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Privileged and confidential

Terry Lodge, Attorney at Large
Via e-mail

RE: Geologic Conditions at the Perry Nuclear Power Plant in Lake County, Ohio

Dear Attorney Lodge;

Per your request, please find this letter report documenting the existing geologic, hydrogeologic and soils conditions in and around the area of the Perry Nuclear Power Plant in Lake County, Ohio. This report is not meant to be a comprehensive analysis of all the documents related to the site. Rather, it addresses a list of geologic, soils and engineering topics that should have been considered as part of the site selection, development, design and construction. This is a basic list that I was considering as a student and in my earliest professional positions during those years. To have failed to undertake this level of review could have created fatal flaws in the structural integrity of the facility that cannot be corrected now that it is built. This review includes listings of geologic hazards, both natural and man-made. This information in this report has been gathered from publically available documents available to anyone choosing to undertake a comprehensive evaluation of the natural conditions in and around the facility. A significant amount of this information was available when the plant was originally sited although not in these electronic forms. It is my understanding that the State of Ohio notified the Nuclear Regulatory Commission (NRC) and the US Department of Energy (DOE) of possible seismic activities in the region and recommended against siting it there in the first place. Therefore, both the NRC and DOE should be fully aware of the information contained in this report. If they are not, they have been failed by their site selection and development team. I am simply documenting already existing information that should have been considered when the plant was originally envisioned and must be considered now again as it goes for renewal.

It I my understanding that this renewal is for only 20 years but there is no information provided as to the necessary eventual removal of the facilities from the site or their final storage placement elsewhere. I also did not notice any mention of the planned design life of the facility. In the 1970s, a 37-year life expediency was a typical pre-renovation figure for new construction and the plant has reached that point. The materials that make up the Perry Nuclear Power Plant cannot remain at the current site indefinitely as conditions at the site will change radically before the materials stored at the site are no longer a threat to human health and the environment.

My qualifications for this review

I am a 75 year old Earth Scientist. I have a BS Edu. in Earth Sciences from The Ohio State University earned in 1974. My field work was in Ohio and the Appalachians. I have an MS in Geology and Mineralogy from The Ohio State University earned in 1978. My major for my MS was glacial geomorphology. I also studied the economic and stratigraphic geology of Ohio, hydrogeology, mineralogy and structural geology (geophysics). My field work was in Ohio and Wyoming. I then went to work for the Mid-Ohio Regional Planning Commission where I was a Water Quality Planner III and then the Franklin Soil and Water Conservation District where I was the first Urban Conservationist in Ohio. I had researched and written my MS Thesis (A Geologic and Land-Use Development Survey of Blendon and Plain Townships, Franklin County, Ohio) for the two agencies. My special duties with the agencies were surface water hydrology, soils suitability for building sites and on-lot septic systems, construction site inspections; cement basement wall integrity and sediment and erosion control.

In 1982 when our Federal and State funding ran out, I began working for private engineering consulting firms usually on public projects. I was named to the Ohio Department of Health's Private Water and Wastewater Review Board which I served for 9 years. In 1985 I was part of a team of geologists and civil engineers who inventoried and mapped on foot, 40 miles of the Miami-Erie Canal from the Lake Loramie spillway to Delphos Ohio. We located and assessed 110 of the original 111 structures of locks, dams, lakes and spillways along the 40 mile stretch to determine structural integrity and repair needs as well as the structural integrity of the canal itself and the surface storm water and tile drainage flowing into the canal. This stretch, which includes Grand Lake St. Marys, the largest manmade lake in the world until the Aswan Dam was built in Egypt, still carried lake water into the canal as cooling water for the St. Marys municipal electrical power plant. This project was undertaken for the Ohio Department of Administrative Services who owned the Canal lands at that point in time. The canal lands are now owned by the Ohio Department of Natural Resources (ODNR).

In October 1986, I joined the firm of Bennett & Williams Environmental Consultants Inc. I soon became their senior geologist and later their senior scientist. Truman Bennett had built Ranney style ground water collector wells all over the world and he was heading up the team of scientists who developed US EPA's ground water pollution protection mapping program, DRASTIC, which was published in 1987 (Aller et al., 1987). DRASTIC mapping has been used in more than 70 countries around the world, including all of Ohio. They sent me to study geotechnical engineering and laboratory procedures with Robert Dunbar, owner of Dunbar Geotechnical Engineers and Laboratory. Mr. Dunbar was responsible for the geotechnical engineering for many of the substructures of the high rise buildings in downtown Columbus, Ohio and we provided the groundwater dewatering programs needed to keep the substructures dry during construction. Most of my work at Bennett & Williams has centered on the development of public ground water supplies and the protection programs required to keep them safe, site suitability evaluations for multiple applications ranging from landfills to building sites and the evaluation of contaminant migration from a variety of contaminating land uses ranging from oil and gas wells and coal mines to industrial hazardous waste landfills. In 1986, I was named to the Governor's Oil and Gas Regulatory Review Commission and served on that Commission until it was completed in 1987. In 1987, I was elected to the Governing Board of Supervisors for the Franklin Soil and Water Conservation District where I served for 9 years and then became an Associate Supervisor, an appointment I still hold.

Hydrogeologists around the world were noticing that groundwater was recharging faster and contaminants were moving more rapidly from the surface than could be accounted for using standard geotechnical testing procedures. We kept encountering vertical fractures in our subsurface investigations and wondered if they might play a part in the transport. This was becoming a serious issue here in Ohio so Bennett & Williams sent me back to The Ohio State University for a research PhD program to see if we could figure out what was controlling this rapid migration.

I joined the Dept. of Soil Science, studying under Dr. George Hall who was also the OSU Coop Extension State Soil Scientist. Since no one, anywhere in the world, knew what the controlling factors were, Dr. Hall convened the Ohio Fracture Flow Working Group under the umbrella of the Ohio Academy of Science to try to figure out what was happening and if we could predict their existences. The Working Group included representatives from every State and Federal agency and every university in the state who were working on soils, glacial materials, hydrogeology, contaminant transport and agricultural engineering. At one point in time we had members representing 86 different specialties and subspecialties. It took us all, combing back through historical records more than 100 years old, undertaking site investigations, collecting samples and running countless laboratory tests to determine the who, what, when, where, why and how of the fracture formations and their roles in water and contaminant migration but we finally solved the puzzle. Our work explains the conditions in the eastern glaciated US and Canada that controls the fracturing processes. Our work confirmed conditions from Iowa and Wisconsin to Ohio and Pennsylvania and has been used to evaluate similar conditions around the world.

As Dr. Hall's last graduate student, I was charged with organizing and coordinating the Task Force. When he retired, Dr. Ann Christy,(now Associate Dean and Director for Academic Programs, College of Food, Agricultural and Environmental Sciences and Professor in the Depts. of Food, Agricultural and Biological Engineering and Environmental Engineering), Michael Angle, (recently retired as the ODNR State Geologist and Chief of the Div. of Geological Survey) and I took over the coordination of the Working Group and co-edited the two special issues of the Ohio Journal of Science published in 2000 and 2006. I sat for my general examinations in the fields of Science Education, Geology, Hydrogeology, Soil Science and Geographic Information Systems which means I am qualified to teach in all five of those fields at the university level. I finally completed my PhD in 2004, majoring in the chemical and physical properties of soils and their underlying geologic materials and minoring in geographic information systems. I then joined the Dept. of Food, Agricultural and Biological Engineering where

I served as an Adjunct Professor until I turned 65 while still working for Bennett & Williams, teaching classes and supervising graduate students even beyond my retirement date. I still maintain a part-time position with the firm of Bennett & Williams Environmental Consultants Inc. as their senior scientist.

In 1996, I was named to the Sharon Twp. and Worthington, Ohio Union Cemetery Advisory Board. My roles on the Board, where I still serve, are in the fields of geology, soils, hydrogeology, streambank stabilization and the active restoration of the Ozum Gardner Homestead. Ozum Gardner was the master brick maker for early Worthington and the surrounding area. All the old brick buildings in the area were made from his bricks. He bought his farm in 1821. The family burying ground on his farm, begun in 1831, has become Flint Cemetery. His final homestead, which was built in sections from about 1830 to the mid-1860s from his left over bricks, is being restored and renovated as the permanent offices for the Cemetery. I have learned much about the structural integrity of old brick and cement structures as we work to stabilize and then renovate the building.

I have served as a technical advisor to a series of public and non-profit environmentally related organizations in Ohio and beyond for decades. Since 1990 I have been addressing the issue of the natural radioactivity and its decay chains from coal, coal ash and oil and gas drilling wastes. I have spent countless hours researching the migration of heavy and radioactive metals and their attachment to our clay minerals and colloids, radium isotopes in solution and radon gas migration. I have lectured on the potential for contamination of public water supplies from these sources and what communities can do to protect themselves from contamination. My research has also included enriched nuclear materials and man-made radioactive materials.

Material reviewed for this evaluation

I have read and reviewed four documents written about the Perry Nuclear Power Plant site. They are the following:
Original Safety Evaluation Report SER, 1982
https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML20054F514

Supplemental SER, 3/31/86
https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML20141P078

Updated Final Safety Analysis Report (NFSAR) Chapter 2, January 2003
https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML21361A214

NRC internal memo dated 9/1/11
https://www.nrc.gov/docs/ML1203/ML12037A027.pdf

In addition, I read and reviewed the following USEPA web sites:
Aller et al., 1987
https://nepis.epa.gov/Exe/ZyNET.exe/20007KU4.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1986+Thru+1990&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C86thru90%5CTxt%5C00000001%5C20007KU4.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

https://www.epa.gov/radtown/nuclear-power-plants

https://iwaste.epa.gov/guidance/radiological-nuclear/high-level-waste

https://www.epa.gov/radiation/radionuclide-basics-tritium

https://semspub.epa.gov/work/HQ/175261.pdf

https://www.epa.gov/sdwa/drinking-water-regulations-and-contaminants and all the extensions

https://www.epa.gov/radon

https://www.epa.gov/sites/default/files/2014-08/documents/ohio.pdf

https://odh.ohio.gov/wps/wcm/connect/gov/497d9b2f-5e96-4aa6-bca8-5582803bd2b8/Radon+County+Maps.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDDM3000-497d9b2f-5e96-4aa6-bca8-5582803bd2b8-nF3BXsj

The following NRC web site:
https://www.nrc.gov/waste/high-level-waste.html

The following US Geological Survey web sites:
https://pubs.usgs.gov/of/1993/0292e/report.pdf

https://www.usgs.gov/publications/earthquake-hazard-associated-deep-well-injection-a-report-us-environmental-0

The following ODNR web sites and extensive conversations with various Divisions staff over the decades:
https://ohiodnr.gov/discover-and-learn/safety-conservation/about-ODNR/geologic-survey/glacial-geology/ice-age-in-ohio

https://ohiodnr.gov/static/documents/geology/MiscMap_BedrockGeology_2017.pdf

The Ohio Geologic interactive map web site and the extensions
https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

https://gis.ohiodnr.gov/MapViewer/?config=oilgaswells

https://gis.ohiodnr.gov/MapViewer/?config=OhioMines

https://ohiodnr.gov/discover-and-learn/safety-conservation/geologic-hazards/landslides

Nelson & Valachovics, 2022
https://ohiodnr.gov/wps/wcm/connect/gov/e3fe9649-96b9-427d-baf2-c6b92b8d4fd7/OFR2022_1_Nelson_2022_web.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_K9I401S01H7F40QBNJU3SO1F56-e3fe9649-96b9-427d-baf2-c6b92b8d4fd7-otRSTWy

Harrell, McKenna and Kumar, 1993
https://ohiodnr.gov/static/documents/geology/RI144_Harrell_1993.pdf

The Ohio Journal of Science Special Issues:
June-September 2000 (the whole journal is listed here from beginning to end)
https://kb.osu.edu/collections/b8bc52d3-2bdf-55c5-8f49-656ec32ac2ed

Allred, 2000
https://kb.osu.edu/server/api/core/bitstreams/403c8a86-0573-531f-ae98-7aef8764d95a/content

April, 2006 (the whole journal issue is listed here from beginning to end)
https://kb.osu.edu/collections/9719bfb1-1998-5583-8a2f-8b11bd98f394

Bruno, Szabo and Foos, 2006
https://kb.osu.edu/search?query=April%202006&scope=26dee3b3-05fb-57ce-9059-eb615033b352&spc.page=1

The Premier Precast Concrete web site:
https://premierprecast.com/concrete-lifespan/#:~:text=How%20long%20does%20concrete%20last%20on%20average%3F,installation%20methods%20and%20construction%20style.

The University of California Davis Soils Web Site:
http://soilmap2-2.lawr.ucdavis.edu/gmap/

Eun Kyoung Kim's 2007 PhD Dissertation:
Use of soil texture analyses to predict fracturing in glacial tills and other unconsolidated materials

https://etd.ohiolink.edu/acprod/odb_etd/r/etd/search/10?p10_accession_num=osu1196080474&clear=10&session=109712337392113

Wikipedia Utica Shale oil and gas plays map:
https://en.wikipedia.org/wiki/Utica_Shale#/media/File:Utica_Shale_assessment_-_01.jpg.

Images from several other Wikipedia sites, noted in the figure sources.

Fairport Harbor Morton Salt Mine photos:
https://www.researchgate.net/figure/The-Morton-Fairport-Harbor-Mine-is-13-km-from-the-Perry-Nuclear-Reactor-The-site-is_fig1_271855364.

https://www.businessinsider.com/photos-of-salt-mine-2000-feet-below-lake-erie-2016-5.

GSA Today:
https://rock.geosociety.org/net/gsatoday/science/G357A/article.htm

Periodic Table of Elements, including isotopes:
https://ptable.com/?lang=en#

Personal communications with Dr. Edward Rice, former assistant professor of History at The Ohio State University Main Campus and Mansfield branch, on the history of Ohio Settlement and the WWII scrap metals drives. (His father coordinated the drive in Charleston, WV. and Ed, born in 1933, was old enough to remember the efforts clearly)

Personal communications with Lyndella Andrews, then president of the Miami-Erie Canal Society, St. Marys, Ohio (now the Miami and Erie Canal Corridor Association, https://www.meccainc.org/) on the construction of the Miami-Erie Canal and the impacts of the Grand Lake St. Marys 1986 earthquake.

Personal communications with Chief Silverio Caggiano, retired battalion chief, Youngstown Fire Department on the impacts to the built environment from collapsing mines and old oil and gas wells.

Personal communications with Jamie Addis Rice, MS Agricultural Economics, The Ohio State University on the projected costs and real costs to the environment over time of environmentally impacting land uses.

Personal communications with Adam Rice, homeowner, Worthington, Ohio on the Ohio Shale radon gas mitigation from a basement.

Personal communications with Dr. Richard McClish and Gene Johnson, geologists, on the Ohio Dept. of Energy, US DOE, Battelle oil shale research project for extracting oil from the Ohio Shale by retort.

Personal communications with Todd Houser, MS, CPSS soil science on the heating and expansion of Ohio Shale to create an expanded lightweight, more stable aggregate.

Introduction

When considering potential sources of contamination emitting from a nuclear power plant, it is important to consider the weakest point of potential contamination, what events could trigger the migration of contaminants away from their containment and the routes that contamination would take. The US EPA has a very robust set of documents available on line that discusses nuclear power plants and potential accidental releases from these plants. That information begins here, https://www.epa.gov/radtown/nuclear-power-plants. Their web sites were chosen for review because they do not have a vested interest in siting and operating these facilities but they most certainly will be involved in a clean-up operation if/when an accidental release occurs at the Perry plant. They identify three sources of radiation that can be released from the site. This includes enriched uranium, low-level radioactive wastes and high-level radioactive wastes. While we know from our past experiences with the Portsmouth, Mound and Fernald uranium enrichment facilities here in Ohio that offsite contamination could and did occur, it is the storage of high-level radioactive waste on site for the next 20 years and in perpetuity that causes the greatest concern. The web site states:

> "Spent nuclear fuel is highly radioactive and stored in specially designed pools containers. There are no high-level waste sites designed for permanent, long-term storage in the United States. High-level radioactive waste must be stored on-site at each individual nuclear power plant, currently in units called dry cask storage units."

US EPA further notes that "if you are near a facility that manages radioactive waste, follow safety instructions." "Radioactive materials and other contaminants from waste can be very dangerous inside the body."

The Agency later goes on to state in their web pages that each nuclear power plant is required to have a safety plan in place and that such a plan should be available for review by the general public. I would recommend that you request a copy of that plan and make certain that it is adequate. Of special note, see how they address releases from the secondary storage units.

US EPA further documents at this web site, https://iwaste.epa.gov/guidance/radiological-nuclear/high-level-waste

> **"Storage, Disposal, and Transportation**
>
> "High-level radioactive waste is highly controlled and tightly regulated by the U.S. Nuclear Regulatory Commission (NRC); however, defense reprocessing wastes are not regulated by the NRC. Because much of the nation's HLW consists of spent nuclear fuel, the majority of HLW is stored

> on-site at nuclear power generating facilities (See also Locations of Independent Spent Fuel Storage Installations, U.S. NRC). There are two storage options for high-level waste: wet storage or dry storage. The majority of spent nuclear fuel in the U.S. is stored in wet storage (2).
>
> "Wet storage – spent nuclear fuel rods are stored submerged in water in specially engineered storage pools. Spent fuel from a nuclear reactor is moved from the reactor to the storage pool through a channel in the plant, thereby reducing worker exposure. The water in the pool acts as a radiation shield and a cooling medium for the spent fuel rods. Wet storage requires a relatively high level of maintenance and operational diligence.
>
> "Dry storage – after a sufficient cooling period (typically 1-2 years), spent nuclear fuel rods can be stored vertically or horizontally in dry storage casks. The casks are usually placed on concrete pads located on-site at the nuclear power generating facility. Dry storage is usually employed when wet storage pool capacity has been reached.
>
> "High-Level Waste Disposal Regulations, Guidance, and Communications (U.S. NRC)
>
> "There is currently no permanent disposal facility for high-level waste. HLW must continue to be stored at commercial reactors and selected DOE facilities.
>
> "Most of the transportation of spent nuclear fuel in the U.S. occurs between commercial reactor facilities owned by the same company so that storage space can be efficiently utilized. The NRC regulates spent fuel transportation through regulations that ensure shipment safety and security, and through regulations that specify the requirements for shipping containers themselves. See also U.S. NRC, Transportation of Spent Nuclear Fuel."

Finding an actual listing of the radioactive elements contained in the spent fuel rods has proved to be difficult. From my readings, it appears to be a whole series of radioactive elements going through a series of decay chains. Some of them are naturally occurring and some are manmade. One NRC site indicated that the spent fuel rods would be radioactive for "hundreds of thousands of years" (https://www.nrc.gov/waste/high-level-waste.html. Therefore, when considering the safety of the Perry Nuclear Power Plant, we have to assume that the long-term storage of spent waste on site in wet or dry storage is the most vulnerable part of the system to leakage of radioactive materials to the soil, water or air. We also must take into consideration that no place on earth has been stable for "hundreds of thousands of years".

In point of fact, the Perry site has been overrun in the last 125,000 years by a series of continental ice sheets, approximately ½ to 1 mile in thickness during both the Illinoian-aged and the Late Wisconsinan-aged ice advances of the Pleistocene. Those ice sheets would have caused irreparable harm to any on-site storage facility. There is no reason to assume that more ice sheets will not visit the Perry site sometime in the future in the next "hundreds of thousands of years". As Seen in Figure 1: Ohio clearly is on the edge of the Pleistocene ice age advances as shown on this graphic from the ODNR Div. of Geological Survey, But it is also clear from this graphic that the Perry site was well buried.

So by creating electrical energy at a nuclear power point, society is creating a "forever" waste stream that must be managed and protected from humans and the environment basically forever. That makes this source of electricity extremely expensive if the full cost of waste management was factored into the cost per kilowatt hour. Clearly, since the US continues to use nuclear energy to produce electricity those future costs are ignored and simply factored into the responsibility of future generations who did not benefit from their creation. In the field of economics, this is considered pass through negative externality costs to society, ignored on the bottom line and the true costs to the environment over time have not been factored in here (Jamie Addis Rice, personal communications).

Long term durability of cement and steel

What do we know about the long-term integrity of cement and steel, the materials used to encase materials found to be radioactive for "hundreds of thousands of years"? What could happen to the aging cement and steel at the site in the next 20 years, given that the buildings on site are now already approaching 40 years old?

Cement is strong but very brittle and does not hold up well long term to water and temperature fluctuation. Nor does it hold up well to earth tremors such as earthquakes. Additionally, cement concrete is permeable. Water passes through it over the course of a year, allowing the internal steel rebar within the concrete to get wet. Steel is more malleable to a certain level but even it rusts in time when exposed to water. When the rebar steel in concrete rusts, it expands, causing the cement concrete surrounding it to crack and spall.

So how long does concrete last? It depends on a number of factors. This question is addressed in detail at the web site for Premier Precast Concrete, a company actively involved in the production of concrete for building applications, https://premierprecast.com/concrete-lifespan/#:~:text=How%20long%20does%20concrete%20last%20on%20average%3F,installation%20methods%20and%20construction%20style. They say "30 to 100 years" although we know that the Roman sea walls of concrete have lasted 2,000 years but not without wear and tear. Given the age of the current facility, that means that the cement concrete at the Perry site could be in failure at any point in time in the future or could even be in failure now since the site is now approaching 40 years old. Has anyone checked to see if it is currently failing and if so, how did they evaluate the integrity? This is of special concern for the walls that are buried in the earth.

This information mirrors my own personal experience with concrete. Our community swimming pools here in Worthington (Franklin County) are about 70 years old, double their expected lifetime at construction and their replacement has been a hot topic at school board and city council meetings for a number of years now. They either have to be replaced or closed. My 63 year old cement block basement walls in my house are also showing signs of decomposition and have been undergoing repair for the last five years. The older brick buildings in St. Marys showed significant damage from the 4.5 earthquake there in 1986. Brick, mortar, and cement concrete are brittle. If there is too much shale in the aggregate mix, it spalls. It can also spall from temperature changes or from being exposed to freezing temperatures before it was fully cured. Clearly, the construction materials are not going to survive for "hundreds of thousands of years" and they may even be failing now.

In point of fact, mankind as we know us, as a civilization has not lasted the "hundreds of thousands of years" that the spent fuel rods will continue to be radioactive. The last ice sheets from the Late Wisconsinan ice advances only melted off Niagara Falls about 10,000 years ago. Stainless steel also is not expected to last "hundreds of thousands of years". Therefore, we must assume that the first point of failure at the Perry Nuclear Power plant will be the wet and dry storage locations for the spent fuel rods. If/when the storage pools crack, rust and leak, where will the radioactive water in those pools go?

A short summary of the Geologic History of Ohio

To understand the following discussions and to put everything into a relative stratigraphic and age relationship, it is critical to understand the geologic history of Ohio. The ODNR Div. of Geologic Survey has prepared a number of publications, newsletters and educational leaflets on the topic. Ohio only has a Precambrian, Paleozoic, and Quaternary or Pleistocene bedrock and glacial geologic history. During the other geologic eons, Ohio was dry land and there is no geologic record, only a significant period of erosion. I have included here a download of the Bedrock Geology of Ohio for further reference as Figure 2 in this report. The color coded time scale on the second page provides additional context. This map also documents the major confirmed fault lines.

Soils

Soils are the uppermost gateway for the migration of water and contaminants that move with water moving from the surface of the earth to underlying aquifers. Soils form on/in the uppermost geologic materials at any given site. In glaciated Ohio, they form on/in materials left by the Pleistocene (Quaternary) ice advances and the pro-glacial lakes that formed in front of those advances. The soils of the area can be viewed on the University of California Davis web soil survey site, Figure 3. While this information would not have been available in this format when the plant was constructed, the same information would have been available in paper format through the Lake Soil and Water Conservation District.

There are three specific groups of soils mapped at the site. The predominant soil is the Mo which is 90% Minoa (lake plain footslope), 5% Stafford (beach ridge footslope) and 5**%** slopes 2 to 4%. This large area that underlays the facility has an engineering rating of very limited for dwellings with or without basements and small commercial buildings. Therefore, from a soils limitation, this site should not have been considered for this application. The lake shore in front of the plant is mapped as CoF. This soils group is primarily 85% Colonie, a lake plain soil that is very steep, 25-50% slope, with some 5% Oshtemo (terrace), 5% Otisville and 5% Tyner (lake plains). These bluff areas would be considered unstable and subject to erosion from wave action and landslides. Please note the northern portion of the site, including one of the cooling towers, are built over this soils association. To the east along the lake and to the southwest of the site, the soils are mapped as EnB, 90% Elnora (beach ridge), 5% Colonie (lake plain) and 5% Stafford (beach ridge).

These soils range from loams to loamy fine sands. Therefore, based on all the work of the Ohio Fracture Flow Working Group (see discussion of my qualifications), we would expect the finer-grained soils to be drained by both primary and secondary porosity. The Minoa soils are rated as hydrologic class B/D meaning that the matrix is very poorly drained but would respond to agricultural tile subsurface drainage which takes advantage of secondary macropore porosity. The Colonie are hydraulic class A soils, basically a sandbox. The Elnora soils are hydrologic class A/D, meaning that the matrix is also poorly drained but would respond to agricultural subsurface tile (secondary macropore) drainage. Those soils that are classified as sandy loams and sands would drain through primary porosity but that would be rapid, like a sand box.

To understand the two drainage systems, I have included the USDA Soils Textural Triangle from Eun Kyoung Kim's 2007 PhD Dissertation from The Ohio State University Dept. of Food, Agricultural and Biological Engineering as Figure 4 where she took historic documented fractured soils data and hundreds of soil sample "mud pies" that she made to determine the limits of grain-size and clay mineralogies that control secondary macropore fracturing porosity. The area on the triangle in white, fractures. The area in pink is so coarse that it does not need to fracture to drain. Her research has since been internationally published in peer reviewed scientific and engineering journals and is well accepted worldwide.

What does this mean for leaks to the soils?

If there are leaks from the wet and dry storage containment systems, the radiated water would move quickly through the secondary fractures to the underlying glacial materials and bedrock and then out to the lake which is the hydraulic discharge point for this area of Ohio. We know, from the site documents that ground water levels at the site range from 3-5 feet below the surface of the ground, falling to 11 feet below ground's surface at the bluffs.

Were these factors considered when the Perry plant was engineered and built?

No they were not. The major engineering design report was authored in 1982, a quarter century before Dr. Kim's research was published. The site was subject to geotechnical testing and evaluation which deliberately measures only primary matrix porosity and permeability. In fact, back then, if subsurface testing cores encountered secondary fracturing, those portions of the cores were discarded and not subjected to testing. It was exactly because these testing methods were failing to provide the supporting data to explain the physical parameters that we were experiencing that the Ohio Fracture Flow Working Group was convened in 1993, after the facility was built and in operation. Therefore, the understanding of the site hydrogeology and engineering design of the site was based on only partial and faulty information. The issue of secondary fracturing in glacial materials application to construction was addressed in the 2000 Ohio Journal of Science article by Barry Allred of the USDA Agricultural Research Service (https://kb.osu.edu/server/api/core/bitstreams/403c8a86-0573-531f-ae98-7aef8764d95a/content). His summary and conclusions call into question the original design calculations for saturated Hydraulic Conductivity, Consolidation, Shear Strength and site softening over time for sites like that found at the Perry Plant. That means that the facility is already undergoing structural changes that were not anticipated when it was originally built.

I am not aware of any further site evaluations for the Perry plant that would lead to a recalculation of the design criteria and/or involve an in-depth evaluation of existing conditions to see if the site construction has been compromised over time. At a minimum, Ohio researchers know that the core design calculations were wrong because actual field conditions were not considered.

Glacial history of the area and remaining deposits

As stated above, the Perry site has been overridden by continental ices sheets a number of times during the Pleistocene. It has also been at the bottom of a series of glacial lakes that formed in front of the advancing ice sheets. Therefore, we can expect to find remnants of glacial drift (tills), old lake bottoms (varved deposits) and beach ridges. Those deposits were identified in the 1982 engineering report but their properties were not fully understood.

The current Perry site can be seen in the satellite coverage from the Ohio Geologic Interactive Map site in Figure 5. When queried for unconsolidated glacial coverage, this same view is mapped as follows on Figure 6. The plant is centered below the grid line that can be seen running south out of Lake Erie. By clicking on the area of the plant, we learn that there is approximately 60 feet of unconsolidated materials under the plant. These are Pleistocene in age and consist of finer-grained low lime glacial tills, varved lake deposits and beach ridge sandy deposits. This is important information because it tells us the type of materials that the wet pools are constructed into. Unless they are more than 60 feet deep, they are in unconsolidated materials. Any leaks from the wet and dry storage containment areas will be moving through these materials either down to the underlying bedrock or as base flow into Lake Erie.

Figure 7 shows a photograph of what the Ashtabula glacial till underlying the plant looks like. This is a dense, fine-grained glacial till but water and contaminants move through the secondary fractures. This photo was taken at the Geneva State Park in Ashtabula County. The source of the photo is from Bruno, Szabo and Foos, 2006.

Figure 8 is a photo of varved lake clay deposits with secondary fractures. Water and contaminants move through the secondary fractures. The light and dark bands in the photo are the annual deposits in the bottom of the lake. This photo is from the north side of the lake.

Figure 9 is a photo of a sandy beach ridge deposit. Here the materials are so coarse, like a sandbox, that water and contaminants flow quickly between the grains of sand. This setting has matrix primary porosity. This photo was taken at Oak Openings Metro Park in Toledo, Ohio.

To better understand the glacial conditions at the site, I recommend reading the paper by Bruno, Szabo and Foos, 2006 (scroll down through the pages at this address to get to the article) (https://kb.osu.edu/search?query=April%202006&scope=26dee3b3-05fb-57ce-9059-eb615033b352&spc.page=1). Bruno mapped the Lake Erie bluffs from Euclid Ohio to the Ohio-Pennsylvania state line as the field work for his 1988 MS thesis from the University of Akron. This paper, studying a block of Ashtabula glacial till taken from the bluff at Geneva State Park on the west edge of Ashtabula County will be representative of conditions underlying the Perry site. This 2006 paper clearly documents the presence of fractures with depth in the till and shows how the weathering process along the fractures alters the chemical and physical composition of the parent materials. When this is combined with the information in Allred (2000), the reader can begin to understand why the outdated geotechnical analysis of the Perry site is not predictive of the actual site conditions.

Were the Geotechnical site limitations fully understood when the site was designed?

No they were not because many of the summary publications that would have identified the issues of secondary porosity impacts at the site were published after the site investigations and analyses were completed. Historical papers did exist but it would have required a dedicated effort to find them. The USGS Water Resources Columbus Field Office did accomplish that research and published it in the 2000 issue of the Ohio Journal of Science (Haefner, 2000) Please see the discussion about the change in understanding geotechnical properties mentioned above (Allred, 2000; Bruno, Szabo and Foos, 2006). To the best of my knowledge, these considerations were not updated.

Likelihood of Ground Water contamination

The movement of water into the subsurface can be viewed in a number of ways. The first consideration is the potentiometric flow lines in the unconsolidated materials. The second is the potentiometric flow lines in the bedrock. In this coverage, both sets of flow lines mirror the surface topography. The unconsolidated flow lines are in thicker brown and the bedrock lines are in black. Surface topography is in the thin light brown lines. The contours of these two systems as well as surface topography can be seen in Figure 10 which is taken from the ODNR Interactive map.

There are two sources of ground water under the plant, the unconsolidated sands and gravels which yield 5-25 gallons per minute which are shown in Figure 11 from the ODNR Interactive map. This supply would be adequate for a residential property or a very small farmstead. There is also the uppermost bedrock aquifer, here the Ohio Shale, a notoriously poor source of water. It is commonly rated as less than 5 gallons per minute. That aquifer is shown in Figure 12.

Figure 13 shows the Groundwater vulnerability rating for the area of the plant. The only reason the rating is this low is because the identified aquifer is the shale. The area is described on Figure 14. Both of these figures are from the ODNR Interactive map. For a better understanding of the ground water pollution potential DRASTIC mapping, please see Nelson and Valachovics, 2022 (https://ohiodnr.gov/wps/wcm/connect/gov/e3fe9649-96b9-427d-baf2-c6b92b8d4fd7/OFR2022_1_Nelson_2022_web.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_K9I401S01H7F40QBNJU3SO1F56-e3fe9649-96b9-427d-baf2-c6b92b8d4fd7-otRSTWy).

Of most importance, from this map polygon, we learn that the static ground water levels in the unconsolidated materials is only 5-15 feet below the surface so there is a very good possibility that the wet storage pools, if dug to any depth at all, are sitting in saturated conditions at least part of the year. This estimate of the depth of groundwater at the site agrees with the reported depth of 3-5 feet below ground surface. While they are under drained, water will be passing by the outside walls as well as being contained inside the pools. That would place water both outside and inside the concrete, perhaps speeding up the weathering and decomposition of the concrete pools.

While the original designs took into consideration the importance of underdrains, they badly misinterpreted the movement of ground water through the soils, glacial materials vadose zone and the saturated unconsolidated materials. Their assumption of matrix movement for contaminants bears little resemblance to what actually is happening at the site. Water and contaminants move predominately if not almost exclusively through the secondary fracturing systems at the site. Only the beach sands are permeable enough to drain through the matrix. This transport system can have significant impacts on the structures at the site where the water movement affects buried and hidden structures. Given that the buildings are already completed, it is now impossible to check the foundation excavations or impacts to the structures where they are built into or on top of the ground surface.

I strongly suggest that the responsible parties at the site read the two special issues of the Ohio Journal of Science, 2000 and 2006 (https://kb.osu.edu/collections/b8bc52d3-2bdf-55c5-8f49-656ec32ac2ed and https://kb.osu.edu/collections/9719bfb1-1998-5583-8a2f-8b11bd98f394) starting with the Allred, 2000 paper (https://kb.osu.edu/server/api/core/bitstreams/403c8a86-0573-531f-ae98-7aef8764d95a/content), After completing a review of those papers, that they create a list of places at the site that they can evaluate and do so immediately. Where they can't, they need to be monitoring the insides of the structures for indication of failures from the outside. For instance, are concrete walls leaking? Is gas migrating into enclosed spaces? Given the geologic setting, failure should be expected and it should be expected sooner than later. Once a problem is detected through monitoring, it is usually too late to remedy the situation and the area has to be closed and abandoned because failure has been reached. This is especially true of the wet and dry storage areas.

Water wells in the area

The area that is Lake County today was originally settled by American settlers from New England shortly after 1800 as part of the Western Reserve. Beginning with the earliest settlers, water wells were hand dug and then drilled for almost a century and a half before records began to be collected. No one knows how many hundreds of these old wells exist in the County or how many, if any, were properly abandoned and grouted shut before modern land uses covered the landscape. These old wells provide both a direct conduit for surface contaminants to enter the ground water and for natural gas and radon from the underlying Ohio Shale to move into the built environment. More about that situation when the bedrock is discussed.

There are only a few identified water wells located in/near the Perry plant. They are shown here on Figure 15 as very small blue dots. One is a 1946 well into shale that was drilled for the Gospel Workers Society, probably former owners of the land before the Perry Plant was built. That well is shown in Figure 16. It was noted as having no fresh water, salt water at 135 feet (in the Ohio Shale). It may or may not have been properly abandoned when the plant was built. If not, like all the earlier dug and drilled wells, it is an open conduit to underlying aquifers and should be properly grouted shut.

The other well belonged to John Carroll University, drilled in 1965, and may have been part of their seismic network. That well is shown as Figure 17. It is noted on the well log completion form as being a dry hole, sealed. When the information from these water well logs is evaluated, there is considerable supporting evidence that any significant amount of ground water will move along the top of the bedrock and discharge as base flow to Lake Erie. This means that any contamination from the site that enters the ground water pathways will most likely end up in the lake. The only way that old wells can be located is through historic property searches and a field survey conducted by walking the site in a small grid pattern before the site is disturbed for development. I find no reference that that activity took place.

As can be seen on the USGS topography map for the site, the Lake will be the same ultimate outlet for any contaminated surface flow as well. At a minimum, all of the springs and seeps located on the face of the bluff in front of the plant should have been located and included in a ground and surface water monitoring program. The ground water in monitoring wells, if they have them, at the located springs and seeps on the Lake shore and the surface water/storm water impoundments, again if they have them should be tested for signature radiation components. I have not found information that this is actually a practice in place. This is especially problematic both because of the collection of spent fuel rods in the wet and dry storage areas but also because of the continued releases of tritium into the environment. Both the natural and man-made radioactive elements have Safe Drinking Water Maximum Contaminant levels which are not to be exceeded and Maximum Contaminant Level Goals. Please see the following US EPA web pages for further clarification (https://www.epa.gov/radiation/radionuclide-basics-tritium;
https://semspub.epa.gov/work/HQ/175261.pdf;
https://www.epa.gov/sdwa/drinking-water-regulations-and-contaminants and all the extensions).

While Lake Erie is large and there would be a dilution facture, it's not advisable to use the Lake as a contamination sink. Therefore, it is imperative that at all times, absolutely no contaminants leave the site. Given that the high-level radioactive wastes are going to be radioactive for "hundreds of thousands of years" and that there is no place on earth where they could be safely stored for that length of time, assuring that there will not be migration of contaminants into the Lake is unlikely. Assuming that there will be no migration to the lake within the next 20 years is less well understood because it appears that there have already been a number of releases from the facility.

Bedrock

The bedrock under the Perry plant is the Devonian-aged Ohio Shale. The Ohio Shale has many properties, most of them negative. This formation is the orange band that runs through the center of Ohio on the Bedrock Geology map of Ohio from the Ohio River to Lake Erie and then east along the lake (see Figure 2). This is a black, carbon rich shale formation, full of sulfur, and known for its "rotten egg" smell to the water in the formation. It varies in thickness. Here in Central Ohio where it beds out, it is approximately 400 feet thick under the eastern part of Franklin County (Columbus). Here it is only classified as the "Ohio Shale", and not broken up into members.

In the greater Cleveland area, including Lake County, where it is covered with Mississippian-aged sandstones and shales to the south, it can be up to 700 feet thick and is broken up into three members, the basal black Huron shale, the middle Chagrin Shale which is grayer in color and the capping black Cleveland Shale. When drilled down to the formation in southeast Ohio around Marietta, it is approximately 2,000 feet thick having been deposited in the Appalachian Basin.   Further to the south east of Lake County in Ohio and beyond, the base of the Ohio Shale is designated as the black Marcellus Shale which is currently being horizontally drilled and fractured for the unconventional development of oil and gas production. Here in Lake County, the Ohio Shale is too thin and too near the surface to lend itself to unconventional horizontal drilling.

Negative limitations for the Ohio Shale

Figure 18 shows the bedrock at the Perry site and identifies it as the Ohio Shale. Because the Shale is a black, carbon rich shale formed in an anaerobic marine environment, it is rich in the organic materials that serve as the food source to microbes that create our natural gas and oil here in Ohio. Because of that factor, the Ohio Shale is considered an "oil shale" even though it is not thick enough or deep enough here in Lake County to be successfully drilled on a commercial basis. It does, however, generate methane and radon gas and is one of the more significant sources of methane and radon gas migration into confined spaces.

Radon gas is the second most common cause of lung cancer after smoking in this country and has been regulated by the US EPA for decades (https://www.epa.gov/radon). Harrell, McKenna and Kumar, 1993, (https://ohiodnr.gov/static/documents/geology/RI144_Harrell_1993.pdf) map the Ohio Shale as a major contributor to the generation of radon gas in Ohio. While the levels in Lake County are not as high as they are in other places in Ohio, the success at sealing off air egress from confined spaces can enhance the levels of radon gas within a structure.

Testing for radon gas levels is now a common practice when properties are sold. The US EPA level for remediation is very low, only 4 piC/L, in air. When Adam and Jamie Rice purchased their 1950s built home in Worthington, Ohio situated over the Ohio Shale, the previous owners had the basement air tested when they bought the home and it was below the 4 piC/L level and so required no remediation. However, while they lived there, they had taken steps to seal the crawl space under the kitchen addition and the radon levels in the basement had risen to 8 piC/L. This situation required the Rice family to add a new radon gas extraction system to the basement to bring the radon down to safe levels. I saw no information in the documents I reviewed that demonstrated radon monitoring at the Perry facility. If it is not routinely done, it should be undertaken immediately for the health and safety of the work force there.

The Ohio Shale also generates methane gas and has been drilled for that purpose on a small volume effort for more than half a century. This practice is discussed below under oil and gas wells. However, more importantly, just by being there, it off gases methane gas. The quantities of oil and methane held in the Ohio Shale are sufficient enough to have been investigated by the Ohio Dept. of Energy for extraction. The formation was not going to be drilled, it was going to be mined and retorted. During the heating process, the available oil and methane gas would be collected (McClish and Johnson, personal communications). The efforts were undertaken during the 1970s oil embargo but were abandoned when the embargo was lifted and oil prices dropped. The Ohio research showed that the process would be cost effective if oil reached the price of $35.00 a barrel at 1980 prices.

But this study brings up another limitation of the Ohio Shale; methane also migrates out of the shale naturally and builds up in confined spaces. Since natural methane is basically odorless, it's spiked with hydrogen sulfide so we can smell gas leaks in our homes. While there is hydrogen sulfide in the Ohio Shale naturally, there may or may not be enough to alter the smell of methane buildups in confined spaces. Buildings in Ohio have been known to explode and burn from the buildup of methane gas in their basements. In addition, breathing methane gas is a health hazard for workers. I found no information indicating that the facilities were being monitored for the buildup of methane gas in confined spaces. If that is not currently being done, it should be implemented immediately.

Ohio Shale has structural properties that cause it to expand when it is heated. This works well when this is a planned activity as it creates a more stable lighter weight aggregate (Todd Houser, personal communications) but if it is heated in an unplanned manner, the expansion can create structural pressures on the walls of confined spaces such as basements and pools. This pressure can be significant, enough to compromise the integrity of those structures. I saw no information in the documents that I reviewed that indicated that heat was being separated from the Ohio Shale on site. Furthermore, many of the activities on site, such as storing spent fuel rods in water filed pools, create situations where waste stray heat is generated. The facility must institute an ongoing investigation to insure that waste stray heat is not reaching the Ohio Shale on site. The expansion of that shale, already in place, could structurally undermine the facilities at the site.

The Ohio Shale is notoriously weak as a building foundation. Where it is encountered in the Columbus area where high rise buildings are planned, it is common practice to design extra wide footers under the buildings to allow the weight to be distributed over a larger area (Robert Dunbar, personal communications). When the Main Library at The Ohio State University was remodeled in the 1970s, the new spiral staircase that connected the floors between the new and older parts of the building was set on Ohio Shale. I was working in the building at the time and was working on my MS in Geology and Mineralogy. When constructed, it was found that the weight of the spiral staircase turned it into an augur and it began to rotate and drill into the underlying Ohio Shale. The staircase had to be redesigned and rebuilt so that the weight of the staircase was carried by the bridges that linked the old and new portions of the library at each floor level. I did not notice any information that indicated that the Perry plant was being monitored for structural settling and potential building compromises from that process. If that activity is not being done, it should be instated immediately.

Ohio Shale weathers easily and spalls. When used for concrete aggregates, the Ohio Dept. of Transportation limits the percent of shale in the aggregate used to make the concrete used for roadbeds. Each shale piece becomes a weak point that compromises the structural integrity of the resulting concrete. In addition, when used for fill, it weathers quickly and decomposes into its original clay and silt materials. That's why it is heat treated and expanded to stabilize it before it becomes a more structurally sound building fill material (Todd Houser, personal communications). Was the aggregate used to make the concrete at the facility screened to remove shale particles? Was the Ohio Shale "fill" used at the site heat treated and expanded to stabilize it before it was used? If these two processes were not undertaken, then the concrete and the structural integrity of construction over the Ohio Shale "fill" could well be compromised. If not already a part of the common inspection process in place, an inventory of these conditions should be undertaken immediately.

The rest of the Ohio rock history

All of the earlier bedrock formations, erosional zones and plate tectonics noted elsewhere in the State can be found under the Perry Plant if a deep rock core is extended.

Figure 19 documents the top of the Precambrian bedrock under the Perry Plant. It is between 5,200 and 5,300 feet below the surface, dipping towards the lake. That depth translates to about 1.6 Km below the ground surface, a very important figure in later discussions of manmade and natural geologic hazards.

Manmade Geologic Hazards

There are two major sources of manmade geologic hazards in Lake County near the Perry plant. They are historic and current oil and gas and salt production wells, and surface and underground mines.

Wells

Oil and gas wells have been drilled in Ohio since 1860. In the intervening 163+ years, there are estimates that up to 300,000 wells were drilled statewide. At this point, we do not know where at least half of them are. There are several reasons for that. Originally there were no formal records kept of drilling locations. In addition, many of the wells played out before WW I or WW II. When that happened, the metal casings from those idle wells were pulled as part of the national metal drives for reclaimed metals to be recycled for use in war materials production (Edward Rice, personal communications). Most, if not all, of those wells were never properly closed and grouted shut. Usually the surface opening was blocked by a pile of rock boulders or a black locust fence post. If the land owner was lucky, the fence post sprouted and grew into a black locust tree that effectively blocked the opening. If not, those fence posts will be coming to the end of their lives and will be rotting out, thereby opening up the old well to the surface again. We see this happening over and over again all over Ohio (personal communications, Chief Silverio Caggiano).

Old well locations can sometimes be detected by using a methane detector and walking fields in a close grid pattern. Pennsylvania has a volunteer program that is mapping their old lost wells that way. If the lands have stayed in a family for many generations and are still in agriculture, the family may know that the “rock pile” in the south 40 (acre field) is blocking an old well but with each passing year those connections end and our lost oil and gas wells stay lost. Those old wells become major conduits for the upward migration of methane and radon gasses. They also serve as conduits to transport contaminants from the surface to underlying ground water base flow or aquifers and to the underlying Salina Formation.

Because of all the factors above, it is impossible to know if there are any abandoned and orphaned wells at the site. The only way to be reasonably sure that there are none is to tightly grid the site and walk it with an active methane detector. That activity has to be conducted BEFORE the site is developed to prevent building over an old open well. I found no information that such an activity was carried out. That activity does not guarantee success but it is the only technique that has a chance of being successful. Metal detectors won’t work; the casings were pulled in the older wells. In the very earliest wells, the casings were made of hollow logs. This technique could also have uncovered old water wells since they can release methane to the surface from the black Ohio Shale below.

There is a significant number of either orphaned but identified wells or producing wells in Lake County surrounding the Perry Plant. There appear to be upward of 100 wells in Lake County. Those wells can be seen on Figure 20.

A review of the wells show that most of them are located in the early Silurian-aged Clinton sands. There are a few that are found in the higher Ohio Shale. There probably are a number more Ohio Shale wells that were drilled for private property use that were never reported to the State. In this part of the state, it is not uncommon for a farmstead to have a small Ohio Shale well for heating and cooking at the farmhouse. Often, when the land uses change, these wells are not properly abandoned and grouted closed. They become routes of migration for methane and radon gasses to move into the newly built environment. They also become conduits for the movement of contaminants and water downward from the ground’s surface.

There are only two active salt water injection wells in the county (mapped in pink), and they are both located in the Clinton Sand. In this part of Ohio, the Clinton Sand is in the range of approximately 3,000 feet or just under 1 Km in depth. All of these wells are significantly above the top of the Precambrian which is almost twice as deep. This depth becomes important when considering earthquakes.

The lower Utica Shale (upper Ordovician in age) is mapped through much of eastern Ohio as an oil shale. At this point in time, it is not actively being drilled in Lake County but that situation could change. The location of the unit can be seen in Figure 21.

Mines
There are two types of mines found in Lake County. One is surficial and near surface sand and gravel mining and the other is the off shore Morton Salt mine under Lake Erie at Fairport Harbor. The sand and gravel reserves under and east of the Perry plant are approximately 30 feet thick. That unit can be seen on Figure 22.

There appear to be several active and inactive sand and gravel excavation operations south and southeast of the Perry plant as shown on the Mines of Ohio map, Figure 23.

The Fairport Harbor Morton salt mine is in the Upper Silurian-aged Salina Formation above the Clinton Sands. It is a thick evaporative sequence that has been mined in various locations in Ohio for road salts, production materials and gypsum for wall board construction materials. The mine was first opened in 1959 and typically produces rock salt for road deicing. A discussion of the mine can be found at this Research Gate web site, https://www.researchgate.net/figure/The-Morton-Fairport-Harbor-Mine-is-13-km-from-the-Perry-Nuclear-Reactor-The-site-is_fig1_271855364. It includes a map that shows the proximity to the Perry plant, here reproduced as Figure 24.

There are some fascinating photos and videos from the salt mine that runs 3 miles out under Lake Erie. There are some excellent ones at this web site, https://www.businessinsider.com/photos-of-salt-mine-2000-feet-below-lake-erie-2016-5. I have included one as Figure 25. It is important to remember that this mine, while currently in operation, will not operate for "hundreds of thousands of years" and perhaps not even for 20 more years. When the mine is eventually abandoned and the lake water breaks through the mine roof, the area will destabilize and the salt will dissolve, further expanding the destabilized the area.

It is critically important to remember that the Salina Formation, currently being dry mined and solution mined (see below) also lies UNDER the Perry site. The formation is contiguous over the whole region, in fact over much of the state, and it's all connected. This situation could create conditions at the Perry plant that would compromise the integrity of the wet and dry high level radioactive waste storage facilities. Solution of the Salina Formation could destabilize the whole facility. The ownership of mineral rights under the site and the surrounding area DOES NOT preclude the natural dissolution of the formation if surface water enters the formation. That could happen from the salt mining process but it could also come from old abandoned oil and gas wells because the oil and gas reserves often came from formations BENEATH THE SALINA, the Clinton Sands are deeper than the Salina Formation so any surface and ground water draining down old wells can interact with the Salina Formation. Owning the mineral rights do not create impenetrable walls around the facility; they just keep out active planned mineral extraction. It is unclear how soon into the future that destabilization will occur.

The Salina Formation is also solution mined with Class III wells (see above). There are several in the area but I was unable to locate a map for their locations on the ODNR web site.

Natural Geologic Hazards.

Natural geologic hazards at the site fall into three categories; landslides, shoreline erosion and seismic activities.

Landslides

The landslide issues are addressed on the ODNR Div. of Geological Survey at this link, https://ohiodnr.gov/discover-and-learn/safety-conservation/geologic-hazards/landslides. The link shows a generalized map of landslide prone areas of Ohio, here reproduced as Figure 26, and provides a link to additional information found in the GeoFacts 8: Landslides in Ohio publication. The generalized Ohio map showing the potential for landslides along Lake Erie at the Perry plant is here presented. The location of the Perry plant is clearly encompassed in the area identified at Lake County.

It is unclear at this point how much consideration was taken about the potential for landslides into Lake Erie at the site but since the geotechnical analyses for the engineering design were incorrect, it is doubtful that any considerations developed in 1982 would have actually mirrored real life conditions at the site. It is my understanding that there have been recent landslides along the shoreline near the Perry plant.

All of the soils mapped as CoF should be considered prime landslide areas. That mapping unit extends under the plant on the north edge and included the location of the cooling tower to the north. Since these soils have an F slope (25-50%), it is not clear how they were ever leveled off to be used for building sites. If they were filled with soils, then all the concerns voiced in Allred, 2000 apply. If they were bench cut and graded, then Allred, 2000 also applies. If they were filed with aggregate, then there are concerns about surface water moving through the aggregate into any primary and secondary permeability conditions that can exacerbate the potential for landslides by wetting the landslide scarp. While slides can be reactivated by cutting the toe of the slope (i.e. wave action at the beach), they can also be reactivated by loading the top (i.e. building a cooling tower on top of them) or saturating them with surface or ground water.

Shoreline Erosion

Shoreline erosion is a real hazard that may or may not have been considered when the site was designed. There is significant information on the ODNR Div. of Geological Survey web site addressing the issue of shoreline erosion. The coastal mapping of the area around the Perry plant can easily be seen in this view of the ODNR Interactive map, here Figure 27. The two 2018 photographs that show the Perry plant property are shown here from west to east and are here reproduced as Figures 28 and 29.

Again, it is not clear to me at this point how much consideration, if any, was made for the active process of shoreline erosion at the Perry plant. Over the years, whole sections of the shore line including communities have ended up falling into the Lake. The early documents record the shoreline eroding at the rate of 5 feet a year. They also state that the north edge of the facility was 300 feet south of the shoreline. At that rate, the shoreline will have eroded 215 feet since 1980 and will erode another 100 feet in the next 20 years, placing the northern edge of the Perry plant at the northern edge of the Lake Erie shoreline bluffs. Given that the high level radioactive wastes at the site are supposed to be harmful for “hundreds of thousands of years”, it would strongly behoove the Perry plant to take this geologic hazard into serious consideration and to armor the bluffs at the Lake, fully understanding that landslides can develop behind the armoring, thereby dumping the structural armoring into the Lake and exposing new faces of the bluffs, closer to the plant, to shoreline erosion. Without such safety precautions, it is possible that the shore line will reach the plant in the next 20 years. It is my understanding that this issue has finally been recognized and will be addressed, again in 2024.

Seismic activity

Seismic activity is probably the most important hazard that the Perry plant faces. A review of the 1982, 1986 and 2003 reports indicate that the initial and follow-up evaluation for the potential of earthquake impacts to the Perry plant is unrealistic. The 1982 report quotes Eardley (1962), claiming the site is located in the “central stable region tectonic province” and that there should be no concern about earthquakes. In the 1986 update after the 5.0 quake in Lake County, the new evaluations spent much time discussing the quakes in Anna, Ohio, in the Maysville, Kentucky area, at the North Anna reactor in Virginia and one in upper New York State, again assuring everyone that the 1986 quake was an anomaly. That assurance was again provided in the 2003 report. There was significant discussion about faulting found in the Devonian shale that was attributed to glacial ice deformation.

In point of fact, the Devonian faulting is not the root of the significant earthquake potential surrounding the Perry plant. Neither are the Lake County quakes being triggered by deep injection wells. Having said that, USGS and ODNR have now collected information on earthquakes and contaminant migration at four sites in Ohio where injection wells play a very important role. These include the Class I hazardous waste well in Ashtabula County, active drilling and Class II injection wells in Mahoning County (Youngstown), Class II injection wells in Athens County (Torch) and Class II injection wells in Washington County (Marietta) as well as a few other random areas across the state where unconventional oil and gas wells are being drilled and/or Class II injection wells are being used. The Calhio well in Lake County is suspected but not confirmed as being a source of earthquakes and should be watched carefully. Therefore, it is premature to assume the Class II injection wells in Lake County could never create significant earthquakes or even that they could not do so in the next 20 years.

When the current earthquake map is reviewed, it is clear that the Perry plant is sitting in the middle of swarms of recent earthquakes. While the 1986 5.0 quake appears to be the largest one to date, there dozens and dozens that have happened since then, including a 4.2 just this year (2023). A review of the ODNR interactive map shows this pattern. There are also several historical quakes of significance in the County, including a 4.4 event in 1943. This earthquake map is here reproduced as Figure 30.

What is most important is the depth of these events. They tend to be clustered in a 2.31 to a 6.0 Kms zone beneath the surface. This range puts them squarely in the Precambrian. This is critically important to understand because they are not only natural, they are tectonic and therefore can neither be stopped (which could be possible with man-made quakes) nor can their occurrence be predicted with precise accuracy. All we can know for sure is that they are happening; they appear to continue to be happening and that it is not possible to predict when, where or how strong the next quakes will be.

Significant time was spent analyzing the Anna Ohio and Maysville Kentucky quakes to determine if quakes in Lake County could result in significant damage to the plant. They did not study the 1986 4.5 quake in St. Marys, Ohio which has some compelling information when applied to the Perry plant. The 5.0 quake was on the same order of magnitude as the largest of the historic Anna, Ohio quakes. In addition, it must be remembered that the earth is able to transfer seismic motion for a significant distance. Both the July 1980 Maysville Kentucky quake and the 1986 4.5 quake on the east end of Grand Lake St. Marys, Ohio were felt in Franklin County (Columbus) by myself.

The 1986 4.5 quake resulted in some significant structural damage to some of the older buildings in St. Marys. Those older buildings, many built of local red brick, are brittle and they cracked or showed other structural damage. The canal and the brick structures are shown in Figure 31. The porch fell off Lyndella Andrews's 1800s red brick house.

More importantly, the Ohio Fish Hatchery below the east dam on Grand Lake St. Marys is fed, in part, by ground water wells and those wells began to flow and continued flowing for six months. More importantly, the dams at each end of the lake held. Since the lake is at a higher elevation than the cities of St. Marys and Celina, this was critically important to the surrounding communities which would have sustained extensive damages if they had failed. The dams held and did not crack because they are NOT CONCRETE dams. They are actually very plastic. They were built before 1850 by erecting vertical palisades of large tree trunks with their bottom ends buried in the earth, a technique well developed during the 1600s and 1700s for fort building by the French, English and Americans. These wooden palisades where then buried underneath tons and tons of earth which was dredged out of the future lake bottom with horse drawn pans and plastered over the logs both front, back and over the tops of the logs. These are earthen dams with wood cores. The dams and spillways were then armored with huge blocks of cut stone, at least 3 feet wide, three feet thick and more than three feet long. The stone was carefully dressed and dry laid so they could slide across each other if need be. The dams could shift without cracking and so did not fail. That construction can be seen in Figure 32 and the historic photo Figure 33.

Looking back further to the 1811-12 quakes centered in New Madrid, MO, estimated to have been in the 7-9 range centered in the Precambrian, the surface events were so strongly felt that the Mississippi River reversed it course, actually flowing up river for some time, The town of New Madrid fell unto the river, the Reelfoot Lakes were created, structural damage occurred to buildings in Cincinnati and church bells rang in Boston. So a quake does not have to be right under the plant to do significant damage if it is strong enough because the plant is brittle.

Some speculation has been raised that the 1986 5.0 quake was man made because of active injection wells in the area. However, as discussed above, the two operating salt water injection wells in the area are in the Clinton sand, less than a Km below the ground surface. This is far shallower than would be expected to trigger the 2.31 to 6.0 Km deep quakes happening in the area. Even the Class I Injection well quakes in Ashtabula County were at the shallow end of the quaking system, at 2.5 Km and that well was set in the Mt. Simon sandstone in the base of the Cambrian, right on top of the Precambrian-Cambrian interface.

The only logical conclusion is that they are natural quakes and something (s) is/are happening in the Precambrian that is shifting to allow these quakes to occur. The actual cause is still up for debate. The traditional explanation is that it is activity on the Grenville Front; see the cross section of the Bedrock map of Ohio, Figure 2. However, more recent research brings that interpretation into question. The 2018 article published in GSA Today reflects some of the more modern interpretations of the Precambrian subsurface,
https://rock.geosociety.org/net/gsatoday/science/G357A/article.htm. The graphics from that paper, here reproduced as Figure 35, show how our understanding of subsurface conditions has changed.

This new interpretation explains the connection to the Anna and St. Marys Ohio quakes and the Maysville Kentucky quake but it does not explain the quakes in and around Lake County. Perhaps this new seismic activity in the area is the evidence needed to extend the upper Michigan section of the Midcontinent rift zone line southeast into northeast Ohio. A review of the ODNR Interactive map showing fault lines does not produce complete clarity on this topic. That coverage, shown here, documents a mapped known fault line in Lake County, some inferred fault lines in the area and an inferred approximate unconformity.

Perhaps all this new seismic activity in the area will help ODNR to refine their understanding of the subsurface structure of the Precambrian and improve our ability to pinpoint and predict future earthquakes. At this point in time, all that is known is that the quakes are natural, in the Precambrian and appear to be tectonic in nature, also that they are continuing, increasing in number and strength and should be planned for. Given that they are natural, stronger quakes should be expected. Also, that it is clearly unrealistic to assume that the Perry plant will be stable for the “hundreds of thousands of years” that the high-level radioactive wastes currently stored on the site will remain radioactive. To even assume it will be stable for the next 20 years is a gamble based on inconclusive evidence and a crap shoot. The known and implied subsurface faults in the region around the Perry site are shown in Figure 36. The earthquake records generated in these ODNR graphics come from the historic and current seismic stations in the area. Those sites are here reproduced on Figure 37.

Summary and Conclusions

The following points have been identified in this short report.

1. The full cost of generating electricity at this site has not been calculated and is not being charged. There is no mechanism in place that I have been able to identify to address the cost of storage of the high level radioactive wastes for “hundreds of thousands of years”. Given that all the geological limitations of the Perry site were so badly underestimated in the initial reviews, it is very hard to envision what intermediate and long-term storage at the Perry plant should look like if it is to guarantee absolutely no migration of contaminants from the site. There is no way to assure a stable site for another 20 years since it is impossible to determine that the site is stable now. The current design and construction fails in so many ways and cannot be counted on.

2. Cement is brittle and it ages, steel ages and rusts. It is unrealistic to expect that the wet and dry high level radioactive waste storage facilities at the site will continue to be effective for many more years, let alone assuming the storage facilities are working now. Given that the site is already more than 40 years old since original inception, it is expected that there are already some levels of structural compromises at the site. Buildings constructed in the 1970s and 1980s were typically only designed to last 37 years without major renovation. What is the design life of the Perry plant and how was it determined? Since there appears to be no serious investigations of existing conditions, the current level of compromise cannot be determined. It is also not clear if the facility could be renovated in its current configuration. Another 20 years of aging without serious rehab to the facilities will only degrade the structures further.

3. The soils and underlying unconsolidated materials were only analyzed geotechnically and older methods were used. There appears to be no efforts to re-evaluate the site using currently available information developed here in Ohio. Without a modern reanalysis of the site, it is impossible to determine where failures to the structure are already occurring. Since much of the potential failure sites are buried below ground, it is not possible to determine the structural integrity of the site just by visual observation. Given what we have learned about building on Ohio’s fractured environment, it must be assumed that almost 40 years in, some failures are occurring and that they will only increase in time. There is no way to guarantee structural integrity for the next 20 years given the

physical limitations of the site. There really is no way to fix many of the problems that will or have already developed. The facility can monitor for failure but if/when it is detected, given the nature of the site, it is unrealistic to think that it can be resealed and restabilized. See the discussions on the soils, unconsolidated glacial settings and the limitations of the Ohio Shale as well as the natural geologic hazards. The only way to successfully minimize water moving into the site is to seal the surface over the whole site and install a grout curtain and/or cutoff walls down to bedrock, in effect, enveloping the site. If such a retrofit is considered, then accommodations must be made for the detention/retention of the additionally generated storm water. Such a grout curtain was constructed around the Franklin County Sanitary Landfill in the early 1980s to prevent ground water from moving into the site and compromising the landfill bottom and side wall liners above the underdrains.

4. Only geotechnical hydraulic primary porosity was considered for the soils and underlying unconsolidated materials. Three generations of Ohio soil scientists, geologists and agricultural engineers, the work of more than 100 scientists and engineers, has been collected in two special issues of the Ohio Journal of Science, (June-September 2000 and April 2006). Those two issues should be read and evaluated by those responsible for the site. The references and examples discussed in this paper should be studied for site applications. The site should be re-evaluated under our more modern understanding of conditions at the site. This review should be undertaken with an eye to considering closure of the facility. It's not safe. It may take the next 60 years to decommission the plant and there are no guarantees that it will be structurally stable for the next 60 years.

5. A monitoring program for methane and radon gas incursions and seeps and springs on the bluffs along Lake Erie should begin immediately if not already in place. I found no information in the environmental reports documenting such ongoing programs. The monitoring for methane and radon buildups in confined spaces is required for worker safety and to prevent the enclosed space from exploding because of methane buildup. The documenting of the water quality of springs and seeps draining out of the Lake bluffs is critical to insure that contaminants are not moving off site into the surrounding environment The sampling methods, time sequences, testing procedures and protocol should be documented and reported. At least quarterly monitoring of all water sources including the springs and seeps is recommended. Additionally ground water monitoring wells in the unconsolidated materials and the bedrock should be installed between the facility and the Lake, if not there already, and become part of the quarterly monitoring program. Lake Erie is a Public Water Supply Source Water and so should be protected under the Federal Safe Drinking Water Act and all its amendments.

6. There appears to have been no efforts to search historical property records and field locate old water wells on the site including old hand dug wells. That should

have been part of the site review. All located old wells should have been properly grouted shut and abandoned. The old wells provide conduits to transfer contaminants from the surface and near surface to the underlying base flow to the lake and ground water aquifers. In addition, they provide open pathways for the upward migration of methane and radon gasses from the underlying black Ohio Shale.

7. There appears to have been no effort to locate old abandoned oil and gas wells on the property. That should have been done and all old wells should be properly abandoned and grouted shut. A discussion on how that should have been done is found in that section of the text above. These open conduits provide the same downward and upward transport pathways as that of old water wells. There are currently no horizontal unconventionally drilled wells in the area. That could change if the Utica Shale oil play is developed. The two salt water injection wells in the county are located in the Clinton Sand and are significantly above the earthquake epicenters in the area, at less than 1 Km in depth, well above the Precambrian interface. They currently are not responsible for the continued and increasing earthquake activities in the area of Lake County but that does not mean that they can't be responsible in the future. There already are earthquakes confirmed to be triggered by injection wells in four other counties in Ohio including next door in Ashtabula County. There has been some speculation that the Calhio well also caused an earthquake. No guarantee can be made that they will not become active in the next 20 years if they continue to be used.

8. The future impacts of the failure of the Morton salt mine does not appear to have been considered. While it is hoped that the salt mines will not fail before 2046, because it is also impacted by the continuing deeper earthquake activities, its integrity cannot be assured. It is also unclear how long term solution mining of the Salina Formation will affect the Perry site.

9. The site is subject to lake shore erosion and landslides. The bluff should be hardened to prevent further failure. Outlets for seeps and springs emanating as base flow from the bluffs must be included in the design or hydrostatic pressure will build up over time and cause the bluff protection to fail from behind. An estimate of shoreline failure at an average of 5 feet per year was given in the pre-built reports. The facility was built with the north edge approximately 300 feet south of the Lake bluffs. Assuming a beginning date of 1980, the shoreline is expected to recede 330 feet by 2046. That puts the recessional area within the built environment of the facility. It is my understanding that the shoreline situation is being addressed again and that some form of additional construction is planned for 2024.

10. The seismic activity is real, natural and ongoing. It is Precambrian in origin and appears to be connected to plate tectonic activity. Another series of quakes began in August of this year near Madison and are continuing. At any point in

time quakes higher than the plant design can occur. The earthquakes are the game changer. Given this information, it is hubris on the part of the NRC and DOE to continue to permit the operation of this plant at this location. Most of the environmental reports that propose to understand and predict the earthquake events in the area predate the current activity. They also predate the more modern understanding of their root causes. These are not simple random quakes that just "happen", these are movements triggered by mid-continental plate shifts. Mid-continental plate shifts are the hardest to predict and they can be catastrophic when they occur. The mid-continental rift zone from Kentucky through Cincinnati, Shelby County and St. Marys Ohio to Fort Wayne has been relatively quiet since the mid-1980s. The region around the Perry plant appears to be becoming far more active and the activity may continue for some time, possibly increasing in frequency and strength if the August to November 2023 activity is any indication. To assume that there will be no earthquakes in the next 20 years that will cause structural failure at the plant is an unsupported gamble.

The plant should be decommissioned and all radioactive materials should be moved off site to a more structurally stable location. While a number of the problems at the site might be mitigated, some of them, like the old well inventories cannot be because the site is already built. But the earthquakes are the game changer. Where nuclear power plants have been taken out of commission around the world, earthquakes were often the root cause. The Japan crisis would never have happened without the quake and the resulting tidal wave. France builds their reactors to withstand double the strength of the worst earthquake in the area in 1000 years. That would be more that a 10 here, if we were using the same standards. That would be like planning for another New Madrid quake. Considering this setting and the current earthquake activity that is not at all unreasonable if you imagine the shoreline destabilization and the landslide impacts to the plant if such a quake happened. Meanwhile, the DOE and the NRC must continue to work on long term storage and/or disposal of these high level radioactive wastes that will be radioactive for "hundreds of thousands of years". This has been a deadly gift to bequeath to humanity

This concludes my preliminary analysis of the location of the Perry Nuclear Energy Power Plant and the related environmental reports for the site using readily available scientific and engineering information. Since so much more is known about conditions at the site than was known when it was first commissioned, the only logical conclusion that can be drawn is that the site needs to be closed and decommissioned. To leave it in place and extend it for another 20 years is irresponsible. If it is not closed and decommissioned, the Federal Government must bear full responsibility for any and all current and future damage to the human population and the environment that occurs from the multiple potential failures of the plant.

Thank you for this opportunity to undertake this important site evaluation using modern information sources. If you have further questions and/or need additional information, please feel free to contact me. I can be reached at the above address, email and phone numbers.

Respectfully submitted,

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The Association of Ohio Pedologists
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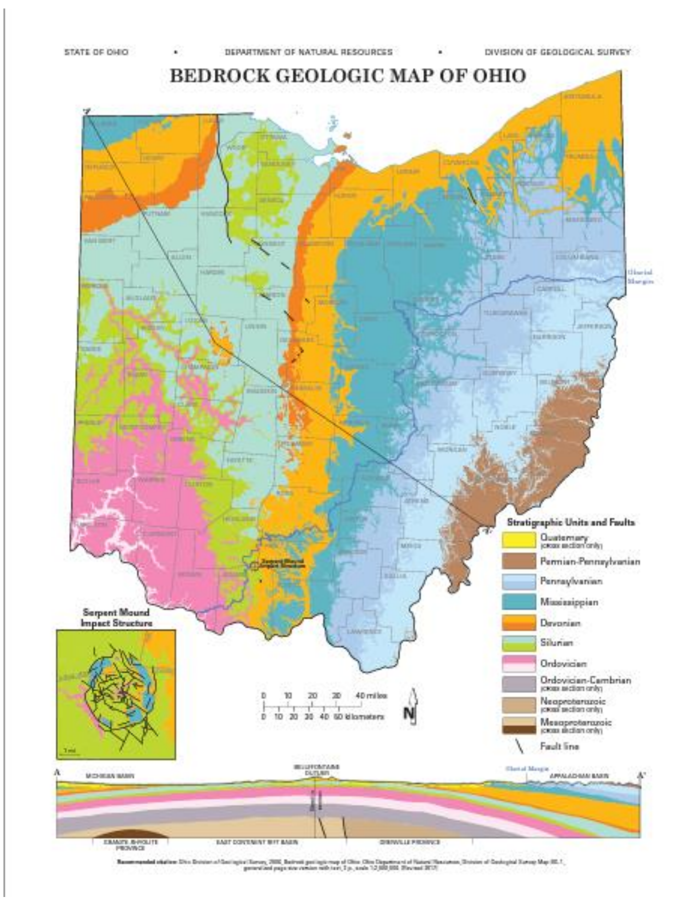
JWR/JR
Copies to File at Bennett & Williams

Figures

Perry Nuclear Power Plant

Figure 1: Ohio clearly is on the edge of the Pleistocene ice age advances as shown on this graphic from the ODNR Div. of Geological Survey graphic, Source: https://ohiodnr.gov/discover-and-learn/safety-conservation/about-ODNR/geologic-survey/glacial-geology/ice-age-in-ohio, Educational Leaflet No. 7.



This map is a generalization of the *Bedrock Geologic Map of Ohio* (Slucher and others, 2006)—the first statewide 1:500,000-scale bedrock-geology map compiled by the ODNR Division of Geological Survey since 1920 and the first to properly portray the bedrock geology that exists beneath the extensive deposits of Quaternary sediments that cover much of the bedrock in the state[1]. Overall, the bedrock geology of Ohio consists of flat-lying to gently dipping carbonate, siliciclastic, evaporite, and organoclastic strata of sedimentary origin that range in age from Upper Ordovician to Upper Carboniferous-Lower Permian. As illustrated in the cross section, older sedimentary, igneous, and metamorphic rocks occur at depth and range from Lower Ordovician to Mesoproterozoic in age. At the surface, an irregular veneer of mainly unconsolidated Quaternary sediments conceal most bedrock units occurring northward and westward of the glacial margin.

Strata of the Ordovician System are the oldest exposed rocks in Ohio and consist mainly of alternating shale and limestone sequences. Silurian System strata are mostly dolomites with lesser amounts of shale. Rocks of the Devonian System consist of two contrasting types. Lower and Middle Devonian-age strata are mainly carbonate rocks, whereas Upper Devonian-age rocks consist mostly of clastic rocks. In Champaign and Logan Counties, Devonian-age rocks occur on a small erosional remnant referred to by geologists as the Bellefontaine Outlier. Coincidentally, the highest topographic point in Ohio (Campbell Hill at 1,549 feet above sea level) occurs also in this area.

The Carboniferous System is divided into two Subsystems, the Mississippian and Pennsylvanian. Mississippian-age strata are mostly shales and sandstones that occur locally in various proportions. Pennsylvanian-age strata consist mainly of a diverse array of alternating sandstones, siltstones, shales, mudstones, limestones, and underclays; economic coal beds occur also in portions of this sequence. The youngest interval of sedimentary rocks in Ohio, the Dunkard Group, occurs only in southeastern Ohio and consists of strata similar in composition to the underlying Upper Pennsylvanian-age rocks; however, the age of the Dunkard Group has been debated since the late 1800s. Dunkard strata contain a well-studied late Pennsylvanian-age assemblage of plant fossils with infrequent early Permian-age forms. Yet, fossil plant spores found in coal beds in the interval only support a late, but not latest Pennsylvanian age. Thus until more definitive fossils are found, geologists are unable to determine the exact age of the Dunkard Group beyond a combined Permian-Pennsylvanian age assignment.

In west-central Ohio, the ancient Teays River system extended across much of Ohio during the late Neogene to early Quaternary Periods and sculptured an extensive network of deeply dissected valleys into the bedrock surface. The spatial configuration of many geologic units on this map clearly reflects the major channel networks of these former drainage systems. Also, four major regional structural geology elements affect the spatial distribution of rocks in Ohio: the Appalachian and Michigan Basins and the Cincinnati and Findlay Arches, which occur between the two basins. Locally, several high-angle normal faults displace rocks in the state.

The Serpent Mound Impact Structure in southern Ohio is a circular area of deformed and broken rocks that is approximately nine miles in diameter. Recent investigations indicate the feature is the result of a meteorite or comet impact believed to have occurred between 256 and 330 million years ago.

Cross section A–A′ traverses Ohio from the northwest to the southeast and intersects the southern portion of the Michigan Basin, the area between the Cincinnati and Findlay Arches, and the western Appalachian Basin, respectively. The stratigraphic units shown in this profile illustrate the broad, arching geometric distortion to the bedrock in Ohio, created mainly by periods of tectonic subsidence within these regional structural basins. For specific details on the various rock units, economic commodities, and geologic hazards within Ohio, see the large-format *Bedrock Geologic Map of Ohio* (Slucher and others, 2006), available for purchase by contacting the ODNR Geologic Records Center at 614-265-6576 or geo.survey@dnr.state.oh.us.

[1] Slucher, E.R., Swinford, E.M., Larsen, G.E., Schumacher, G.A., Shrake, D.L., Rice, C.L., Caudill, M.R., and Rea, R.G., 2006, Bedrock geologic map of Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map BG-1, Version 6.0, scale 1:500,000.

Quaternary (about 1.8 million years ago to present). Unconsolidated sediments: till, gravel, sand, silt, clay, and organic debris. Continental origin. (Shown in cross section only)

Period of widespread erosion

Permian and Pennsylvanian (about 298 to 302 million years ago). Sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, and minor coal. Continental origin.

Pennsylvanian (about 302 to 307 million years ago). Sedimentary rocks: mainly shale, sandstone, siltstone, mudstone, limestone, and some coal. Continental and marine origin.

Pennsylvanian (about 307 to 318 million years ago). Sedimentary rocks: mainly sandstone, siltstone, shale, and conglomerate, with some coal and limestone. Deltaic and marine origin.

Period of widespread erosion

Mississippian (about 322 to 359 million years ago). Sedimentary rocks: sandstone, shale, siltstone, conglomerate, and minor limestone. Marine to marginal marine origin.

Devonian (about 359 to 385 million years ago). Sedimentary rocks: mainly shale and siltstone with some sandstone. Marine to marginal marine origin.

Devonian (about 385 to 407 million years ago). Sedimentary rocks: mainly limestone and dolomite with some shale, and minor sandstone. Marine and eolian origin.

Period of widespread erosion

Silurian (about 416 to 423 million years ago). Sedimentary rocks: dolomite, anhydrite, gypsum, salt, and shale. Marine and restricted marine origin.

Silurian (about 423 to 435 million years ago). Sedimentary rocks: dolomite and shale with some limestone. Marine origin.

Period of widespread erosion

Ordovician (about 446 to 450 million years ago). Sedimentary rocks: shale and limestone. Marine origin.

Ordovician (about 450 to 460 million years ago). Sedimentary rocks: limestone and shale. Marine origin.

Period of widespread erosion

Ordovician and Cambrian (about 486 to 510 million years ago). Sedimentary rocks: mainly dolomite, sandstone, shale, with minor limestone. Marine origin. (Shown in cross section only.)

Period of widespread erosion

Neoproterozoic (between 900 million and 1 billion years ago). Metamorphic rocks: gneiss, schist, amphibolite, and marble; and igneous rocks: granite. Form during collision of tectonic plates. (Shown in cross section only.)

Mesoproterozoic (between 1.0 and 1.2 billion years ago). Sedimentary rocks: sandstone and siltstone; and igneous rocks: basalt and rhyolite. Form during rifting of continental landmass. (Shown in cross section only.)

Period of widespread erosion

Mesoproterozoic (between 1.45 and 1.52 billion years ago). Igneous rocks: granite and rhyolite. Formed during crustal evolution and differentiation. (Shown in cross section only.)

Figure 2: The generalized Bedrock Map of Ohio. Source: https://ohiodnr.gov/static/documents/geology/MiscMap_BedrockGeology_2017.pdf

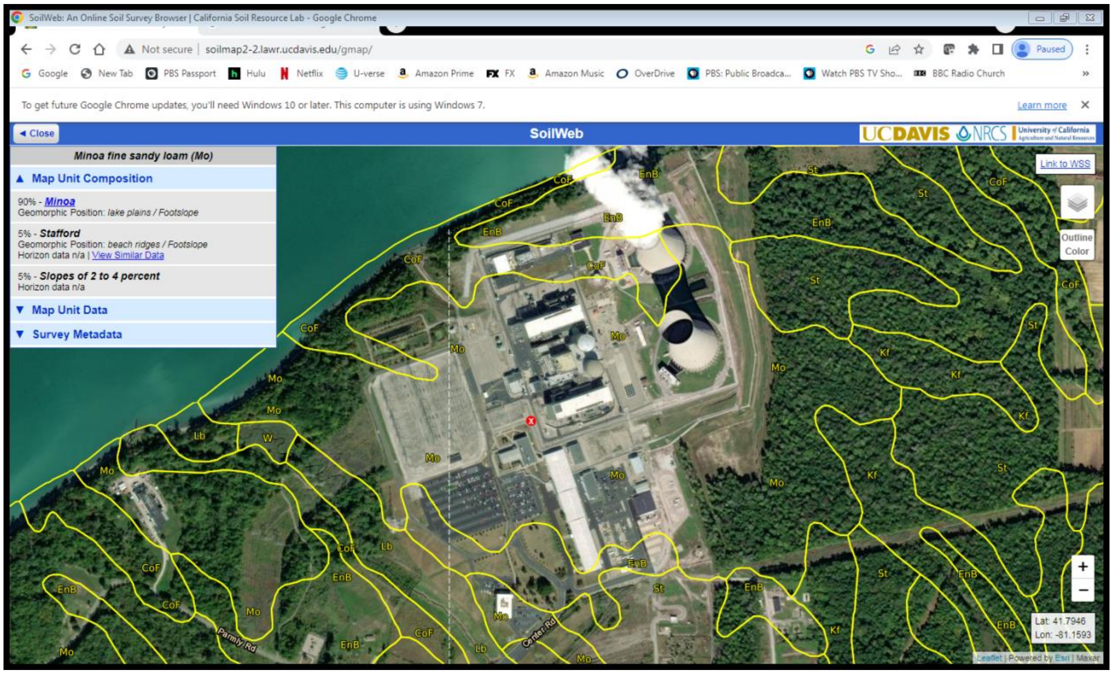


Figure 3: The soils of the area pf the Perry Plant. Source: University of California Davis web soil survey site, http://soilmap2-2.lawr.ucdavis.edu/gmap/

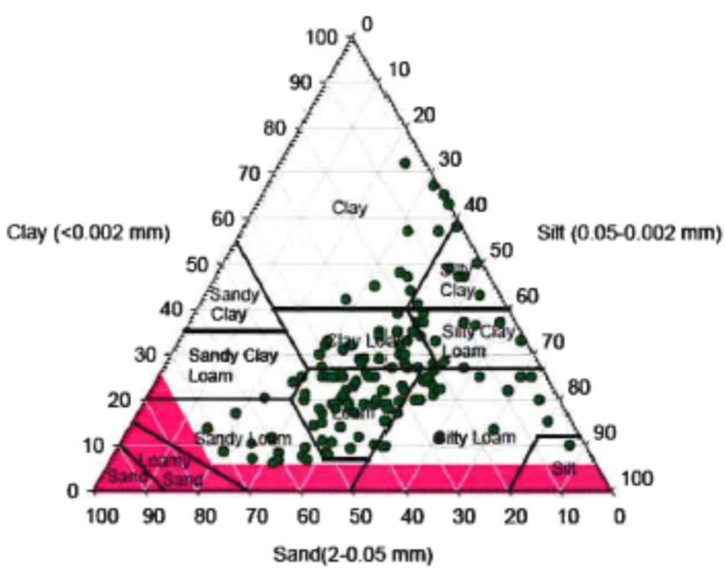


Figure 4: USDA Soils Textural Triangle supporting fracturing. Source: Eun Kyoung Kim's 2007 PhD Dissertation from The Ohio State University Dept. of Food, Agricultural and Biological Engineering (https://etd.ohiolink.edu/acprod/odb_etd/r/etd/search/10?p10_accession_num=osu1196080474&clear=10&session=109712337392113),

Figure 5: The current Perry site seen in the satellite coverage from the Ohio Geologic Interactive Map site. Source: https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

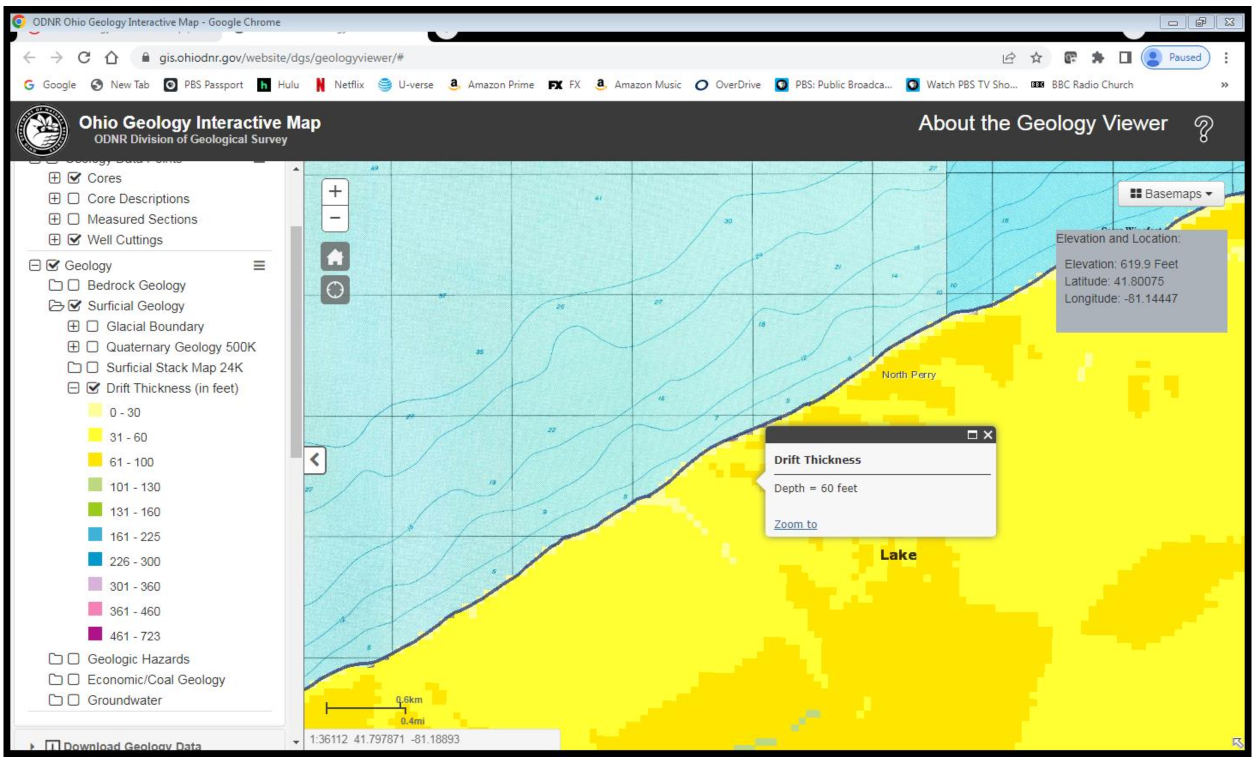


Figure 6, the unconsolidated drift thickness from the Ohio Geologic Interactive Map site. Source: https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

Figure 7, Ashtabula glacial till with oxidized secondary fractures from Bruno, Szabo and Foos, 2006. Source: https://kb.osu.edu/search?query=April%202006&scope=26dee3b3-05fb-57ce-9059-eb615033b352&spc.page=1

Figure 8. Varved lake clay deposits showing annual deposits and secondary fractures. Source: Wikipedia.

Figure 9, Old beach ridges in Ohio, Oak Openings MetroPark, Toledo. Source: Wikipedia.

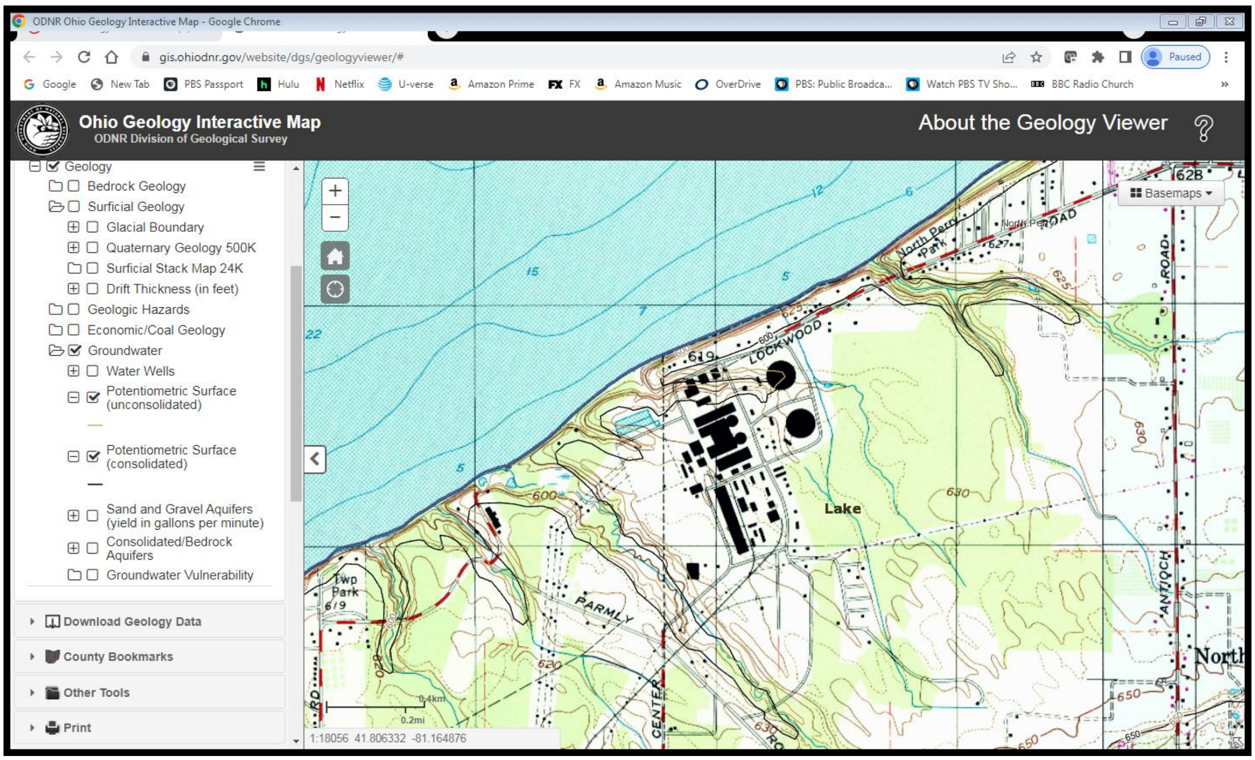


Figure 10: Potentiometric flow lines for the unconsolidated materials in dark brown, the bedrock materials in black and the surface topography lines in the pale brown. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

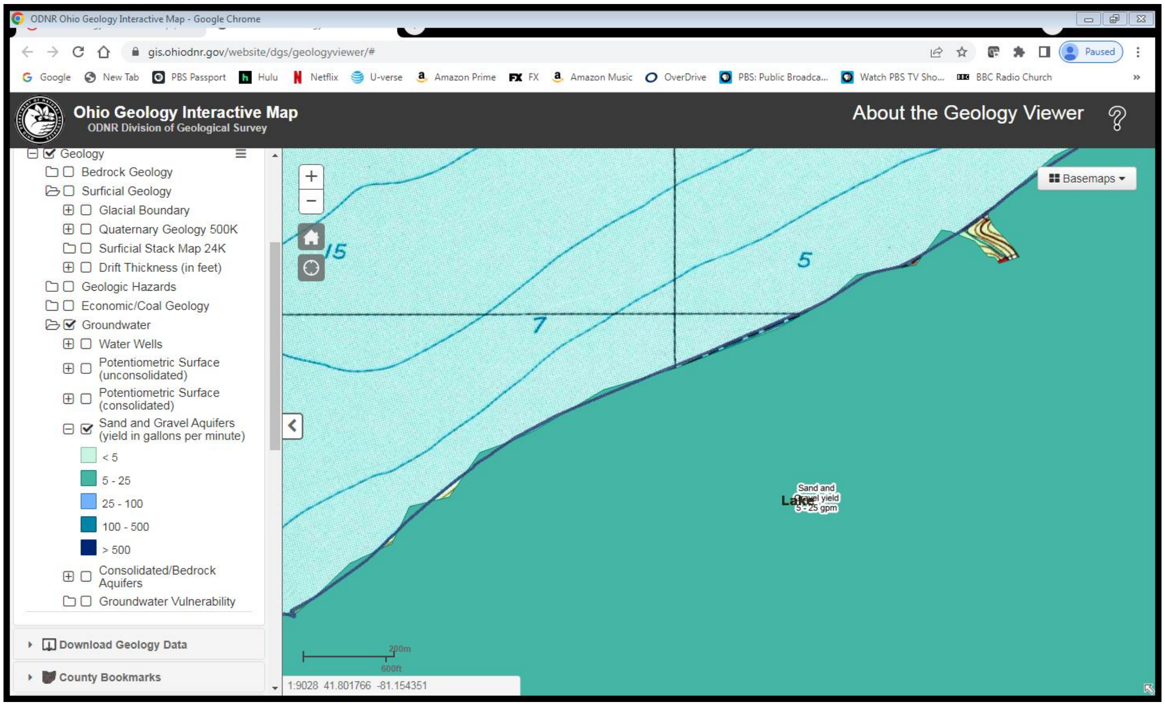


Figure 11: Ground water availability in the unconsolidated aquifer at the site. mapped as 5-25 gallons per minute. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

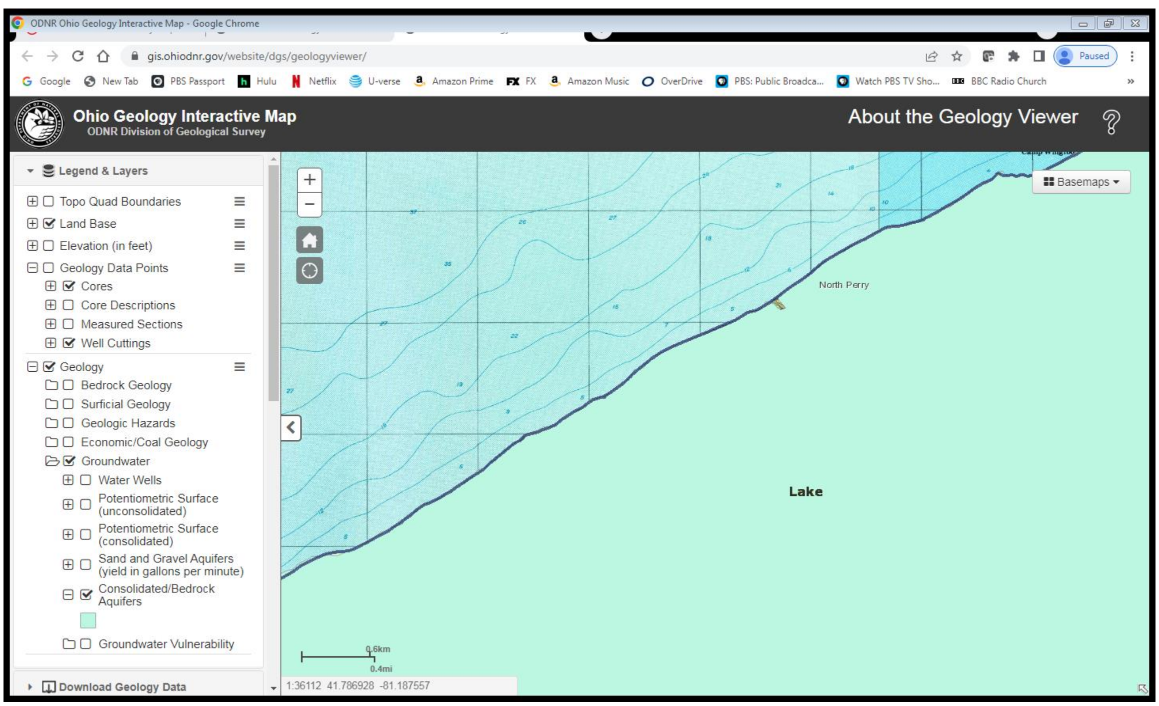


Figure 12: Bedrock ground water availability from the Ohio Shale is typically less than 5 gallons per minute and the water quality is poor. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

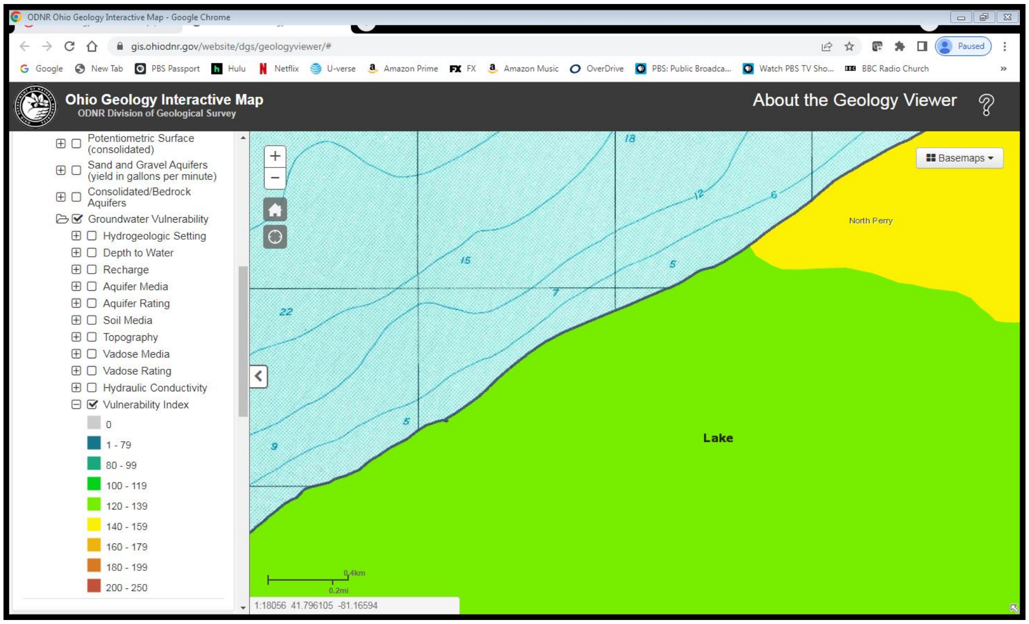
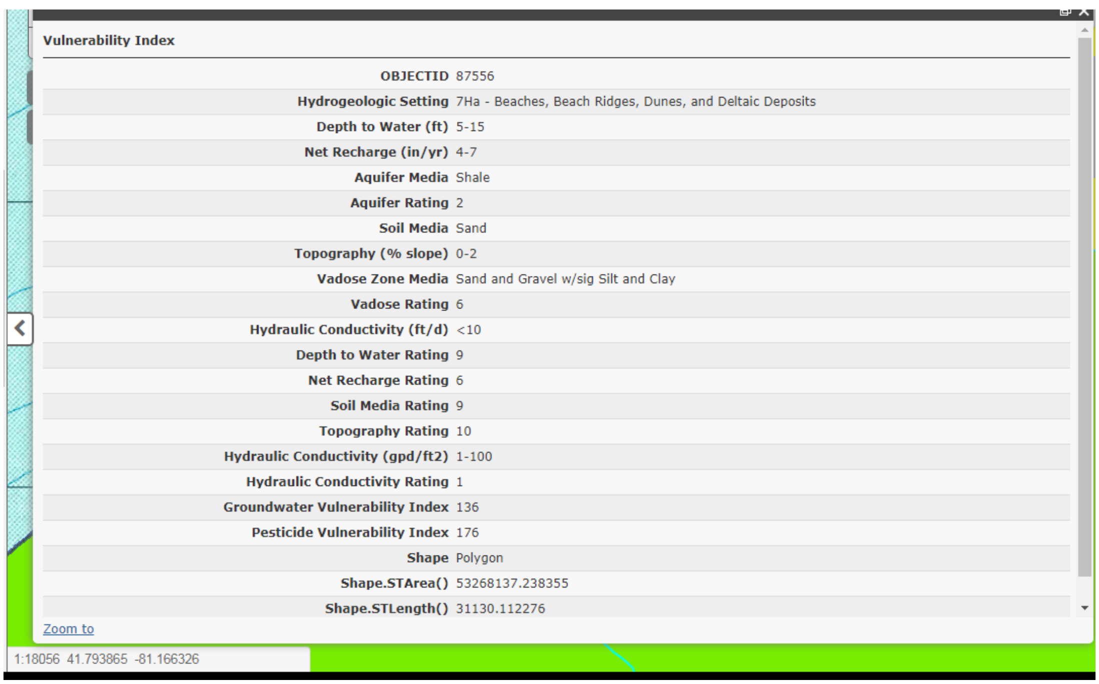


Figure 13: The groundwater vulnerability index map for the Perry Plant area, here mapped as 120-139. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.



Vulnerability Index

OBJECTID	87556
Hydrogeologic Setting	7Ha - Beaches, Beach Ridges, Dunes, and Deltaic Deposits
Depth to Water (ft)	5-15
Net Recharge (in/yr)	4-7
Aquifer Media	Shale
Aquifer Rating	2
Soil Media	Sand
Topography (% slope)	0-2
Vadose Zone Media	Sand and Gravel w/sig Silt and Clay
Vadose Rating	6
Hydraulic Conductivity (ft/d)	<10
Depth to Water Rating	9
Net Recharge Rating	6
Soil Media Rating	9
Topography Rating	10
Hydraulic Conductivity (gpd/ft2)	1-100
Hydraulic Conductivity Rating	1
Groundwater Vulnerability Index	136
Pesticide Vulnerability Index	176
Shape	Polygon
Shape.STArea()	53268137.238355
Shape.STLength()	31130.112276

Zoom to

1:18056 41.793865 -81.166326

Figure 14: The rankings and their weights that make up the DRASTIC score for the Perry site. The total score is this low because the aquifer media here is considered the Ohio Shale which has a very low weight. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

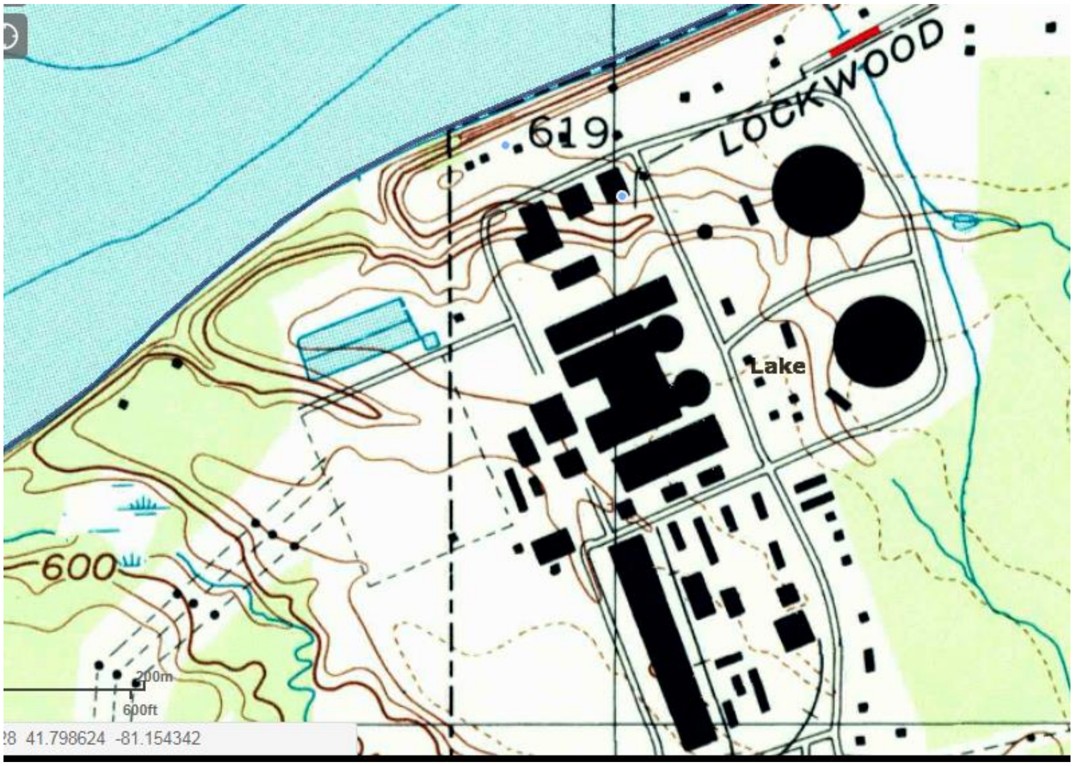


Figure 15: The two identified water wells at the Perry site, here shown as small blue dots. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

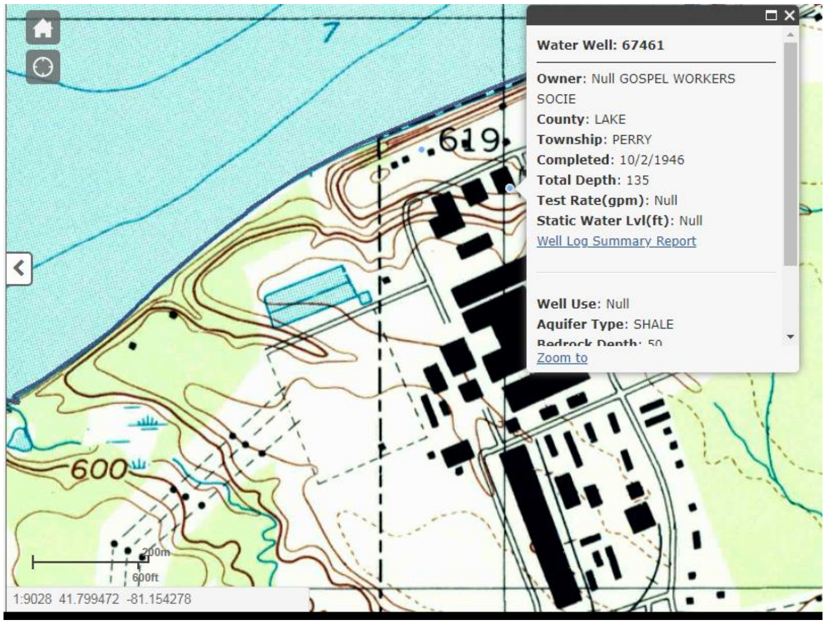


Figure 16: The Gospel Workers Society well at the Perry plant. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

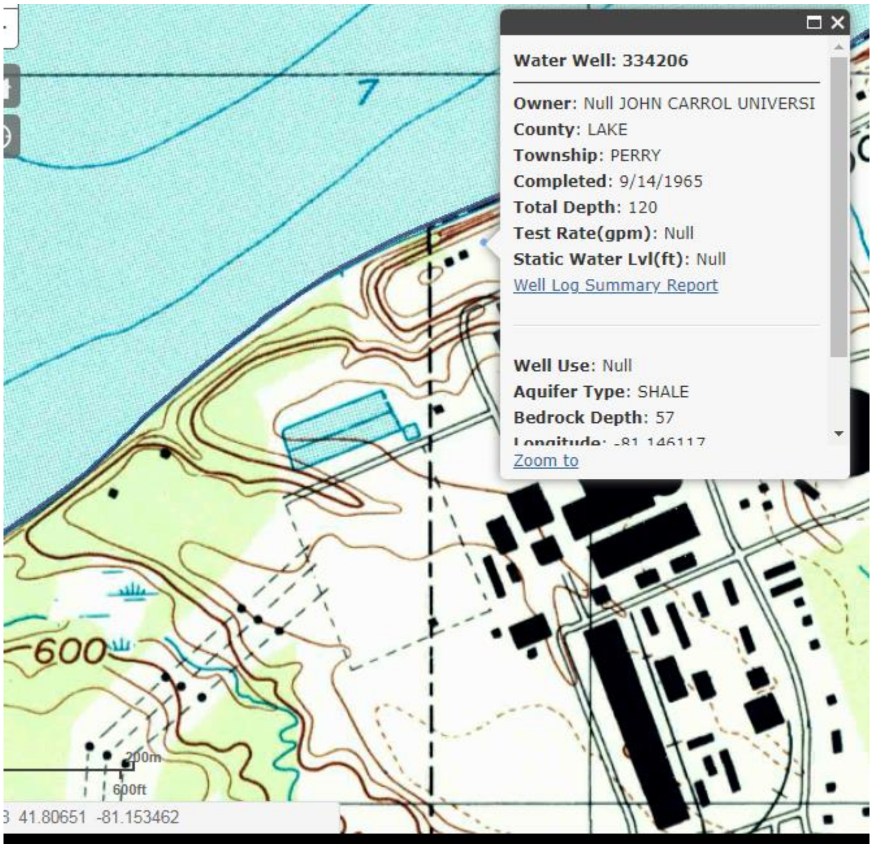


Figure 17: The John Carroll University well just north of the Perry plant. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

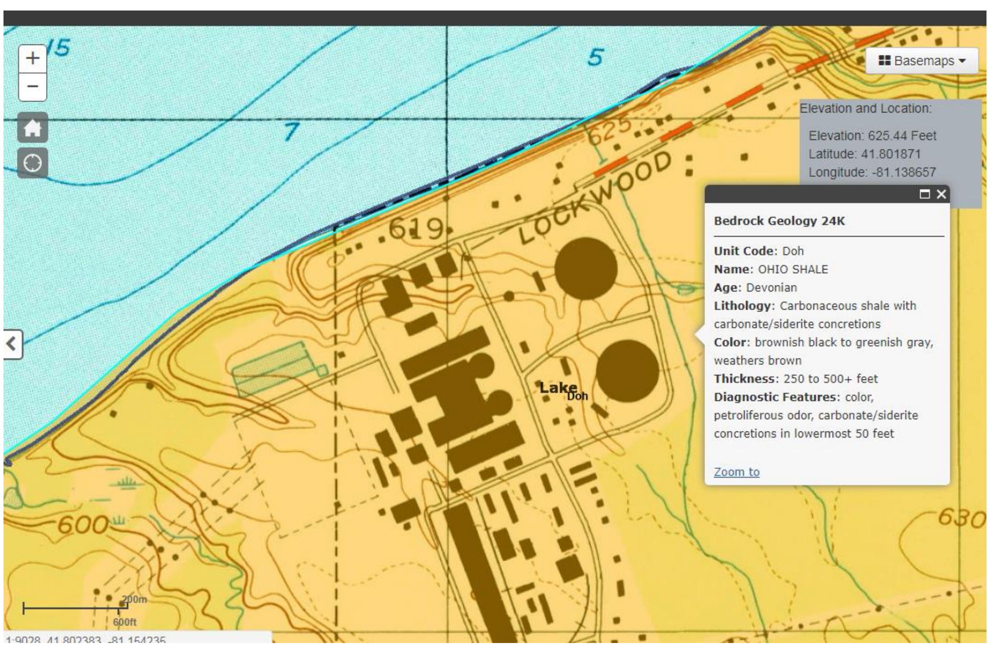


Figure 18: The Ohio Shale bedrock at the Perry site. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

Figure 19: This map shows the elevation contours on the top of the Precambrian bedrock underlying the Perry site. These elevations become critical when analyzing the source of earthquakes in the area. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

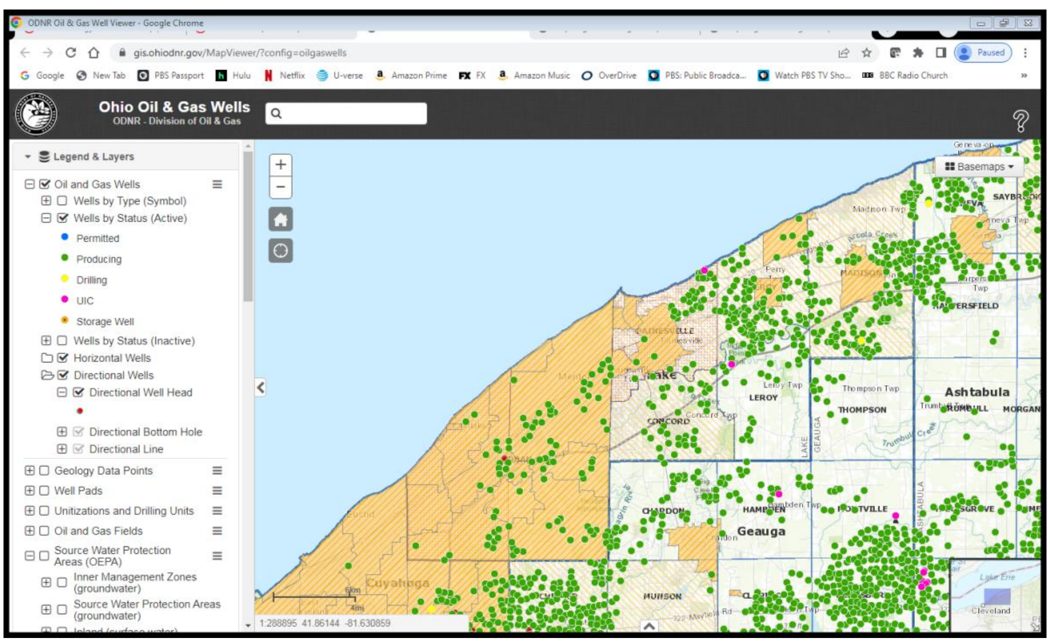


Figure 20: The located oil and gas wells in the Lake County region. Producing wells are in green, injection wells are in pink. The red well is not in service. Source: The ODNR Interactive map, https://gis.ohiodnr.gov/MapViewer/?config=oilgaswells

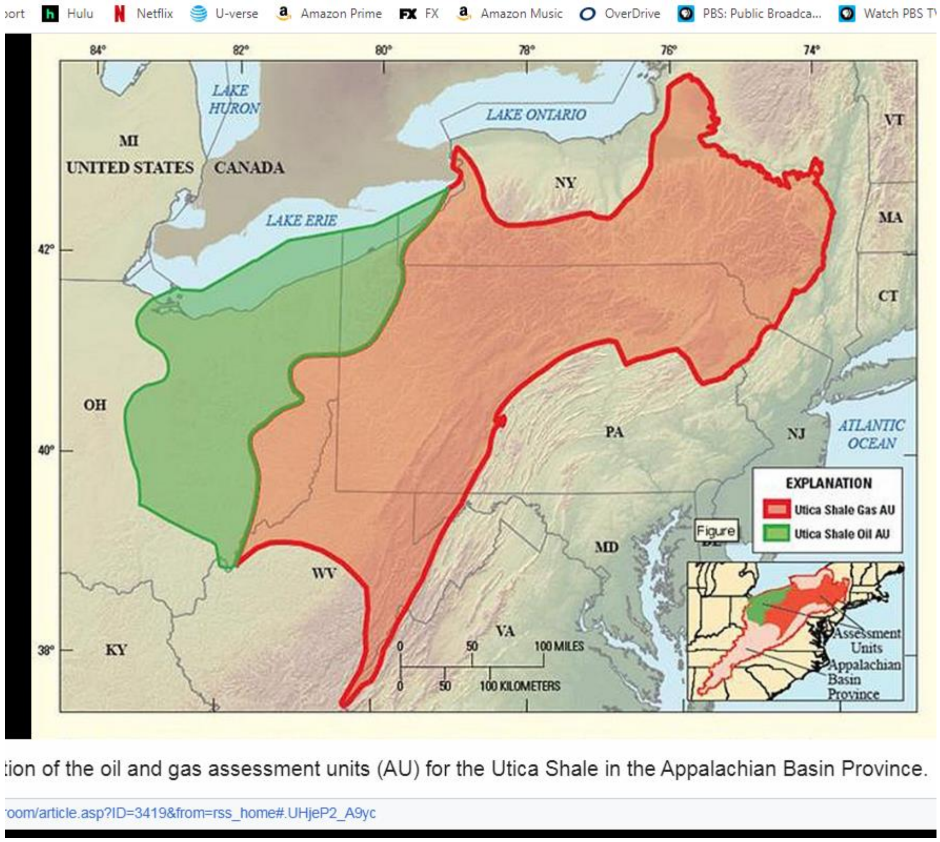


Figure 21: The locations of the Utica Shale gas and oil plays. Source: Wikipedia, https://en.wikipedia.org/wiki/Utica_Shale#/media/File:Utica_Shale_assessment_-_01.jpg.

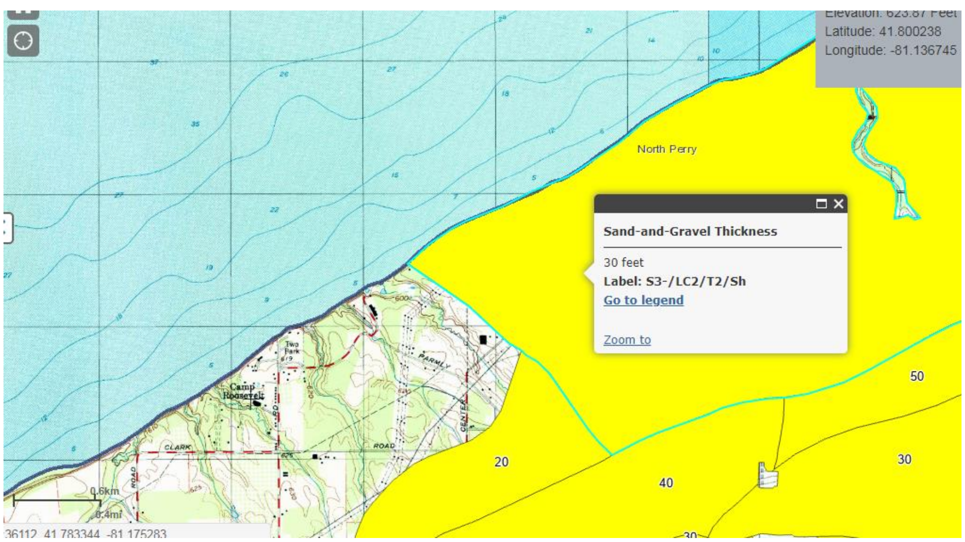


Figure 22: The thickness of sand and gravel in the unconsolidated deposits in the area of the Perry plant. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#.

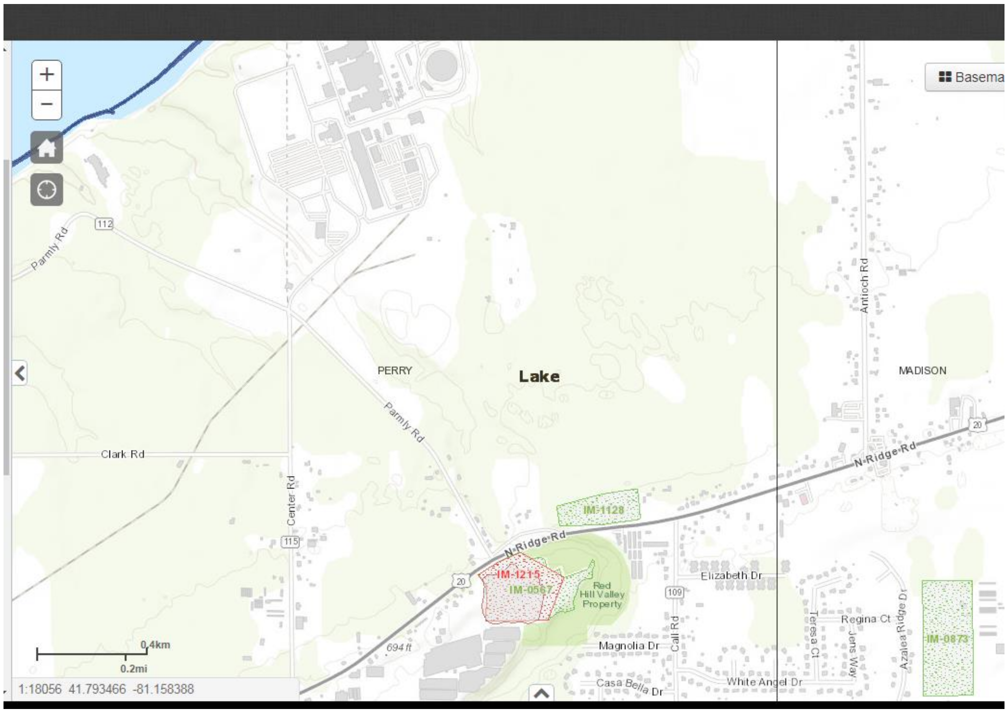


Figure 23: Sand and gravel mines in the area from the Mines of Ohio map. Source: https://gis.ohiodnr.gov/MapViewer/?config=OhioMines

The Morton Fairport Harbor Mine is 13 km from the Perry Nuclear Reactor. The site is convenient to reach—roughly 25 miles east of Cleveland, Ohio—and has a long history of supporting DOE science experiments.

Figure 24: Map of the locations of the Perry site and the Morton Salt Mine. Source: https://www.researchgate.net/figure/The-Morton-Fairport-Harbor-Mine-is-13-km-from-the-Perry-Nuclear-Reactor-The-site-is_fig1_271855364.

Figure 25: Photo from the Morton Salt Mine. Source: https://www.businessinsider.com/photos-of-salt-mine-2000-feet-below-lake-erie-2016-5.

Figure 26: Landslide prone areas of Ohio, including the Lake County shoreline. Source: https://ohiodnr.gov/discover-and-learn/safety-conservation/geologic-hazards/landslides

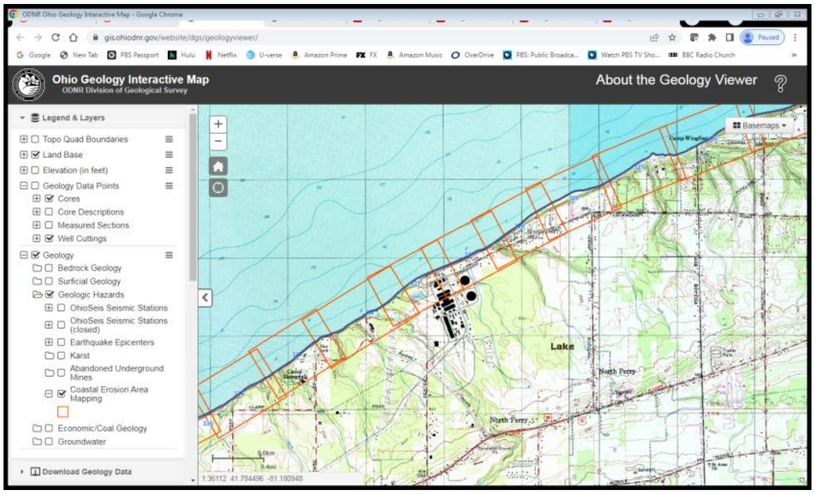
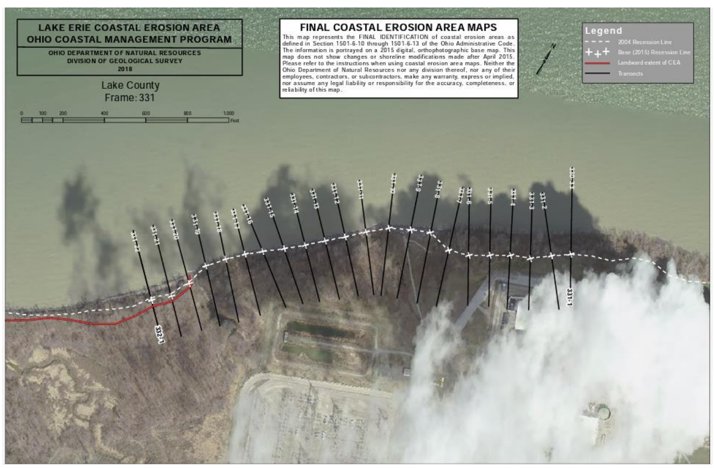
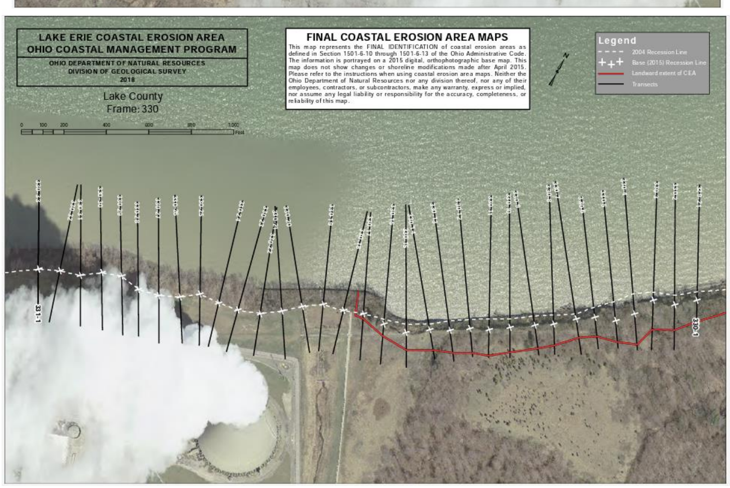
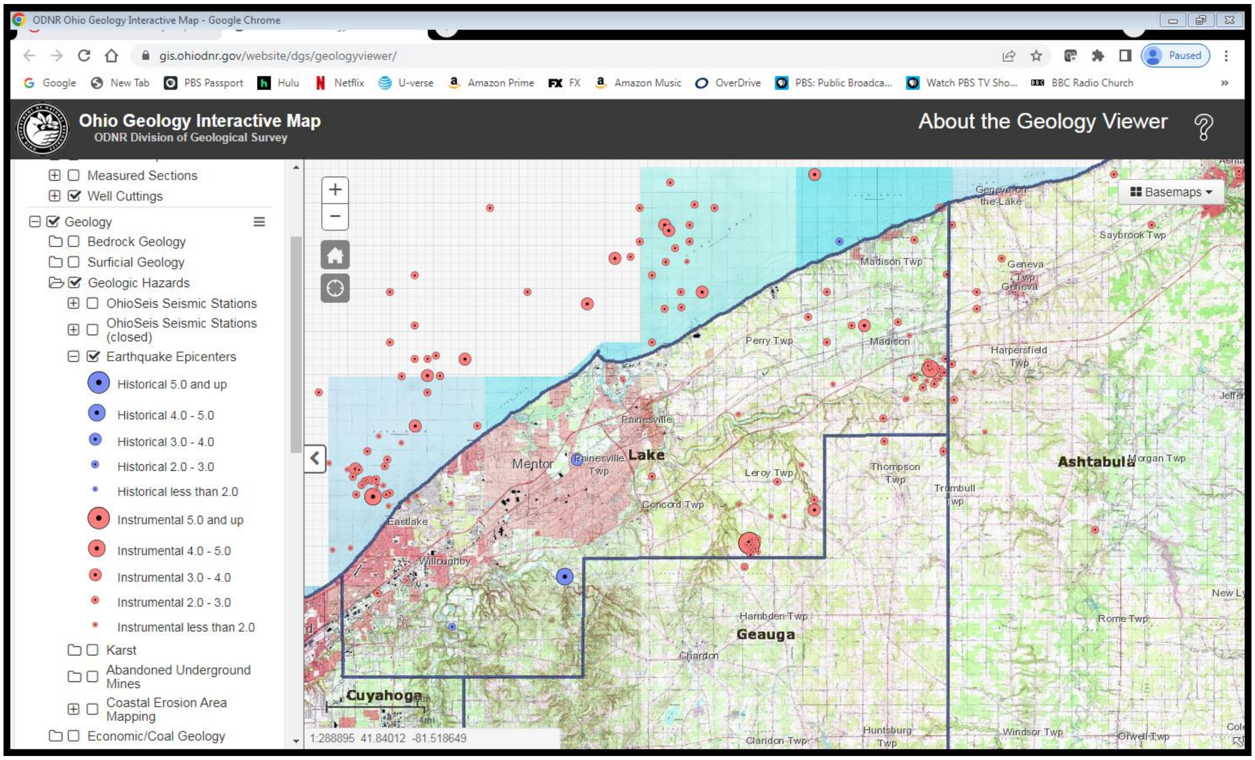


Figure 27: Coastal Erosion Areas Mapping project near the Perry site. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#





Figures 28 & 29: The 2018 photographs of shoreline erosion conditions on the southern shore of Lake Erie in front of the Perry site. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#



[Figure 30: Historic and recent earthquakes surrounding the Perry site.](#) Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

Figure 31: The Miami-Erie Canal as it flows through historic St. Marys showing the red brick buildings that sustained structural earthquake damage from the 1986 4.5 earthquake. Source: https://seemore.org/play/lake-life/the-aqua-life-at-grand-lake/

Figure 32: Photo of the east end spillway looking upstream at the retaining wall for the lake. Notice the size of the dry laid dressed limestone blocks. Source: https://seemore.org/play/lake-life/the-aqua-life-at-grand-lake/

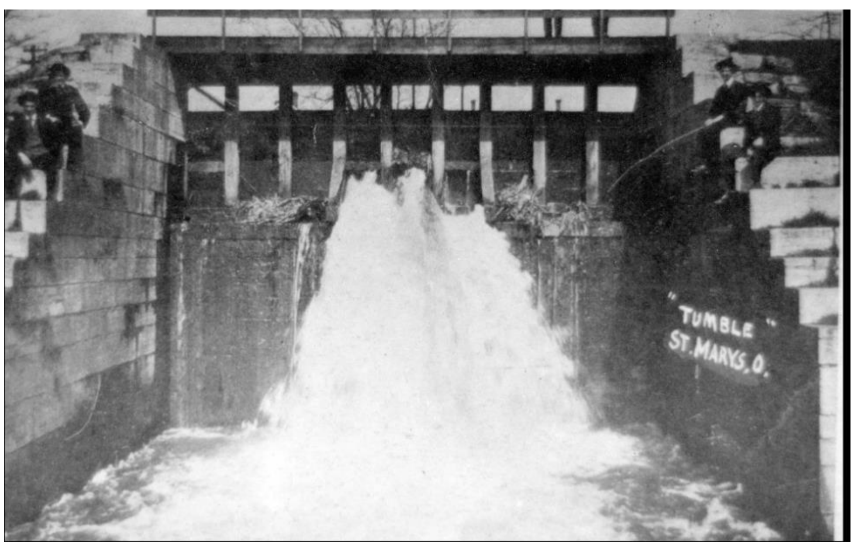


Figure 33: Historic photo of one of the canal locks at St. Marys. Notice the size of the dressed limestone blocks that are dry laid, supporting the lock. Note the young men fishing from the side walls for scale. Source: https://www.meccainc.org/historical-st-marys#&gid=1361465071&pid=21

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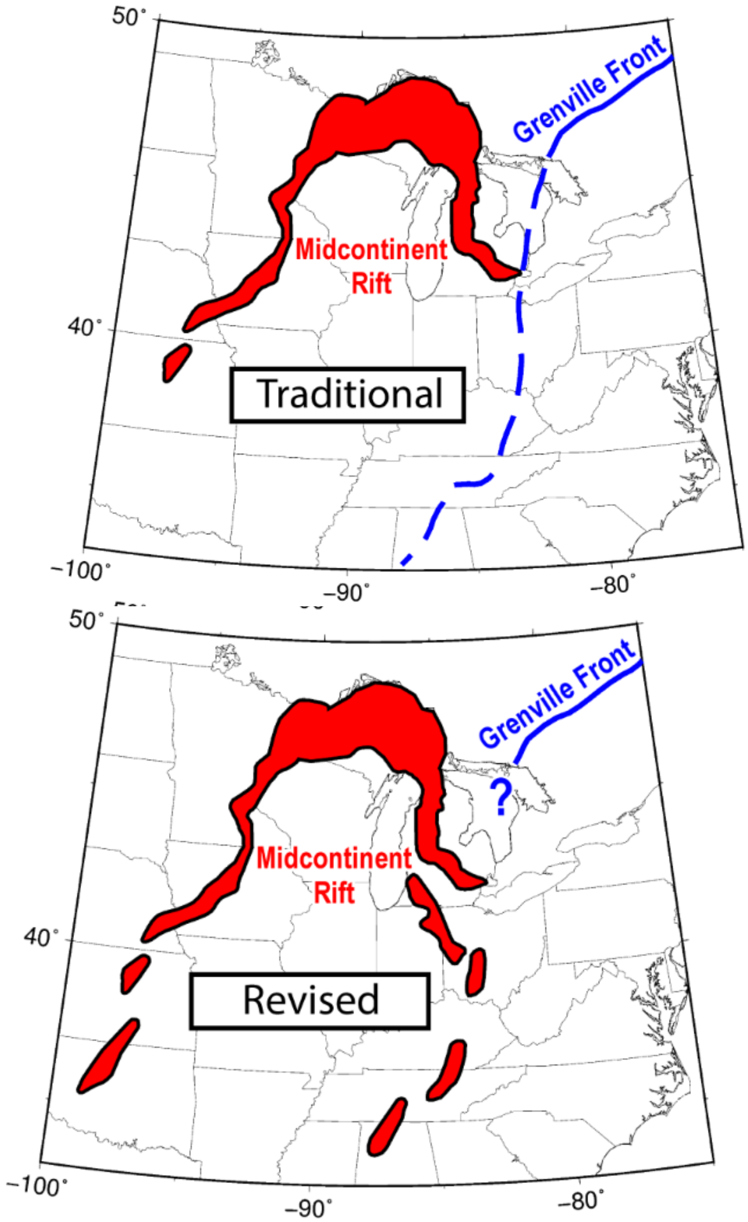

About the cover:
(Top) Traditional geometry for the relationship between the Midcontinent Rift and Grenville Front. The Grenville Front truncates the east arm of the Midcontinent Rift and extends southward along a set of subsurface features indicated by gravity and magnetic anomalies. (Bottom) Revised geometry proposed in this issue by Stein et al. (2018). The previously assumed Grenville Front in the central U.S. is in fact the southward continuation of the Midcontinent Rift. See related article, p. 4–10.

doi: 10.1130/GSATG357A.1

Figure 35: The Historic and current interpretations of the locations of the Precambrian Midcontinent Rift and the Grenville Front. The Midcontinent Rift zone is responsible for the earthquakes in the Anna (Shelby County) and St. Marys, Ohio area. Source: GSA Today, https://rock.geosociety.org/net/gsatoday/science/G357A/article.htm.

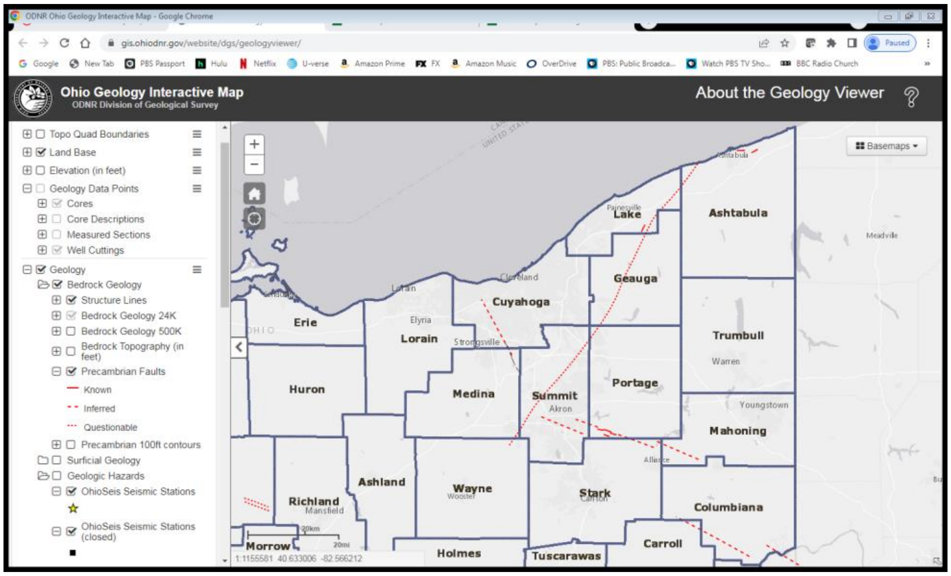

Figure 36: The known, inferred and questionable Precambrian faults in Northeastern Ohio. This map will be updated with the information being gathered from Mahoning County if they are deemed to have extended to the Precambrian. The faults underlying the Ashtabula County hazardous waste Class I injection well site can be seen on this map. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

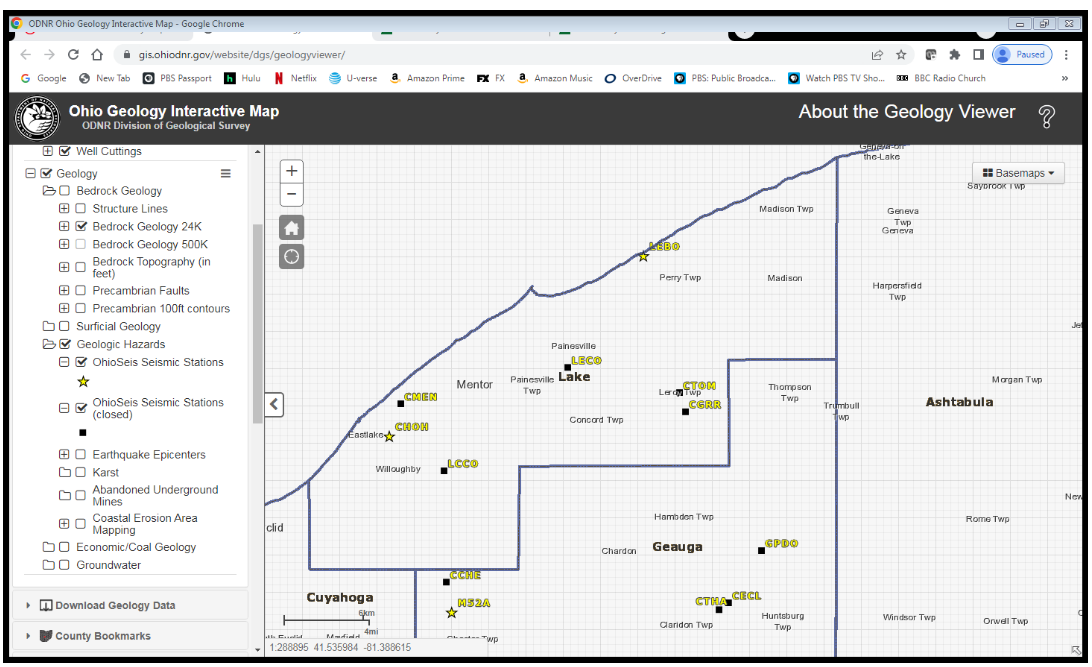

Figure 37: The locations of closed and current OhioSeis Seismic Stations surrounding the Perry site. Source: ODNR Interactive map, https://gis.ohiodnr.gov/website/dgs/geologyviewer/#

References (as ordered in the text)
Web sites checked November, 2023

Reports on the Perry Nuclear Power Plant
Original Safety Evaluation Report SER, 1982
https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML20054F514

Supplemental SER, 3/31/86
https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML20141P078

Updated Final Safety Analysis Report (NFSAR) Chapter 2, January 2003
https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML21361A214

NRC internal memo dated 9/1/11
https://www.nrc.gov/docs/ML1203/ML12037A027.pdf

USEPA web sites:
Aller et al., 1987
https://nepis.epa.gov/Exe/ZyNET.exe/20007KU4.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1986+Thru+1990&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C86thru90%5CTxt%5C00000001%5C20007KU4.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

https://www.epa.gov/radtown/nuclear-power-plants

https://iwaste.epa.gov/guidance/radiological-nuclear/high-level-waste

https://www.epa.gov/radiation/radionuclide-basics-tritium

https://semspub.epa.gov/work/HQ/175261.pdf https://www.epa.gov/sdwa/drinking-water-regulations-and-contaminants and all the extensions

https://www.epa.gov/radon

https://www.epa.gov/sites/default/files/2014-08/documents/ohio.pdf

https://odh.ohio.gov/wps/wcm/connect/gov/497d9b2f-5e96-4aa6-bca8-5582803bd2b8/Radon+County+Maps.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDM3000-497d9b2f-5e96-4aa6-bca8-5582803bd2b8-nF3BXsj

The NRC web site:
https://www.nrc.gov/waste/high-level-waste.html

The US Geological Survey web sites:
https://pubs.usgs.gov/of/1993/0292e/report.pdf

https://www.usgs.gov/publications/earthquake-hazard-associated-deep-well-injection-a-report-us-environmental-0

The ODNR web sites and extensive conversations with various Divisions staff over the decades:
https://ohiodnr.gov/discover-and-learn/safety-conservation/about-ODNR/geologic-survey/glacial-geology/ice-age-in-ohio

https://ohiodnr.gov/static/documents/geology/MiscMap_BedrockGeology_2017.pdf

The Ohio Geologic interactive map web site and the extensions
https://gis.ohiodnr.gov/website/dgs/geologyviewer/#
https://gis.ohiodnr.gov/MapViewer/?config=oilgaswells
https://gis.ohiodnr.gov/MapViewer/?config=OhioMines
https://ohiodnr.gov/discover-and-learn/safety-conservation/geologic-hazards/landslides

Nelson and Valachovics, 2022
https://ohiodnr.gov/wps/wcm/connect/gov/e3fe9649-96b9-427d-baf2-c6b92b8d4fd7/OFR2022_1_Nelson_2022_web.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_K9I401S01H7F40QBNJU3SO1F56-e3fe9649-96b9-427d-baf2-c6b92b8d4fd7-otRSTWy

Harrell, McKenna and Kumar, 1993
https://ohiodnr.gov/static/documents/geology/RI144_Harrell_1993.pdf

The Ohio Journal of Science Special Issues:
June-September 2000 (the whole journal is listed here from beginning to end)
https://kb.osu.edu/collections/b8bc52d3-2bdf-55c5-8f49-656ec32ac2ed

Allred, 2000
https://kb.osu.edu/server/api/core/bitstreams/403c8a86-0573-531f-ae98-7aef8764d95a/content

April, 2006 (the whole journal issue is listed here from beginning to end)
https://kb.osu.edu/collections/9719bfb1-1998-5583-8a2f-8b11bd98f394

Bruno, Szabo and Foos, 2006
https://kb.osu.edu/search?query=April%202006&scope=26dee3b3-05fb-57ce-9059-eb615033b352&spc.page=1

The Premier Precast Concrete web site:
https://premierprecast.com/concrete-lifespan/#:~:text=How%20long%20does%20concrete%20last%20on%20average%3F,installation%20methods%20and%20construction%20style.

The University of California Davis Soils Web Site:
http://soilmap2-2.lawr.ucdavis.edu/gmap/

Eun Kyoung Kim's 2007 PhD Dissertation:
Use of soil texture analyses to predict fracturing in glacial tills and other unconsolidated materials
https://etd.ohiolink.edu/acprod/odb_etd/r/etd/search/10?p10_accession_num=osu1196080474&clear=10&session=109712337392113

Wikipedia Utica Shale oil and gas plays map:
https://en.wikipedia.org/wiki/Utica_Shale#/media/File:Utica_Shale_assessment_-_01.jpg.

Fairport Harbor Morton Salt Mine photos:
https://www.researchgate.net/figure/The-Morton-Fairport-Harbor-Mine-is-13-km-from-the-Perry-Nuclear-Reactor-The-site-is_fig1_271855364.

https://www.businessinsider.com/photos-of-salt-mine-2000-feet-below-lake-erie-2016-5.

GSA Today:
https://rock.geosociety.org/net/gsatoday/science/G357A/article.htm

Periodic Table of Elements, including isotopes:
https://ptable.com/?lang=en#

Personal communications with Dr. Edward Rice, former assistant professor of History at The Ohio State University Main Campus and Mansfield branch, on the history of Ohio Settlement and the WWII scrap metals drives. (His father coordinated the drive in Charleston, WV. and Ed was old enough to remember the efforts clearly)

Personal communications with Lyndella Andrews, then president of the Miami-Erie Canal Society, St. Marys, Ohio (now the Miami and Erie Canal Corridor Association, https://www.meccainc.org/) on the construction of the Miami-Erie Canal and the impacts of the Grand Lake St. Marys 1986 earthquake.

Personal communications with Chief Silverio Caggiano, retired battalion chief, Youngstown Fire Department on the impacts to the built environment from collapsing mines and old oil and gas wells.

Personal communications with Jamie Addis Rice, MS Agricultural Economics, The Ohio State University on the projected costs and real costs to the environment over time of environmentally impacting land uses.

Personal communications with Adam Rice, homeowner, Worthington, Ohio on the Ohio Shale radon gas mitigation from a basement.

Personal communications with Dr. Richard McClish and Gene Johnson, geologists, on the Ohio Dept. of Energy, US DOE, Battelle oil shale research project for extracting oil from the Ohio Shale by retort.

Personal communications with Todd Houser, MS, CPSS soil science on the heating and expansion of Ohio Shale to create an expanded lightweight, more stable aggregate.