Quaternary fluvial terrace and cavern correlation in the Valley and Ridge province, Virginia

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INTRODUCTION

Virginia has some of the earliest described and most extensive networks of caverns in the United States. The Valley and Ridge province of Virginia is home to over 2300 solution caves alone, most of which are found within Lower Cambrian to Upper Mississippian limestone and dolomite bedrock (Holsinger, 1975). During the last few decades, modern mapping tools and techniques have enabled previously unexplored caverns in the region to be described in greater detail, and many previously undiscovered ones to be revealed. As a result, there has been a renewed interest in the utility of caves in solving some of the geomorphic problems relating to landscape evolution which have plagued geologists for almost a century.

Central to this study is the assumption that both caverns and terraces form at, or sufficiently near, the water table to warrant correlation between the two surfaces. If this assumption is correct , then dates of speleothem samples may closely approximate the ages of terraces at similar altitudes above modern river level (AMRL). A similar study relating terraces to former extended base levels was done in the Flint Ridge-Mammoth Cave system of Kentucky with excellent results (Hess and Harmon, 1981, cited in Conners, 1986). Using U-series disequilibrium dating of speleothems in caverns along three rivers in Virginia, this study aims to relate caves with terraces at similar altitudes above modern river level in order to establish fluvial incision rates and landscape evolution models for the Valley and Ridge province.

From Quaternary terrace deposits mapped along the James, Maury, and South Rivers near Lexington, Virginia, statistically determined, preferred terrace altitudes were compared with the altitudes of cavern entrances along these rivers. Paleo-water table was estimated by plotting cave altitude above modern river level against distance from that river, and comparing these points with the modes on the terrace histograms. Initial results indicate that caves and terraces do in fact form at or near the same level, so long as certain assumptions regarding the character of water tables in karst terranes are held to be true. U-series dates indicate that caves are relatively young (< 780 ka), and that the incision rates of the rivers are very fast.

METHODS

Quaternary fluvial terraces and alluvial fans were mapped along the Maury River from Goshen Pass to Glasgow; on the James River, from Iron Gate to Glasgow; and on the South River from the mouth of Saint Mary's River just above Pkin, to its confluence with the Maury River. All deposits were mapped on 1:24,000-scale topographic maps using aerial-photographs combined with field reconnaissance to confirm the presence or absence of river cobbles on suspect surfaces at various elevations.

The frequency of terraces at particular altitudes above modern river level was determined for the James, Maury, and South Rivers by superimposing 100-m grids on the Quaternary deposits maps, and recording the elevation of each point that fell within a terrace; this method is copied from terrace studies along the New River, Tennessee (Mills, 1986). The point count yields the histograms in Figure 1 which show the percentage of total terrace area at any particular 20-ft contour interval (40-ft for the James River) found on each of the three rivers.

Approximately ten caverns were visited in the field in search of datable sediments. Speleothems were collected from five caves in order to determine a minimum age of the cavern based on uranium series ($^{234}U/^{230}Th$) disequilibrium dating, which has become an increasingly accurate method for dating calcite speleothems up to 600,000 years old (Gillieson, 1996). Of the five speleothem samples collected , three yielded dates (Table 1).

In Figure 1, cavern entrance altitude above the modern river is compared with both distance from the river and terrace histograms; these histograms are minus the flood plain in order to accentuate modes at higher altitudes. The paleo-water table levels are drawn where both cave altitudes and terrace altitudes above modern river level appear to coincide. At higher elevations, this admittedly becomes somewhat arbitrary and, at best, only approximates the ancient water-table level. The slope of the paleo-water table graded toward a major river is characteristic of normal water-tables, but is a fact which may or may not be true of water-tables in karst terranes.

"Excessively well drained and saturated soils experience completely different physicochemical conditions and these in turn encourage either the mobilization or precipitation/crystallization of ions within the developing soil profile" (McCraig, 1984).

CONCLUSION

It may not be possible to correlate terraces along the Maury River. There are so many variables during terrace formation and soil development. The bedrock varies considerably from Goshen Pass to Glasgow: sandstone, limestone, dolomite and shale. Mineralogy, grain size, and other characteristics of the soil's parent material are not constant. Also different types of knickpoint migration will affect the terrace levels. More data is needed on terrace formation and soil development. I used only nine terrace segments along the river; with research at more sites, we may gain a better understanding of soil development, terrace formation, and correlation.

Terrace	Location	Distance from mouth (km)	Altitude above Maury River (m)	Depth of pit (cm)	Hue	Texture of uppermost A Horizon	Texture of Lowest B Horizon	Notes
T3	Rockbridge Baths (R.B.)	51	51	150	10 YR 4/4 to 5 YR 4/6	sandy clay loam	silty clay	sandstone cobbles at 1.5 m depth
T2	R.B.	51	29	145	10 YR 5/4 to 5 YR 4/8	loam	silty clay	clay films - coats and bridges in B horizon
T1	R.B.	52	17	142	2.5 Y 4/3 to 2.5 Y 5/4	——	——	topographic low, 7 slope
T0*	R.B.	51	5	173	10 YR 4/3 to 7.5 YR 4/6	loam	sandy loam	manganese deposit at level of spring water table, 1.2 m below surface
WR	R.B.	50	42	210+	10 YR 4/4 to 2.5 YR 4/6	loam	silty clay	very red soil, stong clay films
VMI	Lexington	25	60	240	10 YR 4/4 to 2.5 YR 4/8	loam	silty clay loam	exposed sink hole
HII	Buena Vista	21	13	200	7.5 YR 4/4 to 2.5 YR 4/6	loam	sandy clay loam	thick E/BE horizon
GMP	Buena Vista	17	60	174	10 YR 4/3 to 5 YR 4/6	loamy sand	sandy loam	extremely weathered sandstone clasts at 1.5 m depth
Bee's	Buffalo Forge	9	42	128	5 YR 4/4 to 2.5 YR 4/6	loam	silty clay	very red soil, stong clay films

Table 1: Terrace parameters. Terraces are listed from the upstream chronosequence (with oldest first) to terraces downstream (* T0 is the floodplain).

REFERENCES

Bick, K.F., 1960, Geology of the Lexington quadrangle, Virginia: Virginia Division of Mineral Resources, 35 p.

Birkeland, P.W., 1974, Pedology, weathering, and geomorphological research: Oxford University Press, New York, 277 p.

Boul, S.W., Hole, F.D., and McCracken, R.J., 1973, Soil genesis and classification: Iowa State University Press, Ames, 374 p.

Gardner, T.W., 1993, Experimental study of knickpoint and longitudinal profile evolution in cohesive, homogeneous material: Geological Society of America Bulletin, v. 94, p. 664-672.

Moore, D.M., and Reynolds, R., Jr., 1997, X-Ray diffraction and the identification and analysis of clay minerals: Oxford University Press, Oxford, 378 p.

McCraig, M., 1984, Soil properties and subsurface hydrology, *in* Richards, K.S., Arnett, R.R., and Ellis, S., eds., Geomorphology and soils: George Allen and Unwin, London, p. 121-140.

RESULTS

The histograms for each of the three rivers (Figure 1) show that the South River has a mode from 40-80 ft AMRL, and two smaller modes at 180-200 ft and 300-320 ft. The Maury River has two significant modes, one at 60-100 ft and the other at 160-200 ft AMRL. Choice of modes on the James River histogram is more difficult as the greater contour interval does not accentuate trends quite as well as the 20 ft contours do on the other rivers. However, there does appear to be a greater percentage of terrace area at 80-120 ft, and 240-280 ft AMRL along the James River.

The differences between the terrace-point distributions on the three rivers is subtle. One might expect there to be a linear decreasing trend in the percentage of terrace found at increasingly higher altitudes AMRL. Assuming that the percent area occupied by flood plain has been the same over time, the higher elevations would have experienced a greater period of erosion and would therefore be represented by less area today. Figure 1 shows that each of the rivers has certain elevations at which terrace area is markedly greater or lower. Theoretically, the modes on these histograms represent elevations of the river at which time there was overall flood plain development with relatively little downcutting. Lows between the modes represent periods during which time the river was downcutting.

South River has fewer terraces at higher elevations than do the other two rivers, which can only be accounted for on the basis of topography. South River is in an area of considerably greater relief, and has a steep stream gradient. The rapidly incising river does not allow the flood plain to develop sufficiently for terraces to be formed.

The altitudes above river level of all caverns found near the streams were compared to terrace elevations in Figure 1. The number of caverns generally decreases with increasing distance from, and altitude above, the modern river. However, at some altitudes there is a greater number of caverns, and some of these altitudes correspond with altitudes having greater percentages of terrace area. These altitudes are interpreted to be the paleo-water tables.

U-Th disequilibrium dating of caves requires that certain assumptions be made regarding speleothem development and collection, which may yeild misleading information. One major assumption is that speleothems began to form immediately after the water table was lowered, and the cavern became virtually dry. A second assumption is that flowstone development in the cavern has not been accentuated or retarded by climatic changes since its growth began. Lastly, the sample collected in the cave is one of the oldest speleothems in the cavern. As these assumptions are unlikely to be true for the samples collected in this study, the U-series dates listed in Table 1 represent minimum ages of the caverns. Magnetic polarity of sediments in some caverns may constrain their age.

Dripstone from Brady Cave has a U^{234}/Th^{230} age of approximately 346 ka, and slackwater sediments from the cave had normal magnetism, i.e. younger than the Brunhes-Matuyama reversal at approximately 780 ka. Brady Cave is located about 150 ft above Buffalo Creek (a tributary of the Maury River), and correlates to terraces 150-200 ft above the Maury River. Using 780 ka as a maximum age of the cave, and the U-series age as a minimum, Buffalo Creek is incising at a rate of 65-155 m/m.y.

Speleothems from Little Ol' Dry Hole and Marlbrook Cave were too dirty to get a U^{234}/Th^{230} age, and the age of a speleothem from The Locks (12 ka) indicates that the cave is relatively new. The Locks speleothem yields an unrealistic incision rate of the Maury River greater than 400 m/m.y.

The Turkey Hill Cave sample has a U^{234}/Th^{230} age of approximately 366 ka. Paleomagnetic samples were removed from laminated muds just below the flowstone at Turkey Hill, but the results of the test were wrought with uncertainty. The age of Turkey Hill Cave is somewhat dubious, as the shape and pattern of the cavern passages suggests that it was formed, not at the water table, but predominantly by solution along fractures. However, if it is in fact a bathyphreatic and water table-leveled type cave (Ford and Williams, 1989), then the Maury River is incising at a rate of 135-330 m/m.y.

DISCUSSION

The incision rate derived from Brady Cave on Buffalo Creek (65-155 m/m.y.) is very fast. Other studies in the Appalachian region have estimated denudation rates closer to 40 m/m.y. (Hack, 1980, pg. B13), although the Tennessee River may be downcutting as much as 290 m/m.y. (Delcourt, 1980, cited in Conners, 1986). Obviously the three rivers in this study have not been incising at a continuous rate for the last million years, but rather, have experienced episodic periods of rapid erosion followed by periods of relative quiescence. This is suggested by the pattern seen in the terrace histograms of Figure 1, and supported by numerous studies in Virginia which have shown that rapid climatic changes including glacial-interglacial cycles, and on a small scale, localized intense rainfalls, can produce denudation rates in excess of 1358 mm/1000 yr (Conners, 1986). Likewise, cavern and karst development in Virginia has been greatly influenced by Quaternary climate changes, and could very well have distorted the age of the speleothems collected in this study by retarding or accentuating flowstone growth during periods of unusually high precipitation and/or cold temperatures (Conners, 1986).

Comparison of cavern and terrace altitudes above modern river level appears to be a useful in Virginia, although, unlike the caverns used in similar studies (Webb et al., 1992; Hess and Harmon, 1981, cited in Conners, 1986), the caves along the James, Maury, and South Rivers are small and lack well-developed flowstone, horizontal roofs, or multiple levels. The extrapolated paleo-water tables in Figure 1 are more arbitrary with increasing altitude, except at those places where there is known to be a horizontal passage (i.e., a cavern formed at or near water table).

The questions that were initially posed by the group regarding incision mechanisms and terrace correlation are perhaps better addressed by other research projects presented in this volume. Suffice it to say that terraces and caves do appear to be correlative in Virginia as they appear to be found at similar altitudes above modern river level. Additonal studies in other regions with larger, multi-level caves, and well-developed terraces provide additional support for the cave-terrace correlation technique.

ACKNOWLEDGMENTS

Special thanks are extended to Bob Thren at Washington & Lee University for providing up-to-date information on all known caverns in the study area, and for leading field expeditions to collect speleothem and sediment samples. Thanks are also due to Jeff Dorale (University of Minnesota) for the U-series ages, and to Bruce Panuska (Mississippi State University) for the paleomagnetic work.

REFERENCES CITED

Conners, J. A., 1986, Quaternary geomorphic processes in Virginia, *in* McDonald, J. N., and Bird, S. O., eds., 1986, The Quaternary of Virginia, a symposium volume: Virginia Division of Mineral Resources, Publication 75, p. 1-22.

Ford, D. C., and Williams, P. W., 1989, Karst geomorphology and hydrology: London, Unwin Hyman, 601 p.

Gillieson, D., 1996, Caves: processes, development, management: Blackwell Publishers, Inc., Cambridge, Massachusetts, 324 p.

Hack, J. T., 1980, Rock control and tectonism - their importance in shaping the Appalachian Highlands: U. S. Geol. Survey Prof. Paper 1126-B, p. B1-B17.

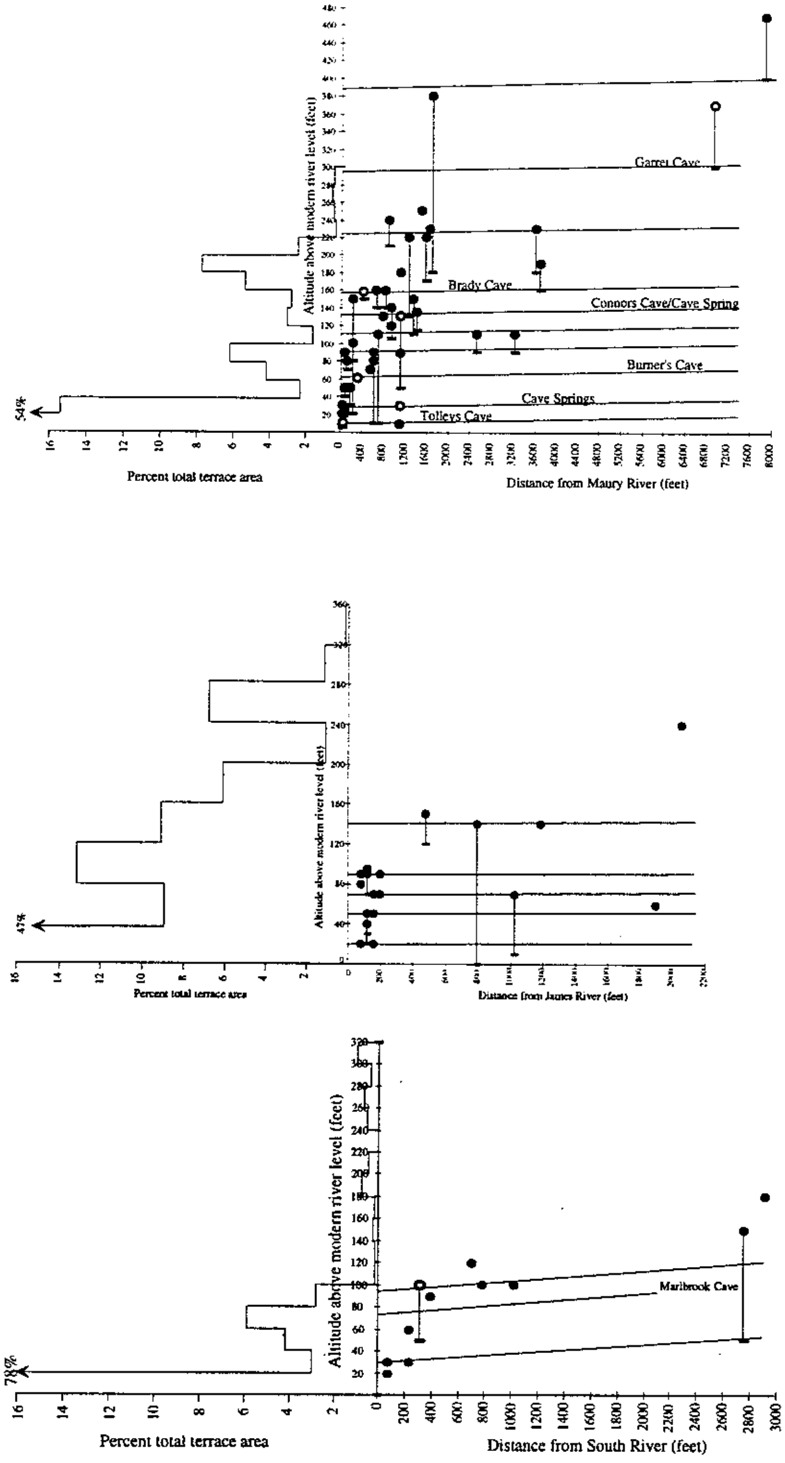
Holsinger, J. R., 1975, Descriptions of Virginia caves: Virginia Division of Mineral Resources, Bulletin 85, 450 p.

Mills, H. H., 1986, Possible differential uplift of New River terraces in southwestern Virginia: Neotectonics: An International Journal of Crustal Dynamics, vol. 1, p. 75-86.

Webb, J. A., Fabel, D., Finlayson, B. L., Ellaway, M., Li Shu, and Spiertz, H. P., 1992, Denudation chronology from cave and river terrace levels: the case of the Buchan Karst, southeastern Australia, *Geol. Mag.*, v. 129(3), p. 307-317.

Table 1. Information relating to caverns where speleothems were sampled.

Cavern	Stream	Altitude of cavern above modern river level (ft)	U-series age	Paleomagnetic data
Marlbrook	South River	100-50	none (too dirty)	---------
Brady	Buffalo Creek	175-150	346,333 + 28,117 - 23,342	normal
Turkey Hill	Maury River	380-180	366,000 + 65,000 - 45,000	normal (?)
The Locks	Maury River	30-20	12,000 + 6,000 - 6,000	---------
Little Ol' Dry Hole	Maury River	~ 50	none (too dirty)	--------



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.

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