North Dakota's Current Seismic Monitoring Capabilities

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Prior to 2008, the state of North Dakota did not have any seismic monitoring instrumentation in place capable of recording earthquakes that could originate either locally, regionally, or globally. Currently, North Dakota has three operating broadband seismic monitoring stations in the south-central and eastern parts of the state (fig. 1). In October of 2008 North Dakota's first broadband seismic monitoring instrument was installed near Maddock, ND (Anderson, 2009) as a part of the USArray Reference Network. The Maddock station was installed ahead of, and in anticipation of, the arrival of the EarthScope Transportable Array (TA) that was slowly traversing the lower 48 states from west to east. From 2008 to 2012 the EarthScope project deployed 36 temporary broadband seismic monitoring stations across North Dakota as it continued its way across the continental United States (Anderson, 2010). The EarthScope TA completed its traverse of the lower conterminous 48 states in the fall of 2013 and is currently deployed across the state of Alaska (IRIS, 2016).

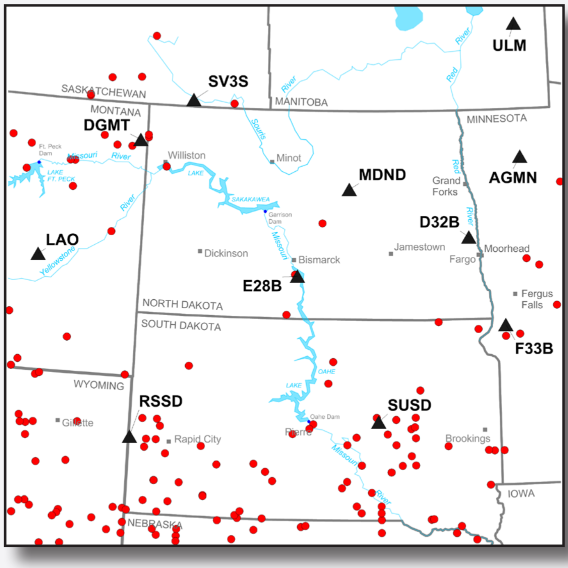

Figure 1. Seismic monitoring stations located in and around North Dakota. Stations (shown as black triangles) include the LASA Array Station near Angela, Montana (LAO), Dagmar, Montana (DGMT), Rapid City, South Dakota (RSSD), Aquistore, Saskatchewan, Canada (SV3S), Huff Hills, North Dakota (E28B), Maddock, North Dakota (MDND), Miller, South Dakota (SUSD), Gardner, North Dakota (D32B), 5 Mile Ranch, Herman, Minnesota (F33B), Agassiz National Wildlife Refuge, Minnesota (AGMN), and Lac du Bonnet, Manitoba, Canada (ULM). The locations of all historical earthquakes used by the USGS in the generation of the latest US seismic hazard maps, non-inclusive of recent induced seismicity in the central US, are shown as red circles (USGS, 2014).

When the TA officially left North Dakota in the summer of 2012, two seismic monitoring stations were selected to be left in place to eventually become a part of the Central and Eastern United States Network (CEUSN). One of these stations is near Huff, 15 miles south of Bismarck-Mandan, and the other station is in the southwestern Red River Valley near Gardner (fig. 2). This brought the total number of broadband seismic monitoring stations in North Dakota to three.

Figure 2. Seismic monitoring station located northwest of Fargo near Gardner, North Dakota shortly after installation. The seismometer is housed in a sealed circular vault just below ground level (buried beneath the excavated soils). The solar panel powering the instrument and supporting electronics is surrounded by protective fencing.

Our closest seismic monitoring station to the west is near Dagmar, Montana and is operated by the Montana Bureau of Mines and Geology's Earthquake Studies Office. A second station, which was once (ca. 1965) a part of the former Large Aperture Seismic Array (LASA), is located near Angela in eastern Montana. The regional station network can provide complete seismic monitoring coverage across North Dakota and includes the following stations: Rapid City and Miller, South Dakota; two stations in eastern Minnesota (5 Mile Ranch and at the Agassiz National Wildlife Refuge); one station in southeastern Saskatchewan at Aquistore, and one in southwestern Manitoba at Lac Du Bonnet. Collectively these stations could be considered to be somewhat of an informal regional virtual seismic network for the state of North Dakota.

Seismometers in Use in North Dakota

The instruments currently deployed in North Dakota are three-component broadband seismometers capable of detecting ground motions over a wide range of frequencies (i.e. a broadband sensor). These seismometers are capable of detecting earthquakes from around the world (fig. 3) in addition to weak motions from regional teleseismic earthquakes and ambient noise (PASSCAL, 2016). The instruments contain three sensors arranged in a unique manner to detect motions in the north-south, east-west, and vertical directions and resolve the signals captured simultaneously and on the same scale (Havskov and Alguacil, 2016). These stations are the northwesternmost in the IRIS-operated CEUSN sub-array, which covers the central portion of the US from North Dakota to Texas and east to the Atlantic seaboard (IRIS, 2015). Inclusion of North Dakota's stations into the CEUSN rather than, say, a western network was based on many factors, but mainly because the geological and seismological characteristics in Earth's crust in the eastern US are different than in the west. In the eastern US the crust is older with less attenuation (meaning less dampening of traveling seismic waves). As a result, seismic waves will carry further in the east than in the geologically younger western US. Stations in the CEUSN are anticipated to operate through fiscal year 2017 under the Incorporated Research Institutions for Seismology program.

Figure 3. The Streckeisen STS-2 is the type of three-component broadband seismometer currently in operation at North Dakota's three active seismic monitoring stations.

Accessing Seismograms and Earthquake Data

Each station continuously records the ground movements measured by the seismometers and can be viewed a number of different ways on the web. An exceptionally convenient way to view data from any station in the CEUSN is through the IRIS CEUSN Network Station Monitor at http://ds.iris.edu/gmap/_CEUSN. Also, the past 24 hours of station data can be quickly accessed by linking to the USArray Station Monitor website, hosted by the University of South Carolina, at http://usarray.seis.sc.edu/. Simply enter the code for your station of interest (e.g., MDND for Maddock, E28B for Huff, or D32B for the Gardner station) and the latest 24 hours of recorded data, in the form of a seismogram, will be displayed. As an example, one of the more devastating earthquakes that occurred recently was the M 6.2 Italian Earthquake near Norcia, Italy on Wednesday, August 24th (USGS, 2016). This earthquake, which occurred nearly halfway around the world, was readily recorded on the seismometers located in North Dakota (fig. 4).

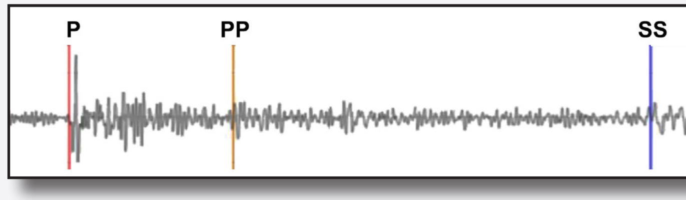

Figure 4. Vertical component seismogram of the August 24th, M 6.2 Italian Earthquake recorded by the Gardner station in North Dakota as extracted using the IRIS Wilber 3 seismic waveform data services extraction application. First arrival of P-Wave (compressional) energy, about 11 minutes after the earthquake occurred in Italy, is marked by the red vertical line on the seismogram. The arrivals of the reflected P wave, denoted as PP and reflected S wave, denoted as SS are marked with the yellow and blue vertical lines, respectively.

In addition to earthquakes, other forms of natural phenomena that release energy in short but intense fashion can also be recorded by the instruments in North Dakota. An example of this would be the severe summer storms that most North Dakotans are familiar with and the associated thunder and lightning commonly produced during these events (fig. 5). Mining activities, such as the infrequent blasting events that are conducted at the coal mines in central North Dakota, can also be recorded on North Dakota's currently operating seismic stations. Rock blasting produces a somewhat characteristic looking seismogram (fig. 6).

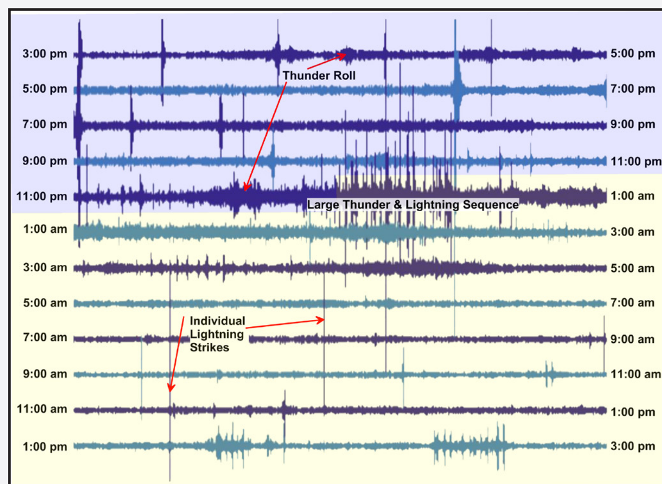

Figure 5. Storm seismogram from the severe summer storms that tracked through south-central North Dakota this past August. This seismogram, from the station located near Huff, ND, covers the 24-hour period from 3:00 pm CDT Tuesday afternoon of August 9th to 3:00 pm the following day. Individual lightning strikes, thunder rolls, and large thunder and lightning sequences are observable on the seismogram.

Comparison of Earthquake Energy Release

In order to gain a better perspective on the earthquakes that have occurred in the state and their comparison to other earthquakes, we can compare them on the basis of the energy that radiates away from the earthquake epicenter as seismic waves. There is a tremendous difference in the amount of energy released between earthquakes of different magnitudes. Generally speaking, each full

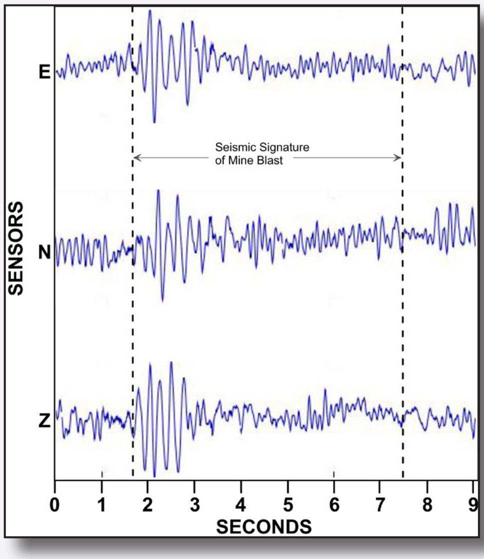

Figure 6. Seismogram from recent rock blasting at the Falkirk Mine in north-central North Dakota showing the characteristic seismic signature of a typical mining or quarry blast.

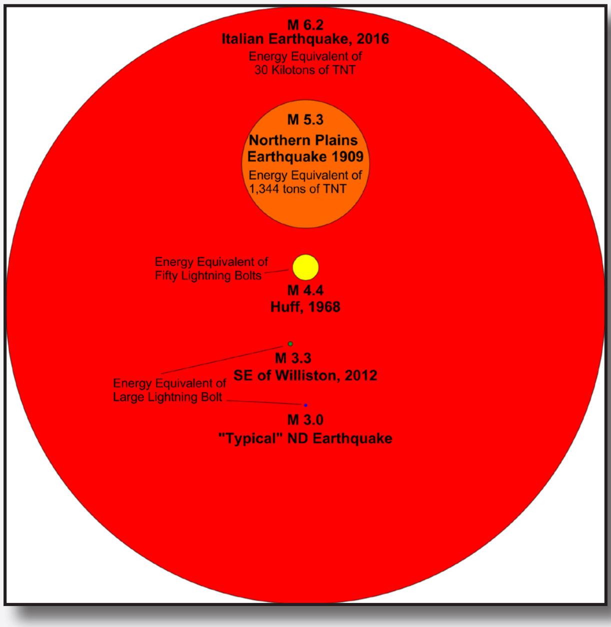

Figure 7. Relative amounts of earthquake energy radiated as seismic waves from earthquakes of interest in North Dakota and the surrounding region and the devastating August 2016, Italian earthquake.

numeric value increase in earthquake magnitude is equal to about 30 times more energy released than the previous magnitude (Bolt, 1988).

The most recent earthquake in North Dakota, the M 3.3 event just southeast of Williston that occurred in 2012, was similar in character to the "typical" minor earthquakes that have occurred in North Dakota over the past century, which were roughly equivalent to the energy release of a large lightning bolt, or about half a ton of TNT (Anderson, 2015). Interestingly, North Dakota's largest and perhaps most well-known earthquake, which also happened to be the first instrumentally verified earthquake in the state, was the M 4.4 event near Huff (Coffman and Cloud, 1970). This 1968 earthquake had an energy release of approximately 50 times the 2012 Williston event and was felt across south-central North Dakota and within the State Capitol building. More importantly, the largest earthquake known historically for the region was the M 5.3 Northern Plains Earthquake of 1909 (Bakun and others, 2011), which is thought to have occurred in northeastern Montana near the Montana, North Dakota, and Saskatchewan border. This earthquake had an energy release that was 22 times greater than the M 4.4 Huff earthquake.

Comparatively, the amount of energy released during the recent devastating earthquake in central Italy, an M 6.2 event, was equivalent to twice that of the atomic bomb used at the end of the World War II (fig. 7).

The July 8, 1968 M 4.4 earthquake near Huff is, to date, the largest earthquake to have occurred in North Dakota, and the first earthquake in the state with an instrumentally verified epicenter.

Looking ahead

Through the vision of IRIS and the continued success of the EarthScope project, along with the continued operation of seismic monitoring stations in and around the state, we are better prepared and positioned to monitor seismic events.

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