Landslides and Your Property

Publication support from Duke Energy

By Paul E. Potter, Mark Bowers, J. Barry Maynard, Matthew M. Crawford, Gerald A. Weisenfluh, and Tim Agnello

Are you interested in buying property with a view? Are you considering a new townhouse along the river? Are you a developer looking to take advantage of the expansion of infrastructure into the hills of northern Kentucky? Then you need information about landslides—what causes them, how to recognize them, and how to manage their effects.

This guide explains the major types of landslides and the geology that causes them, suggests ways to avoid landslide problems, and provides contacts for help.

Why so many landslides? Soil naturally moves downhill on slopes as part of the slow process of erosion. The geologic makeup of our area, however, makes it particularly prone to these movements, which often take the form of damaging landslides. Geologic events in the distant past and in the relatively recent ice ages left very deep valleys that have weak soils on the valley sides. The consequence is that slopes can form landslides in three different ways, namely:

- Creep – slow and shallow (figs. 1–3);
- Translational – fast and shallow (figs. 4–9);
- Rotational – slow and deep (figs. 10–12).

Each has a different cause and is managed in a different way.

What's the risk? It depends on the type of movement and the amount of material involved. Soil movement via creep is usually slow enough to anticipate and manage with modest effort. Translational landslides can rapidly strip all the soil off a hillside and fill the area at the bottom of the slope. Cleanup is extensive and prevention involves significant effort. Rotational landslides are deep and can be devastating; for example, the 1973 Mt. Adams slide in Cincinnati destroyed two streets and sixteen houses, and cost tens of millions of dollars to stabilize.

The Cincinnati area is one of the most active spots in the country for landslides and has among the highest per capita costs to prevent and mitigate their effects. Successful property development on our hills requires an understanding of their underlying structure and of landslide processes. This publication is your starting point.

Types and Examples of Slides

CREEP

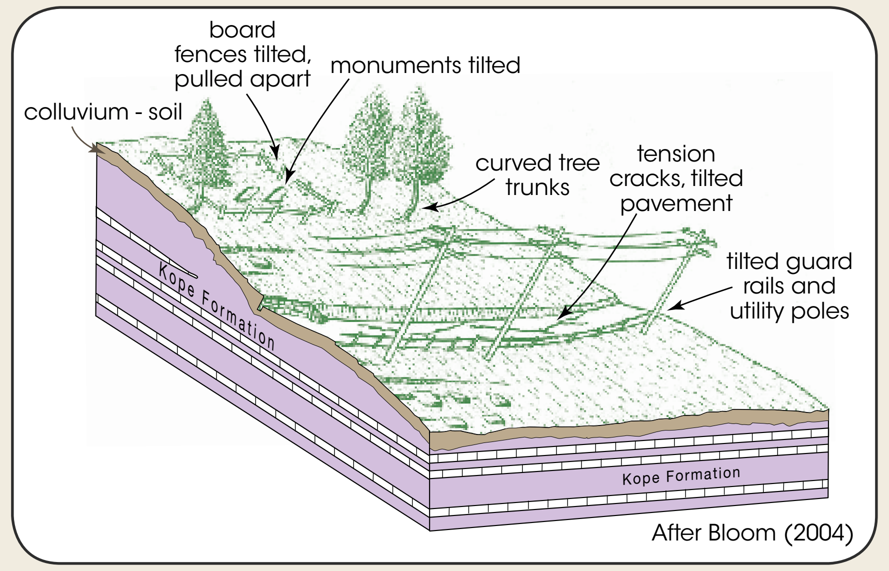


Figure 1. Cracks in walls and roads and tilted poles, fence posts, and trees are evidence of a slow-moving slide, called 'soil creep.' Creep is the most widespread slope movement and can be damaging, but is easily overlooked.

Figure 2. Old, slow hillside creep in colluvium finally breaks this stone retaining wall, in Mt. Auburn, Cincinnati, Ohio. Note the tilted trees.

Figure 3. This long curved crack in a walking trail in Miami-Whitewater Park, Hamilton County, Ohio, reveals soil movement towards a stream to the right. This movement would not be readily apparent in a grassy field.

TRANSLATIONAL

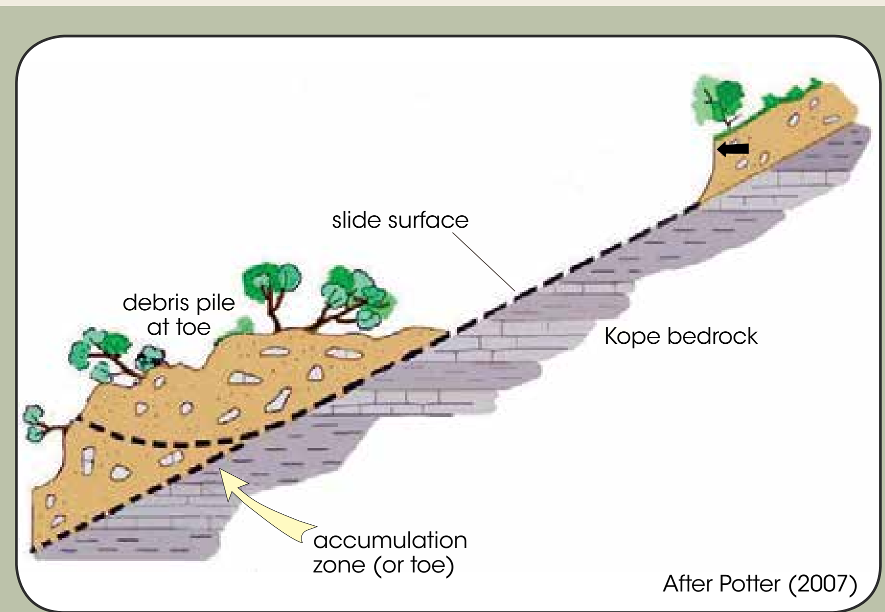


Figure 4. Diagram of a translational slide at the soil-rock contact. These planar failures are common on hillsides in the area, but because the bedrock is not involved, they are relatively easy to remediate.

Figure 5. Head scarp of translational slide along the Ohio River Valley, at Price Hill, Cincinnati, Ohio. The apartments are set in bedrock and so are unaffected.

Figure 6. A small translational slide with debris pile at toe. Note the disoriented trees and exposed underlying bedrock of the Kope Formation.

Figure 7. The toe of a translational slide is overtopping a wall. Note the icicles at the base, evidence that water is flowing along the slide surface.

Figure 8. An unusually large bank collapse in an old gravel pit. Note the scarp at the top and the debris pile at the base. This translational slide verges on being classified as a debris avalanche.

Figure 9. Jumbled trees and mud at the toe of a translational slide that damaged a condominium in Bellevue, Kentucky. Landslides can damage property at the top or bottom of a hill.

ROTATIONAL

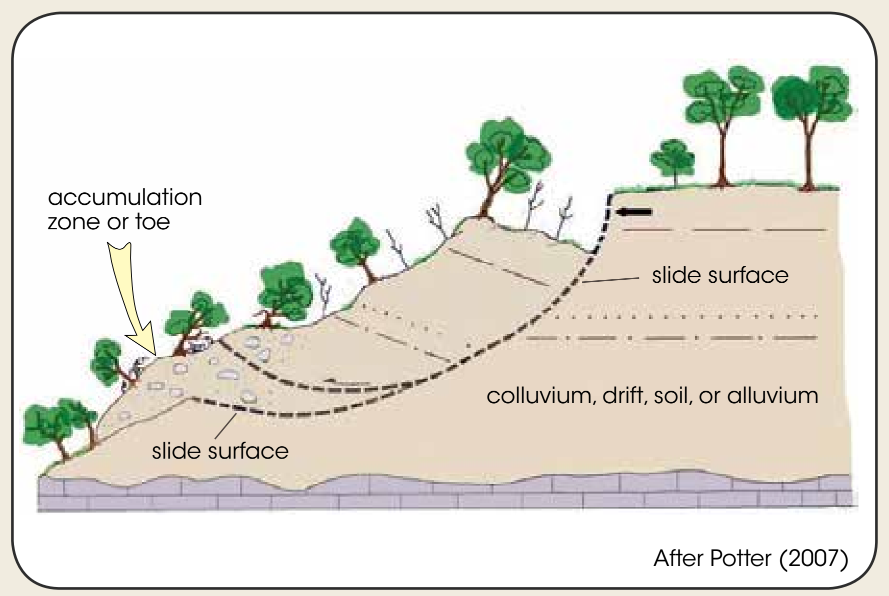


Figure 10. Rotational slides predominate in thick glacial deposits and on stream banks. They also occur where thick colluvium is present at the base of the slope. In our area, this is the most damaging type of slide.

Figure 11. Rotational slide on KY 1486 at Fowler Creek. The fill was placed on top of Kope Formation colluvium, which led to its failure.

Figure 12. Well-defined scarp at the head of a rotational slide in Eden Park, Walnut Hills, Cincinnati, Ohio.

Glossary

Backwater deposits – Clay-rich deposits prone to failure, they are best developed south of the Ohio River. They occur in terraces at the mouths of tributaries to a larger stream where glacial outwash caused a temporary lake to form.

Bedrock – Term used by engineers and geologists when referring to the Ordovician limestones and shales that underlie soil everywhere in the area. The bedrock itself seldom fails, and so determining the depth to bedrock is a key part of any site investigation.

Bridging – Large rock fragments that interfere with proper compaction of finer fill material.

Colluvium – A clay-rich deposit derived from weathering of bedrock that has moved downslope by gravity from its place of origin. It mantles many slopes, and easily fails if disturbed.

Factor of safety (FS) – An estimate of slope stability calculated from the slope angle and soil properties such as unit weight and cohesion. A FS value of less than or equal to 1 indicates a slope poised for failure.

Failure – The rupture of either a solid or unconsolidated material. It can be identified by a displacement, such as a crack in a wall or a scarp in soil. This brittle behavior contrasts with the more flexible deformation of slow creep.

Glacial deposits – Material at the surface deposited by ice 10,000 to 2 million years ago. These include till, outwash, and lake bed clays. Lake bed clays are notoriously unstable and need careful attention.

Head scarp – The upslope end of a landslide where a slide intersects the undisturbed ground surface and initial rupture takes place.

Ice ages – The time period when glaciers repeatedly covered northern North America. In our region, there are deposits of at least three ice advances: the Wisconsin (youngest), Illinoian (older), and pre-Illinoian. Most glacial deposits are north of the Ohio River except lake bed clays, which are extensive in northern Kentucky and in Ohio.

Lake bed clays – Fine-grained laminated deposits of clay and silt laid down in lakes dammed by ice during the Pleistocene Epoch (Ice Age). They are exceptionally unstable, even on gentle slopes.

Lamination – A texture in soil or rock that is made up of very thin (a few millimeters to a centimeter) parallel layers (see fig. 21). The layers may reflect an annual pattern of sedimentation.

Ordovician System – The set of rock formations that make up the local bedrock. It consists of limestone and shale that was deposited in an ancient ocean between 444 and 488 million years ago.

Outwash – Sand and gravel deposits left from the flowing water of melting glacial ice. It is a valuable source of aggregate material in buried valleys and an important source of groundwater.

Pore water pressure – The pressure of water in the pores (small spaces) that exist in rocks and unconsolidated materials. This pressure varies with rainfall, position on the slope, and human activities. High pore water pressures destabilize slopes.

Quarry – A cut into bedrock for the purpose of removing building stones.

Scarp – A break in the ground parallel to the slope.

Slide (slip) surface – The striated surface between two sliding masses. Striations show the direction of movement. This type of surface can be caused by the movement of shrinking/swelling soils as well as by landslides.

Soil – Engineers use this term to refer to any unconsolidated material above the bedrock.

Swelling soil – Soil that reacts to wet periods by swelling and to dry periods by shrinking. It can be damaging to structures if not properly handled.

Terrace – Long, narrow flat area along the sides of a valley. Terraces reflect old river floodplains.

Till – Ice-laid deposit of clay, sand, pebbles, and occasionally boulders.

Toe – The bottom of a slope or a landslide.

Swelling Soils

You may also experience the effects of swelling soils, another feature of our local geology. These are soil types that are subject to extreme shrinking and swelling during dry and wet periods. This movement is independent of slope and, therefore, can happen anywhere. Online maps from the National Resource Conservation Service (NRCS) identify soils having high shrink-swell potential. To learn more about swelling soils, contact the NRCS office in your county.

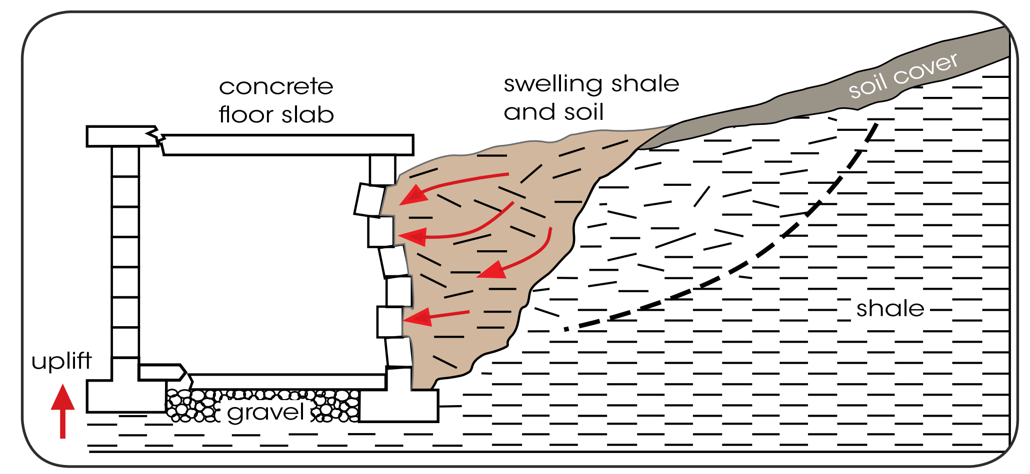
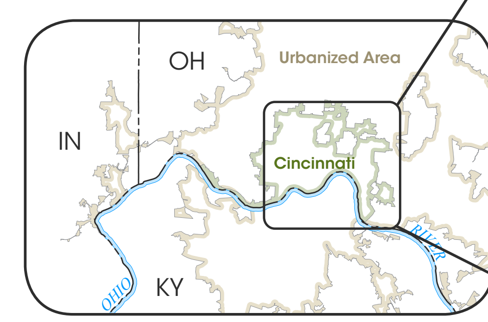


Figure 13. Fill composed of swelling soil can crack basement walls or floors and also make slopes more unstable (Smath et al., 2006).

Topography

Hillsides and slopes in the greater Cincinnati region contribute to its distinctive character. However, the prevalence of this steep topography makes the region unusually prone to landslides. It is important to be aware of landslide hazards when building on slopes.



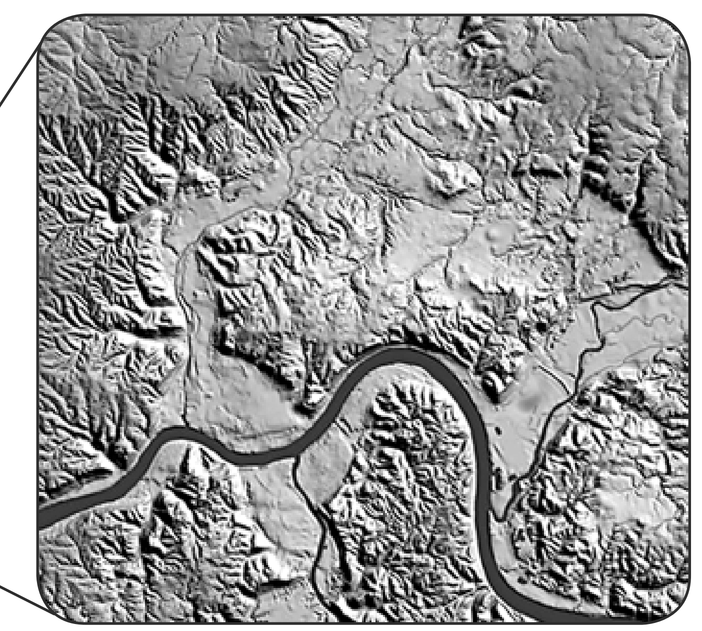


Figure 14. Map showing the landslide-prone topography of the Cincinnati region. Areas having steep slopes are depicted with high contrast on the map.

Shaded relief is based on a 30-meter digital elevation model from the U.S. Geological Survey National Elevation Dataset.

Inspecting a Property

Things to Look For in the Neighborhood

- **Steep slopes** – As hill slopes increase, so does the likelihood of slope failure.
- **Modified slopes** – Human activities are a principal cause of slope failures — cuts and fills; runoff from new roads, roofs, and parking lots; water from overuse of septic tanks and excessive lawn watering.
- **Old limestone quarries** – The crests of many hillsides during the 1800s were sites of limestone quarries in the Fairview Formation (see fig. 19). Shale waste was dumped on the slope below and became part of the colluvium; it can be prone to failure.
- **Presence of clayey colluvial soil or glacial lake clays** – Even thin layers of clay can cause problems.
- **Stream banks** – Undercutting on outside bends and rapid water level fall can cause these to fail.
- **North-flowing streams** – North-flowing streams such as the headwaters of the West Branch of Mill Creek are likely to have been dammed by south-flowing ice that formed temporary glacial lakes, leaving deposits of fine-grained clays and silts prone to failure. Steams draining directly into the Ohio River, such as the Licking River, and Eagle, Laughery, Gunpowder, Mill, Twelve Mile, and Tanners Creeks, also have silts and clays in backwater glacial terraces along their lower reaches.

Site-specific Features to Look For

- **Old landslides** – Honeysuckle-covered slopes with bumpy, irregular surfaces, small closed depressions, often wet (cattails). Old walls, abandoned driveways, and the outlines of foundations are signs that houses were once located there.
- **Tilted trees, poles, posts, and walls** – Inclined or bent trees that are"kinked" upslope close to the ground, and tilted light poles and guardrails indicate hillside movement.
- **Broken or leaking pipes** – Many landslides are associated with cracked sewer or water lines. Locate every line and check for leaks.
- **Cracks in buildings, walls, and roads** – Failures are much easier to see when they cut pavement, walls, or foundations. Look for cracks that line up, have noticeable offset, or have a bow-shaped pattern.
- **Breaks in soil** – Breaks or "scarps" in the soil that are roughly parallel to the contours of the slope indicate active sliding (fig. 15). They can range from an inch or so to several feet in height.

Figure 15. A small, fresh scarp on a gentle slope and tilted fence posts are subtle but important clues that signal sliding. They could easily be missed in dense vegetation.

- **Debris scars** – Narrow, elongated bedrock scars cutting across steep slopes indicate recent translational-type landsliding.
- **Slickensides** – A smoothly polished surface in clays with small parallel grooves shows that there has been movement between two masses of unconsolidated material. They are seen on the slip surface of translational slides.
- **Closed depressions** – Typically a few feet across and commonly marked by wetland vegetation such as cattails.
- **Dipping strata in stream bed or base of large cut** – This is evidence of deep movement in the hillside above and is seen most commonly with lake bed clays.
- **Swelling soil** – Damage to foundations can result from excessive movement of clay soils subject to repeated wetting and drying (fig. 13). Such soils are shown on National Resource Conservation Service maps.

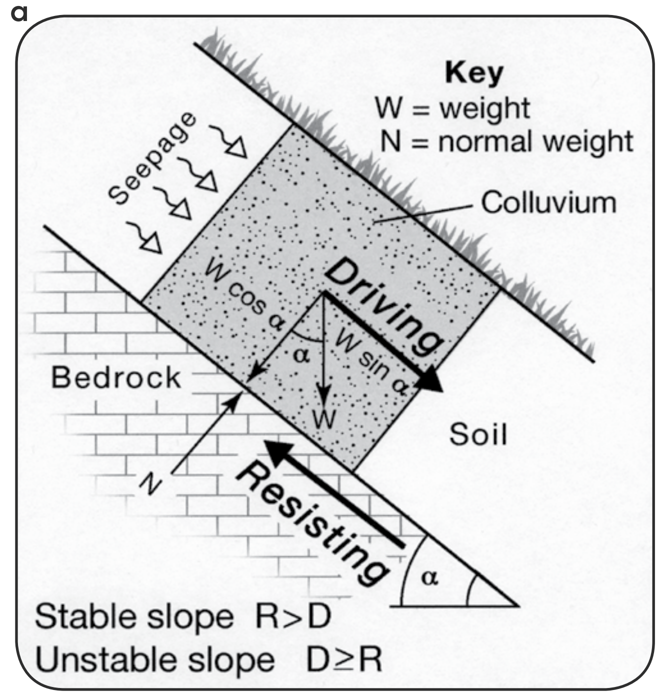
Avoidance and Remediation

Avoidance

- The greatest danger in hillside development is inadvertently building on an old landslide. Research the history of the site and thoroughly inspect for signs of sliding.
- Consult soil and geologic maps early in your evaluation of a building site to be aware of specific landslide-prone soils and rock types. Also check for swelling characteristics and remember that the shale of the Kope Formation is associated with abundant colluvium, which fails readily on slopes.
- Watch for fill placed at the top of the hill and excavations into the bottom of the hill — both are common triggers of landslides (fig. 16).

Remediation

- If there has been a slide on your property, your first line of defense against further movement is water management: deflect or drain water away from the slope. Do not irrigate or use the area for a septic drain field.
- Do not cut trees on a slope. Trees and other vegetation transfer soil pore water into the atmosphere and their roots help tie colluvium to bedrock. If honeysuckle is growing on the slope, replace it with deeper-rooted plants such as maples or water-seeking plants like willows.
- If you have access to the base of the slope, you may need to reinforce it. One strategy is to add a cover of boulders (riprap) as a buttress.



Assessing the risk of failure involves evaluating the balance between forces acting on a soil mass to move it downslope (driving forces) and forces acting to hold it in place (resisting forces) (fig. 16a). Driving forces are enhanced by: increasing slope angle (add fill to the top of the hill or remove it at the base); adding water; and cutting vegetation. You can enhance resisting forces by: diverting water from the slope; draining the slope; planting water-extracting trees such as willows; and building retention structures (fig. 16b).

b

Figure 16a. This diagram depicts the driving and resisting forces that operate on a slope. A numeric "safety factor" can be determined by a formula involving the angles and soil properties.

Figure 16b. A retaining wall of steel piles shows generations of failure along a roadway in Kenton County, Kentucky.

- Place all construction, including driveways, back from the brow of the slope. An expensive alternative is to pier or anchor into bedrock structures on the brow.
- When working on a building site, try to avoid damaging the water and sewer lines that run parallel to the contour of a hillside. Broken water pipes are a common cause of large slides.
- When considering a building site, look carefully at the property itself, but also beyond its boundary lines. Check nearby stream beds for slide toes, look for cracks in neighbors' pavements or walls, and check for tilted posts and poles in the surrounding area.
- If you find signs of sliding or are considering building along a steep slope, a geotechnical investigation should be done. This may include taking subsurface borings across the site and running laboratory tests of soil to obtain an integrated assessment of site stability.
- If there is old fill or thick colluvium, you may need to remove it down to bedrock, then refill, properly compacting the soil. When using the Kope Formation for fill, remove larger limestone slabs to avoid bridging (see Glossary).
- Many slopes require a retaining wall or another type of retaining structure (figs. 16 and 17). These can be of a variety of designs, but all require engineering and construction expertise.
- If it is necessary to cut into bedrock, do not allow deep cuts or drilled shafts in the Kope Formation to stand open and uncovered for long periods. Even short periods of weathering can cause serious deterioration.

Figure 17. A special caged structure called a gabion wall reinforces a steep slope in Pulaski County, Kentucky.

The Kope Formation

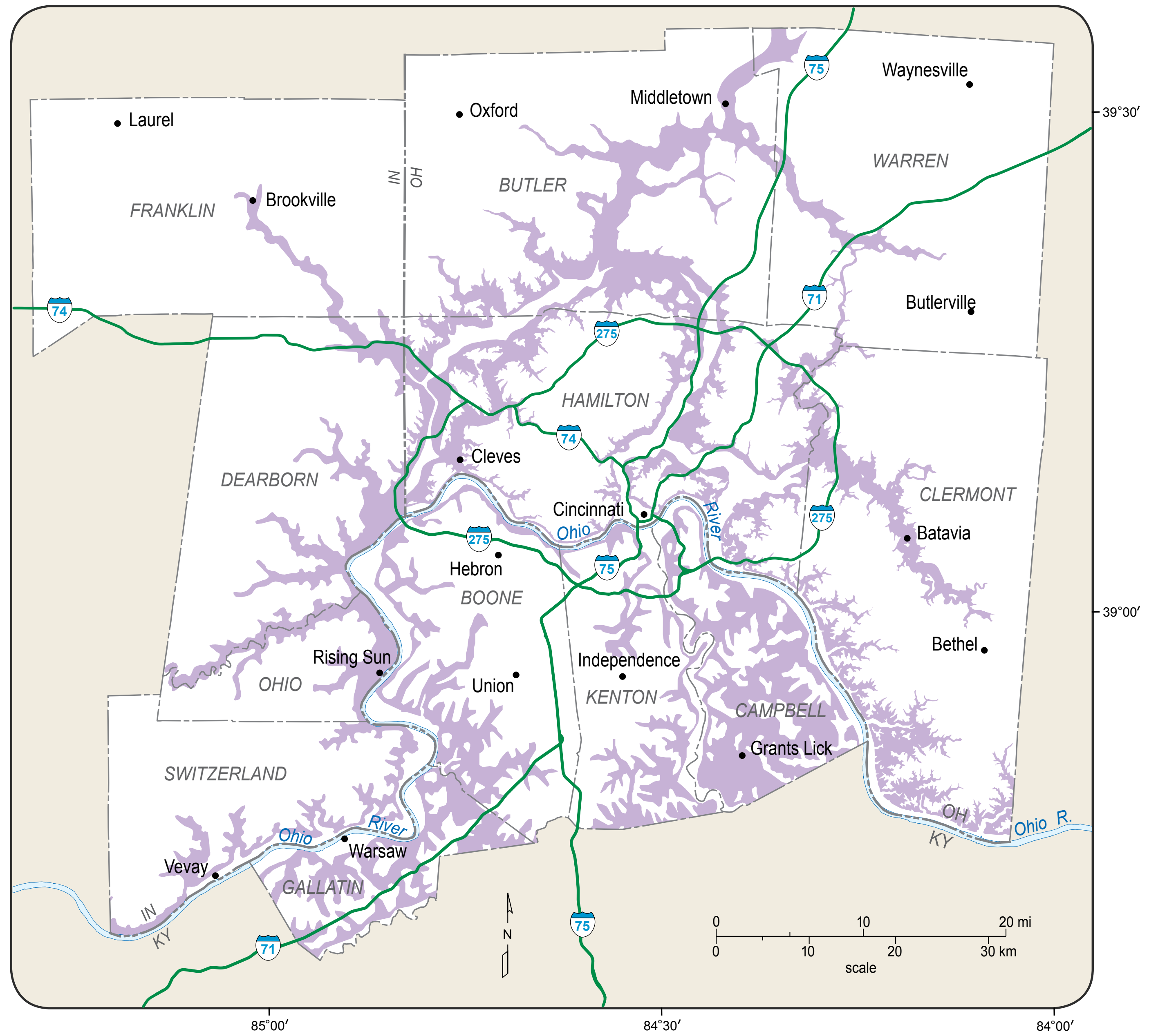


Figure 18. Distribution of the Kope Formation (purple) in the Cincinnati area; it is the dominant bedrock in many valleys. The Kope is easily recognized as a rock unit composed of shale (see fig. 19).

(Map compiled by the Kentucky Geological Survey with cooperation from the Ohio and Indiana Geological Surveys.)

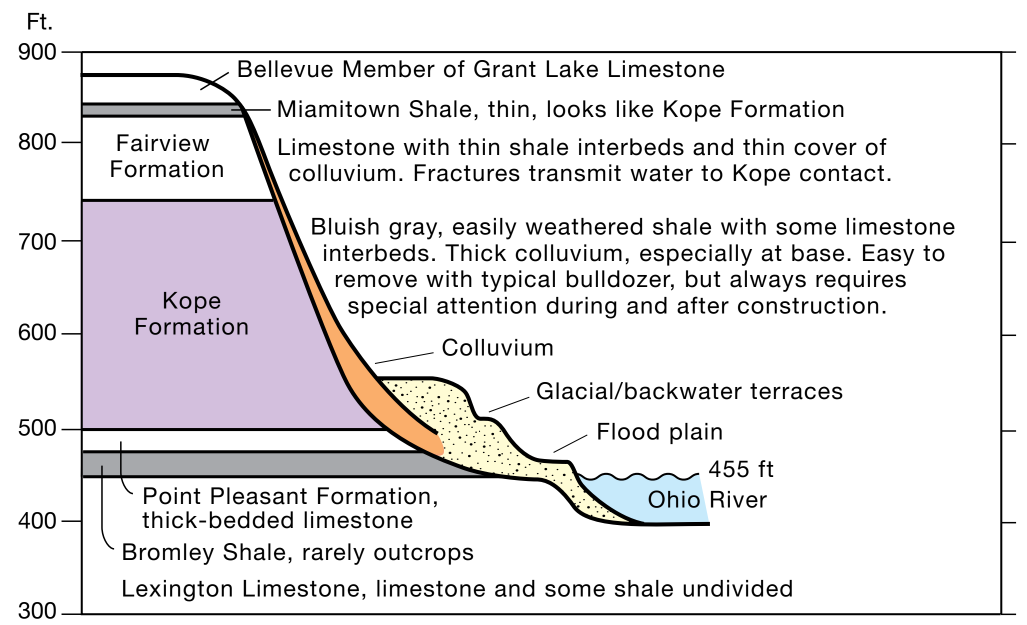


Figure 19. This illustration of the bedrock column in the Cincinnati area shows two units prone to landslides: colluvium (orange) on top of Kope Formation bedrock and glacial deposits (yellow) along the base of the slope.

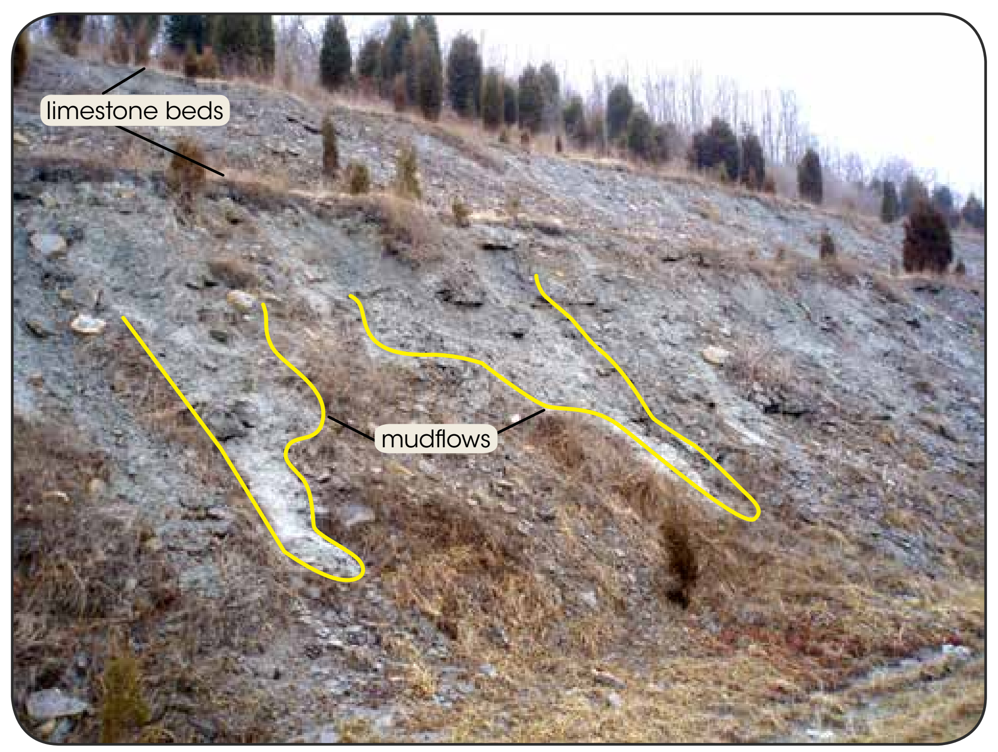


Figure 20. Outcrop of the Kope Formation, which is mostly shale (gray) with thin limestone beds (rust). When the shale gets wet it erodes easily, moving down the slope. Note the small mudflows (outlined in yellow). This type of soil cover fails easily, but the bedrock is not involved.

Lake Bed Clays

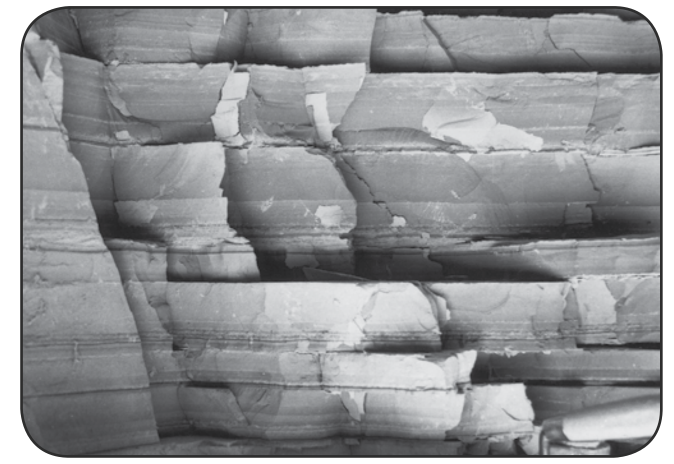


Figure 21. Well-developed lamination in glacial lake bed clays. Such clays are prone to failure even on gentle slopes and are the cause of many of the most serious landslides in the area.

Figure 22. Long headscarp of a rotational slide in lake bed clays along I-75 in Hamilton County, Ohio. This was also the route of the old Miami and Erie Canal, whose aqueduct across Mitchell Avenue collapsed, likely due to lake clays.

Stream Bank Failure

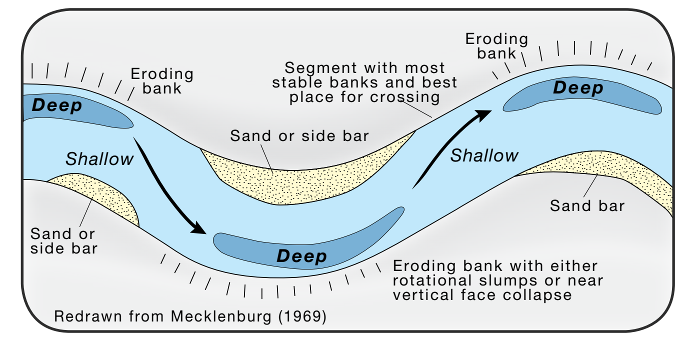


Figure 23. Local streams typically alternate eroding cutbanks and depositing sand bars downstream. Undercutting causes slope failures to occur on cutbanks, some of which can be quite large.

Figure 24. At Banklick Creek in Kenton County, Kentucky, a stream is cutting away the toe of a large, compound rotational slide. Trees dipping into a bank are good indicators of sliding.

A New Technique

Light detection and ranging (LiDAR) technology provides high-resolution elevation maps and many derivative products that reveal landslides better than conventional air photos or satellite images (Crawford, 2012). Landslide identification mapping using LiDAR has proven successful in Kentucky and other landslide-prone areas of the United States. The advantage this data is its potential to identify landslides previously undocumented or not visible on earlier maps (fig. 25).

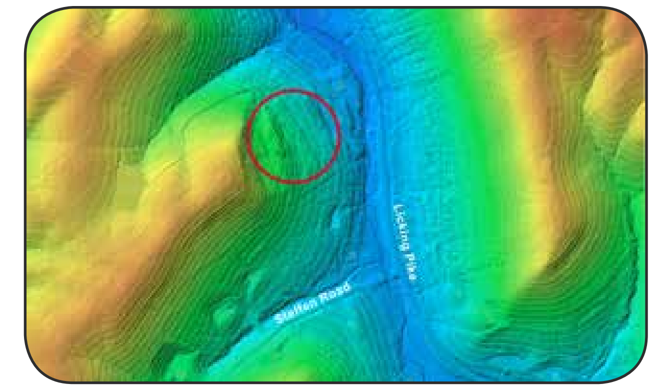


Figure 25. LiDAR images help geologists identify suspect landslide topography.

More Information and Help

Kentucky Geological Survey Lexington, Kentucky 895.323.0510 www.uky.edu/KGS/	Hillside Trust of Hamilton County, Ohio 513.855.7636 hillsidetrust.org
Indiana Geological Survey Bloomington, Indiana 812.855.7636 igs.indiana.edu	Northern Kentucky Planning Commission 859.331.8980 nkapc.org
Ohio Division of Geological Survey Columbus, Ohio 614.265.6578 dnr.state.oh.us/geosurvey	American Society of Civil Engineers, Cincinnati, Ohio Section cincyasce.org
U.S. Geological Survey Hazards Branch Reston, Virginia landslides.usgs.gov	The National Resource Conservation Service (formerly the Soil Conservation Service) websoilsurvey.nrcs.usda.gov

References Cited

Bloom, A.L., 2004, Geomorphology – a systematic analysis of Late Cenozoic landforms, 3rd ed.: Long Grove, Illinois, Waveland Press, 482 p.

Crawford, M.M., 2012, Using LiDAR to map landslides in Kenton and Campbell Counties, Kentucky: Kentucky Geological Survey Series XII, Report of Investigations 24, 12 p.

Mecklenburg, D.E., 1969, Rainwater and development, 2nd ed.: Ohio Department of Natural Resources, Division of Soil and Water, 190 p.

Potter, P.E., 2007, Exploring the geology of the Cincinnati/northern Kentucky region: Kentucky Geological Survey Series XII, Special Publication 8, 128 p.

Smath, R.A., Carey, D.I., Davidson, Bart, Kiefer, J.D., and Daniels, Ken, 2006, Geological map for land-use planning – Campbell County, Kentucky: Geological Survey of Kentucky Series XII, Map and Chart 128, scale 1:48,000.

Useful Background References

Agnello, Tim, 2005, Historic rock quarries and modern landslides in Price Hill, Cincinnati: Ohio Department of Natural Resources, Ohio Geology, no. 2, p. 1, 3, and 5.

Highland, L.M., and Bobrowsky, Peter, 2008, The landslide handbook – a guide to understanding landslides: U.S. Geological Survey Circular 1325, 129 p. (Available online at landslides.usgs.gov or gsc.nrcan.gc.ca/landslides.)

Holzer, T.L., 2009, Living with unstable ground: American Geological Institute, 64 p.

Nuhfer, E.B., 1993, A citizens' guide to geologic hazards – a guide to understanding geologic hazards, including asbestos, radon, swelling soils, earthquakes, volcanoes, landslides, subsidence, floods and coastal hazards: Arvada, Colo., American Institute of Professional Geologists, 134 p.

Nuhfer, E.B., 2004, Geoscience education for realtors, appraisers, home inspectors, and homebuilders: Journal of Geological Education, v. 52, p. 452–461.

Affiliations of Authors

Potter and Maynard: Department of Geology, University of Cincinnati
Bowers: School of Advanced Structures, University of Cincinnati
Crawford and Weissenfluh: Kentucky Geological Survey
Agnello: Ohio Valley Landslides, LLC, Cincinnati, Ohio

OHIO DNR DIVISION OF GEOLOGICAL SURVEY
Thomas J. Serenko, State Geologist and Division Chief

KENTUCKY GEOLOGICAL SURVEY
James C. Cobb, State Geologist and Director

INDIANA GEOLOGICAL SURVEY
John C. Steinmetz, State Geologist and Director

2013