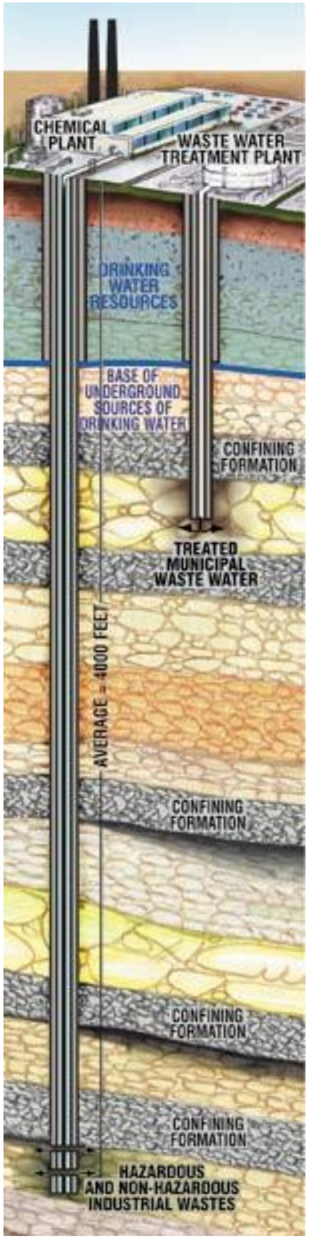

Deep Well Injection: A Position Paper

by Christopher Grobbel, PhD

for Friends of the Jordan River Watershed, Inc.,
and with support of the Freshwater Future, Inc.

September 16, 2010

Geology of the Michigan Basin[1]

The bedrock geology of the Michigan basin and the entirety of the lower peninsula of Michigan may be described as a basin comprised of relatively thick sequences of sedimentary rock (such as limestones, shales and sandstones) formed from ancient, shallow inland seas. The Michigan basin is a subsiding or "intracratonic" basin occupied by salty marine waters during the Paleozoic Era $600e^{+20}$ to $220e^{+10}$ years before present (BP). This low lying or "negative" basin was surrounded by highland or "positive" areas, including the Canadian Shield to the north, Adirondack Highlands to the east and northeast, Wisconsin Highlands and Ozark Dome to the west and northwest, and Cincinnati, Kankakee and Finlay arches to the south. The Michigan basin has also experienced uplifting along its margins, due to intensive continental crustal activities including the Appalachian and Cordilleran (i.e. Rocky Mountain) "orogenies" or mountain formation events. The Paleozoic rocks that underlie Michigan are locally about 14,000 feet thick and rest upon a "floor" of very ancient Precambrian (i.e. older than $600e^{+20}$ years BP) igneous and metamorphic rock.[2] These Paleozoic rocks dip imperceptibly downward toward the center of the Michigan basin at an average inclination of about 60 feet per mile, or less than one (1°) degree. These deposits have also been scoured by erosive forces, buried by unconsolidated glacial "drift," altered by crustal uplift and sagging, and then subject to crustal (i.e. isostatic) rebound following continental glaciation. Consequently, these Paleozoic sedimentary layers form a series of upturned, truncated concentric rings, similar to a stack of nested bowls within a kitchen cupboard. Refer to the bedrock geology map of Michigan on Page 2, bedrock deformation map on Page 3, and the stratigraphic sequence map of Michigan on Page 5.

Calcium-rich limestones form with little void space allowing for fluid storage. Over time limestones become more rigid and in some cases more dense. This results in limestones becoming inflexible and prone to extensive cracking when unevenly supported. Therefore almost all calcium-rich sedimentary deposits within the Michigan basin show extensive joint or fault systems due to uneven isostatic rebound following glaciation and local stresses from solution effects and erosion.[3]

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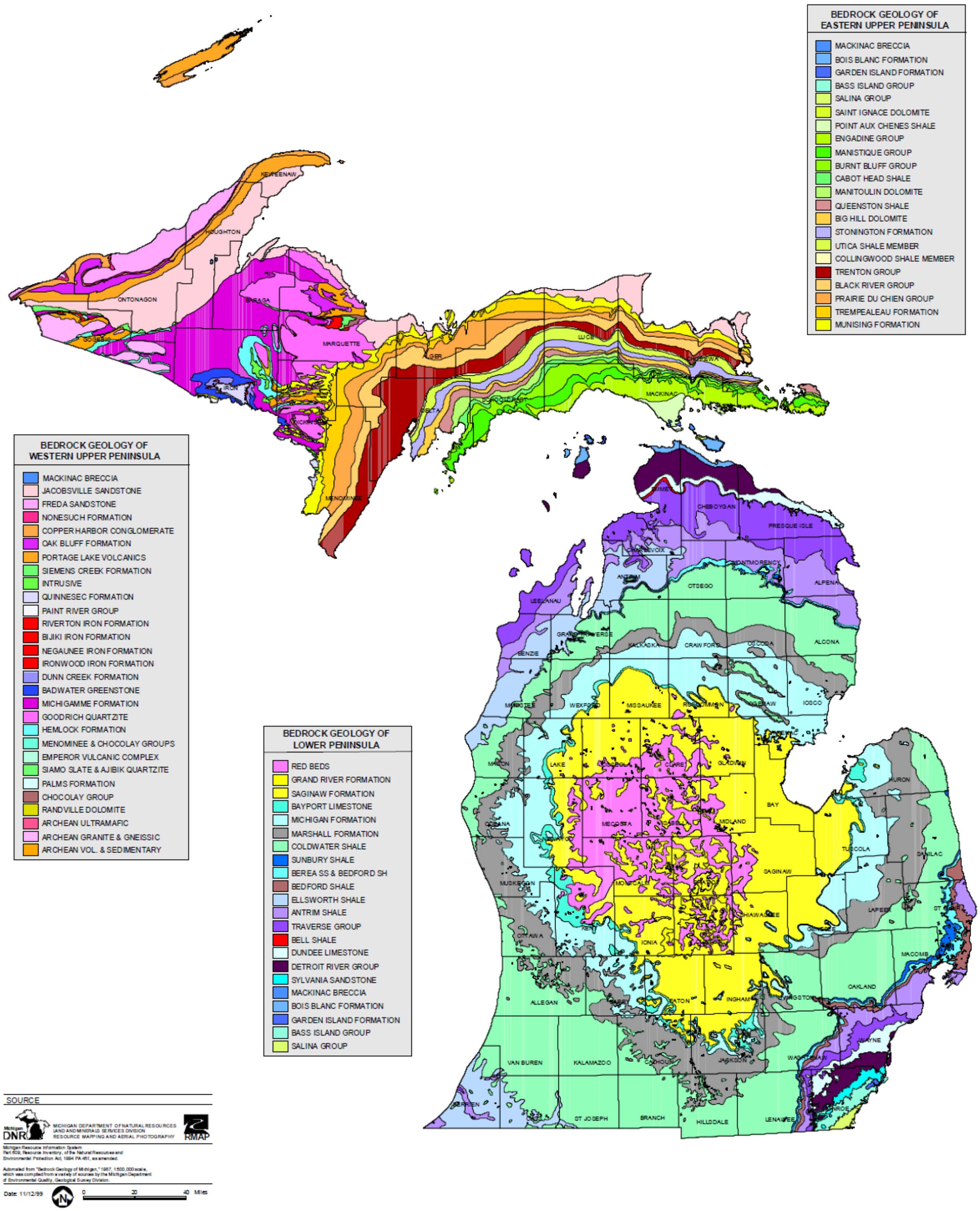
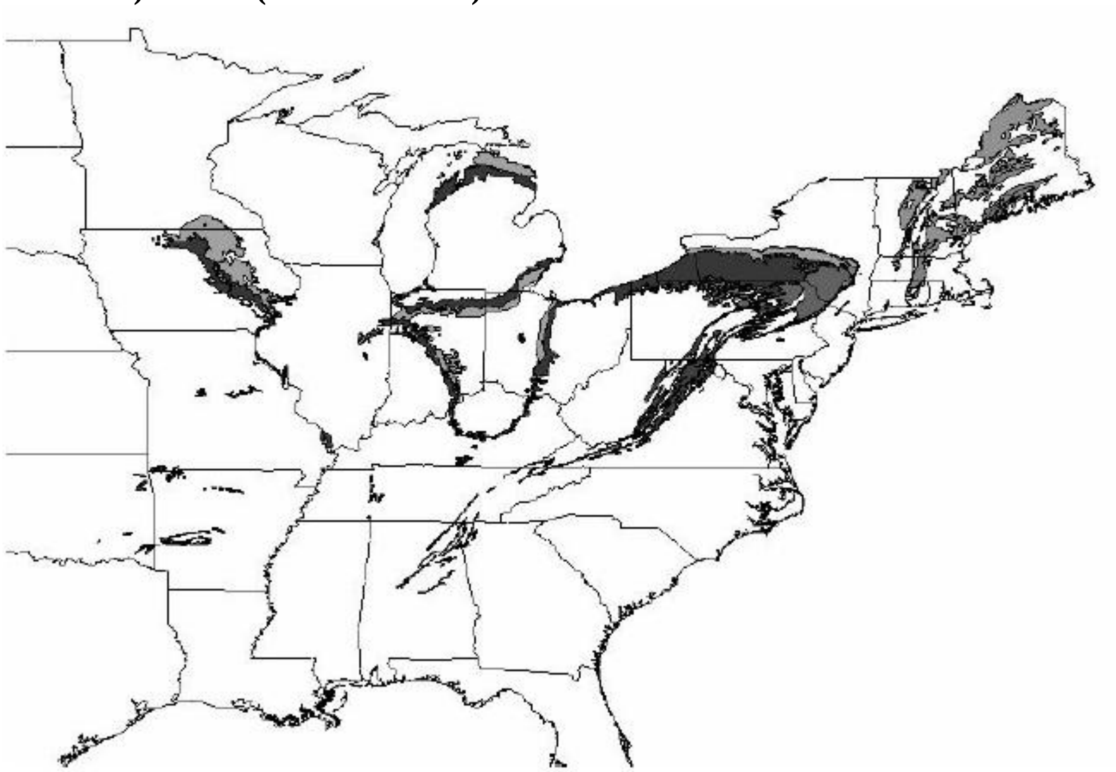
[1] Dorr, John A., Jr. and Donald F. Eschman, Geology of Michigan, University of Michigan Press, 2001, Chapters II and V.
[2] Just west of the Saginaw Bay is the center of the Michigan basin, and all Paleozoic rock beneath any one point is about 14,000 feet in thickness or more than 2.5 miles.
[3] Driscoll, Fletcher G., Groundwater and Wells, 2nd Edition, 1986, p. 31,

1987 BEDROCK GEOLOGY OF MICHIGAN



Source: Michigan Department of Natural Resources and Environment, http://www.michigan.gov/documents/deq/1987_Bedrock_Geology_Map_301466_7.pdf

Devonian Age Rock in the Eastern US Showing Deformation from West (least deformed) to East (most deformed)

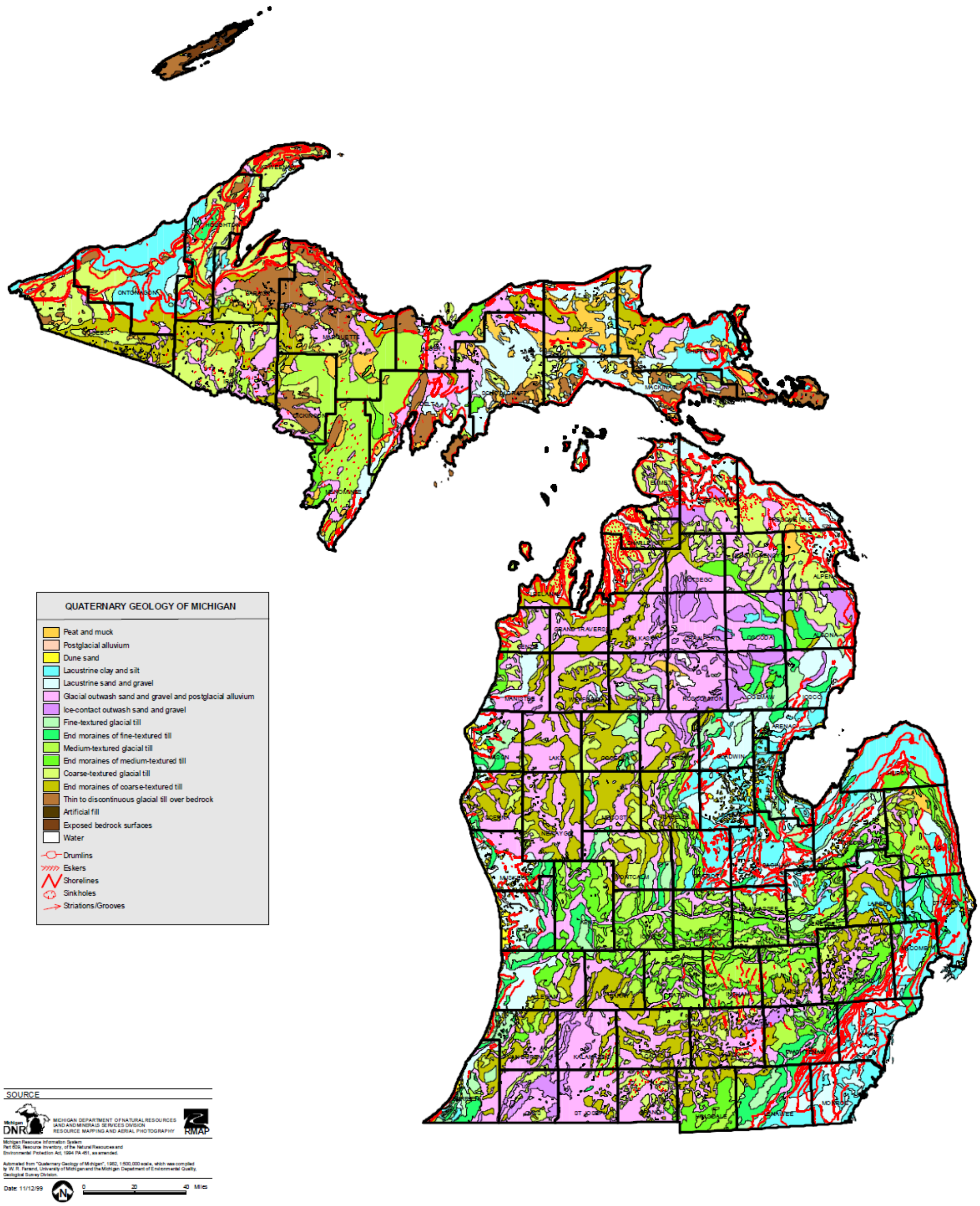


Source: Wood, MTU and Harrison, WMU, 2002, p. 50.

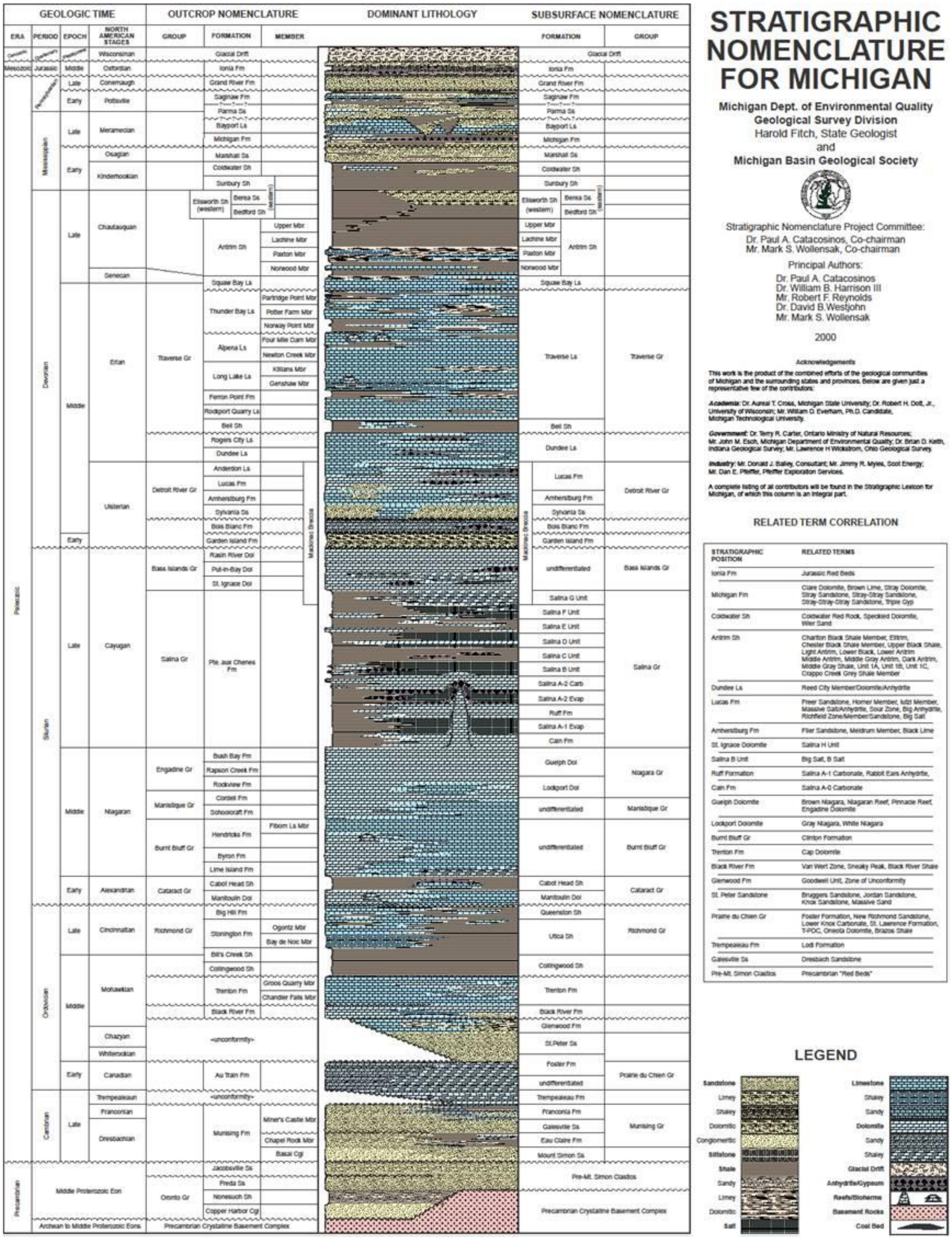
Four major periods of glaciation occurred within the Michigan basin during the Pleistocene Epoch of the Quaternary Period, about 2 million to 10,000 years BP. Specifically, these glacial events include the Nebraskan 2.4 million years BP; the Kansan 1 million years BP; the Illinoisan 800,000 to 300,000 years BP; and the Wisconsinan 150,000 to 12,000 years BP.

These periods of glaciation of the Michigan basin left unconsolidated drift on top of basin bedrock, consisting of sands, silts, clays, gravel, and glacial till, etc., varying in thickness from 600 feet to a few feet or less. Refer to the Quaternary Geology of Michigan map on Page 4.

1982 QUATERNARY GEOLOGY OF MICHIGAN



Source: Michigan Department of Natural Resources and Environment, http://www.michigan.gov/documents/deq/1982_Quaternary_Geology_Map_301467_7.pdf



Source: Michigan Department of Natural Resources and Environment, http://www.michigan.gov/documents/deq.

Late Devonian/Early Mississippian Limestone[4]

Huge quantities of black, organic-rich mud swept into the Michigan basin during the late Devonian/early Mississippian from uplift and erosion in the Appalachian region. These muds were deposited in poorly oxygenated and relatively acidic salty sea floors of the Michigan basin producing oxidation-reduction or "re-dox" conditions. The black, organic muds under such low oxygen conditions decayed extremely slowly and upon being covered and lithified, formed the Antrim shale which grades upward and westward into the gray and greenish-grey Ellsworth shale. The two shales, having formed at largely the same geologic time, grade or "interfinger" near the center of the Michigan basin. Dundee limestone, Rogers City limestone of the Traverse Group limestone also formed during this period, and are of significant economic importance in the state and region possessing oil and being mined to supply raw materials for the steel, chemical, construction, and cement industries.

Karst Geology of the Michigan Basin

Karst is a term that describes regions throughout the world underlain by calcium-rich sedimentary deposits (i.e. limestones and/or dolomites[5]) and/or evaporates such as gypsum or salt that over time develop unique features from chemical dissolution from percolating and slightly acidic rainwater and calcite-poor groundwater.[6] This percolation of slightly acidic precipitation slowly dissolves carbonate rocks, results in the enlargement of existing crevices, open joints, bedding planes, and fractures diverting surface stream flow to underground formations and even resulting is collapse of the land surface.[7] Karst terrains are therefore characterized by caves, steep valleys, sinkholes (existing either as inland lakes or dry sinkholes depending on area groundwater conditions), and a general lack of surface streams. As a consequence karst areas not only possess interesting landscapes with unusual habitats for plants and animals, but possess special problems in water supply, waste disposal, construction and other land uses.[8] Refer to a map of national karst areas on Page 7.

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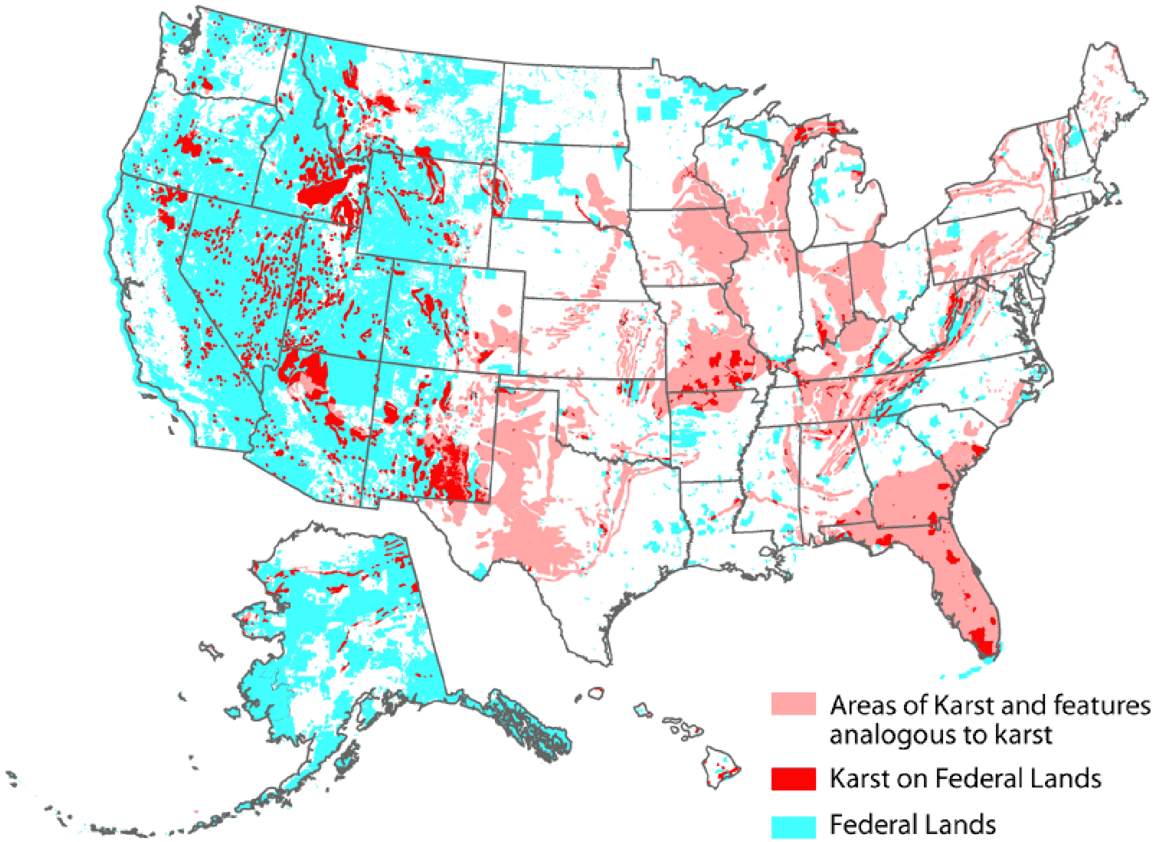
[4] Dorr, John A., Jr. and Donald F. Eschman, Geology of Michigan, University of Michigan Press, 2001, Chapter V, p. 119.
[5] Dolomites are limestones within which magnesium from ancient sea water, during deposition or after lithification, has chemically replaced some calcium, resulting in a significantly strengthened rock.
[6] Strahler, Arthur N., Physical Geography, 1981, Harper Rowe Publishers, Inc.; and R. Allan Freeze & John A. Cherry, Groundwater, Prentice-Hall, Inc., 1979, p.513-515.
[7] Driscoll, op. cit., p. 31; and http://www.caves.org/conservancy/mkc/michigan_karst_conservancy.html.
[8] http://www.caves.org/conservancy/mkc/michigan_karst_conservancy.html.



Source: United States National Park Service, http://www.nature.nps.gov/nckri/map/images/maps/C-04-davies_fedlands_pink_s.gif

Michigan contains some areas of limestone karst within northeastern and southeastern portions of the Lower Peninsula. These areas are limited in extent, which increases their interest and importance. There is also considerable variety in Michigan karst areas: gypsum karst is found in Kent and Iosco counties; a significant amount of surface drainage goes underground in Monroe County, and reappears at "blue holes" in Lake Erie; spectacular sinkholes and earth cracks are found in Alpena and Presque Isle counties; and the broad band of outcrops of the Niagara Escarpment in the Upper Peninsula hosts a number of karst sinks, springs and caves.[9] Refer to the map of karst areas within Michigan on Page 8.

[9] http://www.caves.org/conservancy/mkc/michigan_karst_conservancy.htm

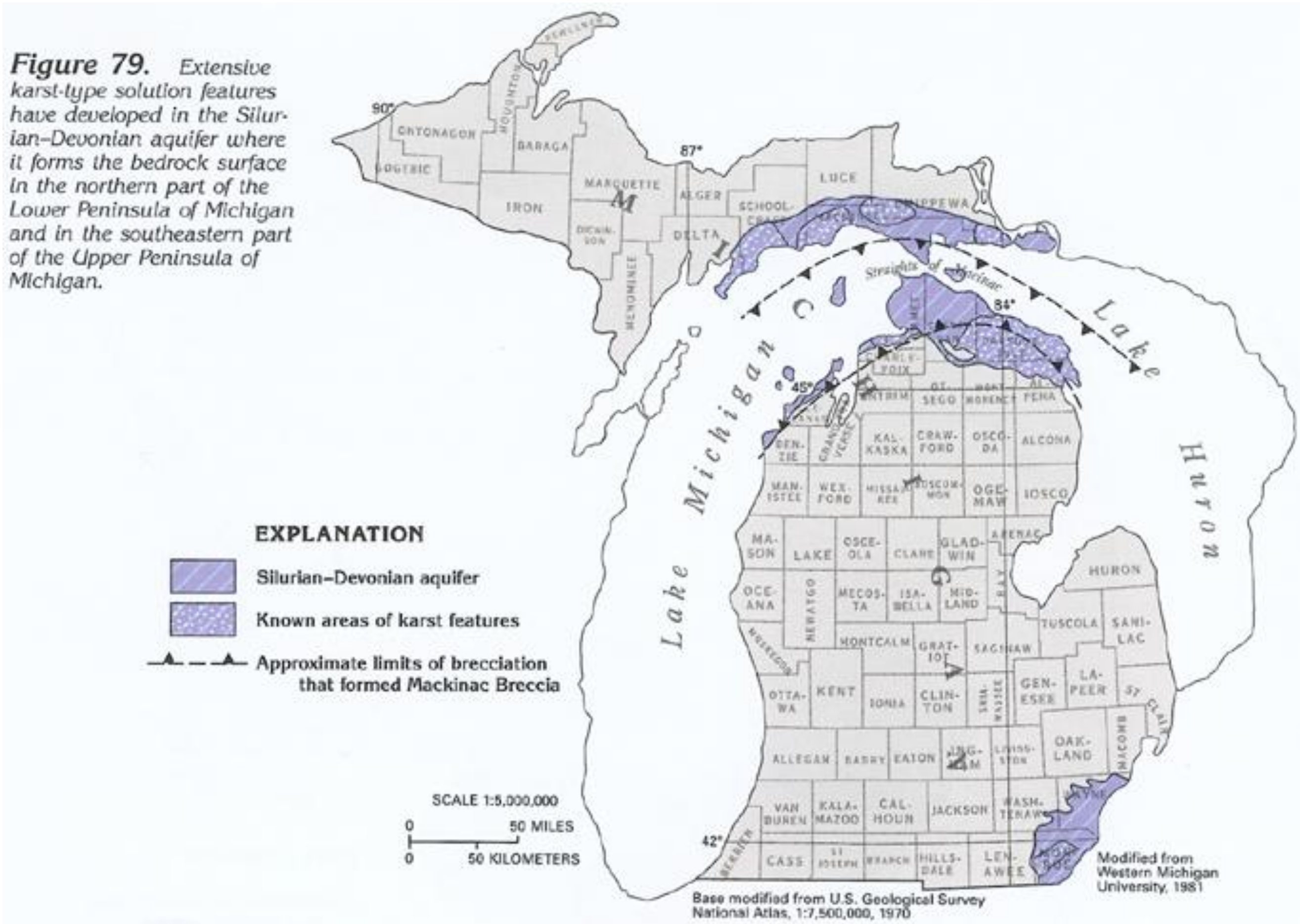


Figure 79. Extensive karst-type solution features have developed in the Silurian–Devonian aquifer where it forms the bedrock surface in the northern part of the Lower Peninsula of Michigan and in the southeastern part of the Upper Peninsula of Michigan.

Source: USGS, http://pubs.usgs.gov/ha/ha730/ch_j/J-Silurian.html.

In the Lower Peninsula of Michigan, carbonate rocks are extensive but are buried deeply beneath glacial deposits. Silurian limestones along Lake Huron between Alpena and the Straits of Mackinac contain several large terrestrial sinkholes up to 1 mi (1.6 km) long and 200 ft (60 m) deep. The sinkholes are interconnected by an extensive fissure system. Normally, the sinkholes are filled with water, but overtime plugs in the fissure system tend to fail and the lakes then drain through the subterranean openings.[10]

Submerged Sinkholes within the Great Lakes

Importantly, in June of 2001 researchers were surprised to discover groundwater from Silurian-Devonian formations upwelling and discharging or "venting" into the waters of Lake Huron just north of Alpena, Michigan.[11] In fact dozens of sinkholes were mapped in the limestone bedrock ten miles from Michigan's northeastern shore and at a depth of approximately 300 feet in Lake Huron.[12] Sink holes have also been mapped within

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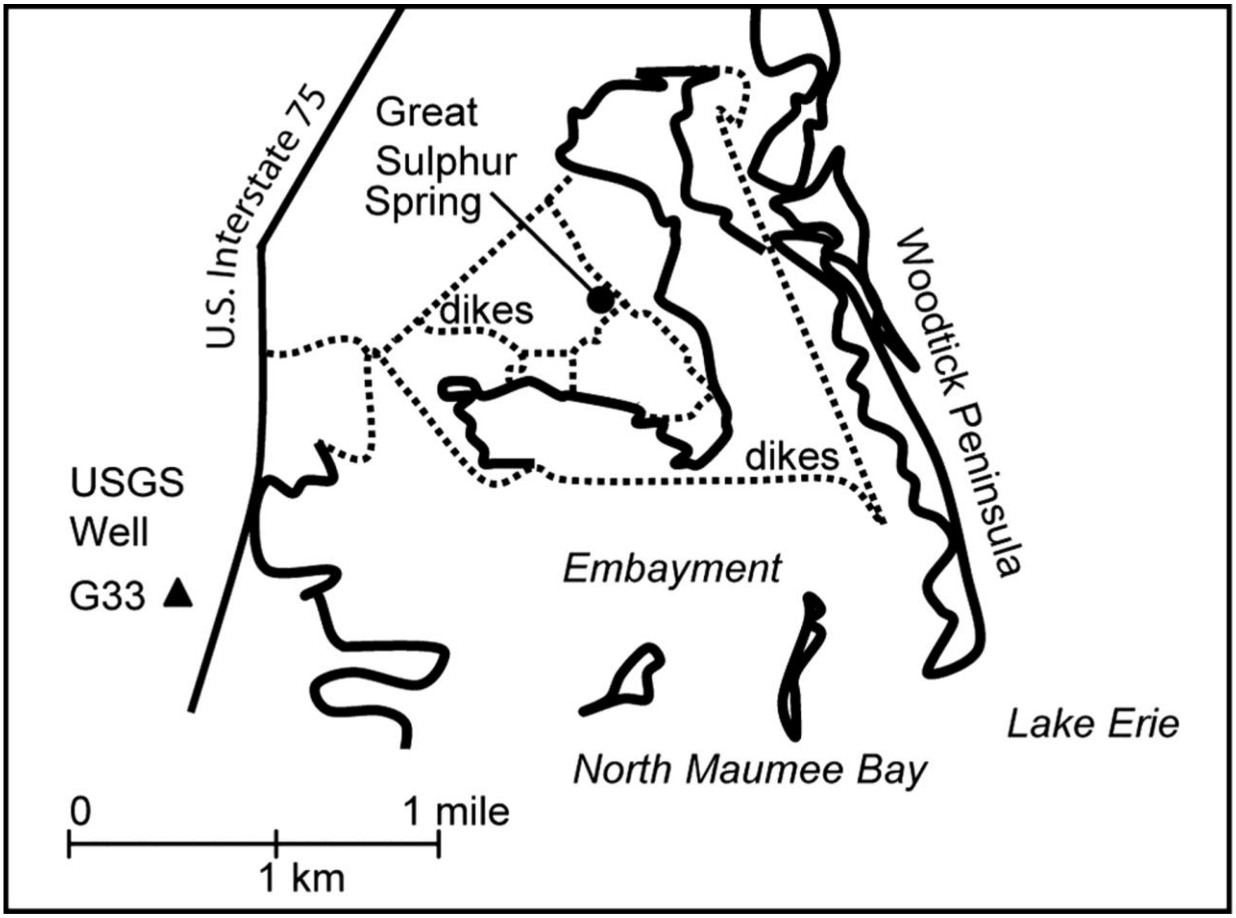
[10] http://www.nature.nps.gov/nckri/map/maps/engineering_aspects/text.htm

[11] National Oceanographic & Atmospheric Administration, "Exploration of Submerged Sinkholes in Lake Huron," www.glerl.noaa.gov, September 2007.

[12] Ruberg, Steven, "Exploration of Submerged Sinkhole Ecosystems in Thunder Bay National Marine Sanctuary, Lake Huron," National Oceanic and Atmospheric Administration, Great Lakes Environmental

Silurian-Devonian formations in Monroe County in the southeast corner of Michigan and northern Ohio directly venting sulfur-rich fluids to Lake Erie.[13]

Silurian-Devonian Karst Formations Venting to Lake Erie, SE Michigan



Source: Chaudhary *et al*., MSU, 2009, http://aem.asm.org/cgi/content/full/75/15/5025.

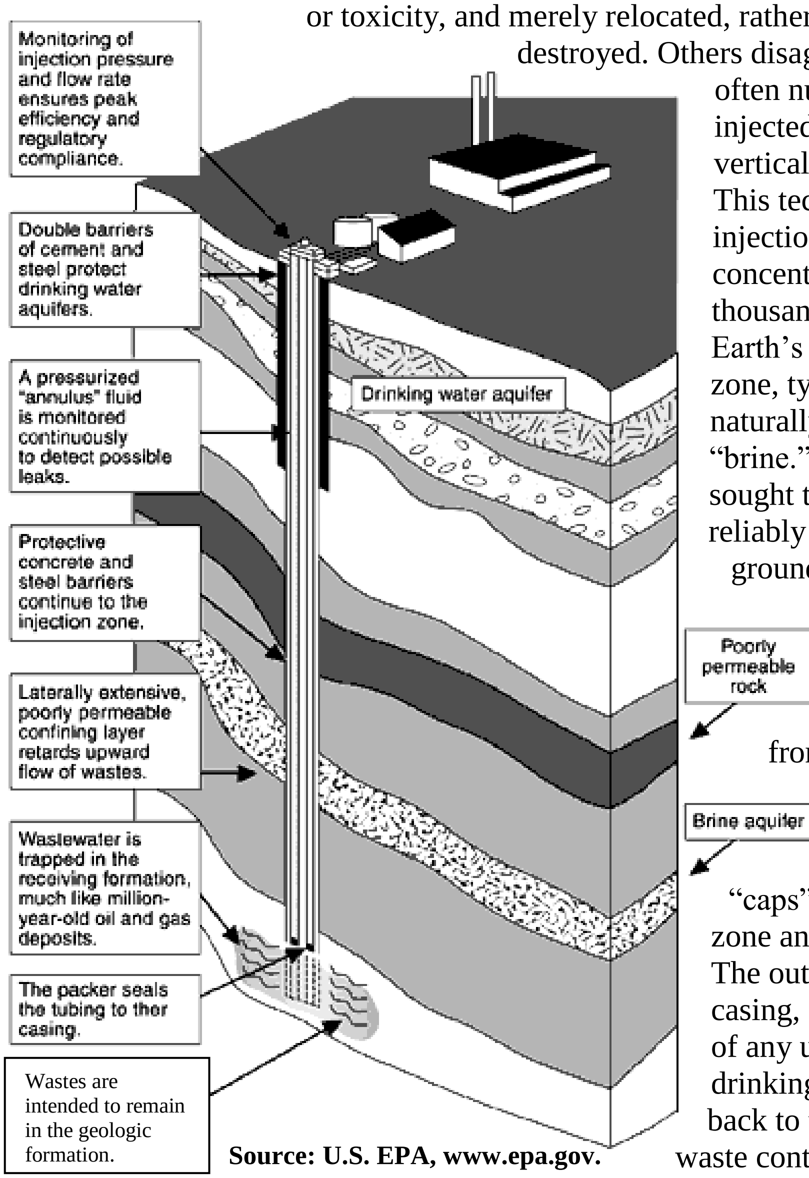
Moreover, researchers believe that the venting of mineral-rich fluids from Paleozoic formations to the Great Lakes in other locations is likely, though presently poorly researched or understood. This is especially true within northwestern Michigan and the south shore of Michigan's Upper Peninsula along Lake Michigan. Clearly, the injection of liquid wastes within Silurian-Devonian formations at locations from which direct hydraulic connection or "venting" to the Great Lakes or other surface waters must be precluded.

Laboratory, www.glerl.noaa.gov/resz/Task_rpts/2006/eosruberg06_1.html; Ruberg, S.A., D.F. Coleman, T.H Johengen, G.A. Meadows, H.W. Van Sumeran, G.A. Lang and B.A. Biddanda, "Groundwater Plume Mapping in a Submerged Sinkhole in Lake Huron," Marine Technology Society Journal, Summer 2005, Vol. 39, No. 2, pp. 65-69; and Biddanda, B.A., D.F. Coleman, T.H Johengen, S.A. Ruberg, G.A. Meadows, H.W. Van Sumeran, R.R. Rediske, and S.T. Kendal, "Exploration of a Submerged Sinkhole Ecosystem in Lake Huron," Ecosystems, 2006, Vol. 9, pp. 828-842.

[13] Chaudhary, Anita, Sheridan Kidd Haack, Joseph W. Duris and Terrence L. Marsh, Department of Microbiology and Molecular Genetics, Michigan State University, June 2, 2009.

Deep Well Injection Technology

Deep well injection is a method of liquid hazardous and non-hazardous waste disposal. Some contend that fluid wastes injected into near surface or deep bedrock formations[14] is actually a form of storage. As such waste is typically untreated, undiminished in quantity or toxicity, and merely relocated, rather than remediated or destroyed. Others disagree, saying there are often numerous pathways for injected wastes to migrate vertically and/or horizontally. This technology uses an injection well comprised of concentric pipes extending thousands of feet from the Earth's surface to an injection zone, typically possessing naturally occurring salt waters or "brine." Injection zones are sought that are naturally and reliably isolated from the above groundwater used as a fresh drinking sources or "aquifers."[15] Isolation of groundwater drinking water sources from injection zones relies upon the presence of vertically impermeable layers or bedrock "caps" overlying the injection zone and beneath the aquifer(s). The outermost pipe, or surface casing, extends below the base of any underground sources of drinking water and is cemented back to the surface to preclude waste contact with drinking water



Source: U.S. EPA, www.epa.gov.

[14] "Formations" are a set of originally continuous rock strata which have a common suite of rock and fossil characteristics, see Dorr, John A., Jr. and Donald F. Eschman, Geology of Michigan, University of Michigan Press, 2001, p. 90.

[15] EPA defines an underground source of drinking water as an aquifer or portion of an aquifer that supplies a public water system (PWS) or contains enough water to supply a PWS; currently supplies drinking water for human consumption or contains water with less than 10,000 milligrams/liter of total dissolved solids (TDS); and is not exempted by EPA or state authorities from protection as a source of drinking water (40 CFR 144.3).

aquifers.[16] Within this surface casing is a long string casing that extends to, and typically within, the injection zone.

Perforations, or an open bottom of the long string casing, convey liquid wastes into the injection zone or injection "formation." Liquid waste is typically injected through fiberglass injection tubing within the long string casing. The space between the long string casing and injection tubing is called the "annulus." The annulus of a deep injection well is filled with an inert, corrosion inhibiting and pressurized fluid, maintained at higher pressure than inside the injection tubing. This pressure differential is intended to be monitored continuously to detect breaches or other well system failure that might result in releases to the environment. Remote monitoring is typically undertaken and changes in annulus fluid pressure should automatically trigger a well shutdown, Finally, the annulus is sealed from the well bottom with a removable packer intended to prevent injected wastes from backing up into the annulus.[17] Flow of injected waste away from an injection site is optimally sought. Lateral flow away from an injection site/zone can however be impeded by: 1) natural formation fluid toward the injection site; 2) well construction failure; 3) encountering a geologic permeability barrier; and/or 4) encountering a stratigraphic avenue of higher permeability, such as a transmissive fault or fracture (induced or natural), intersection with an unplugged well bore, or a "facies" or change in the reservoir rock.[18] Aside from well failure and injectate encountering an unplugged or improperly plugged deep well, the potential for upward migration along a naturally occurring fault is considered the most serious threat to losing waste confinement within a reservoir formation. Interestingly, the ultimate fate and transport of injected liquid wastes at deep well injection sites, i.e. the movement, residence time and degradation, are generally unknown.

Truly sealed formations effectively hold pressure, as is evidenced by the underground storage of natural gas and the proposed subsurface sequestration of carbon oxides. Michigan has a total of forty-five (45) active underground natural gas storage reservoirs, forty-three (43) within depleted natural gas or oil fields and two (2) within salt caverns.[19] However, many Michigan deep injection wells accept liquid brine wastes by gravity that is without pressurized injection flow. State and federal regulations prohibit pressurized injected waste fluids from causing or propagating fractures within the injection zone and injected fluids are required to be contained within the injection zone for at least 10,000 years.[20] It is unclear how the regulatory prohibition of causing subsurface fracturing or the 10,000 year containment rule are regulatorily assessed or technically monitored over time.

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[16] Smith, John, Deep Well Injection, January 6, 2009, http://rechargedparticles.com.
[17] *Ibid.*
[18] Ohio Department of Natural Resources, Division of Geological Survey, "*Geologic Considerations in Class I Injection*," April 20, 2005, http://dnr/state.oh.us/geosurvey.
[19] US Energy Information Administration, http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/undrgrnd_storage.html#midwest.
[20] Abou-Sayed, A., T.W. Thompson, and K. Keckler, *op cit.*

A Brief Overview of Deep Well Injection in Michigan

According to the U.S. Environmental Protection Agency (EPA), the practice of the underground injection of liquid wastes began in the 1930s when oil production companies began disposing of oil field brines and other waste products into depleted petroleum reservoirs. The 1960s and 1970s saw a significant increase in the deep well injection of oil and gas production wastes nationwide. U.S. EPA, responding to the failure of some wells, issued a policy statement in which it opposed underground injection without strict control and clear demonstration that the wastes will not adversely affect ground water supplies. In December 1974, Congress enacted the Safe Drinking Water Act (SDWA), which required EPA to set requirements for protecting underground sources of drinking water (USDWs). EPA passed its Underground Injection Control (UIC) regulations in 1980. In 1984 Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA), which banned the land disposal of hazardous waste, unless the hazardous waste is treated to meet specific standards. U.S. EPA amended the UIC regulations in 1988 to address the Hazardous and Solid Waste Amendments. Operators of Class I deep injection wells are exempt from the ban if they demonstrate that the hazardous constituents of the wastewater will not migrate from the disposal site for 10,000 years or as long as the wastewater remains hazardous. This demonstration is known as a "no-migration petition." HSWA also requires U.S. EPA to set dates to prohibit the land disposal of all hazardous wastes.

Approximately, 58,000 oil and gas wells have historically been drilled in Michigan.[21] Currently there are more than 1,500 Class II brine disposal wells in operation in Michigan and 170,000 such deep injection wells in 31 states nationwide.[22] The vast majority of these wells are former oil and gas production wells that were converted to brine disposal wells following the depletion of economically viable oil or natural gas production. More recent trends have included requests in Michigan to drill or convert existing brine wells to inject liquid industrial wastes into subsurface bedrock formations. Recent examples in northern lower Michigan include the Hubbell B1-9 well in Whitewater Township, Grand Traverse County; the Cherry Berry well in Acme Township, Grand Traverse County; Weber 4-8 well in Mayfield Township, Grand Traverse County; and Belland/CMS's proposed deep well east of Alba in Antrim County. The average depth of these Michigan wells is slightly more than 4,500 feet. It is very difficult to determine how many of these old wells were improperly abandoned in the past and/or may provide conduit for upward migration of subsurface fluids and/or injected wastes over the long term, i.e. 10,000 years. An example of this the documented upward seepage of injected wastes in improperly abandoned oil wells near Port Huron, Michigan caused by the injection of industrial wastes in neighboring Ontario.[23]

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[21] Presentation by Dr. William Harrison, Professor Emeritus, Geology, Western Michigan University, at "Understanding the Depths of Deep Injection Wells," NCMC, Petoskey, May 20, 2010.

[22] *Injection Wells: An Introduction to Their Use, Operation and Regulation*, Groundwater Protection Council, www.gwpc.org.

[23] Breeden, Charles H., *Measuring the Risks of Deep Well Injection*, Virginia Water Resources Research Center, Bulletin 122, Project A-066-VA, VPI-VWRRC-BULL 122, January 1980, p. 16.

Michigan currently has seven (7) active hazardous Class I, twenty (20) Class I nonhazardous, and 1,519 Class II brine licensed deep injection well sites.[24] Of the active Class I wells in Michigan (some facilities possess more than one well), fifteen (15) are injecting into the Late Cambrian Mt. Simon sandstone, seven (7) into the Middle Devonian Dundee limestone, two (2) into the Middle Devonian Traverse Group limestone, two (2) the Late Devonian Berea and/or Sylvania, and two (2) into the Middle Devonian Reed City dolomite and adjacent formations.

Reported Releases at Deep Well Injection Sites

Part C of the federal Safe Drinking Water Act prohibits the impact to groundwater utilized as a drinking water source from the underground injection of the non-hazardous, Class 1 fluid wastes. In accordance with Michigan's Part 625, R2441 *et seq*. the Supervisor of Wells (i.e. the Michigan Department of Natural Resources & Environment or DNRE) must determine that any proposed deep injection wells and associated surface facilities will: a) prevent waste; b) protect environmental values; and c) not compromise public safety. Michigan's Part 625 R299.2416 requires a permittee to submit a surface facility operations plan to the MDRE, Office of Geological Survey (OGS) for injection well(s) and associated surface facilities before beginning waste injection. Surface facilities operations plans, in part, detail waste volumes to be stored, volumes of formation liquids/pressures to be removed, leak detection and alarm systems, systems testing, monitoring, reporting, and emergency response plans, etc.

The U.S. EPA has stated that since the start of its UIC permit program, "there has not been a documented case of a deep injection well contaminating an underground source of drinking water."[25] Recently U.S. EPA stated in its response to public comments regarding the proposed Beeland Deep Injection Well near Alba in Antrim County, Michigan, that "the likelihood of a leak is very small, and the risk of contaminating the underground source of drinking water is much smaller…based on the protectiveness of the UIC technical specifications…and real-world experience."[26]

However, as acknowledged by the DNRE in its response to public comments related to the proposed Beeland/CMS deep well,[27] releases to the environment and resulting soil impact have been documented at similar sites - albeit at hazardous waste deep injection wells in Mio (i.e. Hoskins Manufacturing Company) and Romulus (i.e. EDS), Michigan.[28] Violations and enforcement actions were also undertaken in 1998 by U.S. EPA against Hoskins Manufacturing Company in Mio, Michigan and New Paris, Indiana.

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[24] U.S. EPA Annual Inventory of Underground Injection Wells, Region 5, http://www.epa.gov/r5water/uic/final_inventory.htm.
[25] U.S. EPA, Answers Questions About Beeland Well Project, Beeland Underground Injection Control Well, Antrim County, February 2008, p. 3.
[26] U.S. EPA Response to Comments (Beeland Group, LLC), February 7, 2008, p. 7.
[27] MDEQ's Response to Public Comments on Permit Application for the Proposed Beeland Disposal Well No. 1, January 28, 2008, p. 12.
[28] Also see U.S. EPA Enforcement Action Database, Fiscal Year 1998, Region 5, Office of Regional Counsel, http:/www.epa/gov/region5/orc/enfactions98/law-sdwa.htm.

Based on professional experience and training, such releases, whether *de minimus* or more significant, most often occur from human error, loading/off-loading, subsurface piping failures, and tank failures from metal corrosion rather than well failure(s).

Two (2) confirmed cases of groundwater contamination from injection well operations have also been documented in Texas, where Class 1 injection wells are currently permitted and operating with about one-half injecting non-hazardous waste and the other one-half injecting both hazardous and non-hazardous waste.[29] Greenpeace has reported that 172 hazardous waste deep injection wells exist in the U.S., nine (9) of them are operating in Michigan.[30] Of these hazardous waste deep injection wells, twenty-two (22) or 12.8 percent have "leaked or suffered holes, and workers were unable to detect substantial leakage from holes in well casings in six (6) other situations."[31] The U.S. General Accounting Office has documented twenty-three (23) cases nationally of drinking water contamination from the operation of deep wells injecting oil and gas wastes.[32] The U.S. EPA also reported the loss of hazardous waste on March 24, 2006 from a 200,000 gallon above-ground storage tank at a hazardous waste deep well injection facility in Vickery, Ohio. The owners of the Vickery, Ohio deep injection well reportedly paid out $30 million in claims to property owners within five (5) miles of the site.[33]

More than thirty (30) municipalities in Florida dispose of waste water from publicly-owned waste water treatment plants through deep well injection.[34] Importantly, U.S. EPA reports that treated domestic waste waters injected into bedrock formations at several locations in Florida (including Miami-Dade area and the City of St. Petersburg) have migrated upward into underground sources of drinking water.[35] The federal National Archives and Records Administration reports that as early as 2001, the upward migration of deep injected municipal effluent was known at forty-two (42) of eighty-one (81) operational municipal deep injection well sites, most of which exist along south Florida's coastline.[36] Incredibly rather than halting further deep well injection U.S. EPA and Florida's Department of Environmental Protection's response was to change Municipal Class I Injection well regulations to require pretreatment and/or "disinfection" of

[29] www.texasep.org/html/wst/wst_4imn_injct.html, March 5, 2008.
[30] Thornton, Joe, "A Shot in the Dark: Underground Injection of Hazardous Wastes," A Greenpeace Report, July 1990; Domino, Andrew, "Unsafe at Any Depth: Romulus Fights Toxic Well," Ecology Center, Ann Arbor, Michigan December 1999/January 2000, pp. 19-22; and Melissa Marra, "Hazardous Waste Deep Injection in Romulus," Environmental justice Information Page, School of Natural Resources, University of Michigan, http://eelink.net/EJ/indiex.html.
[31] *Ibid.*
[32] *Ibid.*
[33] Domino, *op. cit.*
[34] Wastewater Effluent Disposal in Florida, annual inventory for facilities with permitted capacities of 0.1 million gallons per day or more, www2.hawaii.edu/~nabil/disposal.htm.
[35] U.S. EPA Class I Municipal Disposal Wells in Florida, Region 4: Underground Injection Control, www.epa.gov/region4/water/uic/class1_flrule.html.
[36] Treasure Coast Groups Organize to Fight New Injection Well Threat to Coastal Health, April 29, 2009, www.nt2009.com.

municipal waste waters prior to injection into highly permeable coastal limestone formations.[37]

Risks of Deep Well Injection

Factors to be considered in locating a deep well injection site include: 1) the capacity of the geologic unit or "reservoir" to accept and confine the waste (i.e. porosity, permeability lateral extent, consistency and thickness of the reservoir); 2) the structural geology of the setting (i.e. elevation of the injection zone in its geologic setting, density variation between injectate and naturally occurring brines, presence or absence of faults and/or fractures, and the potential for injection-induced earthquakes); and 3) the presence or absence of valuable mineral resources within the potential area of influence.[38] A Michigan Circuit Court judge recently issued a temporary injunction against drilling a proposed deep injection well near Alba, Michigan in part due to likely trespass of injected cement kiln dust leachate on neighboring mineral rights holder's rights and the potential economic value of naturally occurring brines in the proposed reservoir - the late Devonian Dundee limestone and Detroit River Group limestone/dolomite formations.

No deep well injection operation is perfectly safe, but deep injection wells are presumably subject to a very low presumed probability of failure.[39] Nonetheless, thousands of releases of brine[40] and/or associated chemical constituents of petroleum[41] have been released to the environment in Michigan at Class II deep injection wells, production wells and their associated infrastructure - including above ground storage tanks, pipelines and well casing themselves. Such spills resulting in the contamination of soil, groundwater, surface water and other sensitive natural resources are unlawful in Michigan, and site investigation and cleanup are overseen by the Michigan Department of Natural Resources & Environment's OGS. While such spills are legally prohibited by Michigan's Part 201, Environmental Response Act of P.A. 451 of 1994, as amended, OGS assesses such spills and oversees cleanup pursuant to the much more relaxed policies and procedures of Part 615, Supervisor of Wells Act, Part of P.A. 451 of 1994, as amended.

[37] U.S. EPA Class I Municipal Disposal Wells in Florida, Region 4: Underground Injection Control, www.epa.gov/region4/water/uic/class1_flrule.html. The federal rule was effective November 22, 2005.
[38] Ohio Department of Natural Resources, Division of Geological Survey, "*Geologic Considerations in Class I Injection*," April 20, 2005, http://dnr/state.oh.us/geosurvey.
[39] U.S. EPA, Office of Water, Class I Underground Injection Control Program: Study of the Risks Associated with Class I Underground Injection Wells, www.epa.gov/safewater, March 2001.
[40] Brine is typically assessed in the environment through the monitoring of concentrations of Chloride.
[41] Petroleum, although containing more than 200 chemical constituents, is typically assessed and monitored by indicator chemical parameters Benzene, Toluene, Ethylbenzene and Xylene isomers in the environment.

Primary risks and potential consequences of releases of liquid wastes at deep injection well sites include:[42]

1) The contamination of water supplies through upward or lateral migration of waste fluids;
2) Induced earthquakes due to increased subsurface pressures from deep well injection[43]; and
3) Land or subsurface mineral contamination through upward or lateral migration of waste fluids.

Fault Lines in Michigan Paleozoic Formations

According to geologic research and contrary to most depictions, Paleozoic formations within the Michigan basin are "in fact extensively faulted and fractured...especially in the central portion of the basin."[44] Numerous fault lines in these formations run generally in a northwest to northeast pattern.[45] Fault lines identified in the Michigan basin include but are not limited to:

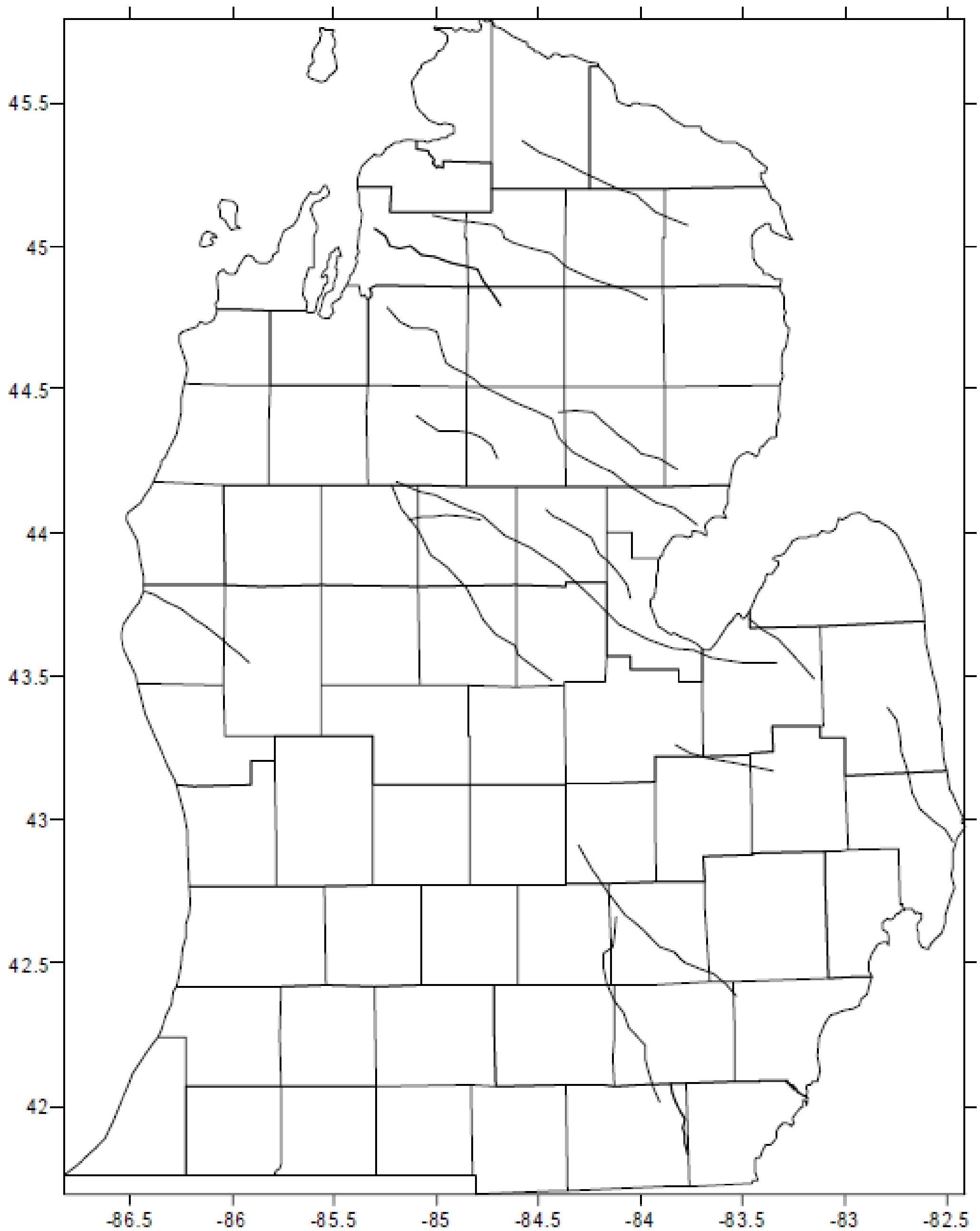
- A fault extending from southern Cheboygan County to northern Alpena County;
- Extending from Antrim County through Otsego and into Montmorency Counties;
- Extending from southeastern Antrim County through Otsego and into northern Crawford Counties;
- A fault within Ogemaw County;
- A long fault line extending from Kalkaska County through Crawford, Roscommon, Ogemaw and Arenac Counties;
- A small fault line extending from Missaukee County to Roscommon County;
- A fault line from Gladwin County to Bay County;
- A fault extending from Clare County to Gladwin, Midland, Bay and Tuscola Counties;
- A fault across Oceana County and continuing into Newaygo County;
- A fault from Osceola County through Clare, Isabella and Midland Counties;
- A fault extending from Sanilac County to St. Clair County;
- A fault across the borders of Saginaw, Genesee and Lapeer Counties
- from Shiawassee County through Livingston County;
- from borders of Livingston County through Ingham and Washtenaw Counties, and extending into Lenawee County; and

[42] Breeden, Charles H., *Measuring the Risks of Deep Well Injection*, Virginia Water Resources Research Center, Bulletin 122, Project A-066-VA, VPI-VWRRC-BULL 122, January 1980, p. 13.
[43] Actually injected liquids can cause increased pore pressure at a pre-existing fault already at or near a critical level of stress, triggering a release of seismic energy, i.e. an earthquake.
[44] Wood, James, Michigan Technological University and William Harrison, Western Michigan University, *Advanced Characterization of Fractured Reservoirs in Carbonate Rocks: The Michigan Basin*, December 2002, p. 3.
[45] Wood, James, Michigan Technological University and William Harrison, Western Michigan University, *Advanced Characterization of Fractured Reservoirs in Carbonate Rocks: The Michigan Basin*, December 2002, pp. 41, 45-47, 50; and Jim McClurg, Department of Geology and Geophysics, University of Wyoming, Antrim Shale Position Paper, undated.

- A small fault in northeast Lenawee County.

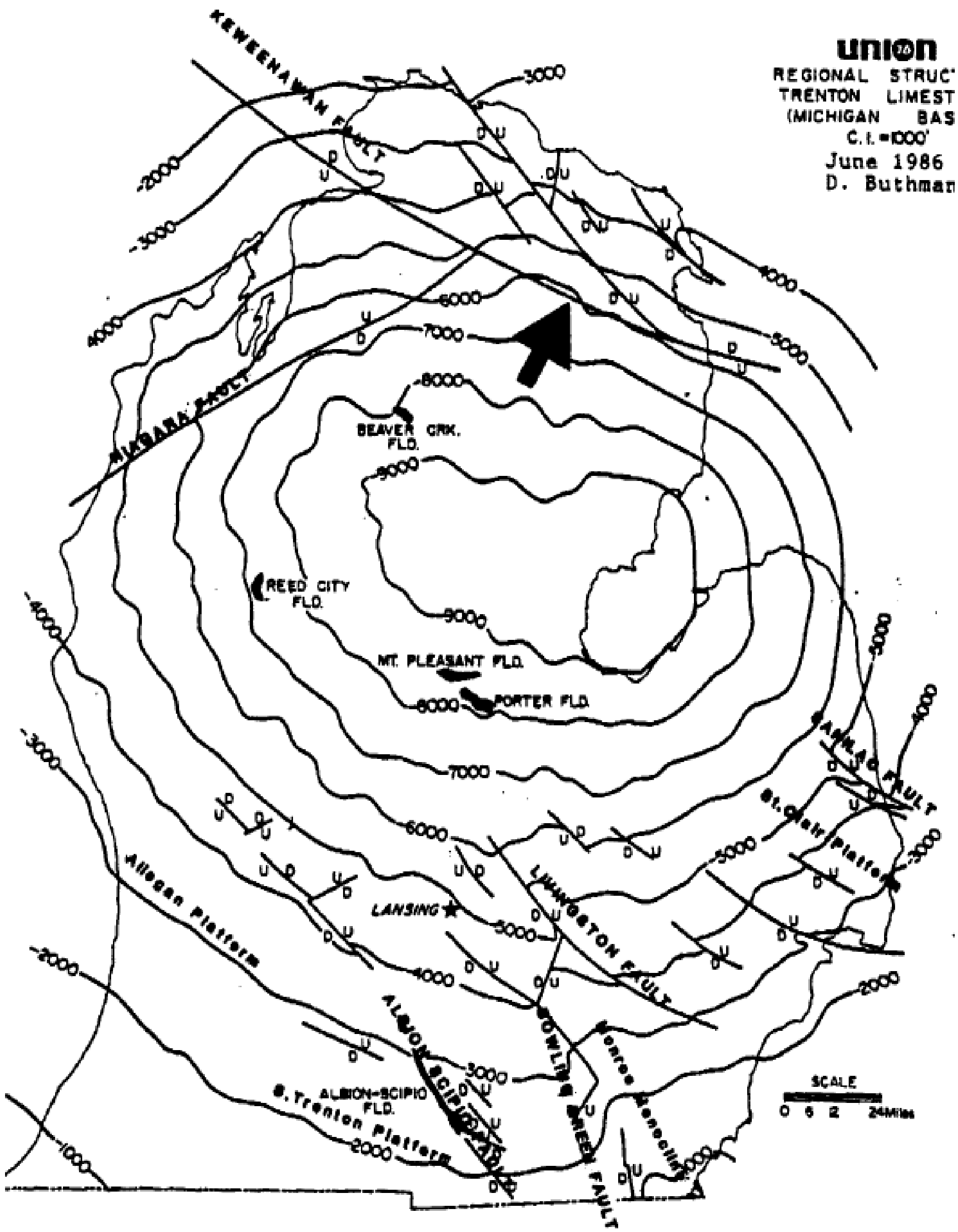
Refer to maps of Michigan basin faults on Pages 17 through 20.

Major Basin-scale Faults in the Michigan Basin



Source: Wood, MTU and Harrison, WMU, 2002, p. 41.

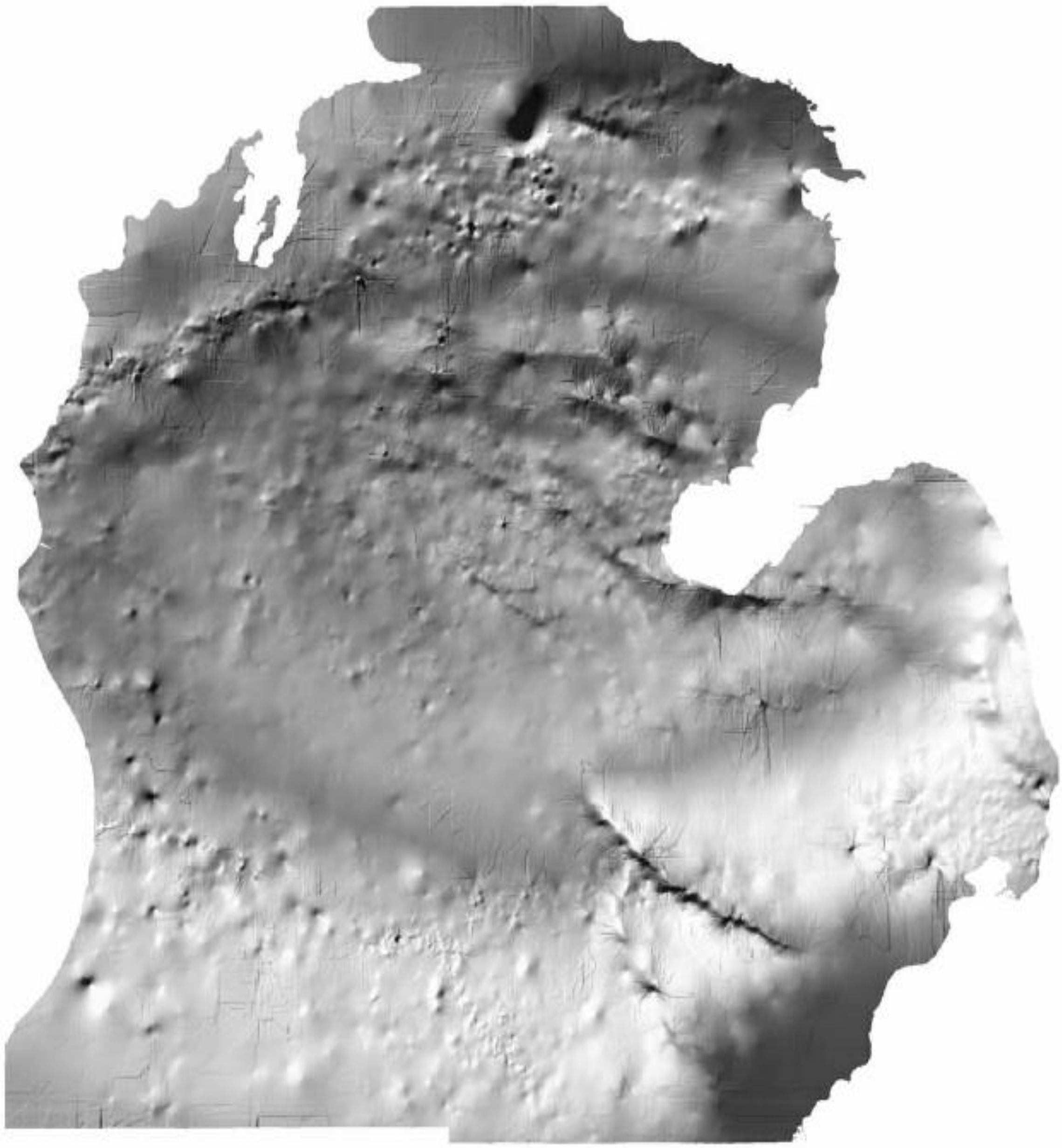
Major Faults Lines within the Trenton Group Limestones in the Michigan Basin



Source: Buthman, D., *Oil and Gas Potential of Northeast Michigan*, in T. Black, ed., <u>Karst Geology of the Northeast Lower Peninsula of Michigan</u>: Michigan Basin Geological Society Field Conference, 1995.

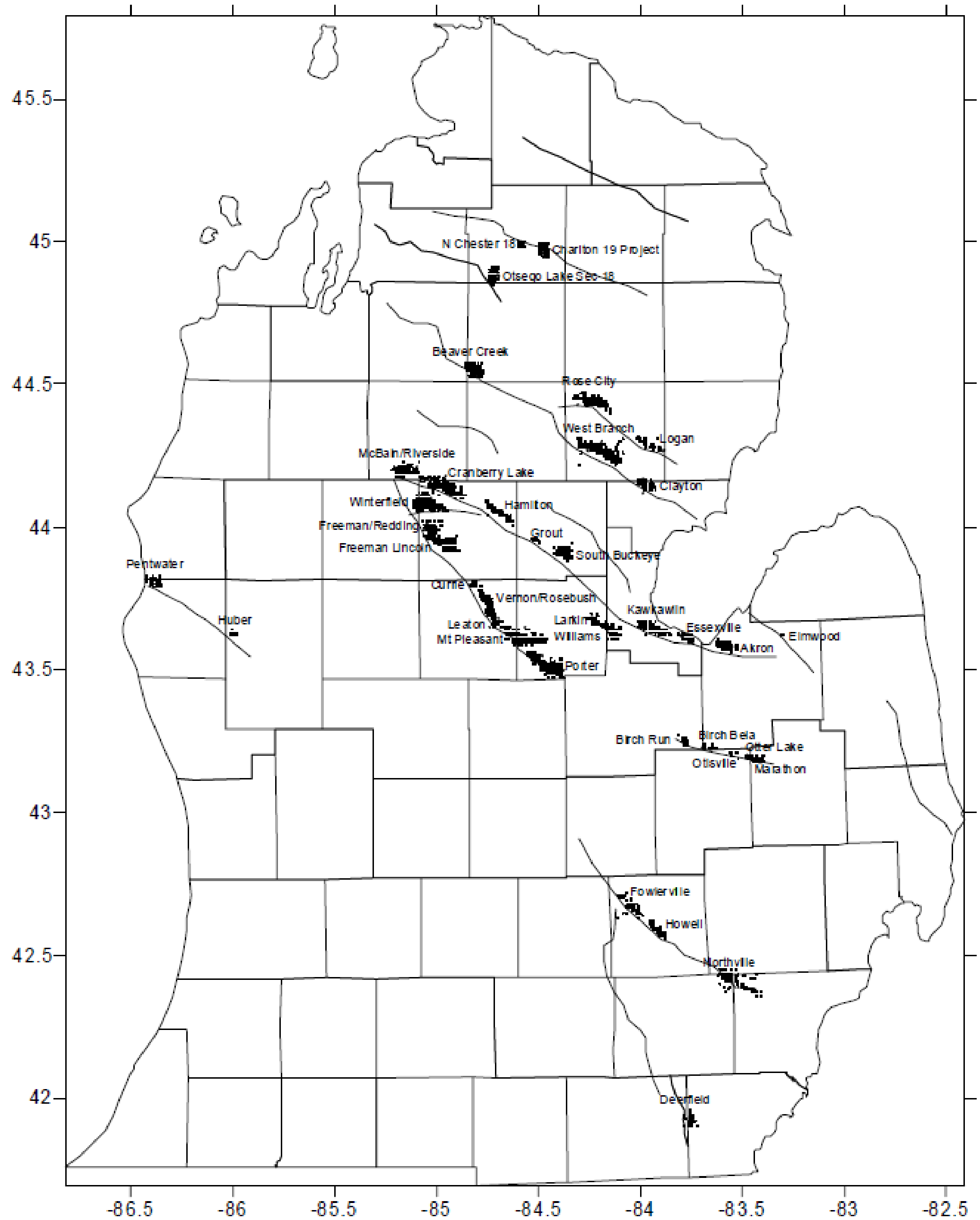
Notably, the Niagara and Keweenaw Faults are known to cut cross the tip of northern lower Michigan within the Paleozoic Trenton group limestone formations.

Structure Map of the Top of the Dundee Limestone Formation, Suggesting the Presence of Basin-wide Subparallel Faults



Source: Wood, MTU and Harrison, WMU, 2002, p. 47.

Large-scale Fault System and Major Oil and Gas Fields in Michigan



Source: Wood, MTU and Harrison, WMU, 2002, p. 50.

Moreover the is a "systematic relationship" between these faults and the number of oil and gas reservoirs in lower Michigan, as major hydrocarbon accumulations consistently occur in small anticlines on the upward thrown side of the faults.[46]

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[46] Wood, MTU and Harrison, WMU, 2002, p. 3.

According to studies, eighty (80%) percent of such spills at deep well injection sites are the result of human error, while the remainder are the result of mechanical failures of loss of system component integrity.[47] Examples include corrosion within pipelines and other system components, especially at welds and joints; plugging the well injection zone from high concentrations of suspended solids (especially > 2 parts per million); system fouling from calcium encrustation and/or iron oxidation (i.e. soluble ferrous ions precipitating as ferric iron when encountering oxygen); and fouling from the induced growth of naturally occurring bacteria with waste streams of high concentrations of organic carbon.[48]

The direct costs of such cleanups can range from a few thousand to several million dollars. Indirect or "externalized" and/or opportunity costs not borne by parties responsible for the investigation and remediation of such spills such as loss of property value, private litigation costs to compel regulatory compliance, the impairment or destruction of fish and wildlife, and other forms of environmental degradation are borne by private landowners and the public.

It has been my experience as an environmental consultant and as a former state regulator overseeing and performing soil and groundwater cleanups in northern lower Michigan, that the OGS' overall record in compelling regulatory compliance and achieving effective cleanups has been poor at some locations. Michigan's OGS is the only segment of the State's environmental oversight agencies that is largely funded by the industry it regulates, i.e. the oil and gas industry through permits and other fees.[49]

To reduce the risk of induced seismic events, the U.S. Geological Survey (USGS) recommends proposed deep well site review to include: 1) a survey of recent and history seismic activity in the area; 2) the measurement of stress in the reservoir rock; 3) an assessment of the absence or presence of faults; and 4) a determination that porosity and permeability of the reservoir rock can transmit and store waste at pressures well-below the failure pressure of the formation. If an area has a risk of seismic activity, a seismic monitoring should be established.[50]

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[47] Breeden, *op cit*., p. 21.
[48] Smith, *op cit.*
[49] Interlochen Public Radio, Points North Program, May 28, 2010.
[50] Ohio Department of Natural Resources, Division of Geological Survey, "*Geologic Considerations in Class I Injection*," April 20, 2005, http://dnr/state.oh.us/geosurvey.

Seismic Activity and Deep Well Injection in the Michigan Basin

Based on geophysical evidence, rift and fault complexes are known to exist within the Proterozoic bedrock basement Michigan basin.[51] Earthquakes have been recorded to have been felt in Michigan since 1811.[52] Other than occurrences in the western Upper Peninsula, earthquakes have been reported and/or recorded to have rocked Michigan on October 20, 1870; February 2, 1872 (three shocks); August 17, 1877; February 4, 1883 (intensity VI with shaking buildings and broken windows in Kalamazoo); August 31, 1886; October 31, 1895; March 13, 1905 (intensity V) felt at Menominee; February 28, 1925; November 1, 1935; March 2 and 8, 1937; September 4, 1944; August 9, 1947 (intensity VI with broken windows, fallen plaster, merchandise thrown from store shelves) felt throughout south-central Michigan; and November 9, 1968.[53] Yet the Michigan basin is considered to be at relatively low risk of seismic activity.

According to the USGS, the last earthquake originating within Michigan occurred on1994 September 2, 1994 and registered at a magnitude of 3.5. Refer to a map of this earthquake location on Page 24. The earthquake occurred west, northwest of the City of Lansing at a depth of 5 kilometers. On June 23, 2010 a 5.5 magnitude earthquake centered along the Quebec-Ontario boarder region in Canada was felt throughout central Michigan, in Chicago, Cleveland, and numerous cities farther east.

Importantly, it has been reported that deep well injection has been linked to multiple "induced" earthquakes caused by increased pressures and reduced fluid friction within naturally occurring brines over large areas in at least two (2) states.[54]

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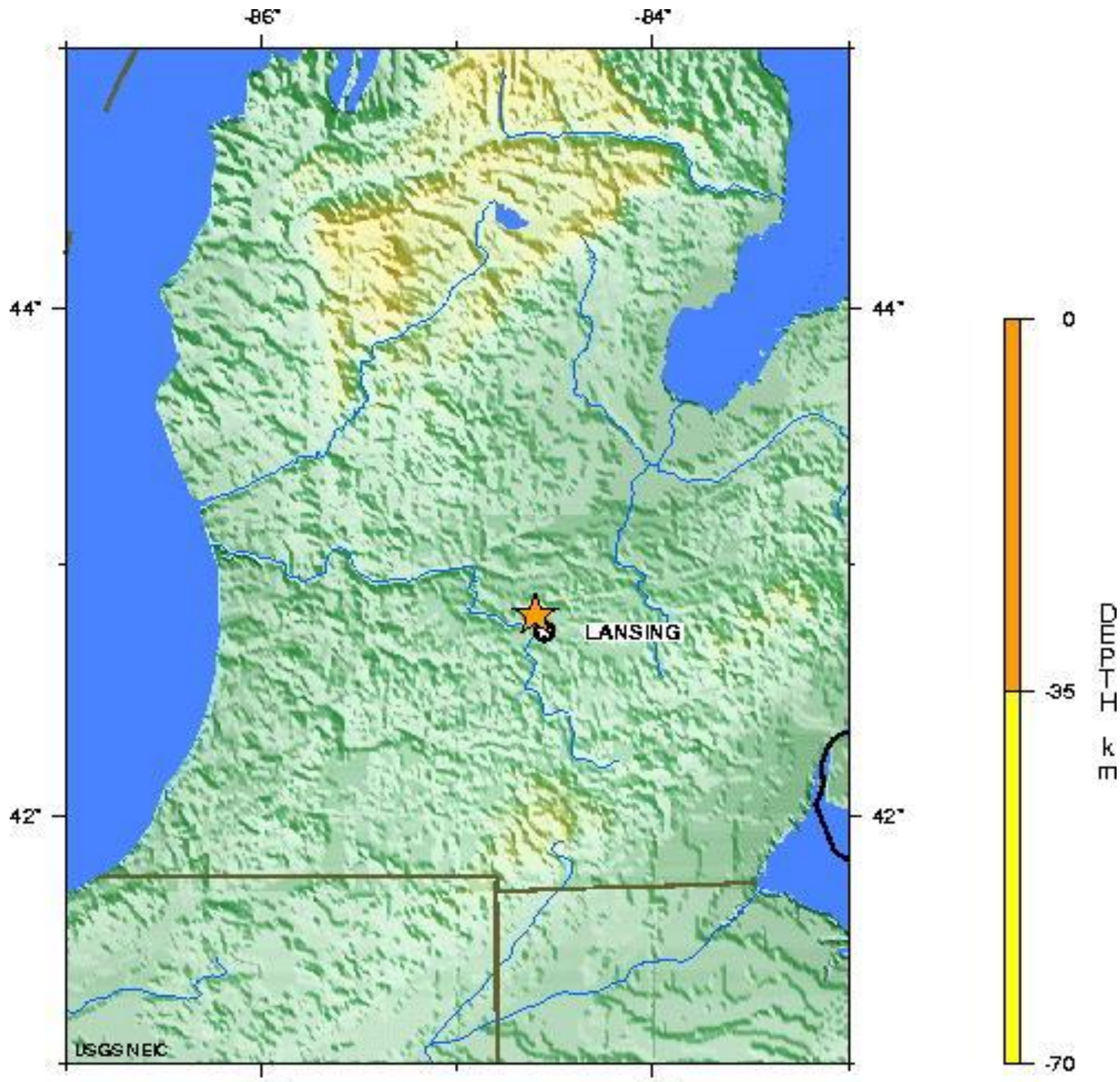
[51] First identified by regional gravity surveys and later confirmed by a 17,466 ft deep bore hole drilled in the center of the Michigan basin. See USGS Fracture Studies Summary: Fracture Patterns and Their Origin in the Upper Devonian Antrim Shale Gas Reservoir of the Michigan basin: A Review, Robert T. Ryder, Open File Report 96-23.

[52] USGS, Earthquake Hazards Program, Michigan: Earthquake History, www.earthquake.usgs.gov/earrthquakes/states/mijcigan/history.php.

[53] USGS, Earthquake Hazards Program, Michigan: Earthquake History, www.earthquake.usgs.gov/earrthquakes/states/mijcigan/history.php.

[54] Thornton, Joe, "A Shot in the Dark: Underground Injection of Hazardous Waste," A Greenpeace Report, July 1990.

Map of Most Recent Michigan Earthquake



MICHIGAN

1994 09 02 21:23:06 UTC 42.80N 84.60W Depth: 5 km, Magnitude: 3.5

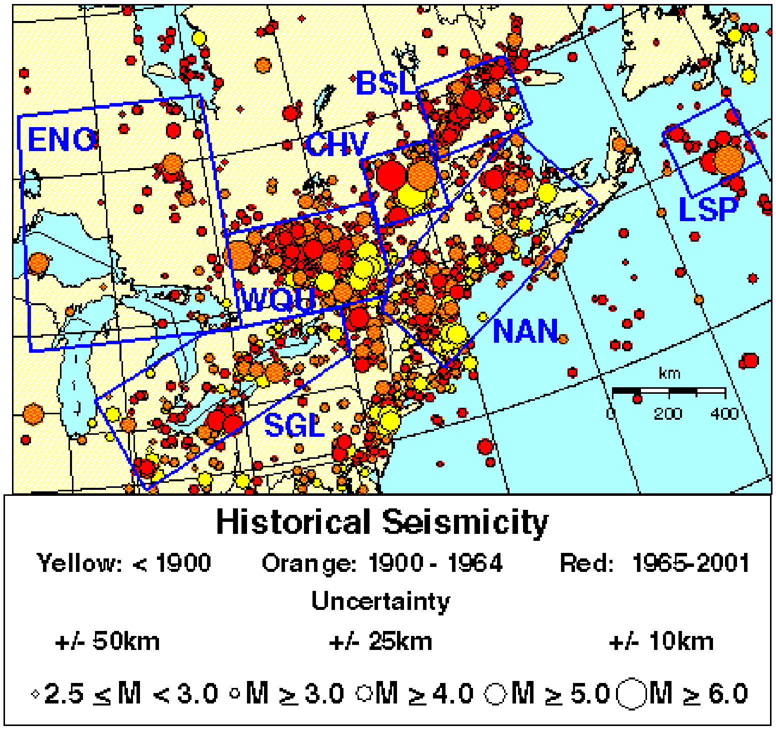
Earthquake Location

Major Tectonic Boundaries: Subduction Zones - purple, Ridges - red and Transform Faults - green

USGS National Earthquake Information Center

Source: USGS,
http://earthquake.usgs.gov/earthquakes/eqarchives/last_event/states/states_michigan.php

Location and Intensity of Historic Earthquakes: Before 1900 to 2001



This figure graphically shows the history of earthquakes in the Great Lakes and other regions, from before 19900 through 2001. Source: Natural Resources Canada, www.earthquakescanada.nrcan.gc.ca/zones/eastcan-eng.php.

Earthquakes Induced by Deep Well Injection

The increase of fluid pressure from the injection of liquids wastes in northeast Ohio and near Lake Erie by the Stauffer Chemical Company into a nearly 6,000 feet deep sandstone formation was implicated by Ohio University researchers to have triggered a 5.0 magnitude earthquake and two aftershocks on January 31, 1986.[55] Two and possibly three prior earthquakes in that area during 1983 are thought by researchers to have likely also been caused by the same deep well injection site.[56] The Ohio Geological Survey and other geologists determined that a sequence of earthquakes of magnitudes ranging from 2.6 to 4.3 that shook downtown Ashtabula, Ohio from 1987 to 2003 were caused by a nearby deep well site injecting hazardous waste fluids near two faults into a 5,900 feet deep basal sandstone formation.[57] The researchers state, "like many faults that rupture in … stable subcontinental region earthquakes, the faults were previously unknown…"[58]

[55] Nicholson, C., E. Roeloffs and R. L. Wesson, "The Northeastern Ohio Earthquake of 31 January 1986: Was It Induced?" Bulletin of the Seismological Society of America; February 1988; vol. 78; no. 1, pp 188-217; and Monastersky, Richard, "Waste Wells Implicated in Ohio Quake," Science News, August 27, 1988.

[56] Nicholson, C., E. Roeloffs and R. L. Wesson, "The Northeastern Ohio Earthquake of 31 January 1986: Was It Induced?" Bulletin of the Seismological Society of America; February 1988; vol. 78; no. 1, pp 188-217.

[57] Monastersky, Richard, "Waste Wells Implicated in Ohio Quake," Science News, August 27, 1988; and Seeber, Leonardo, John Armbruster and Won-Young Kim, "A Fluid-Triggered Earthquake Sequence in

A well-known series of more than 1,500 earthquakes, three over magnitude 5 are known to have occurred from military waste injection at the Rocky Mountain Arsenal near Denver between 1962 and 1967. USGS and University of California geologists also concluded in a 1993 study, "triggered (seismic) events can occur up to several years after (deep) well activities have begun (or several years after all well activities have stopped)… This suggests that the actual triggering process may be a very complex combination of effects, particularly if both fluid extraction and injection have taken place locally. To date, more than thirty (30) cases of earthquakes triggered by well activities can be documented throughout the United States and Canada."[59]

Deep Injection Wells and Not So Deep Injection Wells

Beeland/CMS proposed to construct a Class I nonhazardous deep injection well east of Alba in 2009. This well was intended to dispose of cement kiln dust (CKD) leachate from the up-scale Bay Harbor resort near Petoskey, a former cement manufacturing facility. The well is the subject of a court-ordered temporary injunction, but if built is proposed to inject into the Dundee Limestone/Detroit River Group at 2,450 feet below the surface. Most similar wells in northern Michigan inject nonhazardous liquid wastes into limestone or sandstone formations ranging from 2,118 to 4,391 feet deep, including the Northeastern Exploration well near Vienna Corners east of Gaylord which injects into the same formation at approximately 3,400 feet below the surface.[60] Unresolved questions remain regarding the fate and transport of liquid industrial wastes if injected into the comparatively shallow Dundee limestone and Detroit River Group formations near Alba, and the integrity of the overlying Bell and Antrim shales as capstone layers.

Integrity of the Antrim Shale

State and federal regulators reviewing deep well injection proposals in northern Michigan in 2009 and 2010 stress that upward migration of injected wastes within the Devonian-aged Traverse Group will be adequately contained by the overlying Upper Devonian Antrim Shale and Lower Mississippian Coldwater shale. A USGS study, however, finds "consistent northwest-southeast and northeast-southwest orientations of fracture sets in the Antrim Shale and adjacent Devonian strata across the northern margin of the Michigan basin."[61] Numerous other experts have found that the these shales are highly fractured, "(t)he Michigan Antrim Shale Formation is … a non-typical shale. It is brittle and as a result, is highly fractured increasing the porosity and more importantly,

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Ashtabula, Ohio: Implications for Seismogenosis in Stable Continental Regions, Bulletin of the Seismological Society of America; February 2004; vol. 94; no. 1, pp 76-87.

[58] Seeber *et al, op cit.*

[59] Nicholson, C., E. Roeloffs and R. L. Wesson, "Triggered Earthquakes and Deep Well Activities," Pure and Applied Geophysics, vol. 139; nos. 3-4, September, 1992, pp. 561-578.

[60] The Copper-Standard Automotive well in Otsego County injects nonhazardous liquid wastes in the Lucas/Dundee at 2,645 feet. The Hoskins Manufacturing well in Oscoda County formerly injected nonhazardous liquid wastes in the Lucas/Dundee at 2,903 feet.

[61] USGS Fracture Studies Summary: Fracture Patterns and Their Origin in the Upper Devonian Antrim Shale Gas Reservoir of the Michigan basin: A Review, Robert T. Ryder, Open File Report 96-23.

rendering the shale highly permeable."[62] Refer to a map of Antrim shale fractures on page 28.

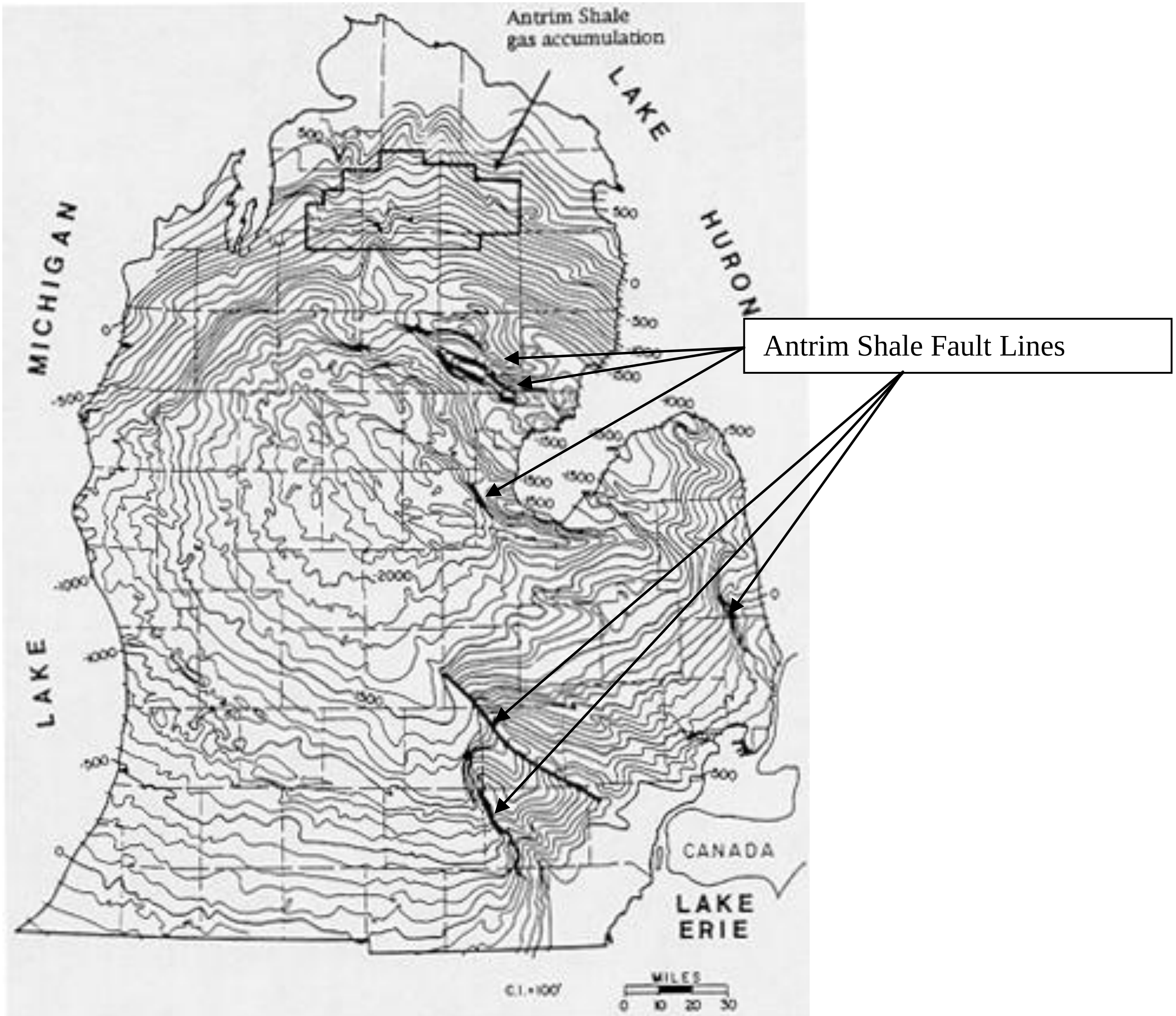
Geologists continue, "far-field Alleghanian (Appalachian Orogeny) compressional stress and associated strains may have had an important effect on Michigan basin tectonics and, consequently, on fractures in the Antrim Shale."[63] And "Post-Pleistocene isostatic adjustment of the crust following glacial retreat accounts for as much as 200 feet of uplift in the northern Michigan basin. Unloading of stored elastic strain in the Antrim Shale caused by glacial rebound may create horizontal (sheeting) fractures and open and (or) enlarge pre-existing sub-vertical fractures."[64] The USGS study concludes that the Antrim Shale east of Otsego County is "well-fractured," and "a direct relationship (exists) between fracture frequency and gas production (in Otsego County.)"[65]

[62] Professor Emeritus Jim McClurg, University of Wyoming, Department of Geology and Geophysics, Antrim Shale Position Paper, undated, and USGS Fracture Studies Summary: Fracture Patterns and Their Origin in the Upper Devonian Antrim Shale Gas Reservoir of the Michigan basin: A Review, Robert T. Ryder, Open File Report 96-23.

[63] Van der Pluijm and Craddock, 1993 as quoted by the USGS Fracture Studies Summary: Fracture patterns and their origin in the Upper Devonian Antrim Shale gas reservoir of the Michigan basin: A review, Robert T. Ryder, Open File Report 96-23.

[64] Farrand, 1962 as quoted by USGS Fracture Studies Summary: Fracture patterns and their origin in the Upper Devonian Antrim Shale gas reservoir of the Michigan basin: A review, Robert T. Ryder, Open File Report 96-23

[65] USGS Fracture Studies Summary: Fracture Patterns and Their Origin in the Upper Devonian Antrim Shale Gas Reservoir of the Michigan Basin: A Review, Robert T. Ryder, Open File Report 96-23.



Source USGS: Michigan basin and structure contour map of the Antrim Shale on the top of the Traverse Group (Fisher and others, 1988). http://pubs.usgs.gov/of/1996/of96-023/figure7.htm

Deep Well Injection and the Precautionary Principle

The precautionary principle states that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is harmful, the burden of proof that it is not harmful falls on those who advocate taking the action. This principle allows policy makers to make discretionary decisions in situations where there is evidence of potential harm in the absence of complete scientific proof. The principle implies that there is a social responsibility to protect the public from exposure to harm, when scientific investigation has found a plausible risk. These protections can be relaxed only if further scientific findings emerge that provide sound evidence that no harm will result. In some legal systems, as in the law of the European Union, the application of the precautionary principle has been made a statutory requirement.[66] Such a regulatory approach should be applied to the state and federal regulation of deep well waste injection in the United States.

Findings

Based on the preceding discussion, I offer the following findings.

1) Deep well injection is actually a form of waste storage as such liquid waste is typically untreated, often undiminished in quantity or toxicity, and merely relocated rather than detoxified or destroyed.

2) Factors to consider in locating deep injection wells include: a) travel distance from the waste source, and associated environmental and public safety risks in waste transportation to an injection site; b) the capacity of the geologic unit or "reservoir" to accept and confine the waste (i.e. porosity, permeability lateral extent, consistency and thickness of the reservoir); c) the structural geology of the setting (i.e. elevation of the injection zone in its geologic setting, density variation between injectate and naturally occurring brines, presence or absence of faults and/or fractures, and the potential for injection-induced earthquakes); and d) presence or absence of valuable mineral resources within the potential area of influence.

3) Numerous induced earthquakes have been documented from deep well injection of wastes in northeastern Ohio, central Colorado, and other locations in the U.S. and Canada.

4) A vast majority of releases to the environment at deep well injection sites are likely the result of human error, while the remainder the result of mechanical failures of loss of well system integrity.

5) Quantifiable environmental and human safety risks accompany the transport of liquid hazardous and non-hazardous wastes by truck from a source to deep well injection sites.

6) Twenty-two (22) or nearly thirteen percent (12.8%) of hazardous waste deep injection wells have "leaked or suffered holes."[67]

7) The U.S. General Accounting Office has documented twenty-three (23) cases nationally of drinking water contamination from the operation of deep wells injecting oil and gas wastes.[68]

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[66] http://en.wikipedia.org/wiki/Precautionary_principle.
[67] *Ibid.*
[68] *Ibid.*

8) Treated municipal sewage injected into bedrock formations at more than one-half (i.e. 42 of the 81) operational municipal deep injection well sites along south Florida's coastline have migrated upward into underground sources of drinking water.

9) Aside from well failure and injectate encountering an unplugged or improperly plugged deep well, the potential for upward migration along a naturally occurring geologic fault is likely the most serious threat to losing injected waste confinement within a reservoir formation in the Michigan basin.

10) Based on geophysical evidence, numerous fault complexes exist within the Paleozoic bedrock of the Michigan basin.

11) Antrim Shale and adjacent Devonian strata are highly fractured, brittle and highly permeable across the northern margin the lower peninsula of Michigan.

Conclusions

Based on the above, I offer the following conclusions and recommendations.

1) The U.S.EPA's regulatory focus in reviewing deep injection well permits is at the well head, i.e. well construction, depth and design, and is largely limited to protecting groundwater used as a drinking water source. The Michigan public is denied meaningful notice or participation in overall environmental and human health protection related to deep injection wells, such as DNRE, OGS' subsequent review of surface facilities associated with deep injection wells approved by the U.S. EPA. Both agencies present an "out of sight, out of mind" attitude when questioned about the ultimate fate and transport of liquid wastes deep injected in Michigan geologic formations.

2) Cumulative environmental and safety risks from waste transport (i.e. trucking, pipelines) and handling should be determined, effectively communicated to the public and considered by regulators within permitting of new deep injection wells or the conversion of existing deep wells to inject new liquid wastes. The travel distance between liquid waste sources and deep injection well sites should be minimized. On-site waste injection should be considered prudent and implemented whenever feasible.

3) Periodic aquifer monitoring should be required within appropriately placed groundwater monitoring or "sentinel" wells at and in the vicinity of deep well injection sites. Such monitoring should continue long-term following the proper closure and abandonment of a deep injection well.

4) A survey of the location and proper abandonment of old oil and gas and old deep injection wells in Michigan should be completed.

5) To reduce the risk of induced seismic events, proposed deep injection well site review should include: a) a survey of recent and historic seismic activity in the area; b) the assessment of existing stress in the proposed reservoir rock; c) a valid assessment of the absence or presence of geologic faults; and d) a reliable determination that the reservoir rock (i.e. porosity and permeability) can transmit and store waste at pressures well-below the failure pressure of the formation.

6) The regulation of future deep well injection of liquid wastes in Michigan should utilize the precautionary principle. This requires deep well injection into suitable formations with multiple, redundant capstones or "seal" layers between the injection zone and the lower-most groundwater drinking water source. The fate and transport of injected waste liquids should be more fully understood and effectively communicated to the public prior to permitting new deep injection wells.

7) The injection of liquid wastes within Silurian-Devonian formations at locations from which direct or potential hydraulic connection or "venting" to the Great Lakes or other surface waters should be prohibited.

8) The potential for the trespass of injected liquid wastes into neighboring mineral rights holdings should be better understood at deep well injection sites prior to regulatory approval.

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