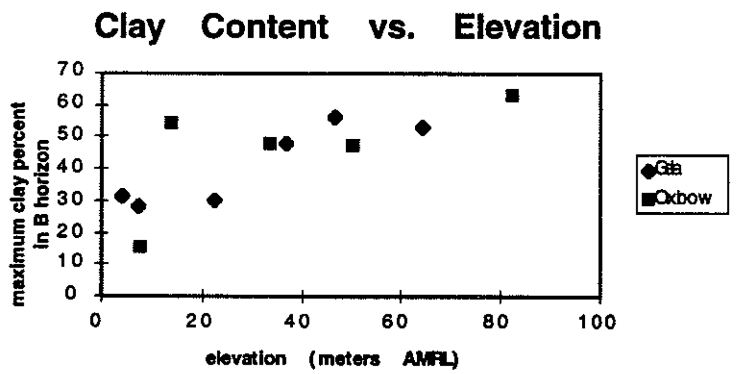

Figure 3: Clay content versus elevation for the two chronosequences. The maximum clay percent of the B or Bt horizon is used for this graph.

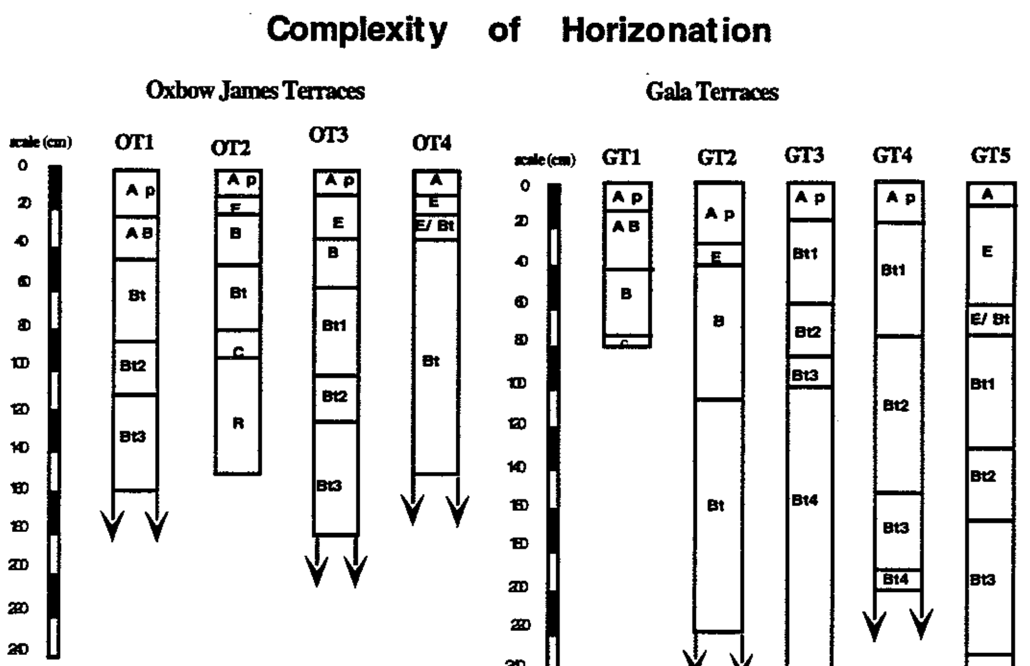

Figure 2: The complexity of horizonation for the two chronosequences. Arrows indicate that the soil pedon extends below the pit depth.

Bringing down the mountains: Rapid incision, escarpment retreat, and flexural uplift in the Appalachian Valley and Ridge province

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INTRODUCTION

The Appalachian Valley and Ridge Province has been the subject of a long-standing, but recently dormant, controversy over modes of landscape evolution. Up until the middle of this century, debate raged over drainage adjustment, the age and origin of Appalachian peneplains, and continental-scale theories of landscape evolution such as William Morris Davis' Geographic Cycle. Most of these early theories relied on tectonic activity to trigger continental-scale geomorphic change. Although in recent decades interest has waned, new papers have suggested dynamic interactions between crustal and geomorphic processes, and have made the Atlantic passive margin the subject of renewed research.

In this study, I document the presence of two incised erosion surfaces, the Floyd Surface and the Valley Surface, in the James River portion of the Appalachian Valley and Ridge province. I present an average rate of James River incision, based on a cosmogenic isotope date of the Valley Surface. Finally, I suggest that escarpment retreat and isostatic rock uplift may account for all of the observed James River incision, without the need for tectonic forcing.

STUDY AREA

This study focuses on the James River and its tributaries upstream of the watergap through the Blue Ridge. Bedrock in this portion of the Valley and Ridge is folded and faulted Paleozoic clastic and carbonate formations (Spencer, 1994). Local relief is greater than 800 meters between the James River and the highest Blue Ridge summits; typical valley-ridge relief is about 500 meters.

The Valley Surface. The Valley Surface consists of a number of coalescing fluvial terraces and pediment remnants. Remnants of the Valley Surface can be found throughout the James system, and are easily correlated; when standing on one remnant, several others are usually visible at the same elevation. Similarly, 7.5-minute topographic maps show a number of surfaces with nearly flat tops at comparable elevations. The bedrock straths of Valley Surface terraces along the James River consistently lie at 60 meters above the river, and pediments descending from high ridges are graded to a similar elevation. Because the Valley Surface is an erosional feature, deposition ages of alluvium in Valley Surface remnants can be used to approximate its age of abandonment and provide an estimate of the average rate of James River incision.

The Floyd Surface. Less than one hundred kilometers to the southwest in the New River basin, a broad low-relief surface with area greater than 3,000 km^2 slopes gently to the northwest from the Blue Ridge in and around Floyd County, Virginia. Similarly, upper reaches of several James System streams descend gently from the Blue Ridge but then drop rapidly to the James River or its major tributary the South River. These upper reaches are graded to an elevation similar to that of the surface around Floyd County, at an elevation of about 900 meters, 700 meters above the present James River where it cuts the Blue Ridge. Remnants of an elevated Valley and Ridge landscape (Harbor, 1996), these upper reaches suggest that the Floyd Surface may have been continuous along the Valley and Ridge.

METHODS: DATING FLUVIAL TERRACES WITH COSMOGENIC RADIONUCLIDES

Here I use the cosmogenic radionuclide ^{10}Be to date a remnant of the Valley Surface. The basic assumptions of dating with cosmogenic radionuclides are that certain isotopes are produced at the earth's surface by the interaction of cosmic rays with silicates and that production of these isotopes decreases exponentially with depth below the surface. In the case of the ubiquitous mineral quartz (SiO_2), neutrons or muons react with ^{28}Si to produce