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The Response of the Kentucky River Drainage Basin to a Lowering of Base Level Control

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THE RESPONSE OF THE KENTUCKY RIVER DRAINAGE BASIN
TO A LOWERING OF BASE LEVEL CONTROL

by

David B. Warwick

A Thesis
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Faculty of The Graduate College
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Western Michigan University
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THE RESPONSE OF THE KENTUCKY RIVER DRAINAGE BASIN TO A LOWERING OF BASE LEVEL CONTROL

David B. Warwick, M.S.
Western Michigan University, 1985

The Kentucky River has responded to a lowering of base level control by: 1) deepening the course of its channel; 2) cutting off meanders as incision proceeded; 3) developing knickpoints on tributaries; 4) widening its valley; and 5) dissecting the upland surface.

Field work involved surveying streams to obtain profiles. Twenty streams covering 125 miles of river from Carrollton to Camp Nelson, Kentucky were surveyed. Knickpoints were defined from these profiles. Data from stream profiles showed knickpoint distances decreasing with increasing distance up river. Map work involved obtaining data for hypsometric curves. Hypsometric integrals were determined from these curves. Data showed an increase in hypsometric integrals with increasing distance up river. Statistical analyses of this data verified these trends. The response of the Kentucky River drainage basin to a lowering of its base level control is differential adjustment to a change in equilibrium states with more of the relict upland surface present with increasing distance up river.
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David B. Warwick
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# TABLE OF CONTENTS

## ACKNOWLEDGEMENTS

### LIST OF TABLES

### LIST OF FIGURES

### CHAPTER

1. **INTRODUCTION** .................................. 1
   - General Setting .................................. 1
   - Study Area ...................................... 5

2. **PREGLACIAL ENVIRONMENT** .......................... 10
   - Teays River .................................... 10
   - The Upper Teays .................................. 11
   - The Lower Teays ................................. 12
   - Preglacial Erosional Cycles .................... 15
   - The Preglacial Kentucky River ................. 16
   - The Preglacial Ohio River ..................... 18

3. **DRAINAGE MODIFICATIONS** ........................... 23
   - Damming of the Teays ........................... 23
   - Ponding of the Kentucky River ................ 24
   - Breach of the Madison Divide ................. 25
   - Deep Stage ..................................... 26

4. **REJUVENATION OF THE KENTUCKY RIVER** ............... 29
   - Causes of Rejuvenation ....................... 29
   - Evidence for Rejuvenation .................... 30
   - Response to Rejuvenation ..................... 31
TABLE OF CONTENTS—CONTINUED

CHAPTER

Field Work ........................................ 41
Hypsometric Analysis ............................... 44

V. CONCLUSIONS ...................................... 50
Statistical Analysis of Data ....................... 50
Findings and Interpretations .................... 54

APPENDICES

A. Hypsometric Curves for Streams Profiled with
Hypsometric Integrals (HI), and Mouth to Tributary Distances (MI). ............ 57

B. Profiles of Selected Tributary Streams of the
Kentucky River Showing Knickpoint Position. .. 73

BIBLIOGRAPHY ........................................... 82
LIST OF TABLES

1. Knickpoint Distances, Hypsometric Integrals, Mouth to Tributary Distance ........ 45

2. Mean, Standard Deviation, Maximum, and Minimum of Field and Map Data. ........ 51

3. Correlation Matrix of Knickpoint Distance, Hypsometric Integral, Basin Area, and Mouth to Tributary Distance ....................... 52
LIST OF FIGURES

1. Escarpments of Kentucky and Indiana ............ 3
2. Location of Study Area ................................ 7
3. Location and Geology of the Bluegrass Region .. 8
4. Preglacial Drainage of the Northern Midwest .. 13
5. Course of the Preglacial Kentucky River from
   Carrollton to Lawrenceburg ...................... 19
6. Proposed Origin of the Ohio River ................ 21
7. Slope and Elevation Comparison of the
   Preglacial and Present Kentucky River ........ 32
8. Slope Comparison of the Kentucky/Teays and
   Kentucky/Ohio Systems ........................... 35
9. Longitudinal Profile Showing Knickpoint
   Migration ....................................... 37
10. Valley Width Versus River Width .................. 39
11. Position and Elevation of Cutoff Meanders .... 40
12. Characteristic Hypsometric Curves ............... 48
CHAPTER I

INTRODUCTION

General Setting

The Kentucky River located in north-central Kentucky originates at the foot of Pine Mountain and flows northwest. The river begins at an elevation of about 2500 feet and descends to 420 feet at its confluence with the Ohio—a vertical difference of approximately 2080 feet. The average slope is 0.9 feet per mile. In its 420 mile length the Kentucky River drains 7000 square miles and has a discharge of 6500 to 10,500 cubic feet per second. The main Kentucky River is formed by the junction of its three forks near Beattyville, Kentucky; the North, Middle, and South. From Beattyville to Carrollton four major streams join the Kentucky River; the Red River, Dix River, Elkhorn Creek, and Eagle Creek.

From Pine Mountain to Irvine the river flows over the Cumberland Plateau, and from Irvine to Carrollton the river flows across the Interior Low Plateau. The Interior Low Plateau is dominated by the Lexington erosional surface (Jillson, 1945; Thornbury, 1965). The Lexington erosional surface also known as the Highland Rim erosional surface is the remnant surface of regional
base leveling during the Tertiary. This gently undulating surface is best developed around the Lexington area. The surface at elevations ranging from 725 feet to 1100 feet is relatively undissected except in the vicinity of the Ohio and Kentucky Rivers. In these areas up to 500 feet of relief exists. Otherwise the present surface is much the same as the surface developed during the Tertiary (Thornbury, 1965).

The major physiographic features of Kentucky as described by Thornbury (1965) are cuestas that have developed on the flanks of the Cincinnati Arch. The leading edge of these cuestas form escarpments that face up-dip to the regional slope. These escarpments, Muldraughs Hill, Dripping Springs, and the Pottsville separate the Bluegrass, Pennyrile, and the Mammoth Cave Plateau provinces of Kentucky (Figure 1).

The headwaters of the Kentucky River flow through sandstones and conglomerates of the Pennsylvanian Pottsville Formation. Closer to Irvine, limestones, sandstones, and shales of the Mississippian Chester, Meramec, and Waverly groups are exposed along the Kentucky River. From Irvine to Carrollton, Kentucky, limestones, dolomitic limestones, sandstones, and shales of Silurian, Devonian, and Ordovician age are exposed.
Figure 1. Escarpments of Kentucky and Indiana.

From the confluence of Red River to Carrollton, Ordovician limestones and shales of the High Bridge, Trenton, Cynthiana, Eden, Maysville, and Richmond groups are present in the Kentucky River channel (Jillson, 1945).

The principal structure in the Kentucky River drainage basin is the Cincinnati Arch. This structure, a large anticlinal feature, has undergone intermittent uplift from the late Ordovician with the last episode beginning in the Pliocene and continuing into the Pleistocene (Jillson, 1945). The Cincinnati Arch extends into northwestern Ohio and Indiana and continues south through Cincinnati into Kentucky. Topographically the highest point of the arch is at an elevation of 1100 feet located at Camp Nelson, Kentucky. From Camp Nelson the southern extension of the Cincinnati Arch, the Cumberland Saddle and the Nashville Dome can be traced into Tennessee and Alabama. In the vicinity of Camp Nelson complex normal faulting with 250 to 350 feet of throw is present. This fault zone known as the Kentucky River Fault is associated with the Cincinnati Arch. The Kentucky River crosses the fault nine times between Camp Nelson in the west and Boonesboro to the east.

Numerous faults associated with the Kentucky River Fault Zone are present in the Kentucky river drainage
basin. In the lower portion of the river from Camp Nelson to Carrollton faulting is minor and effects little control on the Kentucky River and its tributaries. However, the main Kentucky River Fault has influenced the course of the river. The river maintains a northwest course until it reaches Boonesboro, Kentucky. At this point the river follows a southwest course through Clark, Madison, Fayette, Jessamine, and Gerrard Counties. This southwest bend presents an anomalous drainage pattern. The valley becomes subsequent rather than consequent. The Kentucky River Fault trends northeast-southwest. This southwest diversion of the Kentucky River was caused by 350 feet of downthrow on the southeast side of the river. During faulting which may have occurred as early as the Cretaceous Period, the river must have met the obstruction caused by this fault. According to Jillson (1945) this could have caused temporary damming of the river until low points between divides were breached. Apparently this occurred along the southwest strike of the fault and created the diversion.

Study Area

Field work and data collection was conducted in the Kentucky River drainage basin between Carrollton and Nicholasville, Kentucky (Figure 2). The area is entirely
within the Bluegrass region of north-central Kentucky. The Inner and Outer Bluegrass region is typified by gently undulating topography with relief being less than 50 feet. This region is largely a limestone terrain with some minor karst features.

The Inner Bluegrass encompasses the Jessamine Dome (high point of the Cincinnati Arch) and is developed on limestones of the Ordovician Trenton and High Bridge groups. The Eden Shale Belt separates the Inner and Outer Bluegrass. It ranges from 5 to 30 miles wide and varies greatly from the Inner and Outer Blue Grass (Figure 3). The shale allows for maximum surface runoff and erosion subsequently producing hilly topography. The Outer Bluegrass is underlain by rocks of the upper Ordovician Eden, Maysville, and Richmond Group limestones and shales. The topography is much the same as the Inner Bluegrass. The Bluegrass region has undergone little dissection except near major drainage ways.

Significant differences in the study area in stream profiles and topographic relief are present. The Kentucky River flows through the Palisades in the southern portion of the field area. The Palisades are a 20 to 30 mile section of river that is characterized by cliffs and massive exposures of Camp Nelson Limestone.
Figure 2. Location of study area.
Figure 3. Location and geology of the Bluegrass Region.

Here the river is entrenched 350 feet below the upland surface and is very narrow.

Major tributaries to the Kentucky have reached an equilibrium stage, however, smaller tributaries not having reached equilibrium rise above the river in a step-like manner. From north of Frankfort to Carrollton the river valley broadens, cliffs disappear and relief is lower. At Carrollton the elevation of the Lexington surface is 850 feet; thus the river maintains a general relief of 400 feet between the river and the upland surface from the gorge-like Palisades to the mouth at Carrollton (Jillson, 1945).

Entrenchment of the Kentucky River below the Lexington surface is a result of a lowering of base level control. The purpose of this study is to investigate and define the geomorphic response of the Kentucky River drainage basin to this change in base level control.

The differences between Davis' (1899) Geographical Cycle and Hack's (1960) concept of dynamic equilibrium are recognized. Much of Hack's terminology is used throughout this study, however, several concepts of the Geographical Cycle are pertinent and are used with the dynamic equilibrium theory.
CHAPTER II

PREGLACIAL ENVIRONMENT

Teays River

During the Tertiary period much of the northeastern Midwest was drained by a master stream larger than the present day Mississippi River. Tight (1903) named this great river the Teays River. Subsequent work by Ver Steeg (1936), Horberg (1950), and Wayne (1956) have shown that the Teays was the major drainage system for West Virginia, Kentucky, Ohio, Indiana, and Illinois. It began on the edge of the Appalachian mountains in the Blue Ridge of North Carolina near Blowing Rock (Janssen, 1952). From Blowing Rock the Teays flowed northwestward across West Virginia, along the course of the present New and Kanawha Rivers. The Teays left the present Kanawha River valley at St. Albans, West Virginia, and flowed west through what Tight (1903) has described as the Teays and Flatwoods valleys. The river flowed through these valleys into western West Virginia, southeastern Ohio, and eastern Kentucky. The Teays valley coincides with the present Ohio River from Huntington, West Virginia, to Wheelersburg, Ohio. From Wheelersburg the Teays flowed north along the course of the present Scioto River valley.
to Chillicothe, Ohio, where its valley is buried under glacial drift (Ver Steeg, 1936; and Tight, 1903). The Teays continued north through Ohio until it entered Indiana where it flowed west across the Bluffton Plain. The Teays valley in Illinois referred to as the Mahomet-Teays valley by Horberg (1945) entered Illinois in southeastern Iroquois County and continued west for 120 miles to Lincoln, Illinois. The preglacial Mississippi River joined the Mahomet-Teays near Lincoln, Illinois. At this point the Mahomet-Teays turned south and followed the present Illinois River valley and eventually emptied into the Mississippi Embayment.

The Upper Teays

The Teays and Flatwoods valleys represent the former channel of the Teays near Huntington, West Virginia. These two valleys were left as high level abandoned channels and extend from St. Albans, West Virginia, to Ironton, Ohio (Tight, 1903). These valleys were calculated by Tight (1903) to have a slope of 0.6 feet per mile and an average width of 1 mile. The present topography represents the same topographic surface present during the preglacial flow of the Teays. The New River follows the ancient Teays valley and flows in a deeply entrenched valley with an average gradient of 8.5
feet per mile (Thornbury, 1965). Tributary streams of the upper Teays were cut 100 to 200 feet below the average topographic surface. Their valley floors were well graded and the headwater streams had eroded drainage divides until numerous low cols separated the minor drainage basins in the region (Tight, 1903). Stream capture and drainage integration through these low cols caused channel abandonment. This region was apparently approaching a base leveled condition and wide-spread equilibrium (Tight, 1903).

The precursors of the Allegheny and Monongahela Rivers existed during the preglacial flow of the Teays, but drained to the north into the preglacial St. Lawrence River (Figure 4). The divide between these two drainage systems ran north across West Virginia and northeastern Ohio. The St. Lawrence River extended into what is now the Great Lakes region (Janssen, 1952).

The Lower Teays

During the Tertiary Period the Teays in Ohio was the master stream for three major systems; Old Maumee, Miami and Little Miami Rivers. The largest tributaries to the Teays were the Portsmouth, Marietta, and Cincinnati Rivers. The Cincinnati River (Ver Steeg, 1936) flowed north past Hamilton and Dayton, Ohio, to join the
Figure 4. Preglacial drainage of the northern Midwest.

Teays in Northwestern Ohio. The Cincinnati River was the largest tributary to the Teays in Ohio and approximated the course of the present Miami River. This river was the northern extension of the preglacial Kentucky River.

The Teays through Indiana was a steep-walled gorge-like river entrenched in middle Silurian dolomite and the underlying soft Cincinnatian shales (Wayne, 1956). The Teays channel trends westward through central Indiana. The Teays through Illinois, Indiana and much of Ohio is now buried under glacial drift, however, abandoned buried segments of the Teays system are still topographically evident. These valleys are meandering, and entrenched 100 to 200 feet below the upland surface. These Teays-age valleys average 1/2 mile wide with a main valley meander belt of 5 miles wide.

Much of central and northeastern Illinois was drained by the Teays system. The average depth of the Mahomet-Teays valley in Illinois is 200 feet. The valley descent as estimated by Horberg (1945) is 0.14 feet per mile. Fidler (1943) stated that the Teays possessed an average gradient of 0.66 feet per mile towards the Mississippi Embayment. The channel ranges from 4 to 5 miles wide with bedrock elevations generally being less than 400 feet above sea level in Indiana and Illinois. Portions of the Mahomet-Teays valley in Illinois reach a
width of 15 miles. This suggests the development of an extensive floodplain. The low gradient, wide valley, and presence of a floodplain suggests a state of widespread equilibrium (Horberg, 1945). Fidler (1943) suggested that other tributary streams must have also reached equilibrium.

Preglacial Erosional Cycles

The Teays River, a major Tertiary drainage system, stood at or near base level along its entire course for an extended period. Late Tertiary uplift initiated a cycle of erosion referred to as the Lexington Cycle by Wayne (1956). This cycle developed the Lexington erosional surface which has been correlated with the Highland Rim erosional surface of Tennessee. Reaching an elevation of 1100 feet it slopes northwestward to southeastern Indiana and southwestern Ohio to a minimum elevation of 725 feet (Ver Steeg, 1936). Maximum relief on this erosional surface is 200 feet. The Teays and its tributaries drained portions of this erosional surface in broad meandering valleys (Wayne, 1956).

Streams of the Lexington Cycle never reached equilibrium due to the uplift that produced the Parker cycle (Ver Steeg, 1936; Wayne, 1956; Thornbury, 1965). Thornbury (1965) considered the Parker cycle to be an
erosional subcycle. Uplift that initiated the Parker Subcycle caused streams to be rejuvenated and entrench their valleys 200 to 300 feet below the base leveled surface developed during the Lexington Cycle. Near the end of the Parker episode streams began to develop a wide valley phase (Wayne, 1956). This subcycle was prominent from the late Pliocene to the early Pleistocene.

Although the Parker subcycle may have been caused by regional uplift, it could have been produced by downwarping along the Appalachian axis or climatic and drainage modifications (Ver Steeg, 1936, Horberg, 1950). Evidence of the Parker subcycle are evident in the form of terraces along the Teays valley at elevations of 700 to 800 feet. This supports the presence of an erosional surface before entrenchment occurred (Ver Steeg, 1936). Thornbury (1965) stated that disruption of the Teays system occurred during the Parker subcycle. Numerous drainage modifications occurred and it seems likely that the Teays and Flatwoods valleys were abandoned during this episode.

The Preglacial Kentucky River

Most northwest flowing streams in the Interior Low Plateau travelled across the Lexington Highland Rim surface. These streams were meandering and probably
approaching a quasi-equilibrium state. The Kentucky River was one of these northwest flowing streams. It had its inception in the late Paleozoic with the Appalachian Orogeny which uplifted eastern Kentucky and Tennessee to elevations high above sea level. This uplift imposed a general northwest dip on the rocks in this area. The headwaters of the Kentucky are subsequent streams and flow parallel to Pine Mountain. From Pine Mountain the river flowed N 45 W. If this line were extended over Pine Mountain into Tennessee, the Kentucky would have joined the Watuaga River near Kingsport, Tennessee. The Watuaga River may have been the headwaters of the Kentucky River prior to the formation of Pine Mountain (Jillson, 1945). The Kentucky flowed across the Lexington erosional surface in a broad meandering channel through Frankfort to the vicinity of Carrollton, Kentucky. At Carrollton, the preglacial Kentucky made a sharp turn to the northeast. It was joined by the Old Licking River northeast of Cincinnati and continued north through Dayton, Ohio, and finally emptied into the Teays in central Ohio (Swadley, 1971).

Until Swadley's work in the early 1970's much discussion centered around the course of the Kentucky at Carrollton. Jillson (1945) who mapped high level abandoned channels of the Kentucky upstream from
Carrollton, believed that the Kentucky turned to the southwest at Carrollton and joined the preglacial Ohio. Swadley (1971) has mapped high level abandoned channels of the Kentucky from Carrollton to the northeast which proves that the Kentucky did flow to the northeast at Carrollton. Thus the Kentucky drainage flowed through the Cincinnati River and joined the Teays in central Ohio. The northernmost extent of the abandoned channels of the Kentucky is opposite the mouth of the present Miami River. This segment of the Old Kentucky had a river distance of 95 miles and a direct line distance of 50 miles suggesting a very sinuous course (Figure 5). This former meander belt has been shown to be 4 to 5 miles wide. The course of the present Ohio River parallels this old meander belt and is incised 200 feet to late Ordovician interbedded shales and limestones. This abandoned valley is now 200 to 250 feet above the present level of the Ohio and possesses a gradient of 0.5 feet per mile. Terrace remnants are present near the junction of Eagle creek with fluvial deposits lying 40 to 80 feet above the present streams (Swadley, 1971).

The Preglacial Ohio River

Ver Steeg (1936), Fenneman (1916), and Jillson (1945) believed that the preglacial Ohio headed near
Figure 5. Course of the preglacial Kentucky River from Carrollton to Lawrenceburg.

Manchester, Ohio, seventy miles northeast of Cincinnati (Figure 6). Valley narrowing of the present Ohio is evident near Manchester suggesting the presence of a former divide. They believed that from Manchester the Ohio turned to the northeast through the present course of the Little Miami River valley, then west through the Norwood Trough with a southeast direction taking the river through Madisonville. These authors believed that this portion of the river, the Cincinnati River, did not join the Teays but began at a divide north of Dayton isolating it from the Teays system. Southwestern slope on the bedrock channel of the Cincinnati River and general valley narrowing to the north suggest that the Cincinnati River began at this divide. Fenneman (1916), however, mentioned that tributaries of the Ohio in the Cincinnati area flow east whereas the Ohio flows west thus making tributaries enter the Ohio at abnormal angles. There is also a lack of beveling towards the Ohio above Madison and valley narrowing is present at Madison. Ver Steeg (1936) explained that the southwest slope on the Cincinnati River bedrock valley was developed during the Deep Stage after reversal of drainage to the south.

Additional evidence to support the northeast flow at Carrollton and southeast flow of the Ohio at Madison were
Figure 6. Proposed origin of the Ohio River.

cited by Wayne (1956). Above Madison, Indiana, many of the streams that enter the Ohio have a barbed pattern whereas streams below Madison exhibit a more normal relationship (Wayne, 1956). Lafayette gravels characteristic of the Old Kentucky River channel are not found on the undisturbed upland surface west of Madison, suggesting that the Kentucky did not flow in this area (Wayne, 1956). Teller and Dury (1976) studied the meanders of the Old Kentucky between Carrollton and Lawrenceburg, Indiana. Their meander wavelength analysis shows that meander wavelength increases northward implying a northward flow for the Kentucky. It seems very unlikely that the rather small preglacial Ohio could have extended itself across the Cincinnati Arch. Even the Teays, a very large river, took a course around the arch.

Tight, (1956), Fowke (1933), and Wayne (1956) stated that the pre-Pleistocene Ohio headed on the Silurian limestones that underlie the Muscatatuck regional slope southwest of Madison, Indiana. They believed that the Ohio was a relatively insignificant stream prior to glaciation.
CHAPTER III

DRAINAGE MODIFICATIONS

Damming of the Teays

The Teays River persisted in its course for millions of years until Pleistocene ice advanced as far south as northern Kentucky. Ice of a pre-Illinoian glaciation buried the Teays from Chillicothe, Ohio, to its mouth. The upper portion of the Teays was dammed by the advancing ice front. This created large lakes that extended over portions of southeastern Ohio and western West Virginia (Janssen, 1952). With ponding of the Teays slackwater lakes formed allowing the deposition of the Minford silts (Ver Steeg, 1936). Minerals in these silts, most prominent in the Teays and Flatwoods valleys, have been traced to the crystalline rocks of the Blue Ridge. Gravels underlying these silts are very well sorted with the exception of some eight-to-ten inch boulders. These gravels are overlain by a thick sequence of silt ranging in thickness from eighteen to eighty feet (Tight, 1903).

The extensive ponding of the Teays was partially due to the influx of water from the reversal of the Allegheny and Monongahela Rivers. The level of slackwater lakes
associated with these streams was reduced by the formation of spillways between tributary valleys of the Teays (Teller, 1973). Spillway development occurred westward over a series of north-south divides which initiated a new southwest-flowing drainage system along the ice front (Swadley, 1973).

**Ponding of the Kentucky River**

The Cincinnati River like the Teays would have been ponded by the pre-Illinoian advance. The ponded Teays eventually spilled over the divide that separated the Teays and the preglacial Kentucky Rivers. Drainage from the Teays entered the Kentucky system via the Old Licking River. This flow was diverted north of Cincinnati then southwest reversing the flow in a segment of the Old Kentucky River (Swadley, 1971). Once this occurred drainage from the Monongahela, Alleghany, and Teays were diverted along this southwest drainage line into the Kentucky drainage. This massive influx of water caused extensive ponding along the Kentucky. The divide at Madison prevented drainage to the southwest which caused a "deep and extensive lake to form" (Fowke, 1933, p. 109). As a consequence large amounts of sand and silt were deposited along the Kentucky. Jillson (1945) estimated that the lake formed by the Madison divide
reached a depth of about 120 feet. This lake extended up river to the Frankfort-Shelbyville area.

Breach of the Madison Divide

Near Lawrenceburg, Indiana evidence exists for a temporary glacial standstill. Valleys north of this area are filled with till and valleys south of this area are filled with outwash to an elevation of 830 feet. The Madison divide was apparently still intact at this time. When the ice readvanced meltwater once again filled the proglacial lake. The low point of the Madison divide was 850 feet above sea level. If Jillson's (1945) depth estimates of the proglacial lake are accurate, downcutting of the divide would have begun with the southern most extent of the pre-Illinoian ice. Once the divide was breached the lake began to drain taking with it outwash and till (Swadley, 1971). When the Madison divide was breached reversal within the Cincinnati River was complete and a new-ice front channel was formed. Ponded waters from the upper Teays were then drained by this new ice front channel. This new channel became the present Ohio River. Wayne (1956) stated that integration of the Ohio began with Nebraskan ice and was complete with the advent of Illinoian glaciation.

The course of the newly formed Ohio followed a route
from Cincinnati to Hamilton then south to Lawrenceburg, Indiana. The northern portion of this route was dammed by two Illinoian ice advances. This damming established the present channel of the Ohio. This Illinoian advance also dammed the Ohio and Kentucky Rivers in the Carrollton area. When the ice receded the Ohio returned to its old channel whereas the Kentucky established a new channel west of Carrollton (Teller, 1973). Therefore the Old Kentucky River was beheaded by the formation of the new Ohio and as a consequence lost over 100 miles of its channel between Carrollton and its confluence with the Teays.

Deep Stage

The Parker subcycle was interrupted by valley deepening and possible regional uplift. Streams cut below the Parker strath to elevations as low as 360 feet above sea level. This valley deepening stage is known as the Deep Stage (Thornbury, 1965). These valleys are incised and narrow and filled with alluvium, glacial outwash and lacustrine materials (Ver Steeg, 1936).

The Deep Stage of the Teays and Ohio bedrock valleys occurred during the flood stage of the Teays and continued until Illinoian glaciation (Wayne, 1956). During the deep stage the new Ohio entrenched itself 250
feet below Teays age valley bottoms which are 100 feet below the present valley bottom of the Ohio (Teller, 1973). The Deep Stage Ohio cut down rapidly and reached a stage of equilibrium (Ver Steeg, 1936). Rapid downcutting of the Ohio developed because of soft Ordovician shales. Tributaries of the Ohio also began to cut down to maintain the level of their trunk streams. Wayne (1956) stated that the Deep Stage was initiated by a drastic increase in discharge caused by the diversion of the Teays into the Ohio and the influx of glacial meltwater. This caused static rejuvenation of the Ohio and its tributaries in unglaciated areas. Downcutting to the Deep Stage was caused by the shortening of the river's course to the sea by way of the Ohio River to the Mississippi Embayment (Ver Steeg, 1936). This would have caused rapid regrading.

The age of the Deep Stage has been debated considerably. Wayne (1956) and Ver Steeg (1936) assigned it to an interglacial age beginning during the Nebraskan and continuing through Kansan glaciation. Horberg (1945) suggested that valley deepening occurred before Pleistocene glaciation. Presently the age generally accepted is beginning with the ponding of the Teays and lasting until the beginning of Illinoian glaciation.

Evidence for the Deep Stage was found by Thornbury
(1948) in the buried Teays valley. The valley in Indiana is covered with 400 feet of drift. Two cross profiles are present in this valley; a broad meandering valley phase and a deeply incised phase. The broad valley phase was developed during the Parker Subcycle and the incised phase was formed during the interglacial Deep Stage.

Several periods of ponding and erosion occurred during the Pleistocene. Valleys in the northern Midwest and western Appalachian Plateau first stood near base level for an extended period then, uplift initiated the Parker subcycle and rejuvenation of river valleys resulted. Slackwater conditions created by the first advance of continental glaciation, caused rivers to aggrade. Subsequent abandonment of valleys occurred and valley entrenchment of the Deep Stage followed (Tight, 1903).
CHAPTER IV

REJUVENATION OF THE KENTUCKY RIVER

Causes of Rejuvenation

The preglacial Kentucky River flowed across the Lexington erosional surface as a broad meandering stream. The river had equilibrated to its master stream the Teays River. Uplift of the Parker Strath caused the Kentucky to entrench itself 200 feet below the Lexington surface. This caused the preglacial Kentucky to rejuvenate. The river again equilibrated and began to develop a broad valley.

Advance of pre-Illinoian ice interrupted the Parker subcycle. Two major occurrences caused the Kentucky to be rejuvenated again. The Kentucky was dammed by pre-Illinoian ice and was subsequently beheaded by the formation of the Ohio River. The channel of the Kentucky from Carrollton to its confluence with the Teays was completely abandoned and the Kentucky joined the new Ohio at Carrollton. This occurrence drastically reduced the Kentucky's distance to its former ultimate base level control. Massive amounts of meltwater and glacial material caused rapid regrading of the Ohio to its base level control, the newly formed Mississippi River. As
this regrading occurred local base level for tributaries of the Ohio lowered and static rejuvenation resulted. North flowing tributaries lacking glacial meltwater responded slower to this change in base level than did the meltwater laden south flowing tributaries. Therefore, the second rejuvenating event of the Kentucky was caused by a shortening of its distance to the sea and lowering of its local base level control; the new Ohio.

Evidence for Rejuvenation

Thornbury (1965) described the evidence for stream rejuvenation to be topographic discordance, valley-in-valley cross profile, and the presence of entrenched meanders. Topographic evidence for rejuvenation is readily evident in the field area.

Topographic discordance is the most apparent evidence for rejuvenation in the Kentucky River drainage basin. The Kentucky River flows 400 feet below the level of the Lexington surface. Maximum relief on this surface is approximately 50 feet. In the immediate vicinity of the river and its tributaries relief increases to approximately 300 feet; deep valleys and cliffs dominate yet the subdued topography of the Lexington surface is present only a short distance from the river and its tributaries.
Valley-in-valley profiles are common on smaller tributaries where knickpoints are found. The two different valley levels present a valley-in-valley profile.

Several entrenched meanders are present along the Kentucky River. These meanders are symmetrical and steep-walled. Meanders downstream from Frankfort show some asymmetry. This is due to lateral planation eroding the less resistant interbedded shales and limestones of the Lexington Limestone, Kope and Clays Ferry Formations. Classic entrenched meanders are evident upstream from Frankfort where resistant Ordovician limestone of the Tyrone and Camp Nelson Formations are exposed.

Response to Rejuvenation

Rejuvenation effected several changes on the Kentucky River drainage basin. The several abandoned channels of the Kentucky River mapped by Jillson (1945) and Swadley (1971) make the decrease in elevation from its preglacial channel obvious (Figure 7). During each rejuvenating event the river deepened its channel and it is now at least 200 feet below its preglacial level. Some abandoned channels are at an elevation of 800 feet indicating a deepening in some portions of the valley of almost 400 feet. As the channel deepened, its slope
Figure 7. Slope and elevation comparison of the preglacial Pliocene and present Kentucky River.
increased and disrupted the existing steady state. A state of disequilibrium developed between erosional forces. Hack (1960) stated that erosional forces operate at equal rates thus producing a steady state. Energy is continually entering and leaving a system in equilibrium. When external forces change the rate of erosion the equilibrium constant must change to compensate for that change; therefore, if no diastrophic changes occur in the basin and the rates of erosion remain constant the topography will remain constant as well. Topographic form will evolve from one form to another at a uniform rate. If, however, rapid change occurs "relict landforms" may be preserved in the topography until a new steady state is achieved (Hack, 1960, p. 86). Rapid changes affecting the base level control of the Kentucky River interrupted the steady state between erosional forces subsequently causing disequilibrium. The undisseted upland surface is the relict landform and the deeply dissected areas immediately adjacent to the river and its tributaries represent the equilibrium surface. The Kentucky River drainage basin is adjusting from a system in equilibrium with the Teays to a system in equilibrium with the Ohio River.

A portion of the Kentucky River has adjusted its channel to the new system. Slope comparison of the
Kentucky/Ohio system and Kentucky/Teays system show that the more recent system has not reached grades as low as the Kentucky/Teays but is approaching a profile of equilibrium. This suggests that the Kentucky is still actively undergoing change but that it has reached a quasi-equilibrium state (Figure 8). Larger tributaries of the Kentucky have also reached quasi-equilibrium and have adjusted their levels to the Kentucky's.

Daniels (1960) studied the response to man made changes in base level control of a stream in Iowa. A ditch was constructed that shortened a 26 mile section of the Willow River to 20 miles. The slope increased 2.5 to 3.6 feet per mile. Shortly after these modifications were made a knickpoint was observed in the stream channel. The knickpoint began to migrate headward. Passing of the Knickpoint facilitated deepening of the channel, however, channel entrenchment continued after the knickpoint passed. Similar observations were made in the Kentucky River drainage basin. In an effort to equilibrate their stream channels smaller tributary basins—those less than 1 square mile in area have developed knickpoints within their valleys. Knickpoints on tributaries of the Kentucky represent a response of each drainage basin to equilibration of its stream channel. Relative positions of knickpoints represent the
Figure 8. Slope comparison of the Kentucky/Teays and Kentucky/Ohio systems.
extent of upstream migration of the eroding surface (Daniels, 1960). Portions of the stream above the knickpoint are slightly below the upland surface whereas the valley below the knickpoint is as much as 175 feet below the upland surface. This suggests that the knickpoint represents the intersection between the equilibrating portion of the stream channel and a relict equilibrium surface.

Knickpoint migration is caused by undercutting at its base. Material above the undercut slumps into the plunge pool and is removed downstream (Figure 9). Migration of the knickpoint upstream is accompanied by the reduction of the upland surface. Lithology plays an important role in the dissection of the upland surface. More of the Lexington surface has been dissected downstream from Frankfort than upstream. The presence of less resistant interbedded shales and limestones downstream from Frankfort have allowed accelerated dissection of the upland surface. The resistant Tyrone and Camp Nelson Limestones impede knickpoint migration thus reducing the amount of the dissected surface. The amount of dissection and its relation to basin area is discussed in a later section.

North of Frankfort, the valley of the Kentucky River begins to widen and continues to do so until its
Figure 9. Longitudinal profile showing knickpoint migration

confluence with the Ohio. The valley is more than 6000 feet wide at its mouth and narrows upstream (Figure 10). At Frankfort the valley width is approximately twice the river width and at Tyrone the valley and river channel coincide. The only exceptions are small flood plains and point bars in meanders. At Irvine the river valley again broadens and relief decreases. The differential valley widths are related to lithology. The less resistant shales and limestone between Frankfort and Carrollton have allowed a wider valley to form whereas the resistant limestones upstream from Frankfort allow a narrower valley to develop.

Seven abandoned meanders are evident between Frankfort and Carrollton. These cutoff meanders are easily distinguishable in that their meander scars and meander cores are well preserved. Each of these cutoffs is at a different elevation above present river level. The largest cutoff, an almost complete circle, is also the highest at 120 feet above present river level (Figure 11). This cutoff is located immediately upstream from the hamlet of Gratz, Kentucky. Six other cutoff meanders occur at lower elevations with the lowest cutoff at an elevation of 20 feet above river level in Craddock's and Hardin's Bottoms.

These meanders were cut off as the Kentucky deepened
Figure 10. Valley width vs. river width with distance up river.
Figure 11. Position and elevation of cutoff meanders.
its channel. Each cutoff represents a former level and position of the Kentucky River. These meanders were cut off as a result of lateral planation. Upstream from Frankfort no cutoff meanders are present. This is due to the lithologies exposed on the northwest flank of the Cincinnati Arch. The resistant Tyrone and Camp Nelson Limestones of the High Bridge group have been able to withstand "all attempts by lateral planation" to create a break in a meander (Jillson, 1945, p. 47). The resistant Tyrone Limestone is at river level near Frankfort but the dip on this flank of the arch carries it below river level to the north. From this point to the Ohio the presence of less resistant interbedded shales and limestones of the Lexington Limestone, Kope and Clays Ferry Formation have permitted lateral planation to break through low points on meanders thus creating the cutoffs (Jillson, 1945).

Field Work

To help define the response of the Kentucky River drainage basin to a lowering of base level control the relative position of knickpoints on tributaries was determined. The purpose of defining the knickpoint position was to establish any trends and relationships between tributaries and the river that may have been
caused by the lowering of base level. Data for stream profiles were obtained from streams tributary to the Kentucky with basin areas generally less than 1 square mile. Streams with basin areas greater than 1 square mile were believed to be in a state of equilibrium whereas smaller basins exhibited disequilibrium. The purpose of obtaining stream profiles was to determine if a knickpoint existed on the stream channel and if so its distance from the stream's mouth. Profiles were obtained by using conventional surveying techniques. All streams surveyed were first order tributaries of the Kentucky. Each survey began at river level and proceeded upstream until a knickpoint was observed. After the slope of the stream above the knickpoint was determined the survey was ended. Several streams were surveyed to their origin because obvious knickpoints were not encountered. This produced a complete stream profile allowing the knickpoint if present to be identified. During the surveying of each stream contacts between formations and formation members were included in the profile data. Distances from the mouth to these contacts were checked with map distances.

Twenty streams covering the lower 125 miles of the Kentucky River were surveyed. After all data had been collected stream profiles were produced. This was done
with the assistance of a CALCOMP plotter made available through Western Michigan University's DEC System 10 computer. An existing standard X-Y graph program was slightly modified. Data in X-Y coordinates were entered. The CALCOMP plotter plotted and connected these points to produce the profile. The profiles were scaled according to the data set and labeled.

The position of each knickpoint was determined from the profile and cross-checked with field notes. Streams in the lower portion of the study area displayed subtle breaks in slope and some streams showed no knickpoints. Streams presenting a profile of this form were found to flow over the shales and interbedded limestone of the Kope and Clays Ferry Formations. Two conditions may be responsible for the absence of knickpoints on these streams; the less resistant shale has allowed the knickpoint to migrate to its origin or the shale is such that knickpoints are unrecognizable in profile (Appendix 1). Knickpoints upstream from this area show more pronounced breaks in slope. The knickpoints possess a step-like profile which is facilitated by the presence of interbedded shales. This form of knickpoint was found to dominate the streams flowing through the Lexington Limestone. Relief on knickpoints increases with distance.
from the mouth of the Kentucky. This form was present throughout the remainder of the field area.

Knickpoints were defined by a break in slope of each stream. The majority of these breaks were obvious in both profiles and in the field. Lithologic change as a cause for the break in slope cannot be ignored. Some knickpoint distances coincided with lithologic contacts. If no other break in slope was found not to coincide with a lithologic change the profile was discarded. Eighty percent of streams for which profiles were constructed showed knickpoints entirely within a single rock unit.

Upstream valley narrowing indicated a possible trend that can be extended to knickpoint position. It was hypothesized that knickpoints would be positioned closer to the mouth of each tributary with increasing distance up river. Data obtained from knickpoint positions were found to support this hypothesis (Table 1). Exceptions in this general trend were caused by non-uniform basin size. A statistical analysis of mouth to knickpoint distances was performed and is discussed in a later section.

Hypsometric Analysis

To further define trends a hypsometric analysis of each tributary profiled was performed. Hypsometric
Table 1

Knickpoint distances (ft), hypsometric integrals (%), basin area (sq. mi.), and mouth to tributary distances (mi).

<table>
<thead>
<tr>
<th>Knickpoint Distances</th>
<th>Hypsometric Integrals</th>
<th>Basin Area</th>
<th>Mouth to Tributary Distances</th>
</tr>
</thead>
<tbody>
<tr>
<td>137.0</td>
<td>0.7400</td>
<td>0.1685</td>
<td>125.0</td>
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<td>162.0</td>
<td>0.8296</td>
<td>0.2275</td>
<td>117.7</td>
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<td>190.0</td>
<td>0.7860</td>
<td>0.3600</td>
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<td>351.0</td>
<td>0.7932</td>
<td>0.1714</td>
<td>112.9</td>
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<tr>
<td>569.0</td>
<td>0.8028</td>
<td>0.1757</td>
<td>94.5</td>
</tr>
<tr>
<td>184.0</td>
<td>0.6800</td>
<td>0.1051</td>
<td>90.2</td>
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<tr>
<td>1966.0</td>
<td>0.6996</td>
<td>0.3970</td>
<td>82.7</td>
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<td>1800.0</td>
<td>0.7028</td>
<td>0.9320</td>
<td>82.3</td>
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<td>1150.0</td>
<td>0.7332</td>
<td>0.3080</td>
<td>76.1</td>
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<td>3301.0</td>
<td>0.6764</td>
<td>0.4150</td>
<td>72.8</td>
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<tr>
<td>3288.0</td>
<td>0.7328</td>
<td>0.3830</td>
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<td>2290.0</td>
<td>0.6580</td>
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<td>2000.0</td>
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<td>3445.0</td>
<td>0.5936</td>
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<tr>
<td>1483.0</td>
<td>0.6860</td>
<td>0.1397</td>
<td>14.2</td>
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</table>
analysis is an analytical method of relating basin elevation and basin area. The end product is a determination of the equilibrium stage or degree of dissection of each basin. This process reveals the amount of a particular basin that is found within "cross-sectional segments bounded by specific elevations" (Ritter, 1978, p. 183). Data obtained from a hypsometric analysis is displayed in graphic form: a hypsometric curve. This curve represents the relationship between basin elevation and basin area and indicates the distribution of mass above a particular datum. The hypsometric integral produces the shape of the curve and is expressed as a percentage of the volume of the original basin that remains (Strahler, 1952).

The hypsometric curve is produced by using the equations:

\[ X = \frac{a}{A} \text{ and } Y = \frac{h}{H} \]

Where "a" is the area above a particular contour, "A" is the total basin area, "h" is the height of a given contour above a horizontal datum plane, and "R" is the total relief in the basin. Values for these components were obtained from topographic maps. The horizontal datum plane used was river level.

The shape of the hypsometric curve defined the
developmental stage of each stream surveyed. Strahler (1952) described three stages of stream development; disequilibrium, equilibrium, and monadnock. To determine the stage of development the hypsometric integral was computed. This was done by measuring the area under the hypsometric curve and expressing this value as a percentage of the whole. Percentages ranging from 0% to 35% indicates a monadnock phase, 35% to 60% indicates equilibrium, and over 60% indicates disequilibrium.

The hypothesis that two stages of stream development exist in the Kentucky River drainage basin was formulated. These stages are equilibrium and disequilibrium. An equilibrium stage was hypothesized to exist on stream basins near the mouth of the Kentucky. Disequilibrium was hypothesized to exist on stream basins farther up river. Hypsometric integrals obtained support these hypotheses. Stream basins at or near the mouth of the Kentucky River possess integrals at or below 60% indicating equilibrium. Integrals increased as the tributaries distance up river increased. Stream basins at the upstream end of the field area possess integrals at or near 80%—indicating disequilibrium (Table 1).

A characteristic curve accompanies each stage of development (Figure 12). After values for the X and Y components were obtained curves were generated with the
Figure 12. Characteristic hypsometric curves.

assistance of the CALCOMP plotter. The same program was used for the curves as was used for the profiles except the points were not connected. Following the characteristic forms, curves were drawn through the points on each plot. The area under the curve was computed using a dot-grid planimeter. The computer and plotter were used to eliminate operator subjectivity and subsequent operator error, however, error is present in the hypsometric curves due to the higher amount of operator subjectivity. The dot-grid planimeter used was accurate to 97%. Error arose in basin area, and contour area. Attempts were made to limit error thus values obtained are believed to be accurate within plus or minus 5%.
CHAPTER V

CONCLUSIONS

Statistical Analyses of Data

The statistical analyses of data was facilitated by STATPACK, a computer program made available on the DEC System 10 computer at Western Michigan University. The purpose of these statistical analyses was to verify trends that are present in the data and to determine the relationships between different data sets. Variables used from the data sets were knickpoint distance, hypsometric integral, basin area, and mouth to tributary distance. Mean, standard deviation, maximum, and minimum values were computed for the four variables (Table 2). To determine relationships between variables standard correlation was used.

Partial correlations between each variable were computed and are interpreted as follows (Table 3). A Correlation of -0.7145 was found to exist between the knickpoint distance and the hypsometric integral. This suggests that an inverse relationship is present: the higher the hypsometric integral or the greater the amount of the relict upland surface present the shorter the distance to the knickpoint. This result supports the
Table 2
Basic statistics of field and map data.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Maximum</th>
<th>Minimum</th>
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<tr>
<td>Knickpoint Distance (Feet)</td>
<td>1560.75</td>
<td>1213.47</td>
<td>3445.0</td>
<td>137.0</td>
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<td>Hypsometric Integral (Percent)</td>
<td>0.7179</td>
<td>0.0621</td>
<td>0.8296</td>
<td>0.5936</td>
</tr>
<tr>
<td>Basin Area (Sq. Mi)</td>
<td>0.3454</td>
<td>0.2235</td>
<td>0.9320</td>
<td>0.1051</td>
</tr>
<tr>
<td>Mouth to Tributary Distance (Miles)</td>
<td>70.45</td>
<td>34.8</td>
<td>125.0</td>
<td>14.20</td>
</tr>
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</table>
Table 3
Correlation matrix of field and map data.

<table>
<thead>
<tr>
<th></th>
<th>Knickpoint Distance</th>
<th>Hypsometric Integral</th>
<th>Basin Area</th>
<th>Mouth to Tributary Distance</th>
</tr>
</thead>
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<tr>
<td>Knickpoint Distance</td>
<td>1.0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypsometric Integral</td>
<td>-0.7145</td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin Area</td>
<td>0.4823</td>
<td>-0.3838</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td>Mouth to Tributary Distance</td>
<td>-0.6895</td>
<td>0.7358</td>
<td>0.1747</td>
<td>1.0000</td>
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</table>

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hypothesis in that stream basins with higher hypsometric integrals show shorter mouth to knickpoint distances.

A positive correlation of 0.4832 exists between the basin size and the distance to the knickpoint. This suggests that the larger the basin the greater the mouth to knickpoint distance.

The mouth to tributary distance and the knickpoint distance relationship is of foremost importance. At the onset of this study it was hypothesized that the knickpoints would be found closer to the mouth of each tributary with increasing distance up river. A correlation of -0.6895 exists between these two variables suggesting that the greater the mouth to tributary distance the shorter the distance to the knickpoint. This correlation confirms the general trend in the data. Also supporting this is a correlation of 0.7358 between mouth to tributary distance and the hypsometric integral. The strong positive correlation was expected and shows that as mouth to tributary distance increases so does the hypsometric integral. In other words the amount of the relict upland surface present increases with distance upstream.

A small correlation of -0.3838 exists between the basin area and the hypsometric integral suggesting that the larger the basin the smaller the hypsometric integral.
or the higher degree of equilibrium. Hack (1960) mentioned that equilibrium is heavily dependent on the amount of discharge in a basin. Larger basins typically discharge more than smaller basins thus the larger basins contain more erosive energy allowing an equilibrium stage to be achieved more rapidly; therefore, larger basins should possess smaller hypsometric integrals than smaller basins in the Kentucky River drainage basin. This suggests that more of the relict upland surface has been altered into slopes in larger basins.

Findings and Interpretations

Physical evidence of the Kentucky River drainage basin to a lowering of base level control is apparent. The river has deepened its channel by more than 200 feet, dissected the upland surface, developed knickpoints on most tributaries, widened its valley, and cut off meanders as incision has proceeded. Lithology in the basin has strongly influenced this response. The widening of the valley is directly related to the soft shales and interbedded limestones of the Kope and Clays Ferry Formations. These shales and interbedded limestones are also responsible for the lack of knickpoint development on tributaries and the presence of cutoff meanders. This less resistant lithology has
allowed accelerated erosion of the upland surface such that an equilibrium state exists.

Knickpoints become more evident with the appearance of the resistant Lexington, Tyrone, and Camp Nelson Limestones. Streams flowing through these formations exhibit a disequilibrium condition, and knickpoints are closer to tributary mouths with increasing distance up river. These more resistant limestones limit lateral planation thus impeding valley development and promoting a more distinct knickpoint. Streams above the river flow through the Tyrone and Camp Nelson Limestones and exhibit an increasingly higher hypsometric integral with river distance. Knickpoints are present at the mouths of tributaries and valley development is negligible.

The nature of the Kentucky River drainage basin's response is ultimately controlled by the northwest dip of the Ordovician rocks on the flank of the Cincinnati Arch. In the study area more resistant rocks are found up river. Less resistant and younger rocks appear downstream. The presence of these erodable lithologies in the most energetic portion of the stream caused adjustment to equilibrium to occur at different rates with the most rapid rates being downstream and decreasing rates upstream. Statistical analyses of basin area, distance from mouth to knickpoint, hypsometric integral,
and mouth to tributary distance support trends in the data and define relationships between these variables suggesting that the response of the Kentucky River drainage basin to a lowering of base level control has been differential adjustment to an equilibrium state with more of the relict upland surface being present with increasing distance up river.
APPENDIX A
Hypsometric Curves for Streams Profiled with Hypsometric Integrals (HI) and Mouth to Tributary Distances (MI).
$HI = 82.96\% \quad 117\text{ Ml.}$
$H_1 = 78.6\% \quad 115 \text{ Ml.}$
$h_{l}/H$

$H_l = 80.28\% \quad 94.5\text{ Ml.}$
Hi. = 68.0 %  
90.2 Ml.
$h/H$

\[ H_l = 70.28\% \quad 82.3\text{ Mi.} \]
HI = 73.28%  72.8 Ml.
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$H_l = 71.0\% \quad 40.8 \text{ Ml.}$
APPENDIX B

Profiles of Selected Streams Tributary to the Kentucky River Showing Knickpoint Position (designated by solid vertical line).

Note that most stream names were assigned by the author.

Index

<table>
<thead>
<tr>
<th>Stream</th>
<th>Mouth to tributary distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handy's Bend</td>
<td>125.0 miles</td>
</tr>
<tr>
<td>Shakertown Ferry</td>
<td>117.0 miles</td>
</tr>
<tr>
<td>Cog Hill</td>
<td>115.0 miles</td>
</tr>
<tr>
<td>Brooklyn Bridge</td>
<td>112.9 miles</td>
</tr>
<tr>
<td>Camp Otonka</td>
<td>94.5 miles</td>
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<tr>
<td>Gilbert Crk South</td>
<td>90.2 miles</td>
</tr>
<tr>
<td>Lock Hollow West</td>
<td>82.7 miles</td>
</tr>
<tr>
<td>Lock Hollow</td>
<td>82.3 miles</td>
</tr>
<tr>
<td>Turkey Run</td>
<td>76.1 miles</td>
</tr>
<tr>
<td>South Frankfort EW</td>
<td>72.8 miles</td>
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<tr>
<td>Macedonia Church Crk.</td>
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<td>Harvieland Road Crk.</td>
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<td>Shadrack Ferry Crk.</td>
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<td>Dry Branch</td>
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<td>Qarry North Crk.</td>
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</tr>
<tr>
<td>Moxley Sebastian Crk.</td>
<td>14.2 miles</td>
</tr>
</tbody>
</table>

73

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LOCK HOLLOW WEST: TYRONE

LOCK HOLLOW: TYRONE

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BIBLIOGRAPHY


