Bourbon and springs in the Inner Bluegrass region of Kentucky

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ABSTRACT

This field trip explores the role of geology in the origins and production of a distinctly American distilled spirit. Bourbon whiskey originated in the late 1700s and early 1800s in the Bluegrass region of north-central Kentucky. The Inner Bluegrass is marked by fertile, residual soils developed on karstified Ordovician limestones. Corn was grown, ground, fermented, and distilled to yield a high-value product that would not spoil. The chemistry of limestone water (dilute calcium-bicarbonate type with near-neutral pH) limits dissolved iron and promotes fermentation. Many farms and settlements were located near perennial springs, whose relatively cool temperatures (~13–15 °C) facilitated condensation of steam during distillation. We will visit three historically significant springs. Royal Spring in Georgetown was an early site of whiskey production and is one of the few springs in Kentucky still used for municipal water supply. McConnell Springs was the purported site of Lexington’s founding and occupies a karst window in which distilleries once operated. Cove Spring in Frankfort was the site of the first public water supply west of the Allegheny Mountains. We will also tour two distilleries: Woodford Reserve (among the oldest and smallest in the state, and a National Historic Landmark) and Four Roses (listed on the National Register of Historic Places).

INTRODUCTION

Karst terrain, which is formed by the dissolution of soluble bedrock (primarily limestone), is characterized by sinkholes, sinking streams, caves, and springs. Approximately 15% of the contiguous United States (Aley, 1984) and 55% of Kentucky (Currens, 2002) are underlain by soluble rocks. Many communities in karst terrain formed around springs, which provided water for various purposes, including potable use, milling, and cooling. These uses were integral in the development of bourbon whiskey in the Bluegrass region of Kentucky. This chapter reviews the geologic and hydrologic setting of the Inner Bluegrass and the history of bourbon production. A case study illustrates how the stable isotope oxygen-18 differs among various bourbons and how bourbon becomes systematically enriched in the isotope during aging. Finally, we summarize each field-trip stop.

REGIONAL GEOLOGY

The Bluegrass region of Kentucky (Fig. 1) is bounded to the west and south by the Mississippian Plateau, to the north by the Ohio River, and to the east by the Eastern Kentucky Coal
Field of the Appalachian basin. The Inner Bluegrass is defined as the 30% of the Bluegrass region that is underlain by the relatively flat-lying Lexington Limestone (McFarlan, 1943), which is Upper Ordovician in age (Clepper, 2011). The Inner Bluegrass is separated from the Outer Bluegrass by the Bluegrass Hills, formerly known as the Eden Shale belt. Fertile, residual soils (e.g., phosphatic silt loams) and numerous karst features have formed on the Lexington Limestone (Hendrickson and Krieger, 1964; McDonald et al., 1983; Newell, 1986). In the Inner Bluegrass, the Lexington Limestone rests on the underlying limestones of the High Bridge Group. Above the Lexington Limestone is the Clays Ferry Formation, which is composed of interbedded shales and thin limestone layers. Table 1 shows the generalized stratigraphy of the Lexington Limestone and subjacent and superjacent units.

Most of the Inner Bluegrass consists of a gently rolling, karst landscape dominated by fluvial landforms. Relief is typically less than 160 ft (50 m) (Thrailkill et al., 1982). The highest elevations, at ~1100 ft (330 m) above sea level (asl), occur in the central portion of the area. The lowest elevations, which occur along the Kentucky River in the southern and western extremes of the area, range from 469 to 549 ft (143 to 167 m) asl (McGrain and Currens, 1978). Locally, topography varies according to the rock units exposed at or just below the surface. Topography formed on the Clays Ferry Formation consists of narrow, steep-sided ridges with narrow, V-shaped valleys and dendritic drainage patterns. Thin limestone slabs cover steep slopes formed in shales in many places. In the lower part of the Clays Ferry Formation, more gently to moderately rolling uplands prevail, with small sinkholes and localized underground drainage in the limestone units. The topography formed on the upper part of the Lexington Limestone consists of broad, flat valleys, while that formed on the lower part tends to consist of rolling to dissected uplands. Sinkholes and well-developed subsurface drainage (solution conduits) are common. Bench-like

![Inner Bluegrass region of Kentucky](from Paylor and Currens, 2002).
topography is formed on the more resistant shale, bentonite, and limestone layers along hillsides and valleys. The Kentucky River flows along the southern and western edges of the Inner Bluegrass through a deep gorge known as the Palisades, which represents incision by the river of ~330 ft (100 m) below the adjacent land surface (Currens and Paylor, 2009). The topography formed on the High Bridge Group typically consists of cliffs and steep slopes along the Kentucky River and its tributaries. Numerous grikes (sub-vertical to vertical joints that have been enhanced by dissolution) occur within the walls of the gorge. The Oregon and Camp Nelson Formations only crop out at the river and a few meters above it. The Tyrone Formation is exposed in the upper elevations of the cliffs and along the lower elevations of tributaries. The upper few meters of the Tyrone and the overlying Curdsville Member of the Lexington Limestone form more gentle slopes extending into the uplands. At least three levels of the Kentucky River have been identified near its current location. An age of ~1.5 million years for this stage of the river is suggested by radiometric dating, whereas gravel deposits and terraces indicate both a relatively young stage of the river at the lowest levels of its current valley, as well as an earlier, sub-upland stage of the river before incision into the plateau (Andrews, 2005).

<table>
<thead>
<tr>
<th>Table 1: Generalized Stratigraphy of the Lexington Limestone Showing Approximate Equivalences with Major Late Ordovician Chronostratigraphic Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Ordovician</td>
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<tr>
<td>Caradocian</td>
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<tr>
<td>Clays Ferry Formation</td>
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<tr>
<td>Edenian</td>
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<tr>
<td>Lexinton Limestone</td>
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<tr>
<td>Chatafieldian</td>
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<td>Shermanian</td>
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<td>Kirkfieldian</td>
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<td>Rocklandian</td>
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<tr>
<td>Turonian Stage</td>
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<tr>
<td>Blackriverian</td>
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<tr>
<td>Trenton-Maquoketa Unconformity</td>
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<tr>
<td>High Bridge Group</td>
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<tr>
<td>Curdsville Member</td>
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<td>Logana Member</td>
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<td>Tyler Member</td>
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<td>Trenton-Maquoketa Unconformity</td>
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<tr>
<td>Highlandian</td>
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<tr>
<td>Oregon Formation</td>
</tr>
<tr>
<td>Camp Nelson Limestone</td>
</tr>
</tbody>
</table>

*Note: F.R. Ettensohn, Department of Earth and Environmental Sciences, University of Kentucky, personal communication, 2011.*
REGIONAL HYDROLOGY

The majority of the Inner Bluegrass is drained by the Kentucky River and its tributaries. All surface drainage in the region is ultimately confluent with the Ohio River. The climate is temperate, with warm, humid summers, moderately cold winters, and no distinct wet or dry seasons. The Kentucky River basin receives 46 in (117 cm) of precipitation on average annually, of which ~18 in (46 cm) contributes to surface water (Andrews, 2005).

Surface and subsurface drainages are integrated through sinkholes, conduit networks, and springs (Fig. 2). Dye-trace studies by numerous workers in the Inner Bluegrass have delineated groundwater drainage basins that discharge at springs, as mapped by Currens et al. (2002, 2003). These basins are typically <6 mi² (15 km²) in area, but can be as large as 25 mi² (65 km²) (Thrailkill et al., 1982; Currens et al., 2002, 2003). Dye-trace results suggest geologic control of the groundwater basins, with overall flow parallel to northwest-southeast oriented linear features and faults (Currens and Paylor, 2009). In the Inner Bluegrass, groundwater basins have developed where flow in the reaches of former surface streams has been pirated by conduit development (C.J. Taylor, U.S. Geological Survey, personal communication, 2011).

Thrailkill (1985) characterized flow in groundwater basins as dendritic because of the convergence of flow paths from recharge through swallets (openings in streambeds), sinkholes, and other locations. A single groundwater basin can underlie more than one surface drainage basin, and the surface and subsurface basin shapes may have little relationship to each other. Conduits underlying the groundwater basins are nearly horizontal, have gradients approximating those of the surface streams, and are almost at the same level as the springs which drain them, although flow from the swallet recharging a conduit tends to have a much higher gradient. Flow directions in the groundwater basins often have little or no relationship to flow in the surface streams above. The potentiometric surface in the Lexington Limestone is represented by the water surface in the larger conduits where flow occurs under equilibrium conditions (Thrailkill, 1985). As such, it is very irregular in both lateral and vertical extent.

Although subsurface overflows between groundwater basins are known to exist (Currens et al., 2002), interbasin subsurface flow generally appears to be limited to small conduits in the epikarst zone that are shallow and oriented parallel to land surface. Flow follows the topographic slope to emerge at small, high-level springs that tend to be ephemeral. These interbasin areas form part of the catchment areas for large springs draining the groundwater basins. Surface streams and high-level springs are commonly perched on shaly and argillaceous facies within the Millersburg and Brannon Members of the Lexington Limestone (Thrailkill et al., 1982).

In the area of this field trip, Carey and Stickney (2002, 2004a, 2004b, 2005a, 2005b) divided the Lexington Limestone into upper and lower hydrostratigraphic units for the purpose of describing groundwater occurrence. The upper unit was defined to consist of the Strodes Creek, Millersburg, Tanglewood Limestone, Devils Hollow, Stamping Ground, Sulphur Well, and Brannon Members. The lower unit included the Grier, Logana, and Curdsville Members. It should be noted that this does not correspond to the most current stratigraphic delineation of the Lexington Limestone as described in Clepper (2011) and depicted in Table 1. In the upper unit, discharge rates can exceed 100 gallons per min (gpm) (380 L/min) for some large springs and can be 300 gpm (1100 L/min) from wells along large streams (Carey and Stickney, 2002, 2004a, 2004b, 2005a, 2005b). In the lower unit, discharge occurs to numerous springs, and wells can yield...
up to 150 gpm (570 L/min) along large streams (Carey and Stickney, 2002, 2004a, 2004b, 2005a, 2005b).

In general, the quality of groundwater in the Bluegrass region depends on its geologic source and varies considerably from place to place (Carey and Stickney, 2002, 2004a, 2004b, 2005a, 2005b). Major-ion chemistry of shallow groundwater and streams originating in the Bluegrass region is a Ca-Mg-HCO\(_3\) type with near-neutral pH, consistent with weathering of carbonate rocks by meteoric recharge. Total dissolved solids (TDS) range from 200 to 400 mg/L for shallow groundwater and 100–250 mg/L for streams (Hendrickson and Krieger, 1964). In the Inner Bluegrass, groundwater tends to be hard to very hard; the range from 200 to 400 mg/L for shallow groundwater and 100–250 mg/L for streams (Hendrickson and Krieger, 1964). The pH of carbonate-buffered water also promotes fermentation of grains but not grapes (i.e., making beer rather than wine) (Allen, 1998). Popularity of distilled beverages arose in part because water was associated with disease (Murray, 1998). Even the process of charring the oak barrels for bourbon may have begun as a way to sterilize the wood (Crowgey, 2008).

One of the earliest records of a beverage made from fermented corn is that of George Thorpe in the Jamestown, Virginia, settlement around 1622 (Carson, 1984; Regan and Regan, 2007). Corn was harvested in what is now Kentucky starting ca. 1774. Prior to 1778, settlers there could claim 400 acres (162 ha) of land if they would build a cabin and plant corn (Regan and Regan, 2007). As summarized by Fryar (2009), whiskey production emerged in various locations across the Bluegrass region in the 1770s and 1780s. Rye was another grain used to make whiskey; it grew readily and could be used as a cover crop or to feed livestock (Murray, 1998; Crowgey, 2008). Whiskey’s appeal was furthered by the fact that a farmer could earn more than 25 cents per gallon (3.8 L) for whiskey on the frontier, as compared to a mere 10 cents for a bushel (35 L) of corn, which would yield 4–5 gallons (15–19 L) of whiskey (Kroll, 1967).

From the 1790s to the 1830s, technological developments and market forces led to the commercialization of whiskey production in Kentucky. The limited availability of rum, which was distilled from sugar cane grown in the West Indies, gave corn and rye whiskey a market advantage in the United States (Carson, 1984; Crowgey, 2008). Small farmers began to supply grain to larger distillers around 1800, and the range of proportions of grains used in making bourbon was established by 1823 (Regan and Regan, 2007; Crowgey, 2008). James Crow is credited with the standardization of bourbon production in the 1820s and 1830s, examining the science behind brewing and implementing use of thermometers, hydrometers, and saccharimeters (Allen, 1998; Murray, 1998). The mid-1800s brought about the use of a second distillation for purification and increased ethanol content (Pacult, 2003). Besides the grains used and the aging process, the character of bourbon is often attributed to limestone water (Kroll, 1967; Carson, 1984; Murray, 1998; Pacult, 2003; Regan and Regan, 2007). Shallow groundwater and stream water in the Inner Bluegrass contain sufficient O\(_2\) to limit dissolved iron, an undesirable constituent (Hendrickson and Krieger, 1964; Allen, 1998). The pH of carbonate-buffered water also promotes fermentation (Willkie and Prochaska, 1943; Carson, 1984; Murray, 1998; Pacult, 2003). In addition to the suitable chemistry of groundwater, springs were historically desirable because their temperatures (~13–15 °C) facilitated condensation of steam during distillation (Carson, 1984; Fryar, 2009). However, given the need for relatively large volumes of water in industrial-scale processes, the use of springs in bourbon production has waned (Fryar, 2009). For example, Four Roses uses water from the Salt River; Ancient Age and Wild Turkey use water from the Kentucky River; and Bernheim and Early Times use dechlorinated city water (Murray, 1998). Nonetheless, some distilleries still rely on groundwater. Barton uses water from a spring and spring-fed lake; Maker’s Mark also uses a spring-fed lake; and Woodford Reserve uses water from an 80-ft (24-m) well (Murray, 1998).

**Bourbon Production**

Certain criteria must be met in order for a beverage to be considered bourbon. It must be distilled in the United States and have a grain composition of at least 51% corn. The beverage cannot be artificially altered (e.g., by special filters or additives), and it must be aged for at least 2 years in new, charred, white oak barrels. It cannot be distilled higher than 160 proof (80% alcohol) or put into barrels at higher than 125 proof (62.5% alcohol). Within these strict guidelines, distillers create their own distinct flavors by using different water sources, altering the proportion and type of grains, using different yeast strains during fermentation, and/or aging their products for differing amounts of time.

To begin making bourbon, corn, rye (or wheat), and malted barley are ground to a fine powder and dissolved in water. The mixture is heated (commonly in a steam pressure cooker) to produce sweet mash. After this has cooled, a portion of a previous batch, known as sour mash, is added. Sugars in the mash feed yeast, which produces CO\(_2\) and ethanol (C\(_2\)H\(_5\)OH). This fermenting process typically takes 3 to 5 days. The fermented product, also known as brewer’s beer, is sent to a beer still, where steam creates an alcohol-rich vapor. This vapor is condensed to
create a low wine, which is passed through a second still to create high wine (also known as white dog). High wine is placed in new, charred, white oak barrels and put in a warehouse for a minimum of 2 years. During this time, the high wine migrates into the walls of the charred oak barrel, picking up flavors from the wood. Seasonal variations in temperature aid the migration of the product in and out of the barrel. Water and some ethanol evaporate through the wood into the surrounding air (known as the angels’ share). Loss of water through evaporation increases the proof of the product inside the barrel. After the appropriate time frame, the master distiller will sample products and may choose to mix, or marry, barrels to achieve a certain flavor profile for the final product.

Study of Stable Isotopes within Bourbon

Atoms containing the same number of protons but differing numbers of neutrons are called isotopes. There are ~300 stable and 1200 radiogenic isotopes. Stable isotopes have been used to examine a variety of natural processes, including paleoclimatology, elemental cycling (e.g., biomolecules within an ecosystem), thermometry, and reaction mechanisms (Sharp, 2007). Stable isotopes of hydrogen (2H) and oxygen (18O) can be used to differentiate between waters from varying sources (Mook, 2006). Stable isotopes can also be used to evaluate food quality and origin, such as dilution of fruit juices or wine with water (Monsallier-Bitea et al., 2006).

Stable isotope abundances are commonly expressed in delta notation, which compares the rare isotope/common isotope ratio in a sample (sa) to the same ratio in a standard (std). Typically, the rare isotope is heavier (i.e., contains more neutrons). For oxygen, the international standard is Vienna Standard Mean Ocean Water (VSMOW), which has an 18O/16O ratio of 0.0020052. Delta notation is measured in units of per mil (‰) and is calculated using the following formula:

$$\delta^{18}O(\text{‰}) = \left( \frac{{^{18}\text{O}_\text{sa}}}{{^{16}\text{O}_\text{sa}}} \right) \left( \frac{{^{16}\text{O}_\text{std}}}{{^{18}\text{O}_\text{std}}} \right)^{-1} \times 1000$$  \hspace{1cm} (1)

Because of their differential masses, different stable isotopes of a given element can be fractionated by natural processes. Knowledge of these fractionations can help in delineating the fate of stable isotopes in the environment. One type of fractionation is known as the equilibrium isotope effect: because molecules of greater relative mass have greater dissociation energies, there is a preference for the heavy isotope to occur in one phase. The kinetic isotope effect is a result of unidirectional processes such as water evaporating from a puddle. Evaporation causes 18O enrichment in surface waters (Mook, 2006) as 16O preferentially partitions to the vapor phase. Progressive depletion of water vapor in 18O as air masses move from the equator toward the poles is an example of Rayleigh fractionation, which can incorporate both equilibrium and kinetic isotope effects.

We examined fractionation of 18O in bourbon. It was hypothesized that products would become depleted in 18O during distillation, with high wine being isotopically lighter than low wine, and low wine being isotopically lighter than the source water. We also hypothesized that final products would become progressively enriched in 18O during the aging process. Samples were collected at various steps in the bourbon-making process from three distilleries: Wild Turkey and Four Roses (both in Lawrenceburg, Kentucky) and Jim Beam (in Clermont, Kentucky). These samples included tap/source water, low wine, high wine, deionized water, steam, cut water, and final products of varying ages. Samples were taken to the University of Kentucky and stored at 4 °C until analysis. In the stable isotope laboratory, extractions were prepped by adding one to two drops of phosphoric acid before flushing with a 0.3% CO2/He mixture. Equilibration with CO2 was conducted after injection of 1 mL sample prior to analysis on the isotope-ratio mass spectrometer. The $\delta^{18}$O value obtained for the CO2 gas was used as a proxy for the $\delta^{18}$O value of the liquid sample.

There was evidence of Rayleigh fractionation in both the distillation and aging of bourbon. Figure 3 shows that $\delta^{18}$O values decreased through the process from the source water to low wine to high wine. Source water values are similar to a sample of deionized Lexington tap water ($−8.0‰ ± 0.1‰$; C.S. Romanek, C.S. Romanek, C.S. Romanek).
Department of Earth and Environmental Sciences, University of Kentucky, personal communication, 2011). This supports our hypothesis that lighter isotope fractions are removed from the mixture as water and ethanol evaporate in the stills. The evaporation of lighter fractions is also responsible for the heavier $\delta^{18}O$ values of final products. As each distiller’s product ages and water is lost through the barrel, the bourbon left in the barrel becomes increasingly enriched in $^{18}O$ (Fig. 4). Differences in $^{18}O$ compositions among distilleries at each stage of the process may reflect the isotopic composition of the grains used (which were not examined in this study), temperatures of distillation, and/or influences of the particular yeast strains involved. This may indicate a particular isotope signature for each distillery, which could be of future use for quality control. However, further studies would be needed to evaluate this inference.

FIELD STOPS (Fig. 5)
(Note: 1.0 mile = 1.6 km)

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Directions</th>
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<tbody>
<tr>
<td>0.0</td>
<td>Take I 75 S exit 126 for U.S. 62 toward Georgetown/Cynthiana, Kentucky.</td>
</tr>
<tr>
<td>0.4</td>
<td>Slight right onto U.S. 62 W/Cherry Blossom Way.</td>
</tr>
<tr>
<td>1.1</td>
<td>Turn right onto Paris Rd./Paris Pike (U.S. 460 W), continuing to follow Paris Rd.</td>
</tr>
<tr>
<td>1.7</td>
<td>Continue onto E. Main St. (U.S. 460 W).</td>
</tr>
<tr>
<td>2.3</td>
<td>Turn left onto S. Broadway St. (U.S. 25 S)</td>
</tr>
<tr>
<td>2.4</td>
<td>Take 2nd right onto W. College St.</td>
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</tbody>
</table>

Stop A (Mile 2.5): Royal Spring, Georgetown, Kentucky

Royal Spring (Fig. 6) is the primary water supply for the city of Georgetown (population ~21,000), as well as portions of Sadieville, Stamping Ground, Midway, and Lexington. In 1789, Elijah Craig operated a distillery at Royal Spring (Allen, 1998), which was designated the birthplace of bourbon by Richard Collins in his 1874 History of Kentucky. However, subsequent authors identified evidence of whiskey-making elsewhere in Kentucky between 1776 and 1781 (Regan and Regan, 2007; Crowgey, 2008). Royal Spring emerges from the Grier Member of the Lexington Limestone and sustains a tributary to North Elkhorn Creek. A karst conduit system carries all base flow and a large but unmeasured percentage of high flow discharge from the Cane Run watershed to Royal Spring, which is located outside the boundary of the Cane Run watershed.

Cane Run is a fourth-order stream that originates in central Fayette County and flows north into North Elkhorn Creek in Scott County. The main stem of Cane Run is ~17 mi (27 km) long and drains an area of 45 mi² (116 km²). The watershed consists of 25% urban land, primarily in northeast Lexington, and 75% rural land, including farms, light industry, a quarry, and rural and suburban residences. Discharge from the headwater tributaries of Cane Run is sustained in the dry season by urban runoff and interbasinal, perched springs. However, the middle reach of Cane Run is normally dry and only carries discharge during floods. Heavy rainfall causes sudden, large increases of stream flow, followed by a brief recession and then a sudden cessation of discharge. Swallets along the channel of Cane Run govern the partitioning of runoff between surface flow and groundwater. When intense rainfall occurs in the dry season, recharge to the conduit is limited by the hydraulic capacity of the conduit because such events may not fill it to full pipe flow. During the wet season, conduit discharge capacity is close to maximum and surface flow extends further downstream, as conceptualized in Figure 7.

Qualitative and quantitative dye traces have been conducted within the Royal Spring basin in order to delineate the basin boundaries (Fig. 8) and determine groundwater travel times. Groundwater velocities ranged from over 1 mi/h (1.6 km/h) during storm events to less than 0.15 mi/h (0.24 km/h) in dry conditions (Paylor and Currens, 2004). Contaminants may travel more slowly, depending upon their sources and whether attenuation occurs in epikarst or within the conduit (e.g., as a consequence of adsorption onto sediment [Reed et al., 2010]). Using two-dimensional, three-dimensional, and time-lapse electrical resistivity surveys (with salt injection), Zhu et al. (2011) suggested the location of the main conduit of the Royal Spring groundwater basin beneath the middle reach of Cane Run.

Mileage | Directions |
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<tbody>
<tr>
<td>2.6</td>
<td>Head east on W. College St.; turn right onto S. Broadway St. (U.S. 25 S); continue as U.S. 25 S becomes Lexington Rd./Georgetown Rd.</td>
</tr>
</tbody>
</table>

Figure 4. $\delta^{18}O$ values for final products of the Wild Turkey, Four Roses, and Jim Beam distilleries.
Figure 5. Field-trip route map through Inner Bluegrass region (from Google Maps, November 2011).

Figure 6. Royal Spring (photo by A.E. Fryar, April 2009).

Figure 7. Conceptual diagram of flow along Cane Run (not to scale) (modified from unpublished figure, Kentucky Geological Survey).
Figure 8. Inset of mapped karst groundwater basins in Fayette and Scott Counties, Kentucky (from Currens et al., 2002).
13.7 Bear right as U.S. 25 S merges with Newtown Pike (KY 922 S).
14.2 Continue onto Oliver Lewis Way (KY 922 S).
14.4 Turn right onto KY 1681 W (Manchester St./Old Frankfort Pike).
15.6 Turn left onto McConnell Springs Rd. and left onto Cahill Dr.; take the 1st right onto Rebmann Ln.

Stop B (Mile 15.9): McConnell Springs, Lexington, Kentucky

The McConnell Springs site is located in a 26-acre (11-ha) city park within the Wolf Run watershed in Lexington. The springs occur within a karst window, a cave passage unroofed by solution collapse. The Grier, Brannon, and Tanglewood Members of the Lexington Limestone are exposed on the site. The Grier Member, which is relatively transmissive because of dissolution along fractures and bedding planes, underlies ~80% of the site. The park contains more than 130 species of plants, including bur oaks (*Quercus macrocarpa*) that are thought to remain from pre-settlement grassland savannas more than 250 years ago (Friends of McConnell Springs, 2010).

During the summer of 1775, a party from southwestern Pennsylvania, including William McConnell, surveyed land along the tributaries of Elkhorn Creek with the intent of filing land claims with the state of Virginia, of which Kentucky was a part. William McConnell claimed the “sinking springs” that now bear his name (O’Malley, ca. 2006). Legend has it that these pioneers were camped at the springs when they received word of the Battle of Lexington (Massachusetts) and decided to name the settlement after it. The actual town was not formed until 1779. Various land uses have occurred around the springs during the past two centuries, including a gunpowder mill, stock farming, commercial bourbon production, and dairying (O’Malley, ca. 2006). Remnants of dry-stone fences are evidence of Irish and Scottish immigrant masons who began working in the 1830s. The city park was created in the 1990s after a failed effort to develop the site as an industrial park. Adjoining land use remains partly industrial; in particular, Vulcan Materials quarries limestone from the Tyrone, Oregon, and Camp Nelson Formations more than 435 ft (133 m) beneath the springs. However, because of the presence of bentonite near the top of the Tyrone Formation, the permeability of those units is so low that spring flow is not noticeably affected (Currens and Paylor, 2009; Friends of McConnell Springs, 2010).

Blue Hole is the first of two major springs seen in McConnell Springs Park (Figs. 9, 10). The name of this artesian spring is derived from its color, which results from the depth of the orifice (>15 ft [4.6 m]). Water discharging at Blue Hole has been traced from swallets and sinkholes as far as 2.5 mi (4.0 km) south and southwest of the spring (Currens et al., 2002; Friends of McConnell Springs, 2010) (Fig. 8). Discharge at Blue Hole is sensitive to rainfall. Water flows over the surface for tens of feet before sinking; it resurges at the second artesian spring in the park, known as the Boils (Figs. 9, 11). At this location, water is under sufficient pressure (rising as much as 2 ft [0.6 m] above the spring pool after heavy rains) that it appears to be boiling, even though its temperature is ~56 °F (13 °C). Discharge from the Boils flows in a stream channel ~1000 ft (300 m) to the Final Sink, where it disappears.

![Diagram of McConnell Springs flow](image-url)
underground and travels ~0.3 mi (0.5 km) to Preston’s Cave. Discharge from Preston’s Cave flows to Wolf Run and thence to Town Branch of Elkhorn Creek.

Stop C (Mile 35.2): Woodford Reserve Distillery, Versailles, Kentucky

Woodford Reserve Distillery (Fig. 12) traces its origins to 1797, when Elijah Pepper began making whiskey in Woodford County (Kentucky Distillers’ Association, 2010). Distilling on the current 72-acre (29-ha) site began ca. 1812 using water from Grassy Springs Branch of Glenns Creek (National Park Service, 2008; Kentucky Historical Society, 2011). Elijah’s son Oscar Pepper employed James Crow as master distiller in the 1830s (National Park Service, 2008; Kentucky Historical Society, 2011). Leopold Labrot and James Graham purchased the distillery from the Pepper family in 1878 (Kentucky Bourbon Trail, 2006). The Labrot & Graham Distillery operated until 1941 (Bourbon Central, 2011); Brown-Forman purchased it and reopened it in 1996 (Brown-Format, 2004). As a small-batch distiller, Woodford Reserve uses a single, proprietary yeast strain to produce a consistent flavor profile. The mash bill (recipe) consists of 72% corn, 18% rye (to which the spicy character of the bourbon is attributed), and 10% malted barley (Woodford Reserve, 2011). Woodford Reserve uses cypress fermentation tanks and triple distills its whiskey in three copper-pot stills (Fig. 13), depicted in the emblem stamped on the ends of its oak barrels.

<table>
<thead>
<tr>
<th>Mileage</th>
<th>Directions</th>
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<tbody>
<tr>
<td>35.2</td>
<td>Continue on McCracken Pike/Glenns Creek Rd./ Martin Luther King Dr. (KY 1659 N).</td>
</tr>
<tr>
<td>43.9</td>
<td>Turn left onto E. Main St. (U.S. 60 W).</td>
</tr>
<tr>
<td>44.7</td>
<td>Turn right onto High St. (KY 420).</td>
</tr>
<tr>
<td>44.9</td>
<td>Bear right onto Holmes St. (KY 2261).</td>
</tr>
<tr>
<td>46.6</td>
<td>Continue onto Owenton Rd. (U.S. 127 N).</td>
</tr>
<tr>
<td>46.8</td>
<td>Turn right onto Cove Spring Rd. and take the first left onto Deadhorse Rd.</td>
</tr>
<tr>
<td>47.0</td>
<td>Travel to end of Deadhorse Rd.</td>
</tr>
</tbody>
</table>

Figure 10. Blue Hole, McConnell Springs (photo by A.E. Fryar, April 2009).

Figure 11. The Boils, McConnell Springs (photo by A.E. Fryar, April 2009).

Figure 12. Woodford Reserve Distillery (photo by A.E. Fryar, November 2008). Warehouse for aging bourbon is at right.
Stop D (Mile 47.0): Cove Spring Park, Frankfort, Kentucky

Cove Spring Park, which is owned by the City of Frankfort, consists of ~100 acres (40 ha) of meadows, wetlands, and forested ravines within the Kentucky River valley. The park was established in part to preserve Braun’s rock-cress (Arabis perstallata), an endangered wildflower (Frankfort Area Chamber of Commerce, 2011; U.S. Fish and Wildlife Service, 2011). In 1800, settlers impounded Cove Spring to form Frankfort’s water supply, which was distributed through pipes made from cedar logs cut on-site (Frankfort Area Chamber of Commerce, 2011). An overflow tower constructed of locally quarried limestone still stands at the site. Clepper (2011) described the stratigraphy of a 280.8-ft (85.6-m) measured section at the site, which extends from the Tyrone Formation along the valley floor to the upper tongue of the Tanglewood Member of the Lexington Limestone at the top of the escarpment (Table 1).

Mileage  Directions
47.3  From Cove Spring Rd., turn left onto Owenton Rd. and immediately take the ramp onto U.S. 127 S/U.S. 421 N/Wilkinson Blvd.
49.2  Turn right onto U.S. 127 S/W. Frankfort Connector; continue on U.S. 127 S.
67.4  Turn right onto KY 513/Bonds Mill Rd./Hickory Grove Rd.
68.5  Turn right; destination will be on left.

Stop E (Mile 68.5): Four Roses Distillery, Lawrenceburg, Kentucky

In 1888, Paul Jones Jr. trademarked the name Four Roses as a brand of bourbon. The present distillery was built in 1910 in a Spanish mission style unusual for Kentucky. In 1922, the Paul Jones Company purchased the Frankfort Distilling Company, one of six distilleries authorized to produce bourbon for medicinal purposes during Prohibition (Four Roses, 2011). Frankfort Distilling was sold to Seagram in 1943, which produced Four Roses straight bourbon whiskey (as opposed to blended whiskey) only for export for more than 40 years. In 2002, the distillery was acquired by the Kirin Brewery of Japan, which reintroduced Four Roses straight bourbon to the American market (Four Roses, 2011). Four Roses uses a combination of five yeast strains and two mash bills to produce 10 bourbon recipes, each with its own flavor profile. Only one recipe is used in the Single Barrel product, whereas four recipes are combined to create Small Batch, and up to ten recipes are used to create Yellow Label. One mash bill includes 75% corn and 20% rye, whereas the other includes 60% corn and 35% rye; both include 5% malted barley (Four Roses, 2011). In contrast to Woodford Reserve, which ages its bourbon on-site, Four Roses uses warehouses in Cox’s Creek, Kentucky, approximately a 1 hour drive west of the distillery.

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REFERENCES CITED

Bourbon and springs in the Inner Bluegrass region of Kentucky


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