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## EXECUTIVE SUMMARY

# PRELIMINARY REPORT ON THE NORTHSTAR 1 CLASS II INJECTION WELL AND THE SEISMIC EVENTS IN THE YOUNGSTOWN, OHIO, AREA



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## Youngstown Earthquakes

Since March 2011, the Youngstown area has experienced 12 low-magnitude seismic events along a previously unknown fault line. These events ranged from 2.1- to 4.0-magnitude and were recorded by the Ohio Department of Natural Resources' (ODNR) Ohio Seismic Network (OhioSeis). The network works closely with the U.S. Geological Survey to monitor and study all seismic activity within the state. ([Ohio Seismic Network](#))

Prior to the network's establishment in 1999, monitoring earthquakes in Ohio was sporadic at best. In fact, before the network was operational, the Ohio Geological Survey was unable to accurately determine any seismic events below an approximate magnitude of 3.0. A station at Youngstown State University joined the network in 2003.

Before 2011, OhioSeis had not recorded earthquake activity with epicenters located in the Youngstown area. Also, no fault line had been previously mapped within the boundaries of Youngstown or Mahoning County. However, the broad geographical area does have a history of seismic activity, and Mahoning Valley residents have felt earthquakes from nearby faults. In fact, the area has experienced at least three prior earthquakes in the past 25 years. These events include: a 5.2-magnitude earthquake originating in Mercer County, Pa., in September 1998; a 5.0-magnitude earthquake in Lake County, Ohio, in January 1986; and a 3.0-magnitude earthquake in Portage County, Ohio, in August 2000. ([Ohio Earthquakes](#))

## Northstar 1 Class II Deep Injection Well

The 2011 earthquakes are distinct from previous seismic activity in the region because of their proximity to a Class II deep injection well, known as the Northstar 1 well. In fact, all of the events were clustered less than a mile around the well.

Northstar 1 is one of 177 operational Class II deep injection wells primarily used for oil and gas fluid waste disposal. ([Ohio Disposal Wells](#)) Drilled 200 ft. into the basement rock formation known as the Precambrian layer at a depth of 9,184 (ft), the well began injection in December 2010.

Ohio runs its Class II deep injection program on behalf of the U.S. EPA. As a result, the state meets and in many instances far exceeds U.S. EPA standards and regulations for the program ([Comparison Chart](#)). Since the program's inception in 1983, more than 202 million barrels of oilfield fluids have been successfully disposed of, with no reports of subsurface ground water contamination incidents. In addition, no seismic event had been previously linked to operations at any of the state's Class II wells.

The earthquakes and their potential link to the Northstar 1 deep injection well were closely scrutinized by state geologists and regulators, who performed 35 separate inspections of the well from April 26 to Dec. 15, 2011. Each inspection indicated the well was operating within its permitted injection pressure and volume. In addition, ODNR regulators conducted additional testing of the well to determine if injection fluids were entering permitted injection zones. Tracer tests showed injections were reaching appropriate zones and were within permitted injection intervals. However, the tests proved inconclusive with regard to the volume of fluid entering the Precambrian layer. As a result, state regulators requested the well owner plug the Precambrian section of the Northstar 1 borehole, and the well operator voluntarily agreed to the procedure, albeit on a delayed timetable.

With only one seismometer deployed in the Youngstown area, state geologists lacked the necessary data on the earthquakes' depth and exact location to draw a direct correlation between the seismic events and the deep injection well.

## Lamont-Doherty Earth Observatory at Columbia University

In November 2011, newly appointed ODNR Director James Zehringer sought to obtain the additional data. After his first briefing on the seismic activity, Director Zehringer ordered the Ohio Geological Survey to seek an outside research partner and deploy the needed portable seismometers around the Youngstown area. The Lamont-Doherty Earth Observatory at Columbia University had the available equipment and was willing to assist the state. The seismometers were deployed on Dec. 1, 2011. ([Youngstown Seismic Events](#))

On Dec. 24, the newly deployed equipment recorded a 2.7-magnitude earthquake in the area. Data from the portable seismometers was downloaded and analyzed by experts at Lamont-Doherty. On Dec. 29, Lamont-Doherty presented ODNR with their preliminary findings, which indicated the seismic event depth was 2,454 ft. below the injection well.

Based on the Lamont-Doherty data, Director Zehringer instructed ODNR regulators to seek the immediate halt of injections at Northstar 1, either voluntarily by the operator or by agency order. At 5 p.m. on Dec. 30, ODNR inspectors witnessed the shut down of the well. ([Lamont-Doherty Analysis](#))

The next day, the Youngstown area experienced a 4.0-magnitude seismic event. Gov. John Kasich immediately placed an indefinite moratorium on three drilled deep injection wells and one well with a permit pending in the vicinity of the Northstar 1 well.

## Induced Seismicity

Geologists believe it is very difficult for all conditions to be met to induce seismic events. In fact, all the evidence indicates that properly located Class II injection wells will not cause earthquakes. To induce an earthquake a number of circumstances must be met:

- A fault must already exist within the crystalline basement rock;
- That fault must already be in a near-failure state of stress;
- An injection well must be drilled deep enough and near enough to the fault and have a path of communication to the fault; and
- The injection well must inject a sufficient quantity of fluids at a high enough pressure and for an adequate period of time to cause failure, or movement, along that fault (or system of faults).

A number of coincidental circumstances appear to make a compelling argument for the recent Youngstown-area seismic events to have been induced:

- The Northstar 1 well began injection operations in December 2010. Roughly three months later, the first seismic events were noted and were fairly close to the well;
- Subsequent seismic events were clustered around the vicinity of the wellbore;
- Evidence of permeability zones within the Precambrian basement rock is interpreted in some of the geophysical logs obtained from within the Northstar 1 well; and (Logs [A](#), [B](#), [C](#), [D](#))
- Once sufficient monitoring equipment was in place, the focal depths of events were found to be about 4,000 ft (1,220 m) laterally and 2,500 ft (760 m) vertically from the wellbore terminus.

It appears there are observed permeability zones within the Precambrian basement rock in the “piggyback” logs recorded by the Battelle Memorial Institute during the drilling of Northstar 1.

These logs were not available to inform regulators of possible issues in geological formations prior to well operation. Instead, Battelle produced and made the logs available to provide geologists with additional information on the region’s geological formations. In the future, ODNR will require the Class II well owner to provide a suite of geophysical logs germane to the respective injection well.

To establish a better understanding of what may have happened, further analysis and detailed modeling of all factors must be completed on the Northstar 1 well and the surrounding geology. This work is already underway through ODNR and cooperating agencies and institutions.

## Deep Injection Well Reforms

Currently, Ohio meets or exceeds all U.S. EPA standards and regulations for Class II deep injection wells. However, the frequency and location of the Youngstown area earthquakes, detailed earthquake depth data provided by Lamont-Doherty, and specific geological information learned about the well site required ODNR to examine its existing Class II deep injection well permitting process and develop a series of changes that will help address seismic activity concerns.

The reforms listed below will make Ohio’s Class II deep injection wells among the most carefully monitored and stringently regulated disposal wells in the nation. Ohio will seek the following reforms to its Class II deep injection well program:

- Requires a review of existing geologic data for known faulted areas within the state and avoid the locating of new Class II disposal wells within these areas;
- Requires a complete suite of geophysical logs (including, at a minimum, gamma ray, compensated density-neutron, and resistivity logs) to be run on newly drilled Class II disposal wells. A copy of the completed log, with analytical interpretation will be submitted to ODNR;
- Evaluates the potential for conducting seismic surveys;
- Requires operators to plug back with cement, prior to injection, any well drilled in Precambrian basement rock for testing purposes.
- Requires the submission, at time of permit application, of any information available concerning the existence of known geological faults within a specified distance of the proposed well location, and submission of a plan for monitoring any seismic activity that may occur;
- Requires a measurement or calculation of original downhole reservoir pressure prior to initial injection;
- Requires conducting a step-rate injection test to establish formation parting pressure and injection rates;

- Requires the installation of a continuous pressure monitoring system, with results being electronically available to ODNR for review;
- Requires the installation of an automatic shut-off system set to operate if the fluid injection pressure exceeds a maximum pressure to be set by ODNR;
- Requires the installation of an electronic data recording system for purposes of tracking all fluids brought by a brine transporter for injection;

To bolster its earthquake monitoring capabilities, ODNR will purchase four additional portable seismometers. These sophisticated monitoring devices will augment existing seismometers where necessary, and provide state geologists with quick access to detailed data on seismic activity. In addition, ODNR is in the process of identifying an “outside” expert with experience in seismicity, induced seismicity, and Class II injection wells to conduct an independent review of the currently available technical information, as well as information to be supplied by the injection well owners in the vicinity of the Northstar 1 well. This independent analysis will provide a scientific third party evaluation and analysis of all technical information to ensure thoroughness of the process.

ODNR is pursuing these changes to deep Cambrian-Precambrian Class II injection wells either through specialized attached permit conditions or through potential changes to either Section 1509 of the Ohio Revised Code or Section 1501:9-03-01 through 1501:9-03-10 of the Ohio Administrative Code. These recommended changes are being proposed to ensure protection of the health and safety of the citizens of Ohio.

