# Study of the Connection Between Hydraulic Fracturing and Seismic Activity in New York State

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**Abstract**

Earthquakes far away from plate boundaries such as in New York State are not very frequent. An increasing frequency of earthquakes, however, in regions with low-tectonic activity and slow surface deformation, may be considered as an anomaly. With limited or no active major fault lines or tectonic plates boundaries in New York's area, we began looking into different sources of these earthquake occurrences. We looked to fracking to see what the association between drilling and seismic activity would be. We constructed a GIS map with the locations of oil and gas wells in NY State where they were being drilled. Earthquakes were classified into two areas, well and non-well areas. We compared the areas in which earthquakes were active and in proximity to wells operation in New York State. We cross-referenced the magnitude and depth of earthquakes to the frequency that they occurred, and also took into account if the data found were in a well area or a non-well area. We had hypothesized that fracking would have caused a spike in earthquake magnitude and frequency, but what we found was the opposite. In all areas with wells, the earthquakes were almost non-existent. In the areas with no wells, the earthquakes had large depths and higher frequencies. We do acknowledge anomalies within the data showing possible fracking induced earthquakes. In a few cases, we found that earthquakes were in close time and space proximity to the fracking wells. If there were more cases in which this occurred, there could potentially be evidence that fracking has an effect on seismic activity. We do not claim a direct relationship between the two activities, however, we can firmly say that in some cases earthquakes may occur due to the fracking in New York State.

## Introduction

Fracking is known to pollute the groundwater causing methane to get into the aquifer contaminating drinking water as well as pollute the air (Mcdermott et al. 2013). Fracking has been known to cause earthquakes in areas with low tectonic activity. Among these regions, earthquakes have been occurring in mid-America such as Oklahoma a 5.6 magnitude earthquake likely was caused by fracking (Ellsworth, 2013). Studies linking fracking to earthquakes have occurred in many parts of the world including parts of the US, Canada, the UK and the Netherlands (Shultz, Colin. 2013; Voot et al.,2015; Wilson et al.,2018; Shultz, et al., 2018). Mainly what is studied is the frequency and magnitude of earthquakes and their association with the number of wells in the area. Our study adds on to this with the search for earthquakes off of brittle fault lines with active wells nearby.

The entire State of New York was chosen because there were earthquakes and well sites located all throughout the State. The difference between New York State as a study area and other places in the world is that it does not sit near any major active fault lines and does not experience any major recent tectonic activity. New York is home to one fault line, the Ramapo fault, and although there have been some reported earthquakes with possible relation, it has not been active since the Triassic (200 million years ago) (Williams et al. ). Tectonic activity is one of the main driving forces behind earthquakes, so we researched other possible explanations for the earthquakes that do occur in New York. One of these explanations is cave collapses. There have been no reported cases of a cave collapse causing earthquakes in New York, but there is substantial evidence of this in other parts of the world. Earthquakes caused by cave destabilization and possible partial collapsing has been reported in Ardenne, Belgium (Camelbeeck et al., 2018), and in Shandong, China (Wang et al., 2016). Earthquakes in New York State became frequent throughout the 90's up until around 2014. This was the time period that fracking was banned in most areas of New York. These frequent earthquakes became less frequent in the 2015-2020 time period (Figure 2). This was a large reason why we split our histograms into 3 time periods in order to explore a possible association between earthquakes and fracking activity, especially that there is a 5 year time period that shows significantly less earthquakes in New York after fracking was banned in certain areas.

**Methodology**

A GIS map was constructed following related queries to re-classify the earthquake and well data for the period of 1990-2020. We focused on the more trustworthy earthquake data starting around the 90s', especially that New York State earthquakes are mostly of a low magnitude. The wells were classified according to their last date in use and their purpose of operation such as for gas and oil exploration.

A statistical software (SPSS) was used to statistically analyse the data points we retrieved. Two histograms were made to analyze the earthquakes and well sites. The areas with wells and without wells were split into categories to determine whether there were any possible associations in the areas with and without fracking. 30 years of data were reclassified into three-time intervals. The first was 1990-2006. This time period was chosen to focus on a 15 years data set to get a better idea of the area to analyze. The 2007-2020 time period was the second to be analyzed. Considering that fracking was banned in parts of New York State in 2014 which falls into this category. The 2007-2020 time period was then split into 2 time periods. 2007-2014 was the first new time set. This was done to show the time period before fracking was banned. Then the 2015-2020 time period was made to highlight the time period when fracking was banned in New York State. In order to see whether any possible trends regarding fracking and earthquakes exist.

We classified our 30 year period into 3-time intervals. Each time interval was then split into areas with wells and areas without. Doing this allowed us to see where in New York the earthquakes were occurring, and whether or not there were fracking wells within the area of the epicenter of the earthquake. We found that there was a strong association between the frequency of the earthquakes and the

magnitude. (Fig. 2). The magnitude and frequency were both the highest during the time period before fracking was banned in New York.

Bar graphs were made to show the association between the amount of earthquakes per year and the mean magnitude, and the mean depth in respect to the mean magnitude. After creating these graphs, the trends were easily identifiable. Two heat map layers were created to show the density of their occurrence, one for earthquakes and one for wells (Figure 1). This was done to highlight overlapping between the two to find areas of both high well density and high earthquake density searching for fracking causing earthquakes in an area.

**Results**

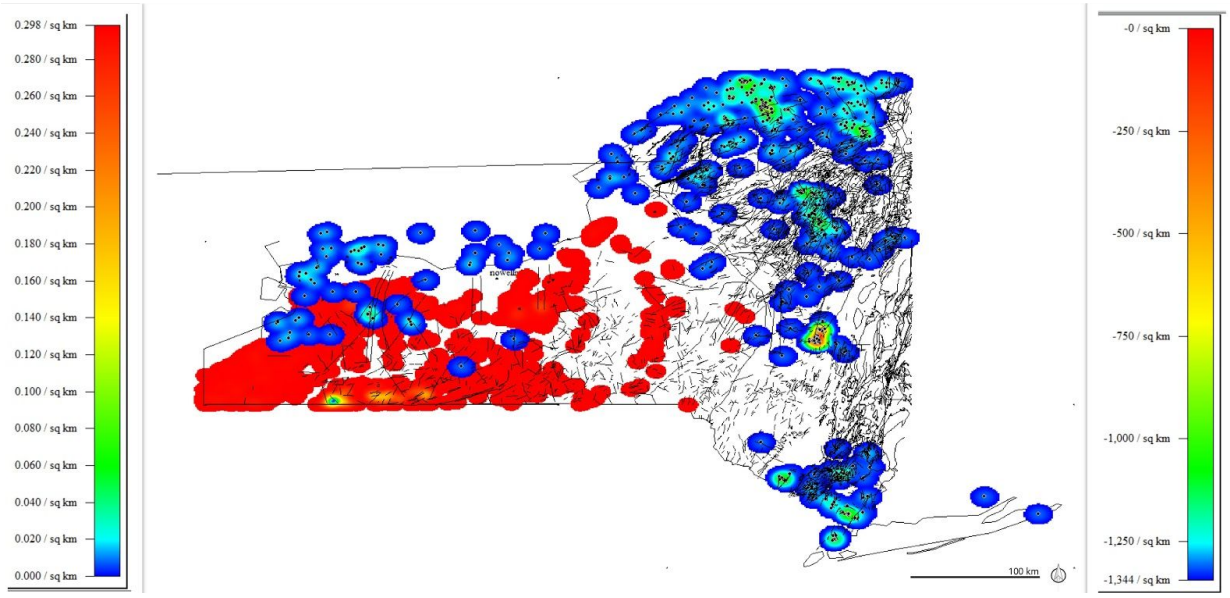


**Figure 1.** Map representing the mean density of earthquakes (low density earthquakes are shown with blue densities at the eastern side of the map while few high densities are displayed with red) versus the density of wells in NY. The left scale representing earthquake density having blue representing the highest density of earthquakes and the right scale representing wells having red representing highest density.

The red densities located on the west side of this map represent the wells due to fracking. The scale on the left represents the proximity that the wells are located. The wells are mostly red which means that the wells are located extremely close together along the Marcellus Shale. The blue densities represent the earthquakes that have occured. The scale on the right represents the proximity that the earthquakes occurred. The range of the scale is much smaller in terms of the distances used because of the number of earthquakes that occured in New York.

These heat maps are used for comparing the density of earthquakes and wells in NY, with scattered lines representing brittle faults. Most of the earthquakes have occurred in Upstate with others scattered throughout the State. Most wells on the other hand are on the western edge of NY mainly along the Marcellus shale. This region was looked at closer for exceptions where earthquakes occured near an active or recently plugged well.

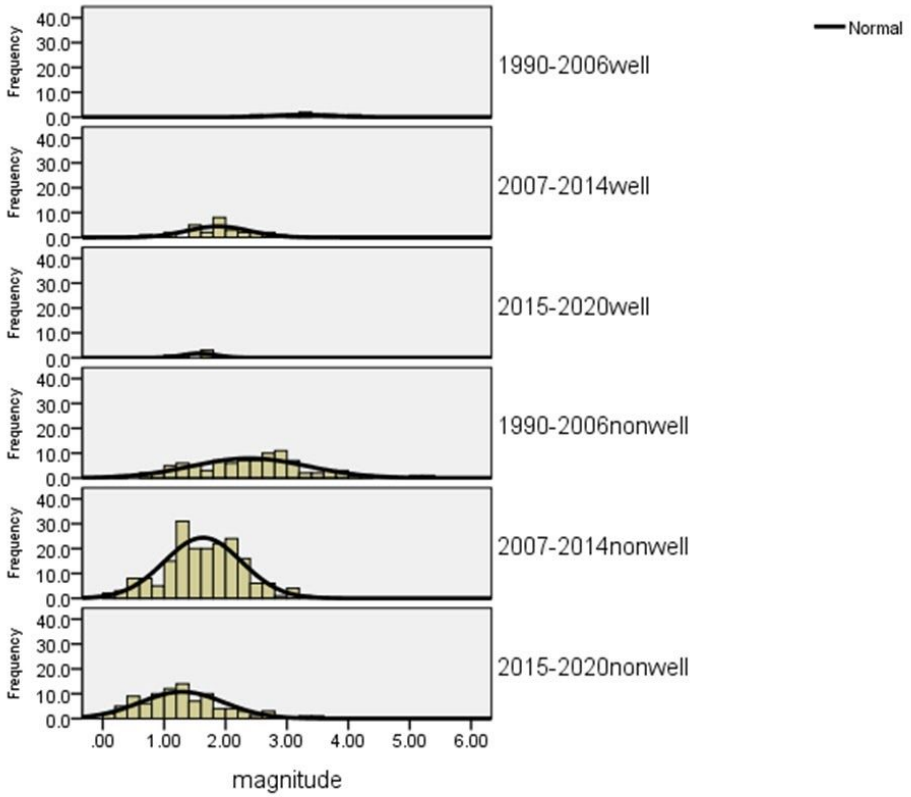


**Figure 2.** Histograms representing the mean magnitude of earthquakes from 1990-2020. With the top three graphs representing earthquakes in areas of New York with wells (mostly west area) and the bottom three graphs representing earthquakes in areas of New York without wells (mostly east Upstate New York area).

During the 1990-2006 time period in non-well areas there was a significant spike in larger magnitude earthquakes, the greatest amount of larger magnitude earthquakes throughout our time period histograms happened in this time period.We found that during the 2007-2014 time period there was the largest number of earthquakes recorded. This falls in the time period where fracking was at the latest stages of operation and still legal in the State of New York. After fracking was banned in 2014 our histogram data for earthquake frequency largely decreased. As seen above in the 2015-2020 time period histogram, the number of earthquakes in general along with the frequency decreased significantly. We

viewed these data sets and acknowledged that the trends showed after fracking was banned the magnitude of the earthquakes significantly declined. This is noticed in both the well and non-well areas, but a significant amount of the decline is found in the nonwell areas.

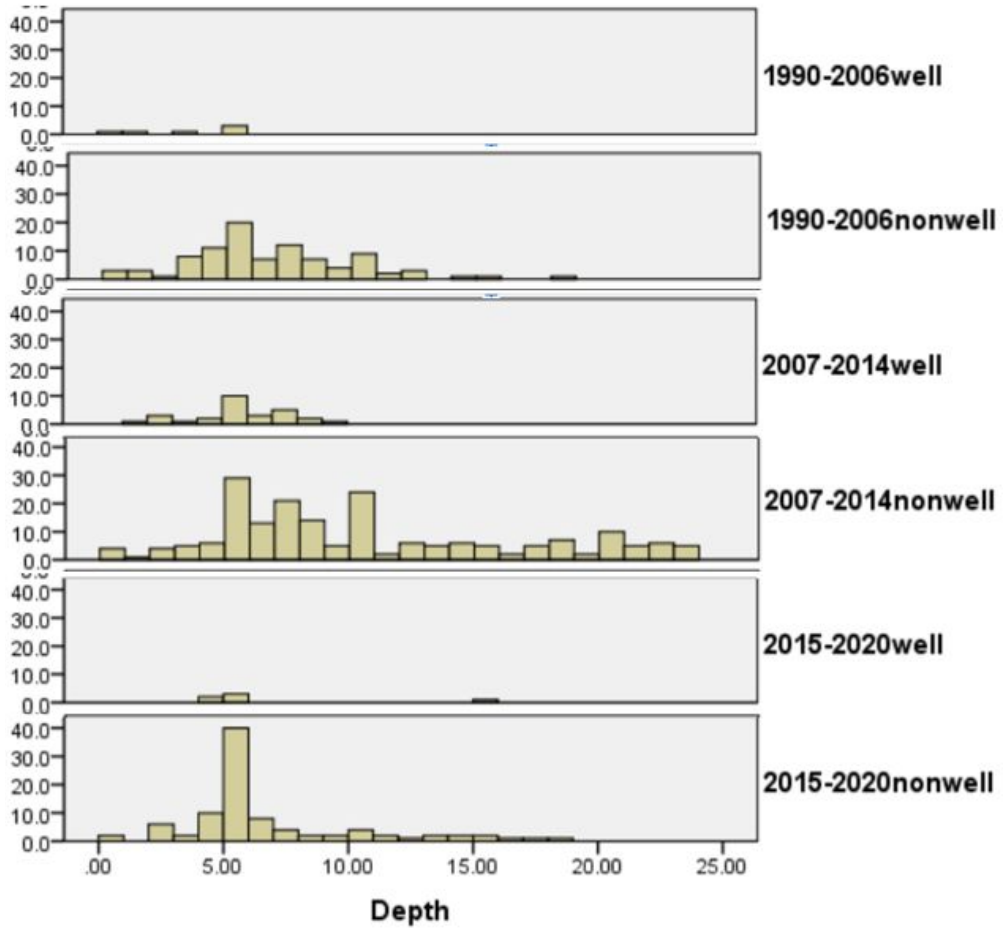


**Figure 3.** Histograms representing the mean depth of earthquakes in NY from 1990-2020. With the top three graphs representing earthquakes in areas of NY with wells and the bottom three graphs representing earthquakes in areas of NY without wells.

In the well areas, the earthquakes that occur are all of a shallow depth. In the areas without wells, the occurrence of earthquakes is much higher with earthquakes occurring at deeper depths as well as 5km. In the 1990-2006 time period, it is clear that there are many earthquakes that occur at the 0-10 kilometer depth. There are very few earthquakes at the larger depths. Looking at the 2007-2014 time period, we see that both the frequency and the magnitude show the highest amounts and consist most of the dataset. There is a visible increase in the data in both the depth and the frequency of the earthquakes. In the 2015-2020 time period the amount of earthquakes at higher depths shows a sharp decrease. As seen in the

1990-2006 time period, there are many more earthquakes at the lower depths. Most of the earthquakes that occur during this time period are found at the 5 kilometer depth (Fig.3). Looking at every time period and site it is evident that the most common depth for these earthquakes is at 5 km.

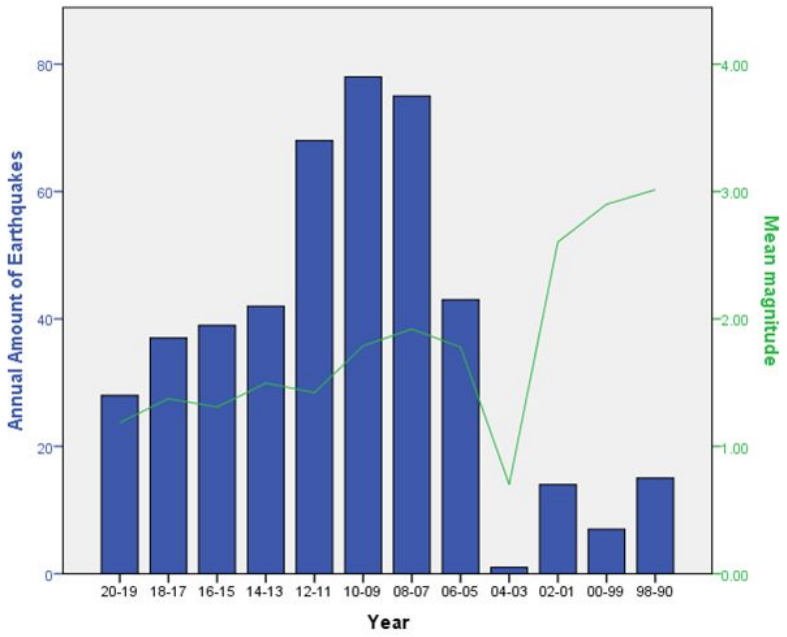


**Figure 4.** The mean magnitude (green line) plotted against a histogram of annual earthquake frequency in NY from 1990-2020 (blue bars).

There is an association between the amount of earthquakes per year and the mean magnitude for that year (Fig. 4). Looking at the bar portion of this graph, there is a noticeable increase in the amount of earthquakes after 2007. This sharp increase is still in the time period when fracking was legal, so there is the possibility that this could have been a reason why there was such a spike in the graph. Following this trend, the red line represents the magnitude. The highest magnitudes shown on this graph are in the 1990's and the early 2000's. Once the spike in earthquakes hit, the magnitude dropped significantly. While the actual magnitude only dropped by 1, it is a dramatic change in our data set. We can infer from this table that since the numbers of the earthquakes are higher, the mean magnitude is much smaller because there are more magnitudes to take into account.

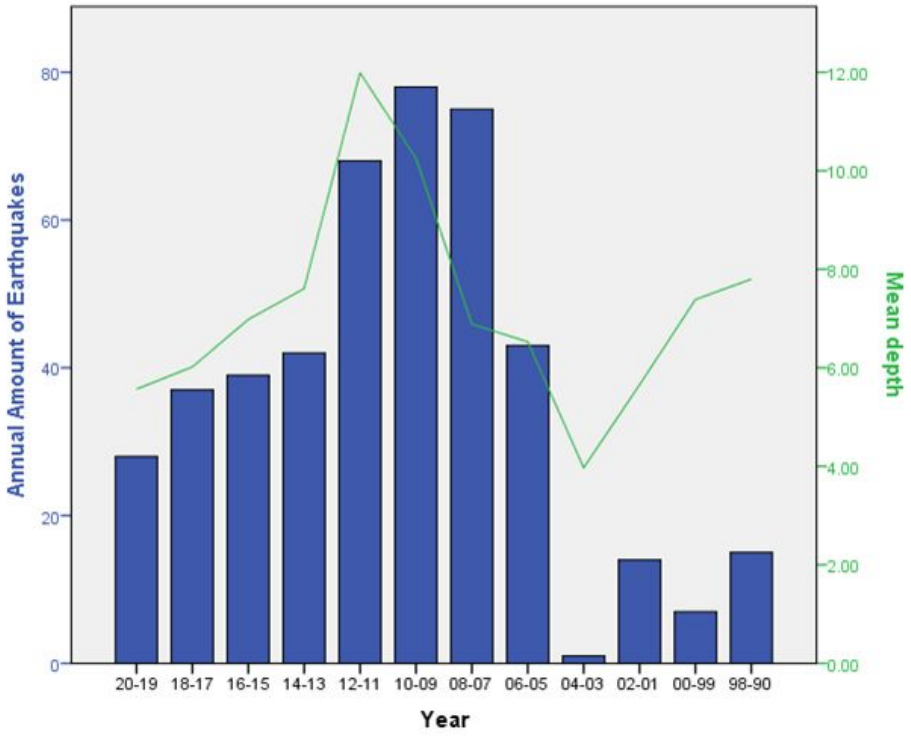


**Figure 5.** The yearly mean depth of earthquakes (green line) plotted against a histogram of earthquake frequency in NY from 1990-2020

The magnitude of the earthquakes were the highest in the 1990's and the very early 2000's. The depth for this time period follows closely to the magnitude of the earthquakes, where there is a decrease in the magnitude there is also a decrease in the depth of the earthquakes. The magnitude begins to increase again causing the depth to also increase. The graph no longer follows a pattern after 2005-2006. The mean magnitude of the earthquakes are all less than 2, meanwhile the depth of the earthquakes are all much deeper than seen in the previous years.

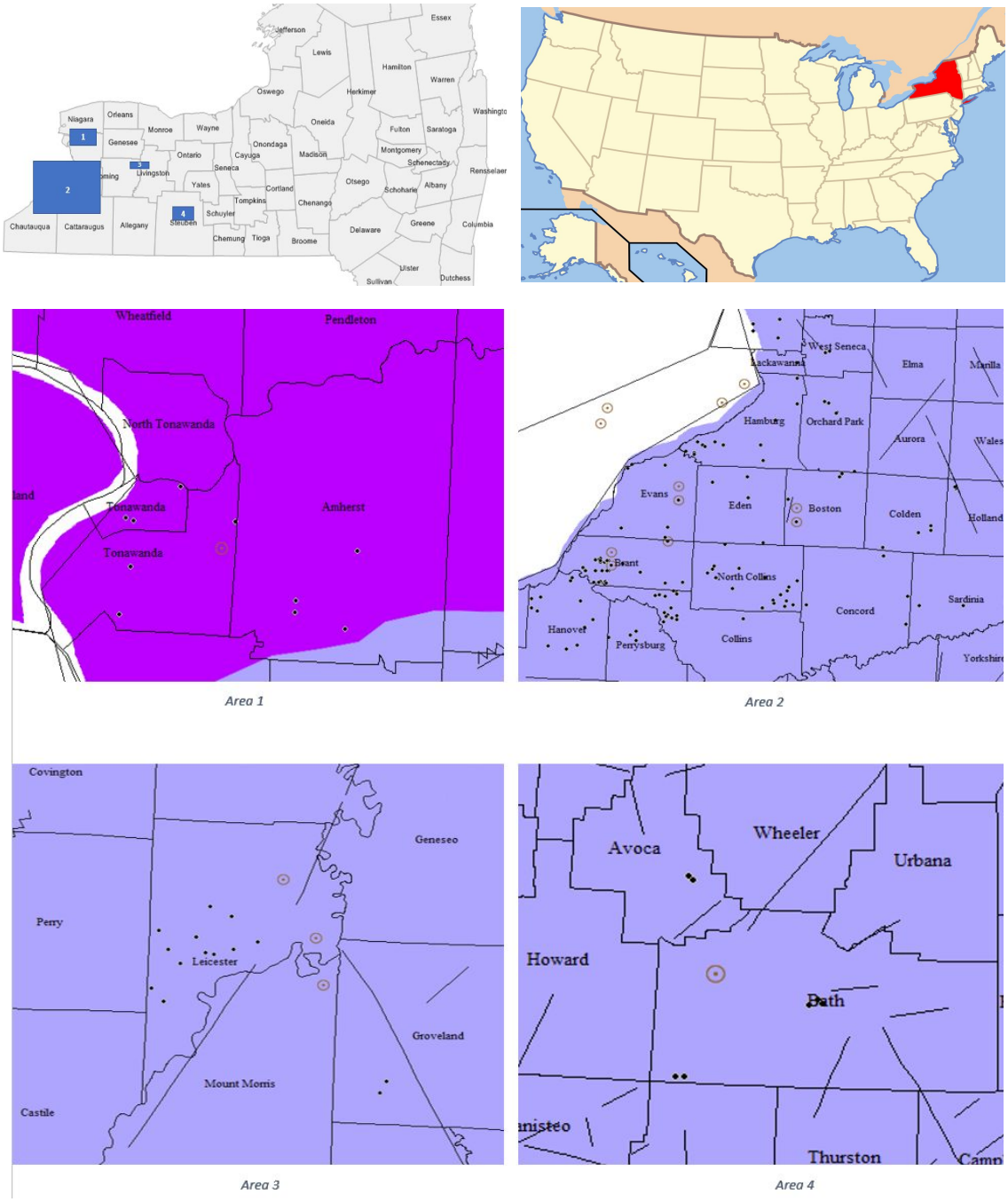


**Figure 6.** These anomalies are the earthquakes (circled dots) that occured in close proximity to wells (regular dots) in that same area that were in use or recently plugged. These earthquakes were found off of the brittle faults (black lines). Lighter purple in this map represents the rock layers are from the Devonian and the darker purple represents the layer is from the Silurian.

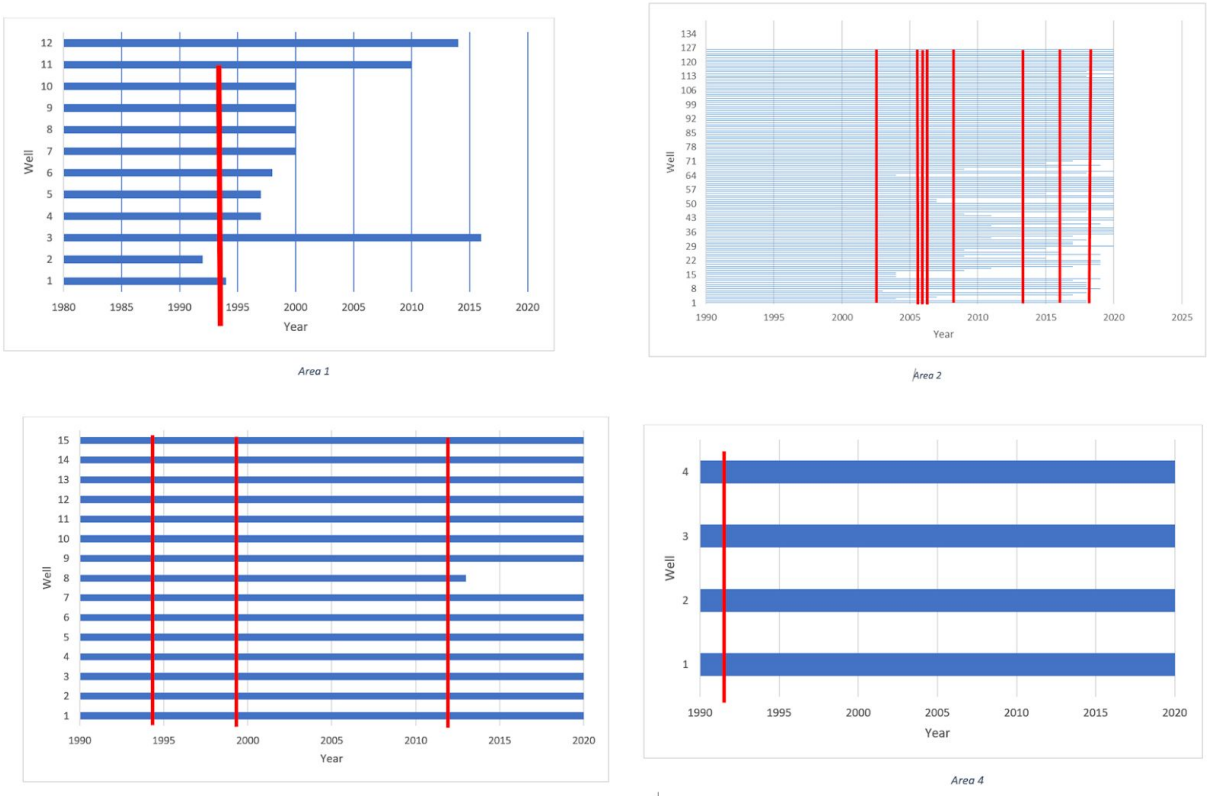


**Figure 7.** Graphs representing the well activity in each area (Blue lines) with the earthquakes that occured in the near proximity on an annual basis (Red lines).

The graphs above each correlate to the images shown earlier. They are labeled by area number in order to provide a clear, analytical viewpoint. The blue lines on the graph represent well operation during 1990-2020. When the blue lines on the graph end, it represents when the well site was plugged. The red lines on these graphs represent earthquakes that occurred during the same time periods. The most activity recorded in these graphs is found in area 2, in which there were at least 8 different earthquakes during a 10 year period that occured in the same area as the well sites.

**Discussion**

Earthquakes that occur in New York occur in non-well areas significantly more than in the areas with wells (statistical insignificant with p-values >.05). Causing the hypothesis that fracking may result in an increase in earthquakes to be shown as incorrect. The earthquakes found in these non-well areas have magnitudes and depths that are much greater than those found in the well areas (Fig. 2 and Fig. 3). The earthquake data for the well sites show stable trends in the relationship between the magnitude and the depth of the earthquakes over specific year intervals. We noticed that during the 1990-2005 time period, there were large spikes in the magnitudes of the earthquakes that occurred. These large magnitude spikes are only found in this time period, with the mean magnitude being close to 3. While this level of magnitude is not a danger to New York State infrastructure, it is important to take into consideration that

it is a significantly larger magnitude than the other years recorded. These magnitude strengths are uncommon for an area that has little to no major active fault lines and no active tectonic activity in a close proximity.

As the histograms show in the years 2007-2014 in non-well areas, earthquakes had a smaller magnitude but had a larger number of earthquakes occurrence. This is the time period that is just before fracking was banned in New York. This is an important piece of information to keep in mind, because while the data sets do not show that the well areas were affected, the nonwell areas were largely affected. As fracking in New York was continuing, the non well area was continuing to show an increase in seismic activity. The largest number of earthquakes occured during this time period with the highest depth (Fig. 3). The mean magnitude, however, has been decreasing. This is most likely because there were more earthquakes recorded, increasing the mean magnitude variance.

After fracking was banned in New York State in 2014, the datasets take a decline in magnitude, depth, and occurrence (Fig. 2) and a significant change in the seismic activity is prominent. While we cannot attribute this change to the banning of fracking, we acknowledge that something has changed in order to make this decrease occur.

Other researchers have been found that fracking is linked to small magnitude earthquakes (Brudzinski et. al 2019) found in central and eastern America. Wells that are deeper in the earth are most likely the cause for these small scale earthquakes. This is because the deeper the well is, the more likely it is to reach the basement rock. This basement rock is the home to the major faults which become more likely to slip and create these earthquakes. The pressure that the fracking produces on the basement rock is creating overlapping rock layers, which is affecting the seismic activity.

Using this information that previously was found (Brudzinski, et al., 2019) we can see in our histogram comparing depth and frequency that our deepest earthquakes were found just before fracking was banned in New York. Solely basing this observation off of their research, we can assume that, like central and east America, the small magnitude and large depth earthquakes may be occuring because of fracking. We have found that there are associations between the time of active fracking and the time of small scale earthquakes, but they are few and far between New York State. If there had been more instances in which this occurred, we would be able to have a firm say in whether fracking in New York has an association with the small magnitude earthquakes.

**Conclusion**

While we have found that there are some earthquakes that occur in the well areas that correspond to the time of the fracking being done, there are very few instances in which it occurs. If more earthquakes occured in the part of New York containing wells then perhaps we could form a more definitive link between fracking and earthquakes. These anomalies in our data sets have been highlighted and acknowledged.

**References**


Bao, Xuewei, and David W. Eaton. “Fault Activation by Hydraulic Fracturing in Western Canada.” *Science*,vol. 354, no. 6318, 2016, pp. 1406–1409., doi:10.1126/science.aag2583.

Bulgarelli, David. “QUAKING THE FOUNDATION: FRACKING-INDUCED EARTHQUAKES AND WHAT TO DO ABOUT THEM.” *JOURNAL OF LAW, TECHNOLOGY & POLICY*, vol. 2017, 2017, pp. 229–248.

Camelbeeck, Thierry, et al. “Earthquakes as Collapse Precursors at the Han-Sur-Lesse Cave in the Belgian Ardennes.” *Geomorphology*, vol. 308, 2018, pp. 13–24., doi:10.1016/j.geomorph.2018.01.030.

Ellsworth,W. L. “Injection-Induced Earthquakes.” *Science*, vol. 341, no. 6142, 2013, pp. 1225942–1225942.,doi:10.1126/science.1225942.

*Energy.gov,* “Shale Gas 101.”, www.energy.gov/fe/shale-gas-101.

Eyre, et al.2019. “Microseismicity Reveals Fault Activation before M w 4.1 Hydraulic-Fracturing Induced Earthquake.” *OUP Academic*, Oxford University Press, 8 Apr. 2019, academic.oup.com/gji/article/218/1/534/5432359.

Mcdermott-levy, Ruth Mcdermott, et al. “Fracking, the Environment, and Health.” *ENVIRONMENTS & HEALTH*, vol. 113, no. 6, June 2013, pp. 45–51.

Seismological Society of America. "Studies link earthquakes to fracking in the Central and Eastern US." ScienceDaily. ScienceDaily, 26 April 2019Schultz, Colin. “Marcellus Shale Fracking Waste Caused Earthquakes in Ohio.” *Eos, Transactions American Geophysical Union*, vol. 94, no. 33, 2013, pp. 296–296., doi:10.1002/2013eo330008.

Schultz, R., et al. “Hydraulic Fracturing Volume Is Associated with Induced Earthquake Productivity in the Duvernay Play.” *Science*, vol. 359, no. 6373, 2018, pp. 304–308., doi:10.1126/science.aao0159.

Voort, Nick Van Der, and Frank Vanclay. “Social Impacts of Earthquakes Caused by Gas Extraction in the Province of Groningen, The Netherlands.” *Environmental Impact Assessment Review*, vol. 50, 2015, pp. 1–15., doi:10.1016/j.eiar.2014.08.008.

Williams , John. “The Marcellus Shale of the Appalachian Basin Is One of the Largest Unconventional Gas Plays in the United States. .” *Water Issues and Marcellus Shale Gas Development in New York*, [last access: 3/24/2020] www.usgs.gov/centers/ny-water/science/water-issues-and-marcellus-shale-gas-development-new-york?qt-science_center_objects=0#qt-science_center_objects.

Wang, Xiangteng, et al. “Source Characterization of Some Collapse Earthquakes Due to Mining Activities in Shandong and Beijing, North China.” *Seismological Research Letters*, vol. 90, no. 1, 2018, pp. 183–193., doi:10.1785/0220180184.

Wilson, M. P., et al. “Fracking: How Far from Faults?” *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*, vol. 4, no. 2, 2018, pp. 193–199., doi:10.1007/s40948-018-0081-y.

Dear Director of the Conference, Prof. Gilbert Hanson,

We are pleased to email our short announcement of research with a title “Study of the Relationship Between Hydraulic Fracturing and Seismic Activity in New York State” to be submitted for the 27th Conference on the Geology of Long Island and Metropolitan New York.

Our research is about investigating potential associations between hydraulic fracking and seismic activity in New York State. The key finding from our research is that there is a minor correlation between hydraulic fracking and earthquakes without excluding such association. We found that in most cases there was no effect on seismic activity from fracking, but that there were a few anomalies.

Should you require any additional information, please let us know to provide.
Kind regards,

The co-authors,

Joyce Bowen, Nicholas Ptak, Avery Reardon, (Hofstra GES Students), and Prof. Antonios Marsellos