# Stratigraphic and Paleomagnetic Evidence for Fluvial Incision Rates of the Upper James River, Virginia

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## INTRODUCTION

Three landscape features near Iron Gate, Virginia, were determined to be abandoned meanders of the James River through sedimentary analysis of auger holes and backhoe pits dug in all three areas (Fig. 1). The meanders were given the names Bryant Meander, Owens Meander, and Soldiers Retreat Meander. Paleomagnetic dating of abandoned meander sediments exposed in the backhoe pits placed the Bruhnes/Matuyama normal-to-reversed polarity transition at approximately 55 meters above modern James River level (AMJRL). This placement allowed the calculation of a minimum incision rate for the upper James River, Virginia as 75 m/m.y. ±24 m/m.y.

## PALEOMAGNETIC DATING OF ABANDONED MEANDERS

**Introduction.** The abandoned meanders provided a unique opportunity to determine a minimum date of when the James River was at various elevations AMJRL through paleomagnetic dating of their sediments. The abandoned meander segments are unique since the channel deposits are buried and preserved through infilling processes almost immediately after their abandonment. Therefore, each of the abandoned meanders contains a buried terrace, above which was generally deposited a fining upward sequence of fine sands, silts, and clays. A paleomagnetic study of field reversals in the sediments above the channel deposits results in a minimum date of abandonment for that part of the river. This date can then be used to calculate an incision rate.

**Collection Process.** Samples were taken in oriented plastic collection cylinders by pushing the cylinder into the pit wall. Samples were primarily taken in horizons of silt to silty-clay size sediments, as these sizes best record detrital remanent magnetization (DRM) (Rutter and Catto, 1995). Samples were taken in a vertical line downwards spaced to adequately cover the sediment horizons with silt to clay sized particles. Only one sample core was taken at each vertical height within a pit. A total of 24 paleomagnetic samples were taken from Bryant Pit 2, Owens Pits 3 and 4, and Soldiers Retreat Pit 5 (Fig. 1).

**Sample Analysis.** Samples were analyzed at the University of Pittsburgh Paleomagnetism Laboratory, in a magnetically shielded room that reduces the Earth's present magnetic field strength to below 2.5 x $10^{-4}$ millitesla (mT) (Sasowsky, 1995). The samples were cleaned using alternating field demagnetization (AF), and then measured in a large-bore ScT cryogenic magnetometer. The process was fully automated and corrected for stratigraphic strike and dip. The AF levels were applied by increasing the demagnetization level at 5 mT steps, from 0 to 50 mT, and then increasing the steps to 10 mT from 50 to 70 mT. The resulting paleomagnetic data were then plotted as Zijderveld (1967) vector endpoint diagrams and on steronets. Analysis of these plots allowed the removal of unstable vector components, which often represent overprints of the current magnetic field (Butler, 1992). Vectors at certain demagnetization levels, which ideally showed linear trends to the origin, were then chosen to represent the stable component of remanent magnetization at time of acquisition. This stable component ideally depicts the Earth's magnetic field at the time of sediment deposition .

**Magnetic Results.** Three general trends were found when the vector endpoint diagrams were analyzed (Fig. 2). Normal-polarity samples generally showed decay towards the origin at high AF levels, while magnetic intensity also fell linearly to well under half of their initial intensity. Sample number 02 was representative of this type of trend (Fig. 2A). Another general trend was for little or no decay towards the origin at high AF levels, while magnetic intensity remained virtually constant. The resulting vector endpoint diagrams showed a clustering of points such as sample 12 (Fig. 2B). This type of plot is most likely attributed to the fact that magnetically "hard" hematite is the primary magnetic mineral in these samples (Butler, 1992). To accurately determine the remanent magnetization of these samples, they would have to be demagnetized at much higher levels, probably through thermal demagnetization, which would be impossible since the samples were taken in plastic containers.
Sample number 24 (Fig. 2C) showed the most convincing reversal. Magnetic intensity only fell to slightly above half of the initial intensity, but the vector endpoint diagram clearly shows that the sample was decaying to a southerly direction. The stereonet plot of this sample also confirmed that the sample was becoming more southerly in orientation. Sample number 18 (Fig. 2D) shows another reversal, albeit more complicated than the last one. This sample does not decay linearly to the origin, and the magnetic intensity only reduced to above half of its initial intensity. However, the sample clearly shows a reversed polarity for its last two AF levels of 60 mT and 70 mT, with both a southerly declination and negative inclination.

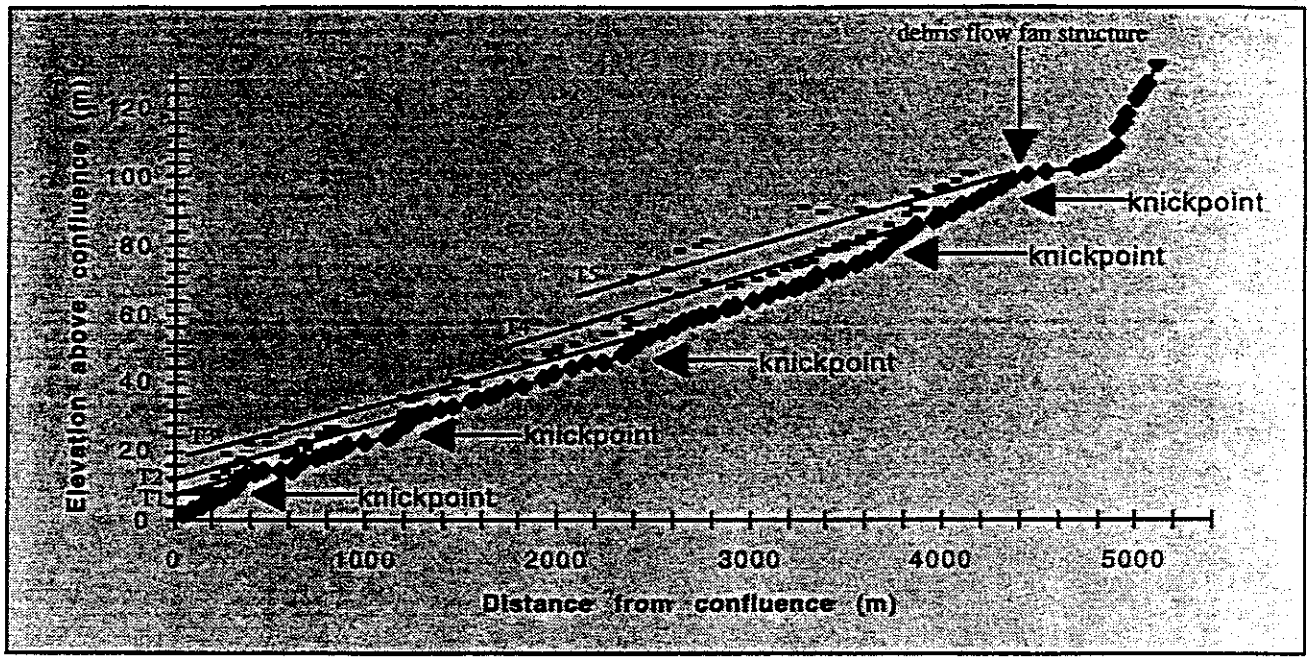


Fig 1. Whistle Creek surveyed profile (diamond symbols) and bedrock terrace elevations (dashed symbols). O meters corresponds to the confluence of Whistle Creek and the Maury River. Terrace levels end abruptly at channel knickpoint locations. Note the debris flow fan structure immediately downstream from the break in slope of the channel floor. The location of this feature suggests a change in the mode of channel bedrock incision at the break in slope of the channel profile.

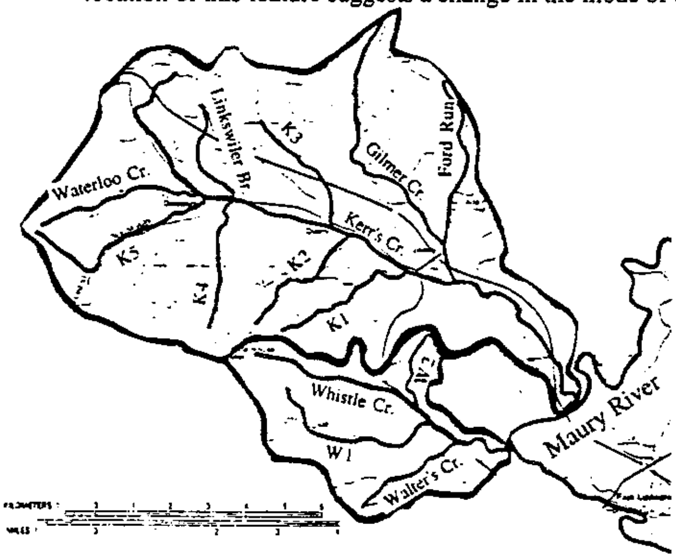


Fig. 2: Map of the Kerr's Creek and Whistle Creek catchments and their confluence with the Maury River. North is oriented vertically upward, and scale is 1:100.000.

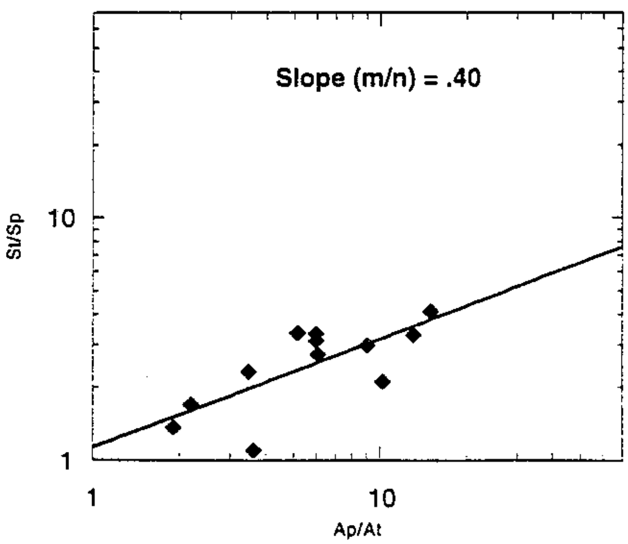


Fig. 3: Plot of Ap/At against St/Sp for Whistle and Kerr's Creek. This data suggest an m/n ratio equal to O.4.

| Parent Stream | Tributary | Ap (ft^2) | Sp | At (ft^2) | St | Ap/At | St/Sp |
|---|---|---|---|---|---|---|---|
| Whistle Cr. | Walter's Cr. | 227826000 | 0.0132 | 37479000 | 0.0361 | 6.08 | 2.73 |
| Whistle Cr. | W1 | 184242000 | 0.0197 | 96840000 | 0.0270 | 1.90 | 1.37 |
| Whistle Cr. | W2 | 82124000 | 0.0229 | 22748000 | 0.0252 | 3.61 | 1.10 |
| Kerr's Cr. | Ford Run | 883962000 | 0.0072 | 59137000 | 0.0294 | 14.95 | 4.11 |
| Kerr's Cr. | Gilmer Cr. | 883962000 | 0.0072 | 171912000 | 0.0241 | 5.14 | 3.37 |
| Kerr's Cr. | K1 | 595588000 | 0.0080 | 58318000 | 0.0170 | 10.21 | 2.12 |
| Kerr's Cr. | K2 | 521016000 | 0.0085 | 57870000 | 0.0254 | 9.00 | 2.99 |
| Kerr's Cr. | K3 | 451878000 | 0.0086 | 75799000 | 0.0266 | 5.96 | 3.11 |
| Kerr's Cr. | K4 | 333338000 | 0.0114 | 55706000 | 0.0379 | 5.98 | 3.33 |
| Kerr's Cr. | Linkswiler Br. | 277925000 | 0.0114 | 21421000 | 0.0376 | 12.97 | 3.30 |
| Kerr's Cr. | K5 | 249413000 | 0.0134 | 113854000 | 0.0227 | 2.19 | 1.70 |
| Kerr's Cr. | Waterloo Cr. | 134449000 | 0.0145 | 38884000 | 0.0336 | 3.46 | 2.31 |

Table 1: Summary of Virginia Valley and Ridge Province data. Ap, Sp, At, St refer to parent stream watershed area, parent stream channel slope, tributary watershed area and tributary channel slope, respectively.

**Interpretation.** The two proposed reversals, numbers 18 and 24, become even more convincing when they are put into a stratigraphic relationship with one another (Fig. 3). The two pits, Owens Pits 3 and 4, that contain these samples were approximately 25 meters apart. The fact that the two pits, side by side, have reversals at about the same place in their magnetostratigraphy strongly supports the idea that these samples represent a period of reversed-polarity. Most of the other samples taken are representative of times of normal-polarity. Some samples plot toward a southerly direction but cannot be entirely interpreted as such since they either have positive inclinations or plot in an almost intermediate direction. These intermediate directions could also be recording the excursions of the magnetic field during a reversal.

## INCISION RATES

**Relative Meander Age.** The stratigraphy created by a downcutting river is opposite to that created in a normal sedimentary deposit. River incision leaves the oldest alluvial features (i.e. abandoned meanders, terraces, and caves) at higher levels or elevations, while the youngest features are at lower elevations near the modern river level (Fig. 4). The Owens and Bryant meanders (Fig. 1) are both approximately 55 meters ± 24 m AMJRL, while the Soldiers Retreat Meander is approximately 17 m ±2 m AMJRL. This relationship means the Owens and Bryant Meanders are of the same relative age, and older than the Soldiers Retreat Meander. The altitudes for the Owens and Bryant Meanders were determined from the Clifton Forge Quadrangle topographic map. The map has a contour interval of 40 feet or 12 m. The error interval when determining the elevation of an object relative to another from a contour map is two times the contour interval, which is 80 ft or 24 m for the Clifton Forge Quadrangle. The Soldiers Retreat Meander has a ±2 m range because an altimeter reading was taken for this pit. Limitations on time and bad weather resulted in the lack of altimeter readings for the Owens and Bryant Meanders.

**Owens Pit Magnetostratigraphy.** The magnetostratigraphy of the sediments within the Owens pits places the time of abandonment for that meander at around the boundary of the Bruhnes/Matuyama polarity epoch, which represents a minimum age of 730 Ka (Butler, 1992). This assumption is based on the fact that paleomagnetic samples within the Owens pits display normal polarities at the top of the pit and reversed polarities near the bottom (Fig. 3). Therefore, the deposition of the Owens Meander sediments capture a normal-to-reverse polarity transition, which possibly occurs at around 2 m below the surface in both pits (Fig. 3). Samples 17, 22, and 23 (Fig. 3) all display indiscernible polarity directions, which could be recording the field reversal itself. Therefore, the James River was at roughly 55 m ±24 m AMJRL at approximately 730 Ka.

**Bryant Pit Magnetostratigraphy**. All samples taken in this pit were of normal polarity. However, one sample taken near the bottom of the pit could possibly represent a reversed polarity, but it could not be interpreted entirely as such since it would not demagnetize at high AF levels. The Bryant and Owens Meanders should be the same relative age since they are both at the same elevation, but the Bryant pit does not record a distinct reversal like the Owens pits. A logical explanation for this is that the two meanders were cut off near the same time, but the Owens Meander channel filled in with sediments faster than the Bryant Meander. The faster infilling of the Owens pit recorded the polarity transition, while slower infilling of the Bryant Meander recorded only normal polarities. Possible reversals could have been recorded in Bryant Pit 2 at depths greater than sampled.

**Soldiers Retreat Magnetostratigraphy**. All paleomagnetic samples taken from the Soldiers Retreat Pit 5 were of normal polarity. This interpretation fits in well with other data, since the Soldiers Retreat Meander is the lowest meander, making it stratigraphically the youngest in a downcutting environment.

**Calculation of Incision Rates.** The presence of a normal-to-reversed polarity Bruhnes/Matuyama transition at approximately 55 m (±24 m) AMJRL allows the calculation of a minimum local incision rate by dividing the age of the transition (730 Ka) by its height AMJRL (Sasowsky, 1995). This rate represents a minimum because there is no way to determine the exact age of the reversed polarities within the Matuyama epoch, however, they can be assigned a minimum age of 730 Ka since they are reversed. The calculation gives an incision rate of $7.5\times10^{-5}$ m/yr., which can be converted to 75 meters per million years (m/m.y.) by multiplying by $10^6$ years. Factoring in the ±24 m for the elevation of the pits from the contour map, results in a ±33 m/m.y. error range for the incision rate. This error range places the high limit of incision at 108 m/m.y. and the low rate at 42 m/m.y., with an average of 75 m/m.y.

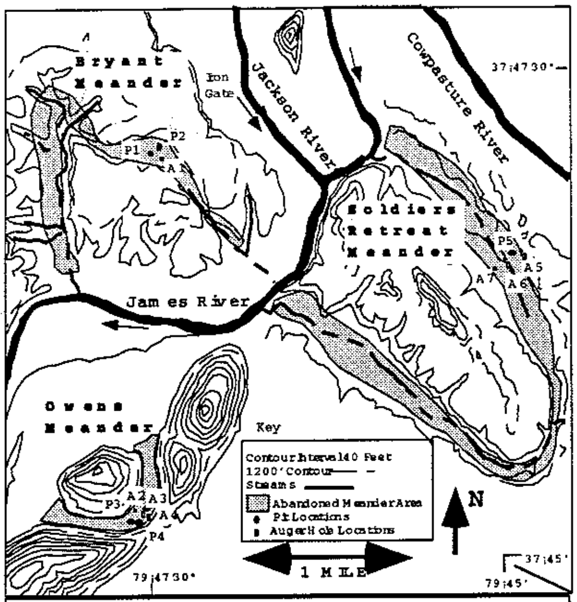


Fig. 1. Local map of study area showing three abandoned meanders and pit locations.

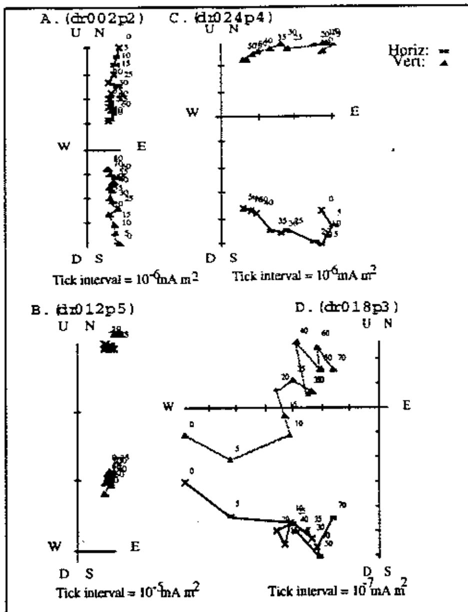


Fig. 2. Zijderveld diagrams for selected paleomagnetic samples. U and D indicate up and down. Blue x's represents horizontal component while red triangle represents vertical component. Numbers next to data points represent demagnetization levels in mT (milliteslas).

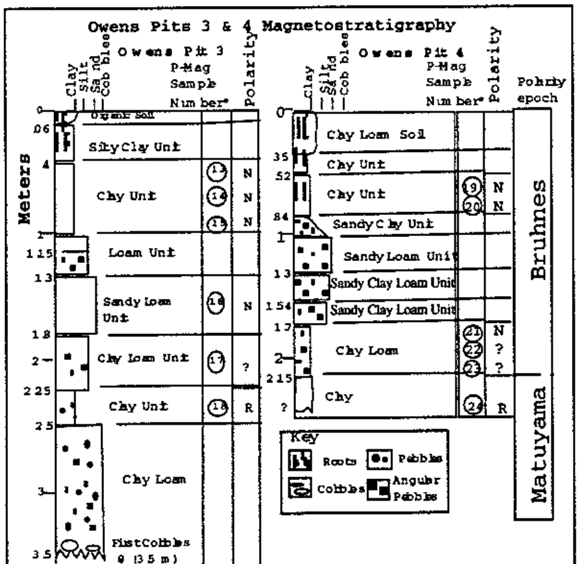


Fig. 3. Polarity of paleomagnetic samples taken in Owens Pits 3 & 4, and likely polarity epoch that they fit into. Relative grain sizes of sedimentary units marked by scale at upper left hand corner.

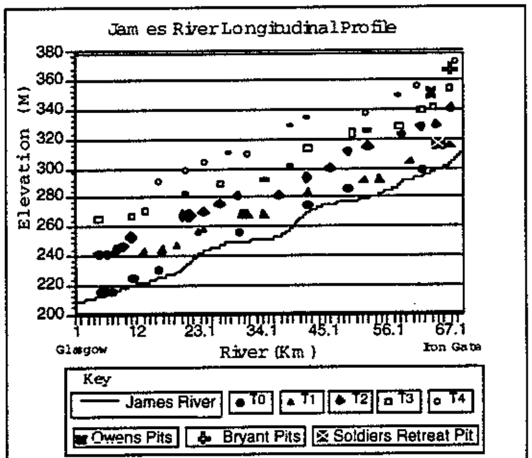


Fig. 4. Longitudinal profile of the James River (solid line) and elevations of mapped terraces.

## CONCLUSIONS

Normal-to-reversed polarity samples recorded in the Owens Pits 3 and 4 (Fig. 3) place the Bruhnes/Matuyama polarity epoch boundary of 730 kA at approximately 55 m AMJRL (Fig. 4). This conclusion, results in a minimum incision rate of 75 m/My (±33 m/My) for the upper James River. These conclusions represent a first attempt to determine an incision rate for the study area. Further work in and around the study area could result in a better interpretation of an average incision rate. Exact elevations for both the Bryant and Owens meanders would drastically narrow the error range of ±33 m/My. The findings of this study warrant further more intensive paleomagnetic sampling of the fluvial features of the area, to create a more complete magnetostratigraphy.

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