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Additional Resources

- earthquake.usgs.gov: Main information page for earthquake information
  - earthquake.usgs.gov/earthquakes/dyfi/: Did you feel it? Help the USGS study earthquakes.
  - earthquake.usgs.gov/research/induced/: Induced earthquake study "Hydraulic fracturing, Commonly Known as 'Fracking,' Does not Appear to be Linked to the Increased Rate of Magnitude 3 and Larger Earthquakes."
- www.cusec.org: Central United States Earthquake Consortium
- www.netl.doe.gov/File%20Library/Research/Oil-Gas/shale-gas-primer-update-2013.pdf: Modern shale gas development in the United States: An update. An overview of the geology and technology of shale gas, including fracking and induced seismicity.
- Fracfocus.org: A chemical disclosure registry with lots of information on how fracking works.
- geology.com/articles/hydraulic-fracturing/: General information on fracking.
- www2.epa.gov/hydraulicfracturing: U.S. EPA information page on hydraulic fracturing.
- water.epa.gov/type/groundwater/uic: U.S. EPA information page on the underground injection control program.
  - water.epa.gov/type/groundwater/uic/wells_class1.cfm: UIC Class I, industrial and municipal waste-disposal well page.
  - water.epa.gov/type/groundwater/uic/class2: UIC Class II, oil- and gas-related injection well page (saltwater disposal and enhanced recovery wells).
  - www2.epa.gov/aboutepa/about-epa-region-4-southeast: Home page of enforcement branch for Kentucky.
  - www2.epa.gov/aboutepa/epa-kentucky: U.S. EPA information for Kentucky.
- eec.ky.gov: Kentucky Energy and Environment Cabinet.
  - eqc.ky.gov: Kentucky Environmental Quality Commission.
  - dnr.ky.gov: Department for Natural Resources.
  - oilandgas.ky.gov: Division of Oil and Gas (regulatory agency).
    - oilandgas.ky.gov/Documents/Oil%20and%20Gas%20Operator%27s%20Manual.pdf: Commonwealth of Kentucky Oil and Gas Well Operator's Manual (summary of requirements and regulations).
- www.lrc.ky.gov/Statutes/chapter.aspx?id=38944: KRS 353, Mineral conservation and development (oil and gas statutes).
- www.lrc.ky.gov/kar/TITLE805.HTM: 805 KAR 1, Energy and Environment Cabinet, Division of Oil and Gas administrative regulations (UIC, deep wells, etc.).

Copies of this fact sheet are at http://goo.gl/lUiqQA. Scan this code with your mobile device:

Induced Seismic Events in Kentucky

Kentucky Geological Survey FACT SHEET

Seismic events can result from natural causes such as fault movement and volcanic activity, or human activities such as mine blasts or injection of fluids into deep boreholes. The magnitude of and distance from a seismic event, along with other factors, determines the amount of shaking that may be felt at the surface. The most frequent seismic events have very low levels of shaking—most of which are undetectable without special instruments located very close to the epicenter of the event. Seismic events that are large enough to cause considerable ground shaking and result in damage to structures and loss of life occur infrequently. With few exceptions, these are naturally occurring earthquakes. Most seismic events triggered or induced by human activity produce only very low-level shaking; however, some instances of wastewater injection have reactivated faults and caused earthquakes of moderate magnitude (Ellsworth, 2013).

Induced Seismic Events

Mine blasts in Kentucky rarely exceed magnitude 2 (Fig. 1); the largest event from a mine blast recorded in Kentucky (magnitude 4.3) occurred on April 10, 1989 (Street and others, 2002). Studies conducted in the United States, Canada, and Europe (Davis and others, 2013; National Research Council, 2013) have found that the largest induced event related to hydraulic fracturing had magnitude 3.8, whereas the largest event related to waste injection had magnitude 5.7. Cases of seismicity being induced by hydraulic and other types of fracturing and waste injection have been documented in states near Kentucky (e.g., Arkansas and Ohio). Although it is likely that hydraulic fracturing induces seismic events in Kentucky, no events of this origin are known to have been detected by the KGS monitoring instruments and are unlikely to cause felt events. Waste injection in Kentucky has the potential to generate seismic events of larger magnitude that resemble natural earthquakes, but no such events have been identified.

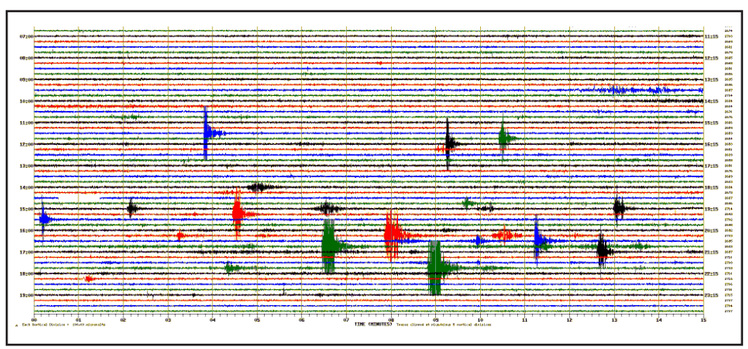

Figure 1. A 24-hour seismic recording from Oct. 29, 2014, at station HZKY in Hazard, Ky.

Mining-related events (blasting and roof falls) are the leading examples of induced seismic events in Kentucky (Street and others, 2002). Figure 1 is a 24-hour seismic recording on Oct. 29, 2014, at station HZKY in Hazard. There were many small seismic events on this date that were related to mine blasts in the Eastern Kentucky Coal Field; the largest events were approximately magnitude 2. Blasting is also associated with limestone quarries and mines throughout the state.

Hydraulic fracturing is the process of injecting water, chemical additives, and fine sand into underground rocks at a high rate and pressure to induce fractures adjacent to the wellbore, allowing gas or oil to flow more freely into the well. Low-level seismic energy is released when the rock breaks. Hydraulic fracturing is regulated by state oil and gas departments. In Kentucky, a working group of regulatory and industry representatives, along with representatives of the environmental advocacy community, are reviewing Kentucky's statutes to ensure they are updated and effective for regulation of this activity. Most well fracturing in Kentucky is performed with nitrogen, but small-scale hydraulic fracturing is used in parts of the state to stimulate low-porosity reservoirs.

A typical fracked well in Kentucky (Fig. 2) is started by drilling through potential groundwater zones. A string of pipe called casing is installed and cemented to surface to protect fresh water. The well is then drilled to the top of the Mississippian Big Lime where a second string of casing is

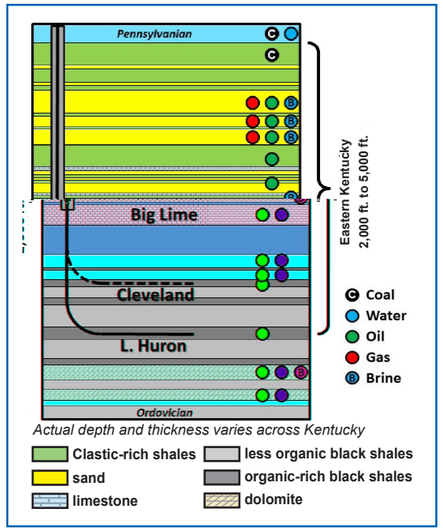

Figure 2. The typical hydraulic fracturing process.

installed and cemented to surface. Below the Big Lime, a curved section is drilled that usually lands at depths ranging from 2,000 to 5,000 feet below freshwater zones in either the Cleveland or Lower Huron Shale. The horizontal lateral is extended up to 4,500 feet. After drilling is complete, tools are lowered into the hole to isolate the shale from the upper part of the well and a mixture of nitrogen, water, and sand the consistency of shaving cream is pumped under pressure through ports in the tool to fracture the shale at intervals called "stages." The tools are withdrawn and the nitrogen-water-sand mixture flows into tanks at the surface where it is separated for treatment and reuse or disposal.

Waste injection is the process of injecting fluids (e.g., brines from oil wells or industrial liquids) into deep porous rocks for permanent storage. Impermeable confining rocks separate the injection zone from fresh groundwater. Waste is pumped down a well at rates and pressures specifically selected to prevent fracturing the rocks. This injection is a cyclic process that occurs over many years. As the fluid enters the target zone, pressure increases around the well because the fluid cannot flow through the rock as easily as it flows in the well. If it approaches a maximum permitted pressure threshold, injection is stopped (the well is "shut-in") and the pressure in the reservoir is allowed to drop as the fluid migrates out through the permeable rock. When the pressure drops, the injection process is restarted. A seismic event can be induced when injection causes the pressure of the fluid in a nearby fault to overcome the friction that prevents the rock from moving in response to regional stresses. Wastewater injection is regulated by the U.S. Environmental Protection Agency Underground Injection Control program; the EPA has granted enforcement to states whose regulations have been certified to meet or exceed the UIC requirements. Kentucky has applied to the EPA to assume regulatory authority over this activity. The locations of waste injection wells are shown in Sparks and others (2013). EPA-regulated UIC wells in Kentucky can be explored online at http://goo.gl/xQZ2QD.

Natural Seismic Events

Earthquakes occur frequently in and around Kentucky, but most of them are too small to be felt. Figure 3 shows locations of earthquakes with magnitudes equal to or greater than 3.0 that have occurred in and around Kentucky (induced seismic events are not shown). The strongest earthquake recorded inside Kentucky's borders was the Sharpsburg earthquake of July 27, 1980, in Bath County. The magnitude-5.2 quake caused an estimated $3 million in damage in Maysville. A 2012 Perry County earthquake (magnitude 4.2) caused some minor damage to the Letcher County Courthouse in southeastern Kentucky.

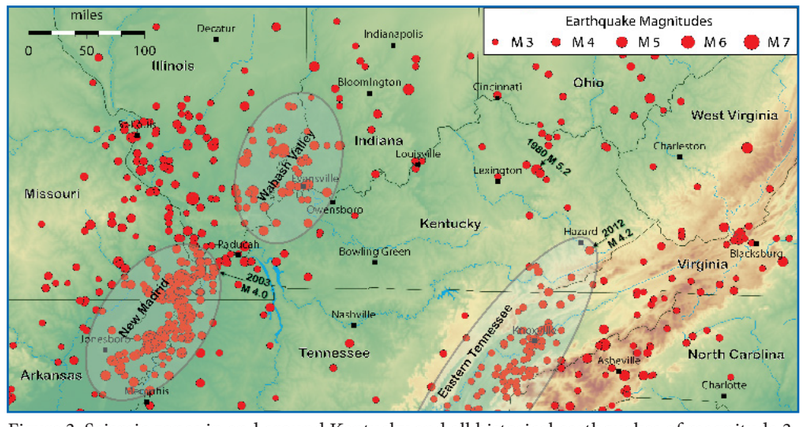

Figure 3. Seismic zones in and around Kentucky and all historical earthquakes of magnitude 3 and greater through 2008. The magnitude-4.2 2012 Perry County earthquake is also shown.

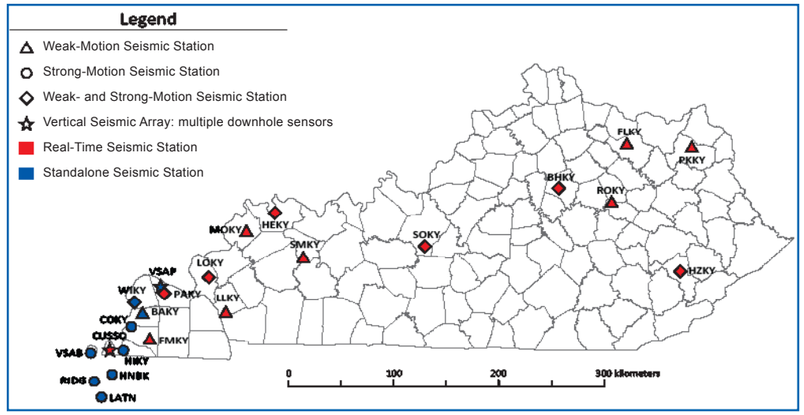

Figure 4. Locations of stations in the Kentucky Seismic and Strong-Motion Network.

The most significant earthquakes affecting Kentucky, as well as the central United States, occurred from December 1811 to February 1812 in the New Madrid Seismic Zone, part of which occurs in far western Kentucky. At least three large earthquakes, each estimated to have been greater than magnitude 7, occurred during that period.

A program on earthquake monitoring and research was initiated in the 1980's through a joint effort by the Kentucky Geological Survey and the Department of Earth and Environmental Sciences, both at the University of Kentucky. The partnership currently operates a seismic network of 17 seismic stations and 15 strong-motion stations (Fig. 4). The network is capable of monitoring any earthquake occurring in Kentucky with a magnitude greater than 2.0, as well as larger earthquakes in the central United States and beyond. To view real-time recordings from the seismic stations of the statewide network, visit the KGS website at www.uky.edu/KGS and click on the "Real-time earthquake recordings" icon.

Potential Risks from Induced Seismic Events

When a seismic event occurs, elastic energy is released in the form of seismic waves. Strong seismic waves from large events propagating along the ground surface create a ground-motion hazard that can damage buildings and other structures or even result in their collapse. As studies have shown (Street and others, 2002; Davis and others, 2013; National Research Council, 2013), very few induced seismic events larger than magnitude 5.0 have occurred. From these studies, and observations of seismic events in Kentucky, we can conclude:

- Hydraulic fracturing, as currently conducted in Kentucky for oil and gas recovery, does not pose a high risk for inducing damaging seismic events, because these jobs are generally small, and most sites are far from population centers.
- Waste injection is known to induce felt seismic events elsewhere, but such events have not been documented in Kentucky.
- Additional research and more monitoring stations near hydraulic fracturing or injection sites in Kentucky are needed to detect small seismic events and improve our understanding of how induced seismicity is related to hydraulic fracturing and waste injection in Kentucky. Such information will help create appropriate regulation and mitigate potential problems.