

Quaternary Erosional History of the St. Marys River, Western Virginia

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INTRODUCTION

As the rivers of the central and southern Appalachian Mountains encounter rocks of varying resistance or as they compete with rivers of the Gulf drainage, the outline of drainage basins changes through divide migration and capture (e.g., Davis, 1889; Thompson, 1939). Divide shifting is particularly true where master streams in competing basins have different slopes. Erosion is favored in the steeper basin and the divide shifts gradually - occasionally abruptly - into the more gentle basin. At the headwaters of the James and Potomac River basins where the uppermost tributaries of the Maury and Shenandoah River basins compete for the available runoff, the steeper streams of the James basin ARE gaining ground at the expense of those in the southern portion of the Shenandoah basin.

The Shenandoah and its headwater streams (Fig. 1) near Greenville (Poor Creek and Pine Run) are the erosional base for large alluvial valleys and alluvial fans that emanate from the Big Levels highlands underlain by Antietam quartzite (Whitcar & Duffy, 1992). Below its headwaters near Greenville, the South River (tributary to the South Fork of the Shenandoah) flows northeast primarily on carbonate rocks with a slope of 3 m/km. It is characterized by a wide floodplain and low valley walls. On the other side of the divide and flowing southwest on the same rock types, the other South River (tributary to the Maury, then James) is a steep (8 m/km), gravel-bed stream. The east side of the river is flanked by precipitous waterfalls cascading from the Shenandoah Valley upland into a deep and comparatively narrow valley. On the Blue Ridge side of the South River lie steep tributaries below dissected remnants of fans or pediments that grade out to the level of the Shenandoah Valley uplands. The difference in headwater gradient between these two basins generates an inequity in the rate of erosion. Greater

erosion allows streams tributary to the James to capture streams from the Potomac basin.

The reasons for the differences in overall basin slope and base level are largely speculative at this time but they are likely related to the length of time since different transverse streams pierced the Blue Ridge and began incising the weaker rocks of the Valley and Ridge. The James basin, presumably, pierced the divide more recently and is expanding at the expense of the previously established Shenandoah basin. We believe that St. Marys River recently—in geologic time—was diverted from the Potomac basin into the James basin because the latter is steeper and has been incising faster in the late Pleistocene (Harbor, 1996). Our study sought to document this supposition and constrain the age of the river capture event.

Sequence of Events

Given the topographic setting near the St. Marys River, inevitable northeast migration of the drainage divide resulted in diversion of streams flowing northwest off the Blue Ridge. It appears that the headwaters of the current St. Marys River fed one of the headwater streams for the Shenandoah River basin. This river flowed out of the current gap in the ridge formed by the Antietam Quartzite at a level of about 640 m (2100 ft), flowed down an alluvial fan surface like those just north of the current St. Marys River, and turned north along the path currently occupied by Pine Run downstream of the current watershed divide near Lofton, Virginia. We refer to this river as the "Lofton River." It may have been joined there, or farther upstream, by other streams the rise in the Blue Ridge. Faster incision by the South River allowed a tributary to cut headward into the fan or along the fan perimeter and capture the "Lofton River". The capture may have taken place in the shale bedrock somewhere

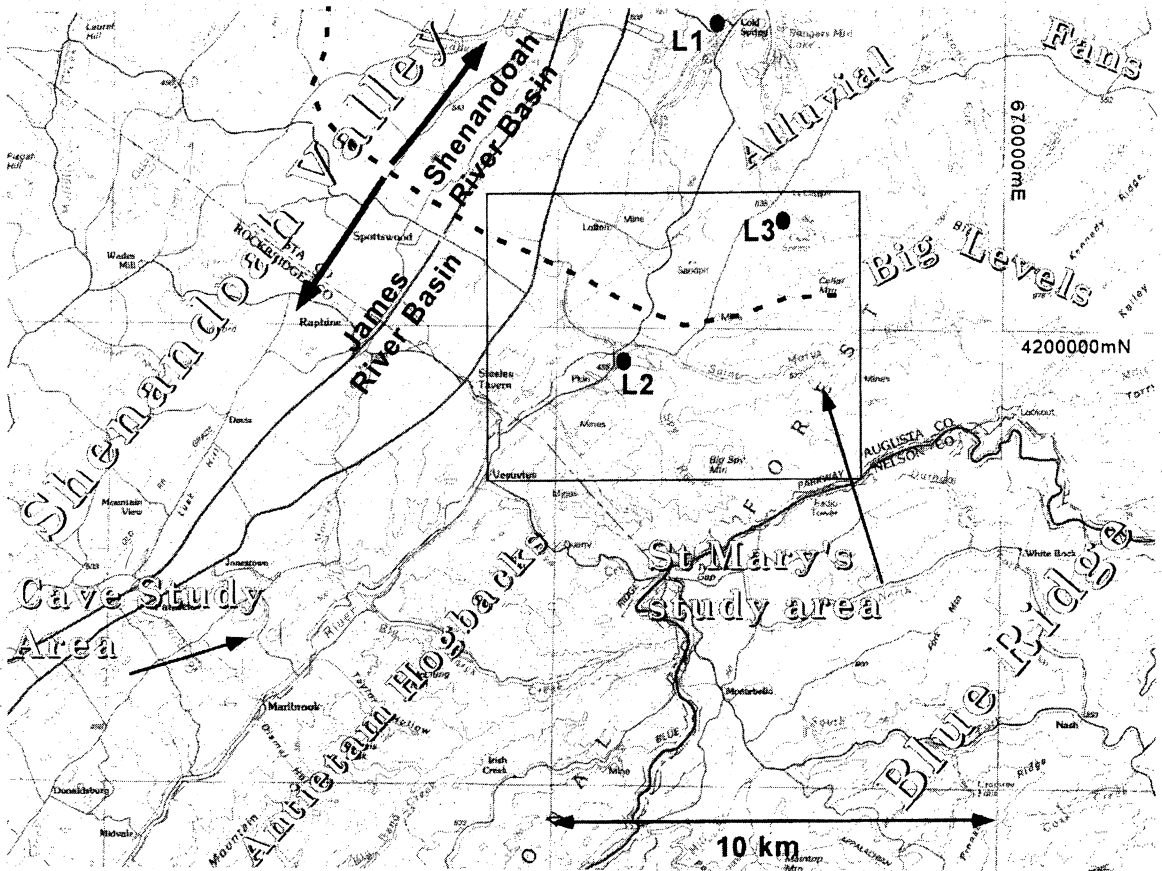


Fig. 1. Location map showing the general topography of the study area and prominent geographic features. Sample locations for sand grain lithology are indicated by L's.

downstream of State Route 608. With increased slope, and perhaps with the creation of an oversteepened reach or "knickpoint," incision migrated upstream into the headwaters area. Since capture, gully and hillslope erosion have removed most of the evidence for the "Lofton River" point of capture. The St. Marys River continues to incise at a rate greater than the streams of the Shenandoah basin.

MATERIALS AND METHODS

We used four approaches to constrain the setting and timing of this event. Geomorphic mapping, including soil and lithologic information, defined the extent and depositional nature of surficial deposits. We used the mineralogical signature and cobble orientation from soil excava-

tions to determine ancient flow direction. Detailed soil information was used to constrain the ages of deposits. The history of the South River, which is responsible for incision of the St. Marys, was illustrated using GIS approximation of stream incision and a reconnaissance study of cave morphology along the South River.

To understand the relationship of the present drainage pattern to possible past arrangements, we evaluated topography in the Shenandoah Valley using digital elevation models with a 30 m grid spacing. Our assumption was that if rapid incision in the Maury River basin is generating basin capture at the margins, then we should be able to identify differences in incision by modeling an "upland" into which the Maury basin is more deeply incised than neighboring basins. A GIS was developed that

would search for the higher parts of a low-relief surface by locating interstream divides. Criteria used in the search were that these low-relief areas had no more than 0.18 km² of drainage above them, were higher than roughly 67% of the surrounding elevations, and were more than 200 m from streams. These steps were necessary to exclude flat areas on floodplains near the major streams.

A model surface was fit to a sampling of these surface remnants, smoothed by low-pass filling (Fig. 2). Subtracting modern topography from this surface yields the amount of incision. The South River has achieved the greatest incision in the southern Shenandoah Valley, in part because of the weak rocks that underlie much of the very narrow river valley, but also because the river appears to have incised across the former drainage basin boundary. This former divide is seen as several highpoints on the model upland southwest of its current divide

position (Fig. 2). Incision of the Maury triggered incision of the South River, which expanded to the northeast following a belt of weak shale northwest of the Blue Ridge. It appears to have captured all of the current drainage that is northeast of Big Marys Creek—possibly all drainage northeast of Irish Creek—since the time when the Shenandoah Valley upland was the local base level of erosion.

RESULTS

Initial study of the Vesuvius and Big Levels quadrangles revealed the basic topography of the study area to be a large alluvial fan projecting out from the gap in the Antietam quartzite where the St. Marys River emerged, with the southern half cut away. Instead, a new fan is being formed roughly 70 m below the old. Mapping of alluvial deposits in the St. Marys River watershed above Vesuvius, including the divide area immediately north of

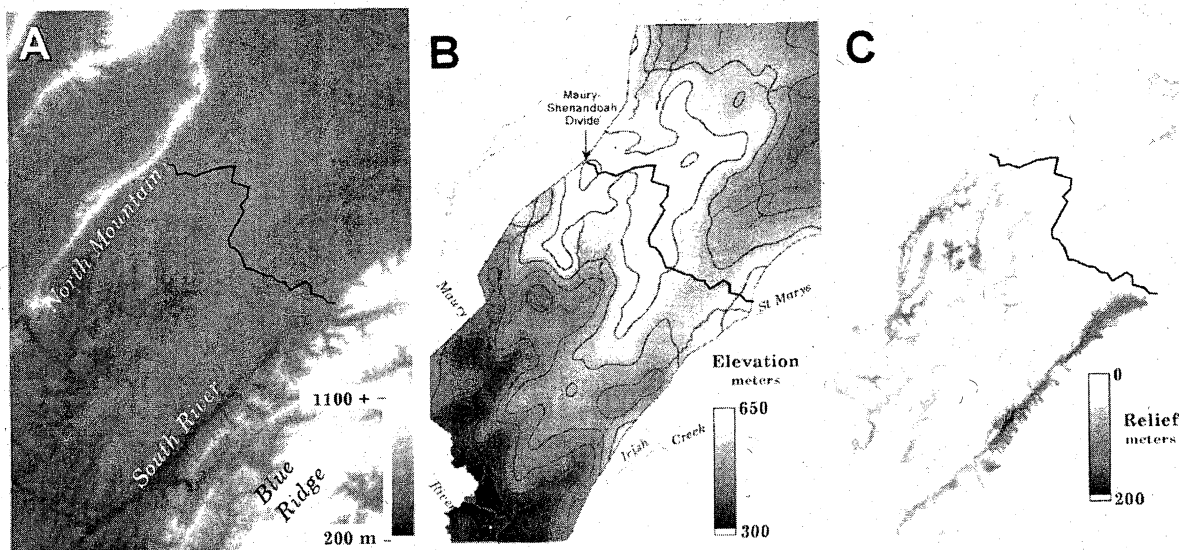


Fig. 2. Maps of the southern Shenandoah Valley showing A) a 30-m spacing digital elevation model, B) the elevation of a model surface created from interfluvial remnants that might once have been part of a lower-relief Shenandoah Valley surface, and C) depth of incision below this surface, created by subtracting modern topography (A) from the model upland (B). Notice the great depth of incision for streams within the Maury basin and the generally minimal incision in the northeastern, Shenandoah/Potomac portion of the map.

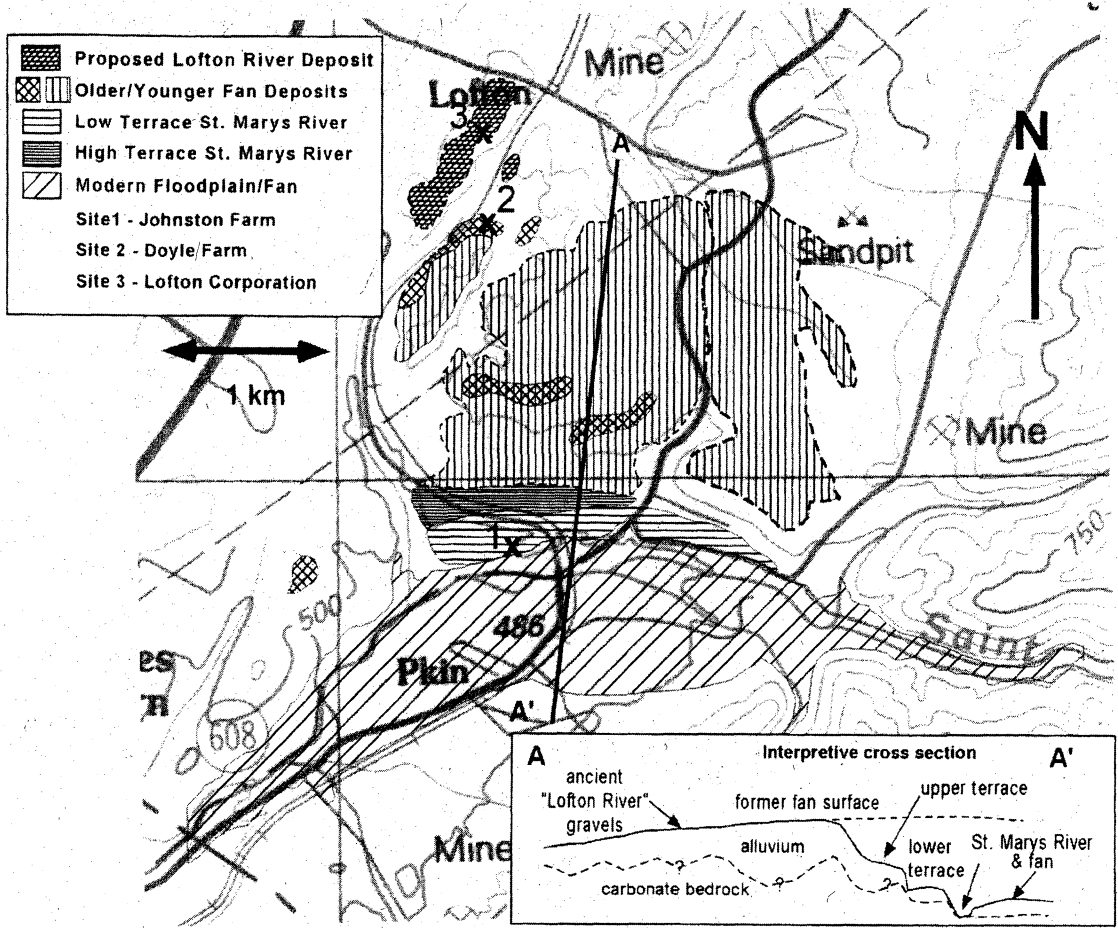


Fig. 3. Geomorphic map compiled from the Augusta Soil Survey and reconnaissance mapping. Site locations (S1, etc) discussed in text.

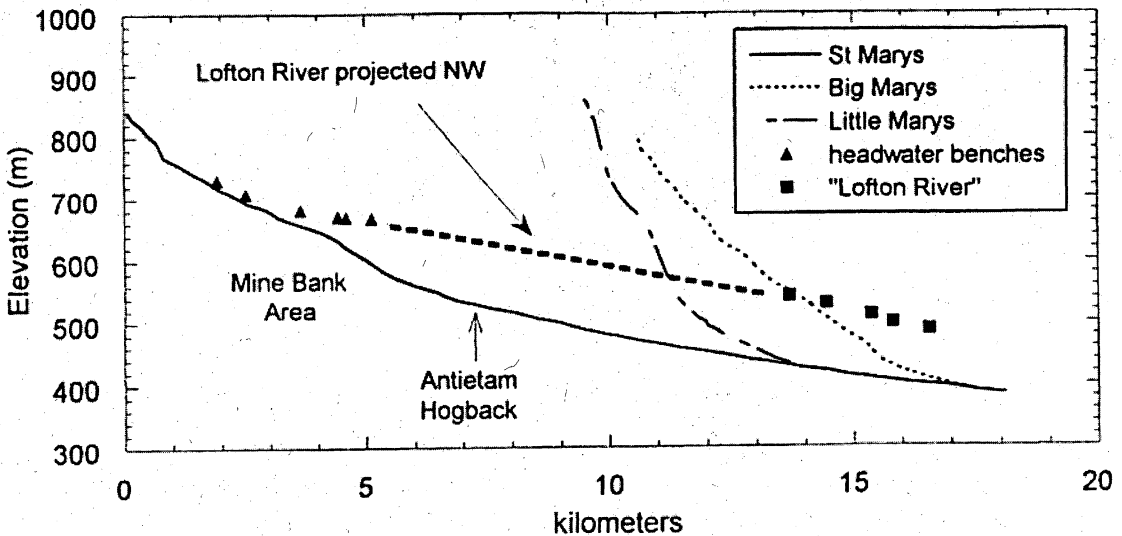


Fig. 4. Profile of St. Marys and "Lofton" Rivers. The "Lofton River" profile is made by following St. Marys River to the Antietam outcrop and then turning gently to the north to follow Pine Run along the base of the modern alluvial fans.

the river along the southernmost flank of the large alluvial fans and the area near Lofton, revealed a broad apron of alluvial material derived largely from Antietam Quartzite. These materials were generally found to underlie three landscape elements; 1) northwest-sloping, ancient fan surfaces that appear to head in the St. Marys drainage basin, 2) terraces and fans emanating from the modern St. Marys gap in the Antietam Quartzite ridge, 3) northeast-southwest trending, gently sloping terrace-like features near the toe end of the fan where it adjoins the residual carbonate terrain of the Shenandoah Valley. In addition, maps show a series of "benches" or gently-sloping terraces in the interior of the St. Marys Wilderness Area.

Soil types mapped on the Augusta County Soil Survey (Hockman et al., 1979) were used to identify the extent of former fan deposits, and using soil development as a proxy for age (e.g., Howard et al., 1993), to differentiate landforms by age (Fig. 3). An older relative age was assigned to those soils that were particularly red or clay-rich, and which possessed highly weathered cobbles of quartzite. Details concerning deposit age are covered in a following section.

Several soils indicated alluvial parent materials; Unison, Burketown, and Buchanan. All three soil types contain quartzite clasts that define the extent of the alluvial fan. The Unison soil series is found in isolated patches atop topographic peaks. The B horizon is extremely red and clay-rich, indicative of great age. Burketown and Buchanan soils also cover much of the fan. These soils are correlated with fan deposits younger than the Unison, yet they are still pre-capture. They are typically less red than the Unison. The benches within the St. Marys headwater area, as well as the slopes of the Antietam hogbacks, consist of the Monongahela series. Like the Buchanan and Burketown soils, the Monongahela soil is probably old enough to predate capture; they are merely colluvial instead of alluvial. The youngest soils of the fan, other than those in the floodplain, appear to be those of the Sherando series. This soil covers the St. Marys River terrace near Site 1 (Fig. 3). Its color does not redden significantly. Other soils developed in residuum of bedrock denote areas away from the fan or where the fan material has been completely eroded. It also became evident that younger soils covered the older Unison soils in many places. Three backhoe pits approximately 2.5 m in depth were dug to examine the soils and alluvial materials at key locations. The pits at Sites 2 and 3 probably both consist of the younger soils developed in material deposited on materials hosting the older Unison soil. This appears to be the case even on the St. Marys River terrace (site 1). Multiple layers of alluvium are common in a fan environment (Whittecar & Duffy, 1992).

The southern half of the Lofton River fan has been cut

away. However, isolated peaks of alluvial soils similar to the fan soils were noted to the west of the river on the edge of the upland (Fig. 3). These deposits contained quartzite cobbles and are mapped as the same soil series as much of the old alluvial fan to the north. These areas are interpreted to be the remnants of the fan prior to the incision of the St. Marys/South River system. We have found alluvial deposits west of the river in just one other location along the South River.

A key aid in determining relative ages of fan soils was the degree of weathering of quartzite clasts. Because these cobbles weather as a function of time, a relative age can be assigned based on the degree of weathering (Whittecar & Duffy, 1992). Quartzite cobbles near the bottom of the pit at Site 3, which is part of the old fan, could be sliced with a knife, indicating a very great age. Higher in the B horizon, quartzite clasts appeared much younger. This arrangement supports the idea of a composite or buried soil profile.

Lofton River

Topographic form near the present-day drainage divide suggests a relict fluvial environment. Site 3 sits atop a long, linear ridge trending northeast. Reconnaissance soil pits dug in the ridge revealed a poorly developed A horizon overlying a thick (30 cm) layer of silt, presumably windblown loess. This E horizon is underlain by a brown B horizon containing quartzite clasts. This stratigraphy suggests an alluvial origin, where floodplain silts are laid atop channel gravels/cobbles, and implies that the ridge is a wide floodplain or terrace without a nearby river. The ridge merges with a terrace of Pine Run just 5 km downstream (northeast).

The "Lofton River" flowed in a valley, the margins of which exist today as the high benches containing iron and manganese ores in the Mine Bank area (Stose et al., 1919) and out onto the fan surface. The slope of the "Lofton River" was probably similar to the current slope of Pine Run, although the latter is slightly incised. We can project the elevation of Pine Run and the deposits found near Lofton up into the St. Marys headwaters (Fig. 4). Here we found iron and manganese deposits that are formed by deep weathering and leaching of limestone saprolite, usually protected by an alluvial or colluvial capping. This process suggests great age and supports the existence of a relatively stable, older land surface now abandoned.

The keystone of our hypothesis is the assumption that the St. Marys River once flowed north to the South Fork of the Shenandoah River. Two types of evidence confirm this flow direction. First, the directions of cobble imbrication near Lofton suggest flow to the northwest (Fig. 5). Cobbles transported by running water typically come to

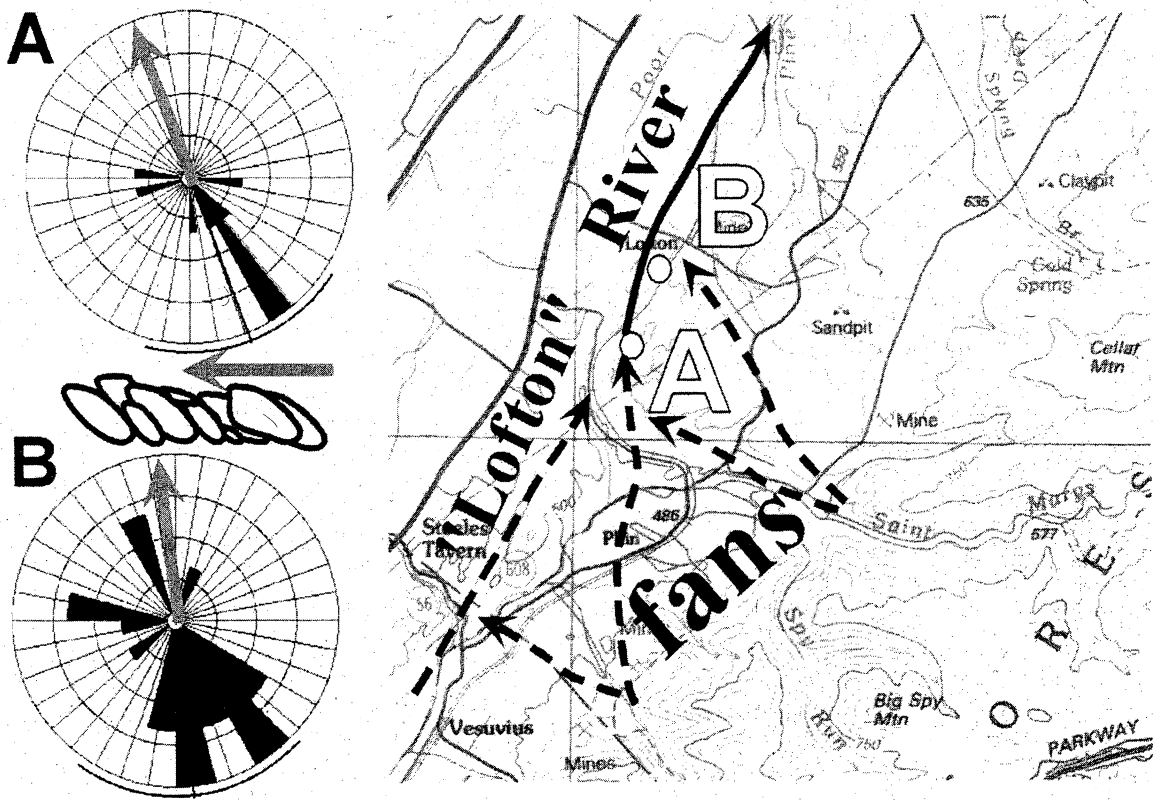


Fig. 5. Cobble imbrication cobbles in two study pits. The rose diagrams on the left give the dip direction of the cobble, and the grey arrow is drawn along the mean to show flow direction.

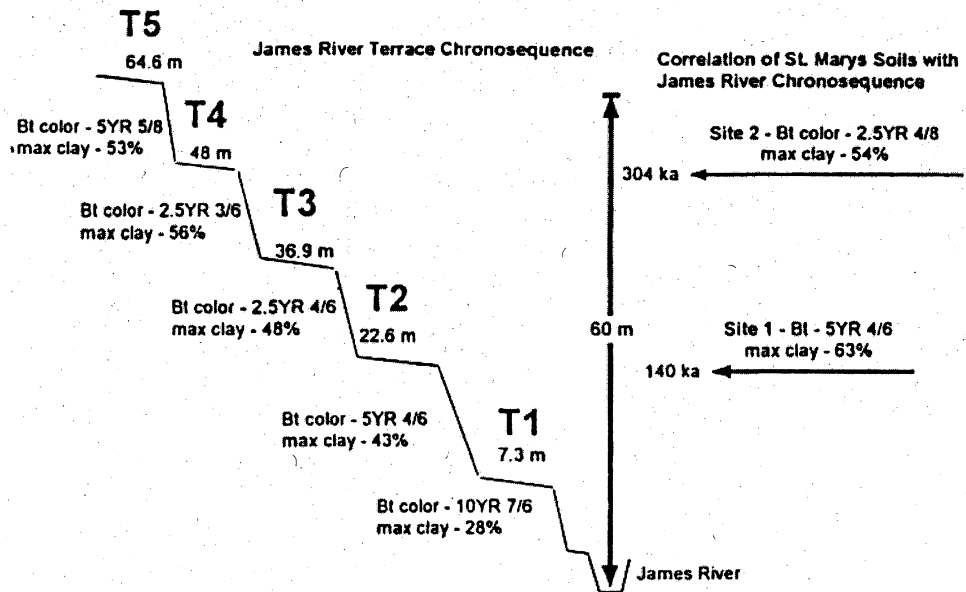


Fig. 6. Comparison of the study area soils to a sequence of soils on the James River near Gala, Virginia (Elliott, 1998). The ages of the James River terraces and the correlative soils in the study area are estimated using the cosmogenic isotope age of a 57 m terrace near Iron Gate, Virginia.

rest with their long axes perpendicular to flow and the largest flat side dipping upstream. Dip direction can vary significantly, but should define a 180-degree arc centered on the upstream direction. We measured the dip direction of between twelve and twenty cobbles in the trenches. All measurements were from cobbles in the lowest 1 m of the pit to avoid problems with disturbances from frost and biological overturning. The soils were Unison, indicating great age. In both cases, data indicate a dip to the southeast, which implies northwest flow. This is consistent with the flow direction of a stream running down or along the toe of the alluvial fan.

The flow direction of the "Lofton River" toward the northeast is also suggested by differences in the mineralogy of the sand grains taken from the ancient river course and its potential headwater areas. The "Lofton River" sample was taken from a more northeastern equivalent of the Lofton terrace exposed at a roadcut along Pine Run east of Greenville ("L1" Fig. 1). Samples from the floodplain of St. Marys River downstream of Spy Run (L2) and along Cold Spring Branch (L3) where it leaves the Antietam highlands constrain the potential source of material that could have been transported out to the "Lofton River" location. The Cold Spring and St. Marys samples differ in mineralogy; only the St. Marys sample contains mineral grains associated with crystalline basement rocks. The St. Marys alluvium contains abundant ilmenite and some rutile, whereas Cold Spring Branch samples contain no ilmenite and no rutile. The "Lofton River" sample has common ilmenite and few rutile. The latter sample is likely to have been changed by great weathering, but still suggests that one source for the sediment was the St. Marys headwaters. The source for the igneous minerals is the Pedlar Formation which formed the core of the Blue Ridge in the study area. None of the mountain streams in the area immediately north of the St. Marys River has headwaters underlain by the Pedlar formation. Of course, other streams to the southwest with basins underlain by crystalline basement southwest of the St. Marys River may also have been part of the headwaters.

Timing

We constrain the age of the capture event by comparing soils in the study area to soils developed in a series of five James River terraces on Devonian shale near the town of Eagle Rock (Elliott, 1998). This soil chronosequence demonstrates increasing soil thickness, soil redness, and B-horizon clay percentage with height above the river. The age of this terrace sequence is itself constrained by cosmogenic isotope dating of quartz pebbles obtained from an abandoned meander 57 m above the James River

near Iron Gate, which is approximately 15 km upstream. This date returns an incision rate of 160(40 m/million years (Erickson, 1998), which we use along with the terrace elevation to determine age. The 60 m terrace correlates well between these two sites along the James River, but we are forced to assume a constant incision rate to determine soil ages at the downstream site. To correlate the James River terrace soils to the St. Marys field area, we rely mainly on the color (Munsell standard notation) and maximum clay percentage in the red, clay-rich B horizon (Fig. 6).

The younger fan remnants and alluvium in the Lofton soil pit (Site 3) give the youngest age for deposits of the Lofton River while the St. Marys River terrace (Site 1) is the oldest deposit post-dating the capture event (Fig. 2). The upper soil profile at Site 2 and the soil at Site 3 match with terraces at or above 48 m along the James. The James River incision rate yields an age of approximately 300,000 years. Site 1 corresponds most closely with the 22.6 m terrace from the James River chronosequence. The color of the clay-rich Bt horizon in both of these terraces match; however, the maximum clay percentage of the Bt horizon was about 50% greater in the Johnston Farm soil than in the James River terrace soil (Fig. 6). The source of increased clay may be in the easily weathered crystalline rocks of the St. Marys River, which are not found in the James River Basin, or in a depositional mechanism that carries more clay-rich sediment, such as a debris flow. Given this caveat, the Site 1 soil was assigned an age of approximately 140,000 years. Capture of the St. Marys River by the James River basin occurred before this date.

The degree of weathering of quartzite clasts indicates that the pre-capture fan had been re-worked for some time prior to capture. According to the Whittecar & Duffy (1992) data, many of the cobbles in the trench at Sites 2 and some in Site 3 may have been deposited as early as the Tertiary. This is extremely old for a surface deposit. Cobbles nearer the top of the trench at Site 2 were not nearly as disintegrated, indicating a younger age. The degree of weathering of these cobbles was similar to those found in the 48 m terrace along the James River (Elliott, 1998). It is clear that the path of the Lofton River migrated laterally across its valley, reworking older deposits and covering them with younger layers. Site 3 appears to support the idea of a relatively young deposit (Buchanan soil) overlying a very old deposit (Unison soil). Similarly, layering of deposits and soils of various ages are found at Site 1. The St. Marys River terrace is not a flat surface; rather it is a rolling plain. The Augusta County Soil Survey (Hockman, 1979) categorizes much of the terrace as Unison, although there is clearly a thin mantle of Sherando soil overlying much of it.

The Shenandoah Valley upland west of the South

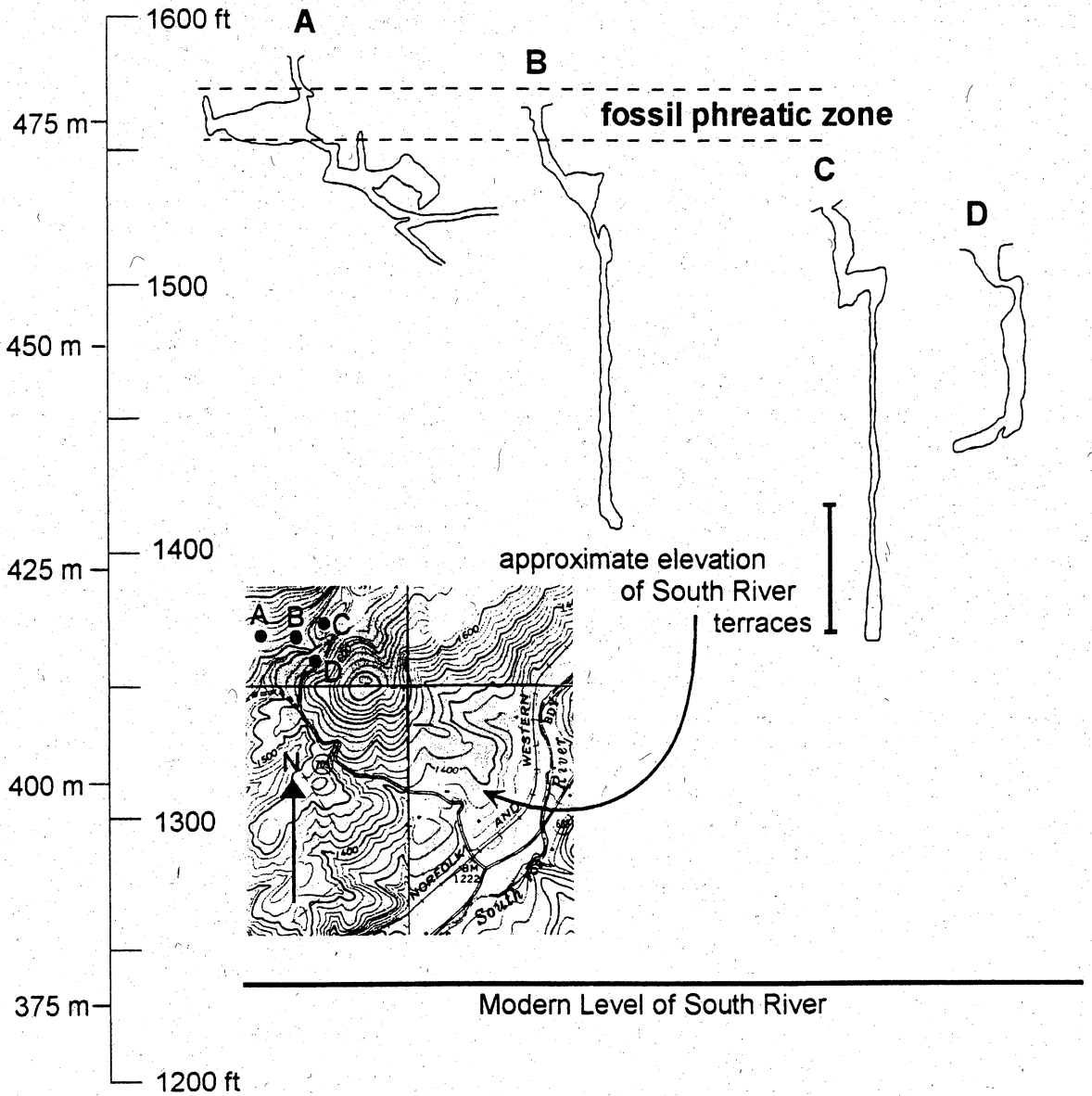


Fig. 7. Cave cross sections showing the narrow fissure shape, possible paleo-phreatic upper rooms, and a depth coincident with terraces of the South River. Cave profile and cross section height and width were measured with tape, compass, and inclinometer.

River near the confluence of Big Marys Creek contains a number of sinkholes and caves, as well as isolated occurrences of quartzite-bearing alluvium. The shape of cave passages below this surface along the South River corroborates rapid incision followed a more stable period when streams flowed farther out into the Shenandoah Valley (Fig. 7). Solution of large caverns often occurs at the elevation of the water table; thus, elliptical passages

record position of a relatively stable base level. Some caves have relatively broad rooms near the surface connected by small passages to the chasms below. The elliptical shape, particularly for cave A, and size of surface rooms suggests they developed when the water table was stable and at least as high as the entrance. The water table level then dropped rapidly, allowing the deep, narrow fissures to develop along structurally-controlled

northeast-trending fractures found throughout the valley. The passages again widen at a depth as much as 40 m (130 ft) below. Room elevations at the bottom of these fissures are roughly coincident with a broad terrace along the South River at an elevation of 425 m (1,400 ft). The modern-day South River lies at 375 m (1,230 ft).

The terraces and cessation of cave incision represent the next period of stability in water table level connected to the South River. Further cave exploration may reveal broad rooms at the bottom of the fissures. In any case, another incision episode followed, lowering the South River to its present elevation.

CONCLUSIONS

The geomorphic history of the St. Marys River region is one of incision. Our evidence suggests that the region went through complex changes to reach its present form. Knickpoint migration is the most probable mechanism for the incision of the St. Marys/South River system. It is also the cause of the drainage divide migration. Cave shape and terrace morphology support the idea of at least two periods of stable local base level separated by rapid incision along the South River, leading up to the St. Marys River. The first of these incision episodes, beginning at most 300,000 years ago along the Maury River Basin, caused a shift in the flow direction of the Lofton River by giving a headwater stream of the South River enough advantage to erode headward into the Lofton drainage. A stable period followed during which many of the Lofton River fan deposits were shifted and reworked. Another incision episode followed, finishing over 100,000 years ago, forming the St. Marys River terrace on older fan deposits. Incision episodes were probably complex responses, with periods of cutting and filling and rapid channel migration across the valley. In this manner, the complex geometry of the present-day alluvial fans in the St. Marys area was developed.

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