DEEP WELL INJECTION OF HAZARDOUS WASTES IN OHIO

A senior thesis presented in partial fulfillment of the requirements for the degree of B.A. in Geology.

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INTRODUCTION

Deep well injection of hazardous wastes has been practiced for the past 17 years in Ohio. Over this period of time some problems have become apparent. I will identify some of these problems and present possible solutions to them.

The following key is used to identify each hazardous waste injection well site on figures 3 through 6.

KEY

SITE NUMBER	SITE NAME	NUMBER OF WELLS
(1.)	Armco Inc. (Armco) Middletown, Ohio Butler County	2
(2.)	Calhio Chemicals (Calhio) Perry, Ohio Lake County	2
(3.)	Chemical Waste Management (CWM) aka: Ohio Liquid Disposal (OLD) Vickery, Ohio Sandusky County	7
(4.)	Empire-Detriot Steel (Empire) aka: Empire-Reeves Mansfield, Ohio Richland County	1
(5.)	International Salt Co. (IS) Cleveland, Ohio Cuyahoga County	1
(6.)	Reserve Environmental Services (RES) Ashtabula, Ohio Ashtabula County	1
(7.)	USS Chemicals (USS) Haverhill, Ohio Scioto County	2
(8.)	Vistron aka: Sohio Chemicals Lima, Ohio Allen County	3

BACKGROUND

The first permits for class I, hazardous waste deep injection wells in Ohio were issued in 1967. During 1968 injection of hazardous wastes was initiated at Empire and Vistron. To date 19 wells have been approved, 18 drilled, and 16 are presently operating in Ohio. 2 wells have been plugged due to severe corrosion of the outer casing. As of 12-31-84, approximately 4.68 billion gallons of waste have been injected into the 18 drilled wells at an estimated rate of 316.8 million gallons per year. Table 1 summarizes well activity dates.

TABLE 1. WELL ACTIVITY DATES

FACILITY	WELL #	DATE PERMIT ISSUED	DATE OPERATIONAL	DATE PLUGGED
Armco	1	3-16-67	5-69	
	2	10-26-67	5-69	
Calhio	1	2-11-71	5-16-74	
	2	4-16-80	5-81	
CWM	1	7-75	6-07-76	8-20-79
	1A	9-05-79	9-27-79	
	2	1-28-76	3-21-77	
	3	1-28-76	8-31-77	
	4	1-28-76	8-31-77	
	5	6-11-80	9-10-81	
	6	6-11-80	9-10-81	
Empire	1	7-20-67	11-22-68	2-71
IS	1	6-71	5-72	
RES	1	3-24-85		
USS	1	5-02-68	10-01-69	
	2	11-16-77	6-79	
Vistron	1	1-25-68	6-28-68	
	2	7-03-69	12-69	
	3	7-15-71	1-73	

PERMITTING PROCESS

The Ohio Environmental Protection Agency (OEPA) is the primary authority involved in the permitting process of class I deep injection wells. There are 5 classes of injection wells. Class I injection wells are for the disposal of hazardous industrial waste. A party wanting to drill and operate an injecton well must do an extensive feasibility study of the proposed area and give the results to the OEPA. The OEPA, after determining if waste injection will contaminate ground or surface water, sends copies of the proposal to the Division of Geological Survey and the Division of Oil and Gas of the Ohio Department of Natural Resources, and to the Division of Mines of the Industrial Relations Department. These organizations review the proposal to determine if the injection of wastes may contaminate any fossil fuel or mineral resources. They then send their recomendations to the OEPA which approves or rejects the permit. If injection is approved, the applicant drills the well if there is no public opposition and gives the OEPA information on the well cores for review. At CWM and IS the wells were drilled before the permits were issued.

The OEPA has recently begun periodic reviews of the permits and site operations to ensure that the wells are operating as originally allowed in the permit. Reviews are also done of the required monthly well operating reports which are sent to the OEPA. The reports contain such information as injection pressures and volumes and amount of time operated.

Class I wells are regulated under the Resource Conservation and Recovery Act (RCRA) of 1976. RCRA deals with the proper handling and disposal of hazardous wastes. In the 1984 RCRA reauthorization, class I wells are to be abolished 44 months from 11-9-84. Presently, research is under way to determine if this is a feasible action. Figure 1 outlines the approving and permitting of class I wells. In figure 1, 3734.12 and 3745.05 refer to sections of RCRA which deal with deep well injection of hazardous industrial waste.

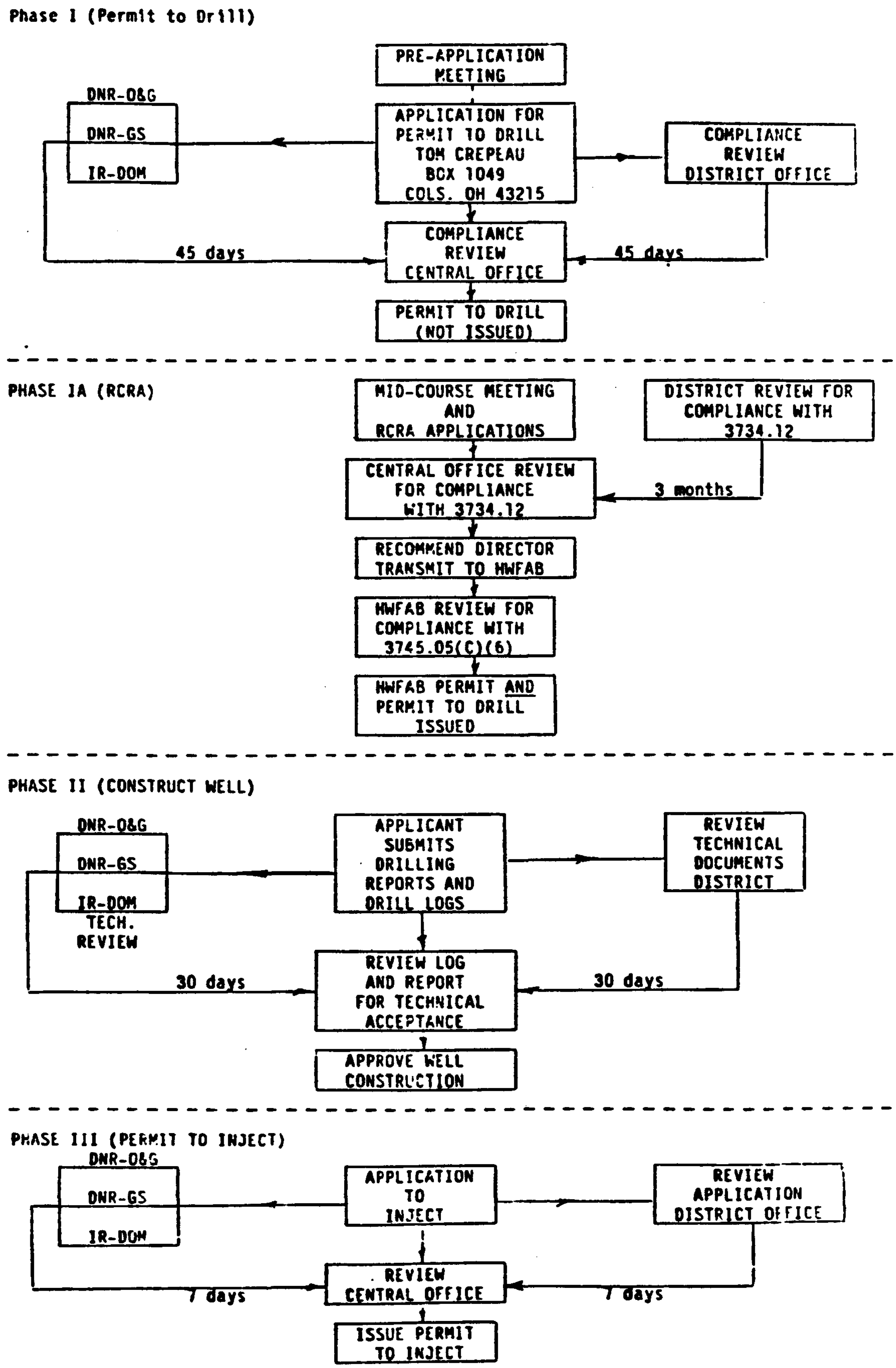


FIGURE 1 HAZARDOUS WASTE PERMIT APPLICATION

from: OEPA files

CONSTRUCTION OF DEEP WELLS

In general, the construction standards for class I wells are as follows. A surface casing is inserted into the drilled hole and cemented in place. This casing is supposed to extend below all fresh water aquifers in the area. An outer casing is then cemented into place from the surface to the top of the injection strata. The waste injection tubing is placed inside of the outer casing and is held in place by a packer at the bottom of the well between the outer casing and the injection tubing. The packer also prevents the injected wastes from migrating up through the annulus and holds the annulus fluid in place. The composition of the annulus fluid varies from site to site and may be composed of oil, treated water, or some other fluid.

Annulus fluid pressure is monitored as a check on the integrity of the well. An increase in pressure may mean that wastes are getting into the annulus either from an injection tubing leak or a packer failure. If there is a decrease in pressure there may be a casing leak allowing the annulus fluid and possibly injected wastes to escape to the surrounding rock formations. Therefore, it is very important to have a closely monitored annulus pressure system. At CWM the poorly monitored annulus system and lack of packers resulted in extensive casing corosion in all 7 wells. Figure 2 shows typical well construction.

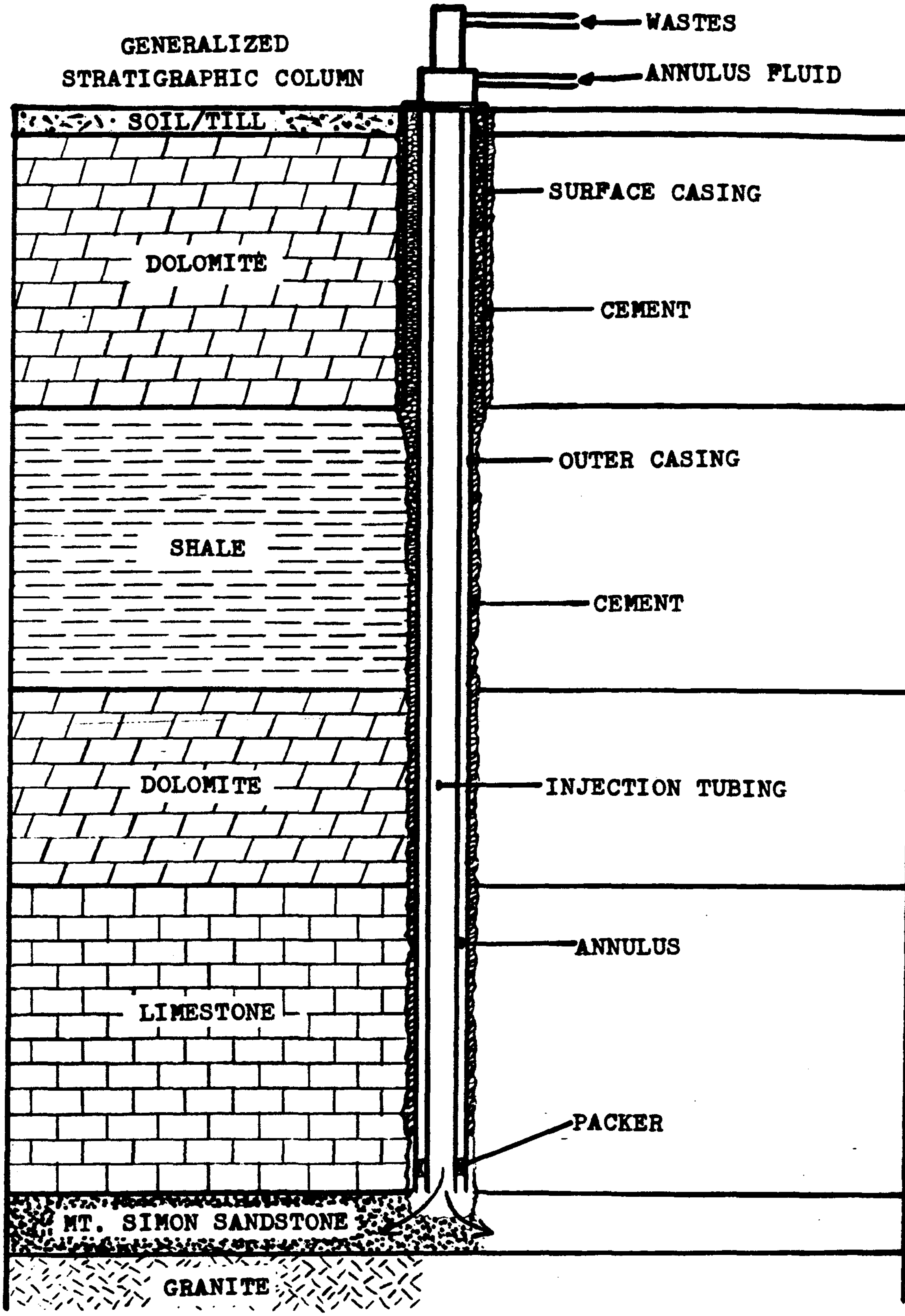


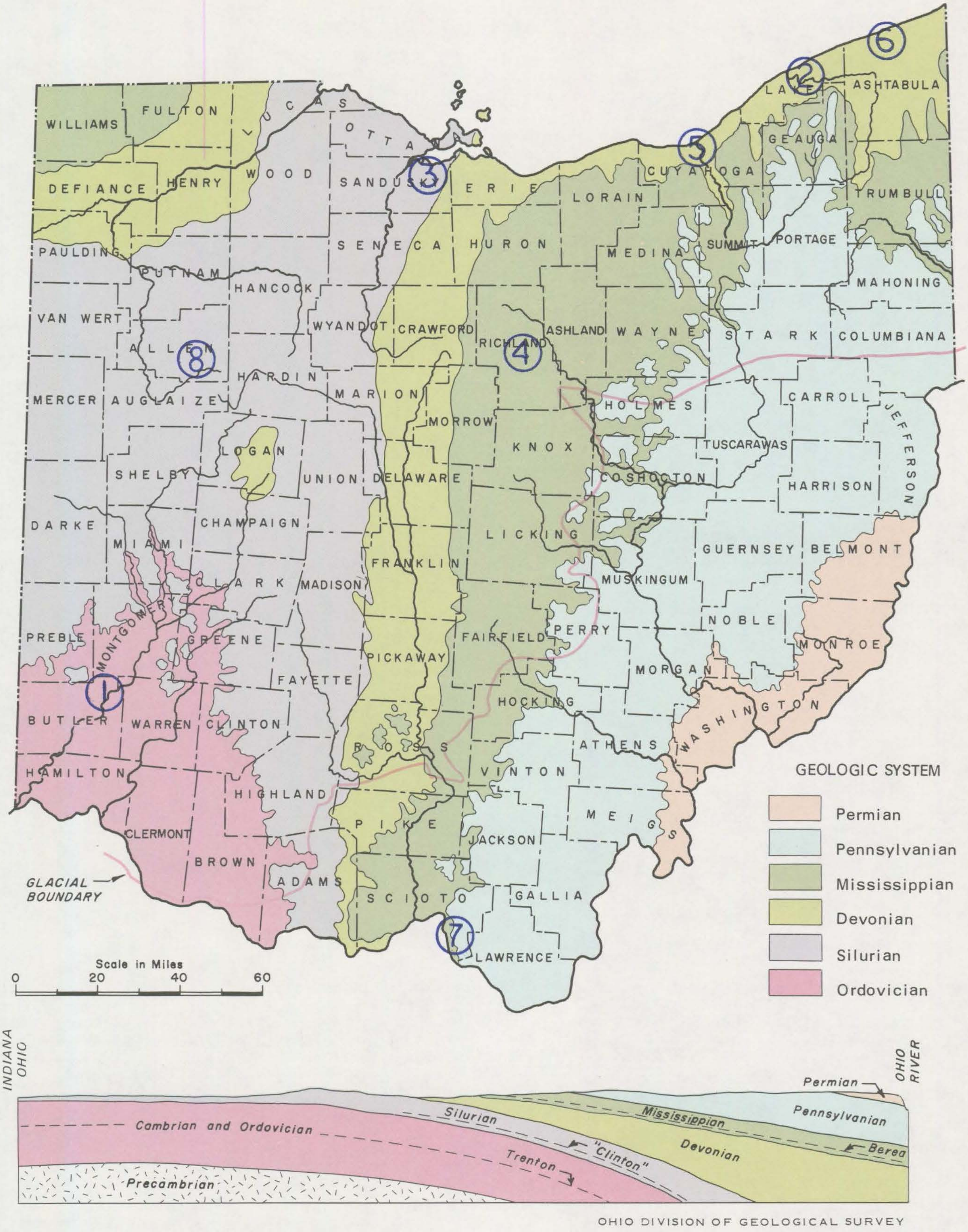
FIGURE 2 WELL CONSTRUCTION

GEOLOGY OF OHIO

In Ohio, the sedimentary strata dip gradually to the southeast from the Cincinnati and Findlay arches near the western side of the state. The geologic systems range from Precambrian and Cambrian in the subsurface to Permian. The prefered waste injection strata is the Cambrian aged Mt. Simon Sandstone which directly overlies the Precambrian granitic basement. The depth to the top of the Mt. Simon at injection sites in Ohio ranges from about 2780 feet near Lima to about 5948 feet near Cleveland. The Mt. Simon is saturated with a highly concentrated brine and is therefore considered by some to be unsuitable for anything but the disposal of hazardous wastes. The Mt. Simon is mostly fine to coarse grained sandstone with some interbedded shale and siltstone and is overlain by beds of dolomite, limestone, sandstone, and shale. The confining capacity of some of these beds is questionable because some of them are used as injection strata in some instances. Figure 3 is the geologic map and cross section of Ohio.

GROUND WATER

A possible serious threat to ground water is posed by deep well injection in Ohio. All of the sites utilize large lagoons for storing wastes until they are injected. Some of the lagoons are merely pits dug in the ground as at Vistron, and some are lined with clay. Over time all lagoons begin to leak, some sooner than others. Leaks occur when the fluid



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GEOLOGIC MAP AND CROSS SECTION OF OHIO

FIGURE 3

holding capacity of the soils surrounding the lagoons is exceeded.

Most of the lagoons are underlain by shallow potable aquifers which usually supply drinking water to the surrounding communities. Because of this, most of the sites monitor the groundwater in the surrounding area for contamination from the wastes.

The deep wells themselves also pose a threat to groundwater. If the outer well casing should develop leaks, the wastes may be injected into formations above the intended injection formations as at Armco, CWM, and Empire. Wastes may also migrate upward through fractures in the receiving and confining beds. Fractures may be natural due to tectonic forces or artificially induced to increase permeability. Another route for waste migration might be through cracks or holes in the cement surrounding the outer casing. Figure 4 shows locations of deep well sites with respect to ground water resources in Ohio.

OIL AND GAS WELLS

Many oil and gas fields have been discovered in Ohio since exploratory drilling began in the 1800's. Thousands of wells have been drilled to varying depths and the locations of many are unknown because initially drillers were not required to report their drilling activities. Until recently, many wells were either left unplugged or were not properly plugged. Because of this, the potential for injected wastes

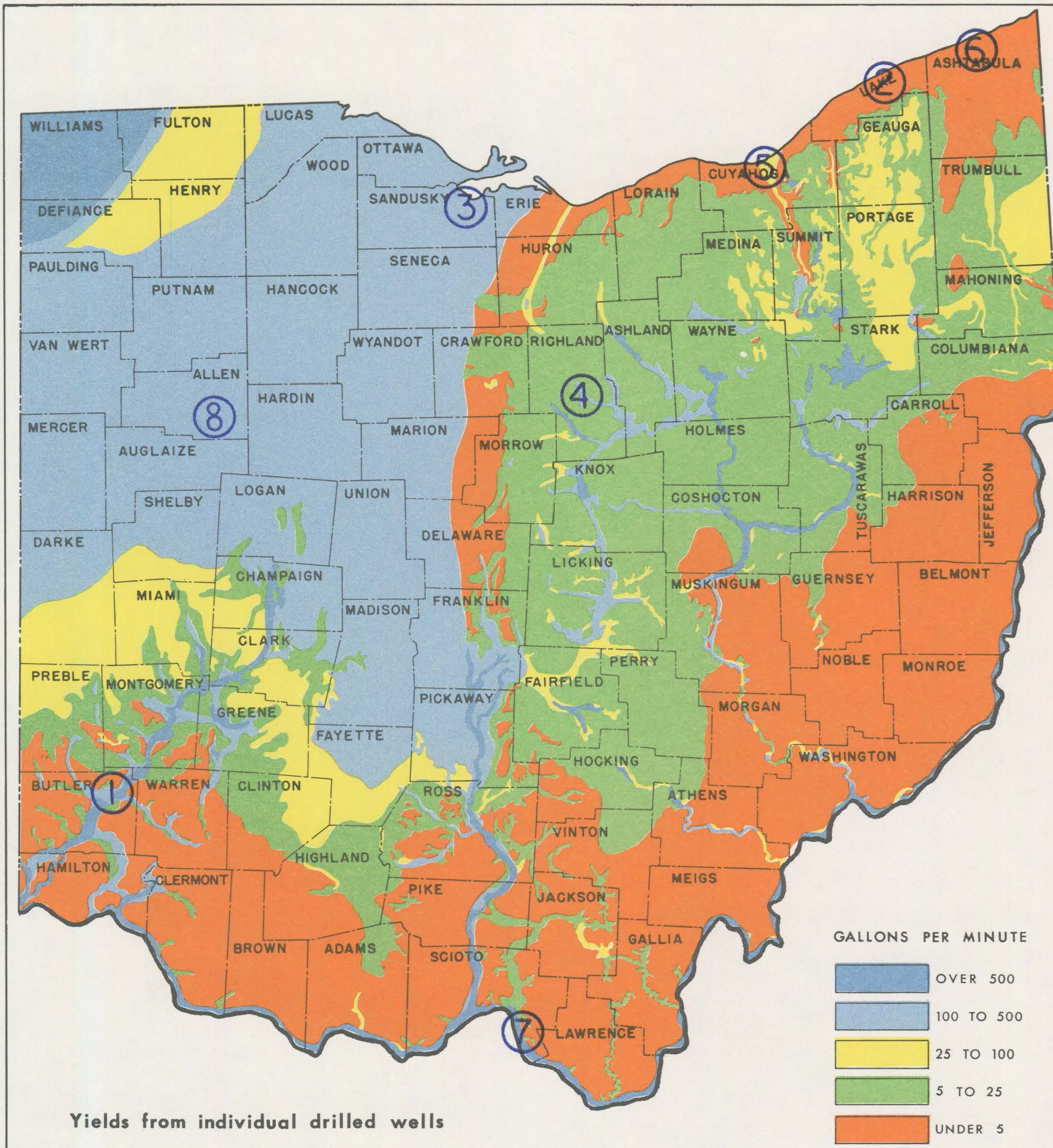


FIGURE 4

GROUND-WATER RESOURCES IN OHIO

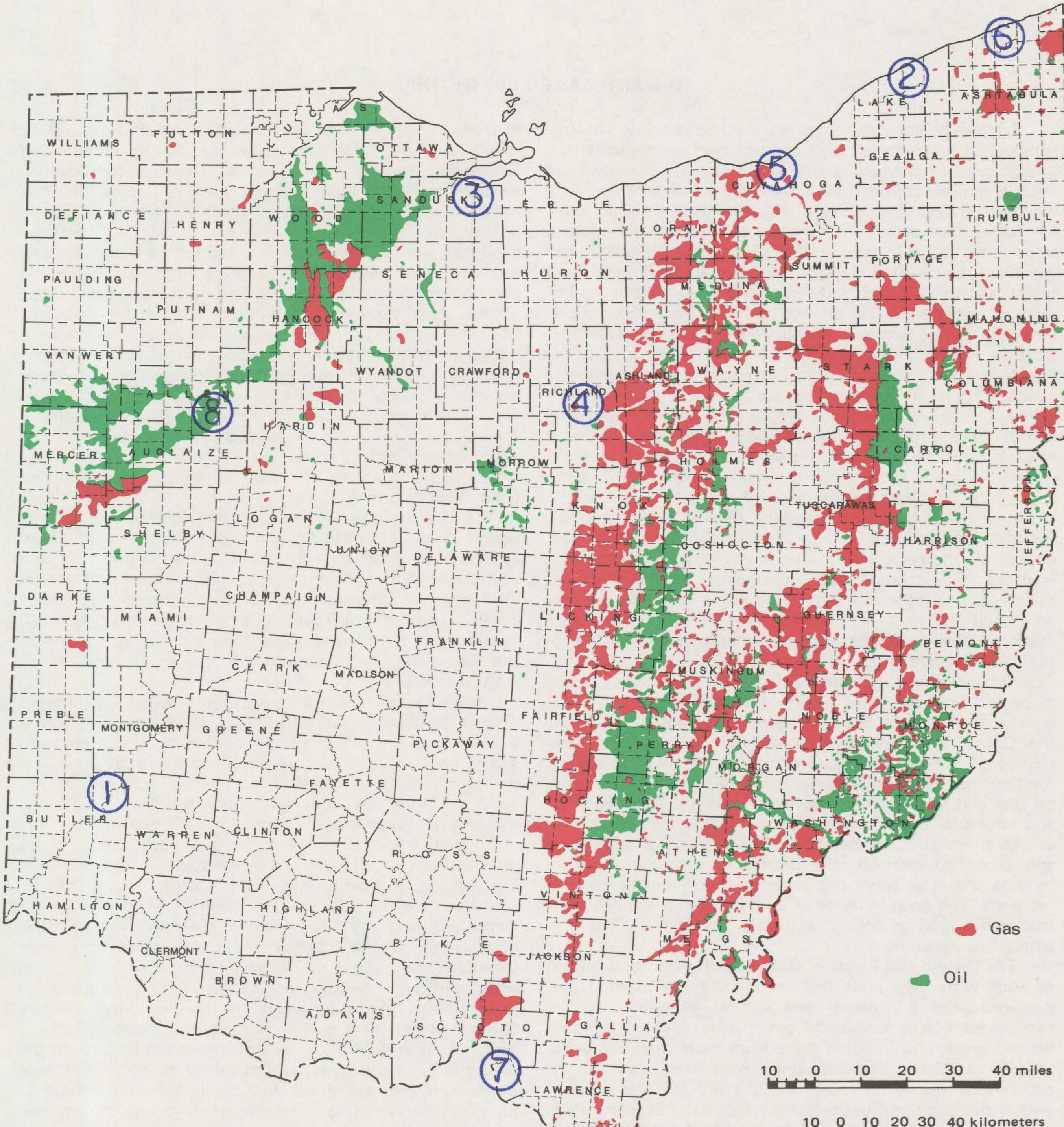
Ohio Department of Natural Resources
DIVISION OF WATER
Fountain Square
Columbus, Ohio 43224

reaching an improperly plugged oil or gas well definitely exists. If this should happen, the injected wastes under high pressures could migrate up the old unplugged, improperly plugged, cemented, or constructed well holes and contaminate fresh water aquifers. Keep in mind that oil and gas drilling has not been limited to the oil and gas fields, test wells have been drilled all over the state. Table 2 provides a summary of information on oil and gas wells drilled in Ohio. Figure 5 shows the locations of injection wells with respect to oil and gas fields in Ohio.

TABLE 2. NUMBER, DEPTH, AND LOCATION OF OIL AND GAS WELLS IN OHIO (through 1975)

PERIOD (Formation)	Estimated # of wells	Normal depth (ft)	Area of dense drilling
MISSISSIPPIAN/ PENNSYLVANIAN	100,000-150,000	500-2,000	Eastern/ Southeastern
SILURIAN/DEVONIAN (Clinton, Newberg, Oriskany)	51,000	1,500-5,000	East-Central
ORDOVICIAN (Trenton)	75,000	1,100-2,000	North western
CAMBRIAN-ORDOVICIAN (Knox)	3,000	2,000-3,000	Central
CAMBRIAN	150	3,000-5,000+	Widely scattered

from: Clifford, "Subsurface Liquid-Waste Injection in Ohio," 1975.



STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

FIGURE 5

OIL AND GAS FIELDS OF OHIO

Areas in which oil or gas is being produced or has been produced commercially since 1860.

A detailed version of this map, at a scale of 1 inch = about 8 miles, also is available. This more detailed map provides data on discovery date, depth, and producing horizon of individual pools, and stratigraphy. Natural gas and liquid petroleum storage areas in Ohio also are shown.

OIL AND GAS FIELDS OF OHIO

Petroleum and natural gas are hydrocarbons (complex compounds of hydrogen and carbon) that are thought by geologists to be chemically altered remains of life that once lived in shallow continental seas which periodically covered the land surface. The chemical constituents of these ancient life forms have undergone complex and imperfectly understood chemical changes in the process of alteration to petroleum and natural gas and have accumulated in the tiny spaces (pores) between individual grains of porous rocks such as sandstone. The oil and gas later moved through interconnections between adjacent pore spaces and accumulated in economically important concentrations known as "pools." Pools accumulate in geologic structures called "traps." Pools of hydrocarbons are not underground lakes, as the term might imply, but simply areas where petroleum and/or natural gas saturate the pore spaces in a porous stratum of rock, termed the "reservoir." The accumulation of oil and gas is aided when the reservoir rock in a trap is capped by an impermeable layer of rock, or "cap rock," which prevents further movement of the hydrocarbons. Petroleum traps are of many varieties and are a principal concern of the petroleum geologist involved in exploration. Hydrocarbon accumulations may occur at or near the surface or at depths of several thousands of feet. Subsurface accumulations may give no surface indication of their existence. The petroleum geologist prepares maps depicting the thickness and structure of various rock strata in order to determine the possible presence of hydrocarbon traps. These maps are prepared from information recorded during the drilling of oil and gas wells. These records are kept on file at the Ohio Department of Natural Resources, Division of Geological Survey. Additional data are obtained from highly sophisticated research devices known as borehole geophysical logs and from surface geophysical surveys. The thickness and structural attitude of potential hydrocarbon reservoirs can be inferred from these data. Through use of such data and other information, the petroleum geologist can determine the most promising areas in which to drill oil and gas wells. The great expense of each individual well requires that exploration be done scientifically and with a minimum amount of "guessing."

The Oil and Gas Fields of Ohio map depicts the location of areas within the state that are currently or have in the past produced oil (green) and natural gas (red). Hydrocarbons have been produced from different geologic units in various areas, and in some areas from more than one unit; indeed, petroleum and natural gas have been produced in commercial quantities from nearly every geologic system within the state, although each system has not necessarily produced oil and natural gas throughout the state. The oil and gas fields in the northwestern portion of the state, for instance, were the site of production in the late 1800's (beginning in 1884) from the Trenton Formation of Ordovician age. This field is now largely inactive. North-central Ohio, principally Morrow County, was the site of oil production in the 1960's from the Knox Dolomite (Trempealeau) of Cambrian-Ordovician age. Oil and gas have been produced in southeastern Ohio from comparatively shallow sandstones of Mississippian and Pennsylvanian age. The north-south trend of oil and gas fields in the east-central part of the state represents production principally from the "Clinton" sandstone of Silurian age. About 80% of the wells drilled in Ohio in 1977 were completed in the "Clinton" sandstone. Many other units have produced oil and gas in the eastern half of the state.

Ohio is not a leading producer of either petroleum or natural gas; however, in the late 1800's Ohio was the leading area in the world in production of these fuels, principally from discoveries in the Trenton Formation in northwestern Ohio. The state may be able to lay claim to the first oil well in the United States, drilled in 1814 in Noble County in search of salt, although Colonel Drake's famous well drilled at Titusville, Pennsylvania, in 1859 ranks as the first well drilled specifically for oil. Commercial drilling of oil and gas wells began in Ohio soon after Drake's discovery, possibly as early as 1859, and by 1860 was a full-scale enterprise, which continues to the present. Large discoveries of natural gas in the state gave rise to numerous industries, many of which are still active.

Shortages of hydrocarbons in recent years have spurred drilling activities in Ohio; in 1977 more than 2,500 new wells were drilled. Production from active oil and gas wells in the state in 1977 was valued at more than $275 million per year; slightly over half of the value is from gas. Oil and gas production in Ohio is of much assistance in supplementing the supplies of energy to Ohio's industries.

The Ohio Department of Natural Resources, Division of Geological Survey, in cooperation with the U.S. Department of Energy and other agencies, has begun an intensive examination of the geology of the shales of Devonian age in the eastern half of the state. The objective of this project is to find ways to extract the large quantities of natural gas known to be contained in this shale. Although the existence of gas in the Ohio Shale has been known for many years, it has been economically feasible to extract it only in limited areas because, in most areas of the state, the gas cannot move readily through the pore spaces in the shale. Utilization of detailed knowledge of the Devonian-age shales, in conjunction with techniques of artifically creating fractures through which gas can migrate to the well bore, may open a new chapter in production of natural gas in Ohio.

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EARTHQUAKES

Certain areas of Ohio have a history of recurring earthquake activity. Earthquakes frequently result in fracturing of the surrounding rock. Because of the fractures, it would be risky to inject wastes in or near areas of earthquake activity because of the probability of the receiving and confining beds being fractured. Calhio, IS, RES and Vistron are located in sections of Ohio where many earthquakes have been recorded. It would seem that these areas may be risky for deep well injection and an especially stringent monitoring program should be in place to detect any migration of wastes.

Deep well injection may cause earthquakes. Injection practices near Denver, Colorado in the early 1960's resulted in many earthquakes until the injection was stopped. Figure 6 shows the locations of deep wells with respect to earthquake activity in Ohio.

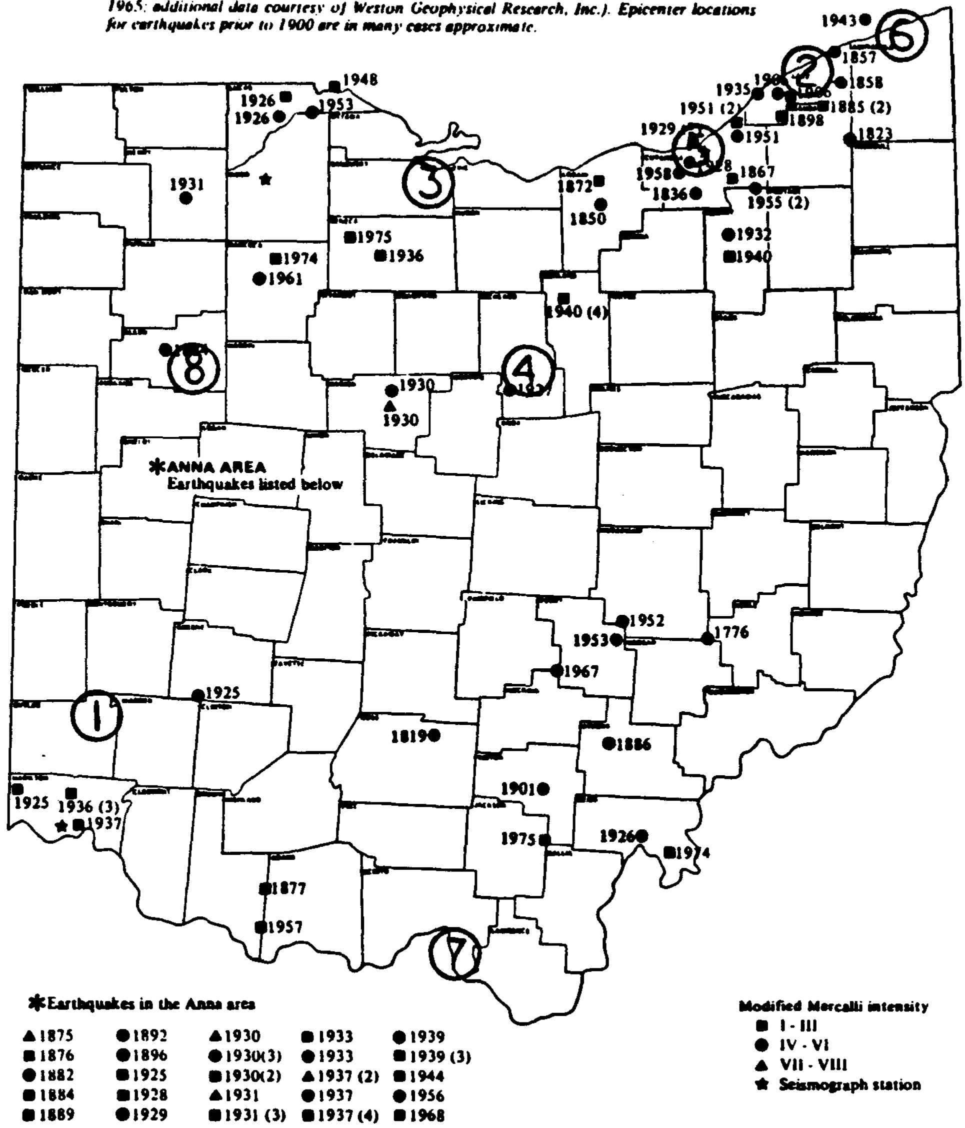
INJECTION OUTCOME POSSIBILITIES

THE BALLOON EFFECT

The balloon effect is a special term I developed to demonstrate the similarities between filling a balloon with air and filling a geologic formation with fluid.

Imagine blowing up a balloon. With each successive breath, pressure builds up inside of the balloon and pressure is exerted on the skin of the balloon. Now seal the balloon

Locations and intensities of earthquakes in Ohio (modified from Bradley and Bennett, 1965; additional data courtesy of Weston Geophysical Research, Inc.). Epicenter locations for earthquakes prior to 1900 are in many cases approximate.



Modified Mercalli intensity scale

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck.

IV. During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.

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FIGURE 6 EARTHQUAKES IN OHIO

and let it sit for a few days. The trapped air eventually dissipates through the skin and the balloon reaches the equilibrium it was at before it was blown up. Blow the balloon up again, only this time do not stop, continue blowing until the skin reaches its limit of elasticity. As expected the balloon explodes from too much internal pressure. Now, blow another balloon up and when it is filled pierce the skin and it explodes, spewing its contents to the surrounding area of lower pressure. The balloon is in equilibrium once more.

Now imagine injecting wastes into a formation with relatively impermeable confining layers. Pressure builds with each successive gallon injected. If injection is stopped, the fluids under built up pressure eventually dissipate (probably through overlying beds) allowing the system to reach equilibrium. If injection is continued, the confining beds may rupture when their limit of elasticity is reached. (This is actually what happens during the intentional fracturing of injection strata.) Another possibility which may happen when the receiving formation is under extreme pressure, is an earthquake occurring. If this happened and the confining layers were fractured, the injected wastes and native brine could be forced up out of the injection strata and into higher layers. The extent of flow out of the injection strata would depend upon the amount of built up pressure behind the fluids.

These examples demonstrate the importance of allowing the built up pressures to dissipate by periodically halting the injection of waste. Another precaution would be to inject wastes at much lower pressures than presently allowed to put less strain on the receiving and overlying beds.

OTHER PHYSICAL EFFECTS

In some of the injection wells, the receiving strata have in some way been intentionally fractured or stimulated (injected with acid or some other such treatment to clear clogged pores) to improve their injection capacity. Normally, wastes are injected between the grains and cement of the receiving strata. Because these pore spaces are so small, high injection pressures are needed to force the wastes in and to compress the fluids and grains of the receiving formation. If the strata surrounding the wells is fractured, the wastes can be injected into the cracks at much lower pressures. It is generally believed that fractures propagated at depths over a few thousand feet in geologic formations such as are found in Ohio are primarily vertical in orientation, therefore the wastes would probably migrate upward when injected into fractured beds. There is a strong possibility that the overlying beds are fractured at the same time the receiving beds are fractured which could lead to wastes migrating much higher than anticipated. Fracturing may be accomplished by explosions or by forcing a large amount of fluid into the formation in a short period of time. When fluid is used, the fractures are usually propped open with sand. The injected wastes probably push these sand grains further into the continually propagated fractures causing the maze of fractures to increase. I would like to note that even though fracturing is considered a dangerous practice, it is done anyway with or without the approval of the OEPA and the ODNR. This practice should be absolutely prohibited in hazardous waste injection wells.

A very important consideration is that the space in the Mt. Simon sandstone is limited. If we continue injecting treatable wastes, this space will be used up prematurely. It may be prudent to save this limited space for highly toxic untreatable wastes and possibly radioactive wastes. We must also consider where the native brines would be displaced to if most of the Mt. Simon were filled with wastes.

CHEMICAL EFFECTS

Many different chemical reactions have been known to happen when hazardous wastes are injected into deep wells. Chemical precipitation has occurred when certain wastes have adjusted to the temperature and conditions of the subsurface. This precipitate plugs pores which results in an increase in injection pressures. Bacterial growth has also caused pores to become plugged. Neutralization of some wastes is thought to occur. Some wastes develop stratified flow patterns when they come into contact with brine because of density differences.

Some reactions that have not been observed to happen but which are possibly occurring or may occur in the future include the formation of more toxic chemicals, the formation of gases which could eventually lead to explosions and fracturing, and solution channels forming when certain acidic wastes flow through fractures in carbonate beds.

Since all of the Mt. Simon brine that has been collected for analysis has been contaminated with drilling fluids, there is no way of accurately determining the reactions which could take place between the brine and waste. Also, the combination of subsurface conditions such as high pressure, heat, and reactions of waste in contact with formation rock and brine are unobtainable in a lab to simulate actual injection conditions.

In an effort to prevent chemical reactions from taking place between the injected wastes and the native brine, a buffer zone of water is injected in hopes of delaying contact between the wastes and brine. Table 3 shows the types of wastes injected.

TABLE 3. TYPES OF WASTES INJECTED

FACILITY	WASTE TYPE
Armco	Spent hydrochloric acid pickle liquor containing iron chlorides, benzene, napthalene, 2-nitrophenol, phenol, and tetra and trichloroethylene.
Calhio	Waste fungicides from the manufacture of Captan and Folpet.
CWM	At least 800 different hazardous industrial wastes high in soluble salts and heavy metals. pH < 2.0.
Empire	Spent sulfuric acid pickle liquor with iron, copper, and zinc. pH < 2.0.
IS	Native Oriskany formation brine.
RES	Titanium dioxide wastes from paint manufacturing.
USS	Phenolic waste water containing alpha methyl styrene and acetone.
Vistron	Acrylonitrile waste water containing sulfate, ammonia, cyanides, aldehydes, nitrites, amides, and organic acids.

EXAMPLES OF WELL FAILURES

PENNSYLVANIA

The Erie, Pennsylvania Hammermill Paper Company well #1 was shut down on 4-14-68 after its outer casing and injection tubing suddenly came out of the ground. The well which received 150,000 gallons of corrosive paper processing waste per day spewed a 20 foot high geyser of wastes out of the open hole. The approximately 200,000 gallons of waste per day comming out of the well were dumped into Lake Erie. After 3 weeks and the escape of about 4 million gallons of waste, the well was capped.

The eruption was caused because the wastes leaked through the injection tubing to corrode the outer casing at the 889 foot level. The outer casing was cemented down to 830 feet. The high injection pressures (approximately 1,250 psi) caused pressure to build up under the cement and the subsequent eruption of the well.

COLORADO

During the early 1960's, the Rocky Mountain Arsenal near Denver, Colorado utilized deep well injection to dispose of waste warfare chemicals and their byproducts. Anywhere from 2 to 9 million gallons were injected per month at pressures of up to 1,050 psi. Over a 4 year period, 710 earthquakes measuring up to 4.3 on the Richter scale were recorded. When the injection stopped, so did the earthquakes.

CALCULATION OF INJECTION PARAMETERS

The following calculations are used to set limits for injection pressures and to determine the zone of waste invasion in deep injection wells.

MAXIMUM SURFACE INJECTION PRESSURE (P)

$$P=(0.75D)-(PgD)$$

where: 0.75 = The geostatic pressure gradient which is based on the degree of slope of the receiving bed. Unit = psi/ft.

D = Depth to the highest well perforation or top of open hole. Unit = ft. Therefore, the deeper the well, the higher the injection pressure.

Pg = Pressure gradient of disposal fluid. It is found by multiplying the specific gravity of the disposal fluid by the pressure gradient of fresh water which equals 0.433psi/ft. Unit = psi/ft. Therefore, the lower the specific gravity of the injection fluid, the higher the injection pressure.

In this calculation, 0.75 is an arbitrary number used to determine generally safe conditions for injection. 0.75 does not take into account areas of weak geologic structures. An example would be areas of natural or artificial fractures. If the injection pressures into fractured rocks are too high, the fractures may be opened wider or propagated, intensifying the problem of wastes flowing through the fractures instead of through the pore spaces. Therefore, 0.75 should be changed for each site depending on conditions to provide maximum safety. Table 4 shows pressures.

TABLE 4. PRESSURES

FACILITY	WELL #	MAXIMUM ALLOWABLE INJECTION PRESSURE (psi)	MAXIMUM APPLIED INJECTION PRESSURE (psi)	ESTIMATED FRACTURE PRESSURE (psi)
Calhio	1	1,690	2,900	2,400
	2	1,690	3,500	2,020
CWM	1A	840	3,300	1,300
	2	840	1,350	1,300
	3	840	1,550	1,300
	4	840	1,600	1,300
	5	840	1,900	1,300
	6	840	2,500	1,300
Empire	1	NA	2,350	NA
USS		1,711	7,000	4,500
Vistron		845	1,250	NA

RADIUS OF INVASION OF INJECTED FLUID (R)

$$R = \sqrt{\frac{V}{7.48 \pi H \theta}}$$

where: R = Radius of invasion of injected fluid. Unit = ft.

V = Total volume of fluid injected. Unit = gal.

7.48 = Number of gallons per cubic foot. Unit = gal/cubic ft.

π = 3.14

H = Thickness of formation injected into. Unit = ft.

θ = Average porosity

In this calculation, the radius of invasion of injected fluids is based on average porosity usually determined from 1 or 2 small samples from well cores. The calculation does not include conditions such as layers of highly impermeable or permeable rock, or density differences between waste and brine, which could cause a stratified flow pattern. It also does not include the very important parameter of permeability, the ability to transmit fluid. Porosity, the percent of pore space, cannot by itself be used to determine the ability of a rock to transmit fluid. For example, pumice is very porous, but very impermeable and therefore will not transmit fluids. Also, when wastes are injected, they probably do not fill up 100% of the available pore space.

From this calculation, the radius of invasion turns out to be a perfect cylinder shape. In reality the injected wastes flow through the areas of least resistance such as highly permeable layers and fractures. So there is no way of really knowing just where the wastes will end up once they are injected. The calculation also does not account for the area of invasion of the displaced brine which is pushed ahead of the injected wastes. Therefore, this calculation shows a conservative waste front and not the actual waste front and pressure front of the wastes plus brine. Table 5 lists injection strata information and table 6 lists volumes injected.

TABLE 5. INJECTION STRATA INFORMATION

FACILITY	INJECTION STRATA	AVERAGE POROSITY (%)	AVERAGE PERME-ABILITY (md)*	AVERAGE DEPTH (ft)	AVERAGE THICKNESS (ft)
Armco	Mt. Simon	13.1	25.1	2940	283
Calhio	Maynardville	6.8	4.2	5488	147
	Rome			5702	43
	Mt. Simon	8.8	2.9	5938	126
CWM	Mt. Simon	14.0	30.0	2803	115
Empire	Mt. Simon	10.4	16.5	4960	NA
IS	Oriskany	NA	NA	NA	NA
USS	Mt. Simon	12.0	26.8***	5514	66
Vistron	Mt. Simon	16.1	80.0** ***	2787	354

*md = millidarcy = .001 Darcy. 1 Darcy = That permeability which will allow the flow of 1 cc/sec. of fluid of 1 centipoise viscosity through a cross sectional area of 1 square cm under a pressure gradient of 1 atm/cm in the direction of flow.

**When tests were run, certain low permeability samples were excluded.

***These samples were tested with gas instead of fluid. Because gas may infiltrate porous media easier than fluids, these figures are probably too high.

TABLE 6. VOLUMES INJECTED AS OF 12-31-84

FACILITY	WELL #	TOTAL GALLONS INJECTED	GALLONS INJECTED PER YEAR*
Armco	1	126,710,146	8,132,900
	2	83,454,939	5,356,500
		210,165,085	13,489,400
Calhio	1	247,489,056	23,392,000
	2	39,150,774	10,936,000
		286,639,830	34,328,000
CWM	1	33,859,200**	10,581,000
	1A	116,746,506	22,238,000
	2	72,364,137	9,337,300
	3	107,636,331	14,685,000
	4	131,388,248	17,925,000
	5	36,537,921	11,242,000
	6	19,723,916	6,068,900
		518,258,259	92,077,200
Empire	1	10,314,933	4,584,000
IS	1	17,665,851	1,657,200
RES	1	0	
USS	1	573,363,000	37,721,000
	2	183,401,000	33,345,000
		756,764,000	71,066,000
Vistron	1	751,292,673	44,945,000
	2	1,375,059,876	90,925,000
	3	765,665,256	63,743,000
		2,881,817,805	199,613,000
TOTALS		4,681,625,773	316,810,800

*These numbers are averages. In some cases injection rates may presently be greater or lesser.

**This number is estimated.

BENEFITS

If injection wells are properly located, constructed, operated, and monitored, deep well injection can be beneficial in that highly toxic untreatable wastes can be disposed of fairly safely. Since the flow of the Mt. Simon brine is considered to be very slow under normal noninjection conditions, the wastes should not migrate very far from the site in a short time span. However, injecting wastes under high pressures will speed up the brine flow. Also, it is not known exactly where the brine flows or discharges.

Unfortunately, at least 1 of the desired criteria is violated at every deep well injection site in Ohio. Calhio, IS, and Vistron are located near areas of relatively frequent earthquake activity. The strata surrounding Calhio, CWM, and USS have been artificially fractured. Armco, CWM, and Vistron are located where the Mt. Simon sandstone is less than 3,000 feet from the surface, thus if a problem does occur, ground water may be more easily contaminated than at deeper well sites. CWM wells were constructed without packers. Armco, CWM, and Empire have been operated when it was known or suspected that the outer well casings were leaking. And finally Armco, CWM, Empire, Vistron and possibly Calhio, USS, and RES inject wastes that can otherwise be treated or destroyed.

It turns out that deep well injection in Ohio is not so beneficial under the present system. The above violations should be eliminated to make deep well injection a beneficial and safe disposal method.

COSTS

Many times it turns out that injecting wastes is much cheaper than any other disposal method and for this reason the practice is increasing in Ohio. Some times it is merely more convenient to inject wastes than to recycle them. For example, spent pickle liquors can be used to treat certain caustic waste waters. This practice would greatly reduce the costs of waste water treatment. Some wastes can be reduced in volume or toxicity by modifying the processes that produce them. Other wastes can be biologically degraded, incinerated, or otherwise treated.

It is recognized that not all wastes can be reduced, recycled, or treated, and it is these wastes that are suitable for deep well injection. But because the system is abused, many wastes are injected that should not be.

An important cost to consider is the cost to society if the improperly injected wastes should find their way to natural resources such as fossil fuels, minerals, and drinking water. If this happened, these resources would be unuseable for many generations, if indeed they would ever be useable again.

TABLE 7. COSTS

FACILITY	PREVIOUS DISPOSAL METHOD	PREVIOUS DISPOSAL COST	DEEP WELL COST
Armco	Release untreated to Great Miami River.	0	Well installation $358,000 (2 wells) Equipment $290,000 Operating cost $50,000/year
Calhio	Discharge to Grand River via Red Creek	0	Well installation $600,000 (2 wells) Equipment $1,000,000 Operating Cost $100,000/year
Empire	Release into Rocky Fork Creek	0	Not available
I.S.	Release untreated to Cuyahoga River	0	Not available
USS	None, installed deep wells when plant was built.	0	Well installation $480,000 (2 wells) Equipment $630,000 Operating cost $110,000/year
Vistron	Incineration and biological degradation	$600,000 per year	Well installation $372,000 (2 wells) Equipment $735,000 Operating cost $60,000/year

SUMMARY OF SITES

(1.) ARMCO INC.

Armco injects approximately 13.5 million gallons of spent hydrochloric acid pickle liquor per year into 2 injection wells. There have been problems with casing corrosion in these wells. Prior to injection, the wastes are stored in holding lagoons. Before the wells were installed, the wastes were released untreated to the Great Miami River.

It has been determined that the Mt. Simon Sandstone in the area is highly fractured. This accounts for the normally low injection pressures of around 30 psi, although at times the injection pressure has been as high as 500 psi as during 1972.

(2.) CALHIO CHEMICALS

Calhio uses its 2 deep wells for the disposal of approximately 34.3 million gallons per year of waste fungicides. Prior to installing the wells, the fungicides were discharged into Red Creek which in turn flows to the Grand River. These fungicides are stored in a 2 million gallon settling pond prior to disposal. Unlike most other sites in Ohio which inject into the Mt. Simon Sandstone, Calhio also ulilizes the overlying Rome Dolomite and Maynardville Sandstone. All three of these beds have been artificially fractured.

Calhio is located in the north east portion of Ohio near an area of recurring earthquakes. Because of artificial and possibly natural fractures surrounding the wells, a very stringent monitoring system should be in place.

(3.) CHEMICAL WASTE MANAGEMENT

CWM is the only deep well injection site in Ohio which collects wastes from many different companies for disposal. In fact because CWM has accepted at least 800 different wastes, no one knows for sure what the exact composition of the injected waste is at any one time. The composition changes with each load of waste chemicals brought in. Approximately 92.1 million gallons of waste per year are injected into 6 wells. 1 well has been plugged.

The incoming wastes are stored in a series of huge lagoons before they are injected. Because all of the different wastes are mixed together in the lagoons, chemical reactions frequently take place and clouds of chemical fumes form over the lagoons and drift across the surrounding houses. There is always a strong chemical odor surrounding the area.

The lab samples are disposed of on site by dumping them down a sink which is hooked up to a septic tank. At times chemical reactions cause the chemicals to bubble back into the sink. The amount of waste disposed of in this manner is probably thousands of gallons.

In 1958, CWM started out as a waste oil hauling business called Don's Waste Oil and in 1961 began accepting hazardous wastes which were stored in unlined oil pits. By 1964, now Ohio Liquid Disposal (OLD), they had received so much hazardous waste that they had to construct additional lagoons for storage. On July 4, 1969 when the swelling chemical lagoons over flowed during a heavy rain storm the neighbors again realized the dangers posed by the site and renewed protesting it, but to no avail. In 1972, a test well was drilled and OLD applied for a permit to inject the wastes into this well. The permit was denied by the Water Pollution Control Board. OLD continued accepting chemical wastes and building additional lagoons and in May of 1975 the decision not to inject was overruled by the Toledo Court of Appeals because they thought that a deep injection well would be the only way to get rid of the millions of gallons of accumulated wastes. In July of 1975, 3 additional deep well permits were issued and injection was initiated into well #1 on April 29, 1976.

The surrounding neighbors continued protesting the site and OLD continued accepting wastes, digging additional lagoons, and drilling more wells. OLD also fractured the lower formations in all of the wells. When well #4 was fractured with explosives, fluids spewed 20 feet into the air. Sometime around 1978 OLD was bought by CWM. CWM was ordered to reduce the amount of wastes stored in the lagoons because of the numerous incidents of chemical clouds and fumes forming over them. CWM's response was to continue accepting more wastes.

The wells at CWM were constructed without packers and as a result, the injected wastes migrated up the annulus spaces and corroded holes through the casings. For years, CWM continued injecting wastes through the corroded wells into all of the formations between the Precambrian basement rock and the limestone aquifer.

The OEPA had Underground Resources Management, a consulting firm, do a study on CWM and found out about the illegal injection activities. It is estimated that more than 60 million gallons of wastes were injected through corroded casings into the formations between the Mt. Simon Sandstone and the limestone fresh water aquifer. In June of 1984, CWM was fined $10 million to be paid over a 10 year period to the state while they continued operations, with the stipulation that they bring the site into compliance with OEPA regulations.

(4.) EMPIRE-DETROIT STEEL

The Empire well was one of the first hazardous waste injection wells in Ohio. Due to the highly corrosive nature of the injected waste sulfuric acid pickle liquor, the well had to be plugged during 2-71 after less than 3 years of use because it was discovered that most of the outer casing had dissolved. This was deduced when the injection pressures dropped steadily from the initial 1,300 psig to around 330 psig near the end of the injection period. It is assumed that the wastes were injected into formations higher than the Mt. Simon because of the severe casing corrosion. During operations, Empire injected approximately 4.6 million gallons per year into the well.

The Empire well is located in the area of the abandoned Newburg gas pool with many active and abandoned gas wells surrounding the injection well. The extent of plugging of the abandonded gas wells is unknown and the wells could possibly serve as a route for the injected wastes to migrate away from the injecton site.

Prior to installing the well, Empire released the wastes to Rocky Fork Creek and has been sending the wastes to CWM for disposal since closing the well.

(5.) INTERNATIONAL SALT

The IS well is classified as a class I well the same as the other wells but it is different, native brine (approximately 1.6 million gallons per year) and not hazardous industrial waste is injected. Because the brine results from an industrial process, the well had to be permitted as class I. At the IS mine in Cuyahoga County, brine from the Oriskany Sandstone drains into the mine shaft. This brine is pumped to the surface and injected back into the Oriskany formation about 600 feet from the mine shaft.

The injection well was initially drilled as an observation well in 1959. As of 1-83 the well was not in operation due to corrosion and leaks in the pumping equipment. Prior to injection and since the well has been inoperable, the brine has been and is now discharged to the Cuyahoga River.

(6.) RESERVE ENVIRONMENTAL SERVICES

RES received their class I permit during 3-85 and drilling of the well was scheduled to begin 5-85. They will be disposing of titanium dioxide wastes high in dissolved metals from the SCM Corp. The proposed injection rate is 50-150 gallons per minute. The wastes are presently being stored in lagoons.

(7.) USS CHEMICALS

USS injects approximately 71.1 million gallons of phenolic waste water per year into their 2 wells which are the deepest in Ohio. The wells were installed when the plant was built. Both wells have been fractured with acid, water, and sand. There have been problems with casing corrosion. The accuracy of their monthly reports is questionable because the volumes are rounded off to the nearest 1,000 gallons.

(8.) VISTRON

Vistron is located near the most active earthquake area in Ohio and injects a larger volume of wastes than any other site in Ohio (approximately 200 million gallons per year). Core analysis has shown slikensided fractures in the Mt. Simon Sandstone indicating fracturing by faulting. The Mt. Simon being only 2,787 feet deep is shallower here than at the other sites.

The injected acrylonitrile wastes precipitate upon cooling and have caused plugging in the Mt. Simon, necessitating injection pressures as high as 1250 psi. The wastes which are stored in unlined lagoons were previously incinerated and biologically degraded. When it was determined that deep well injection was cheaper, the wells were installed. I found no information on ground water monitoring wells.

CONCLUSIONS

Lack of adequate enforcement of deep well injection regulations by regulatory authorities has led to serious abuses practiced by deep well operators. These abuses have led and will lead to the very serious unrepairable problem of wastes migrating out of the injection strata and into higher formations. This may cause contamination of ground water, fossil fuels, and mineral resources.

A possible solution is for the regulatory authorities to strictly enforce injection to be performed on a low pressure intermittent basis only. Injection in areas of intense fracturing should be prohibited as should the injection of wastes which can otherwise be treated or destroyed. The shallowest depth for an injection well should be at least 5,000 feet in most cases.

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