OHIO RIVER VALLEY WATER SANITATION COMMISSION

UNDERGROUND INJECTION OF WASTEWATERS in the OHIO VALLEY REGION

Recommendations for the conduct of regulatory actions including the scope and sequence of administrative procedures and the evaluation of geological and technological factors

developed by the
ORSANCO Advisory Committee on Underground Injection of Wastewaters

AUGUST 1973

An Interstate Agency Representing: Illinois • Indiana • Kentucky • New York • Ohio • Pennsylvania • Virginia • West Virginia

members of the commission

(as of June, 1973)

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OHIO RIVER VALLEY WATER SANITATION COMMISSION

414 Walnut Street Cincinnati, Ohio 45202

August 1973

Foreword

Some six years ago the member states of the Ohio River Valley Water Sanitation Commission (ORSANCO) concluded it would be of mutual interest to appraise policies, procedures and other matters allied to the growing practice of subsurface disposal of industrial wastewaters. Execution of this comprehensive assessment resulted in a report titled "Perspective on the Regulation of Underground Injection of Wastewaters."

This document, which was submitted to the commissioners of ORSANCO on December 1, 1969, addressed itself to: (1) the status of subsurface disposal practice; (2) the questions it provokes with respect to public policy, legislative and legal issues; and (3) suggested procedures to satisfy administrative needs, geological evaluation and technological considerations. It was developed by Edward J. Cleary and Don L. Warner, consultants to the ORSANCO staff.

One suggestion in this assessment was that ORSANCO invite a committee of chief geologists from the eight states and a representative from the U. S. Geological Survey to review the Cleary-Warner findings and offer its recommendations on appropriate policy and procedures. Such a committee was created and its deliberations resulted in the report now presented. Acting on a committee recommendation the Commission adopted on January 11, 1973, a statement of policy concerning underground injection. This statement is reproduced on a following page.

Meantime, the committee endorsed a Cleary-Warner proposal that ORSANCO be charged with the establishment of a registry on injection-well systems in the eight states. In turn, the U. S. Geological Survey found merit in supporting the initiation of such an undertaking and made available a $35,000 grant for this purpose.

Under guidance of the committee and with the cooperation of state agencies the registry is now nearing completion. It reveals that from 1941 to the present some 50 wells have been developed. Of this total, 32 are in operation and 18 others are in categories of standby, continued development or abandonment. Details are documented with respect to pressures, volumes, injection rates, depths, formations used, composition of wastewaters and malfunctions.

In publishing this report the Commission acknowledges with appreciation the efforts of those who contributed to its formulation.

ROBERT K. HORTON
Robert K. Horton
Executive Director
and Chief Engineer

August 1973

Contents

Policy Statement

RESOLUTION NO. 1-73
Policy on the Underground Injection of Wastewaters
Adopted: January 11, 1973

WHEREAS: Underground injection is a technically acceptable method of wastewater disposal or long-term storage whereby pollutants can be removed from the surface environment and placed in isolated underground locations; and

WHEREAS: The techniques, trained personnel and organizations are available within the ORSANCO district for evaluation of the geologic and engineering feasibility of underground disposal and for determination of the risks, if any, that may exist to public health and to the environment;

NOW, THEREFORE: Let it be resolved that the Ohio River Valley Water Sanitation Commission does declare as a policy that wastewater injection may be used when the regulatory authorities with legal jurisdiction have considered other alternative methods of waste management, and that, after weighing all available evidence, have determined that:

I. Underground injection is the best available alternative in the specific circumstances of the case;

II. Geologic and hydrologic conditions will, beyond a reasonable doubt, provide adequate protection of the public and natural resources;

III. The volume, chemical and physical composition, and toxicity of the fluid to be injected are compatible with the geologic and hydrologic conditions;

IV. The necessary safety factors and monitoring devices are incorporated in the design of the injection well and its auxiliary facilities;

V. The waste injection system will be operated in a manner compatible with the geologic conditions, waste character, and system construction;

VI. An approved alternative plan for waste management is available in the event that operational problems occur during the use of the injection system;

VII. The injection well will be properly plugged and marked before abandonment;

VIII. A permanent public record will be kept which documents the complete operational history of the injection system.

Administrative Procedures

Seven steps are identified as essential in the administration of a state program for regulation of the underground injection of wastewater. An additional step is recommended for wells located near state boundaries. The steps are:

1. Preliminary assessment by the applicant of the geology and geohydrology at the proposed well site and the suitability of the wastewater for injection. These initial studies should be made in consultation with the appropriate state agencies;

2. Application to the state agency with legal jurisdiction for permission to drill and test a well for subsurface wastewater injection. The application must be supported by a report that documents all details of the proposed injection system, including monitoring and emergency standby facilities. On issuance of a permit, the applicant will be informed of the geologic and geohydrologic parameters that will be employed by the state in reaching its final determination on feasibility of wastewater injection into the well, anticipated limitations on injection pressure and injected volumes, the probable monitoring requirements, and probable requirements for alternative wastewater management programs in the event that operational problems occur during the use of the injection well;

3. Drilling and evaluation of the well and submission of samples, logs, test information, and a well-completion report to the state;

4. Request by the applicant for approval to inject wastewater into the well. The request should indicate any changes from the original plan in system construction and operating program;

5. Evaluation by the state agency of the proposal on the basis of which it would issue either approval, approval-with-modification, or disapproval of the proposed injection system with respect to the geologic, geohydrologic, and engineering data submitted. On approval, the applicant will be provided with specific instructions as to the operating restrictions and monitoring requirements;

6. Issuance of instructions for operation of the injection system. This embraces requirements that the regulatory agency must be notified immediately if operational problems occur, if remedial work is required, or if significant changes in the wastewater stream are anticipated;

7. Procedures for abandonment of the well in accordance with state regulations;

8. Where a proposed injection system is to be located within five miles of a state border, the appropriate regulatory agency in the adjacent state should be provided with an opportunity to review and comment on the application. Further, this agency should be posted when any significant problems occur during the operation of such a system.

APPLICATION FORMS AND REPORTS

Following is a compilation of suggested forms and outlines of reports that will provide information of record from the time of initiation of a well installation throughout its period of operation and ultimate abandonment.

Listed in chronological order these tabulations are identified and titled as follows:

A-1 Application for a permit to drill and test a well

A-2 Outline of scope and content of a feasibility report to accompany an application to drill and test a well

A-3 Well drilling and completion record

A-4 Outline of a summary record to accompany a request to use a well

A-5 Monthly operational information and record

A-6 Application for permit to plug and abandon a well

A-7 Plugging information and abandonment affidavit

A-1 -- APPLICATION FOR A PERMIT TO DRILL AND TEST A WELL FOR INDUSTRIAL WASTEWATER INJECTION

1. APPLICANT (must be legally responsible party)

   1. Company name ______________________________

   2. Authorized representative ______________ Title ______________

   3. Address ______________________________

   4. City ______________________________

   5. Phone number ______________________________

II. APPLICATION IS TO DRILL ___ DEEPEN ___ OR CONVERT ___ AND TEST A WELL for WASTE INJECTION

III. LOCATION OF PROPOSED INJECTION WELL (to be determined by a registered engineer or licensed surveyor)

   1. County ______________________________

   2. Legal location description ______________________________

      ____

      ____

   3. Approximate distance and direction from nearest town ______________

      ____

      ____

   4. Ground elevation __________ft.

IV. SUMMARY OF PROPOSED PROGRAM

   1. Anticipated total well depth ____________ft.

   2. Proposed injection interval(s) in order of probable priority

Formation Name(s)	Anticipated Formation Depth (top)
______________________	______________________
______________________	______________________
______________________	______________________

A-1 continued

3. General waste character ____

   ____

   ____

4. Proposed injection rate (gpm) __________________________________

5. Anticipated injection pressure   Average ____________ (psi)

   Maximum ______________ (psi)

V. SUBMIT WITH APPLICATION

1. $ __________ Fee

2. Feasibility report (see attached outline)

Report prepared by:

____

(Professional Engineer or professional geologist -- submit brief statement of qualifications with report)

Permit Number: ____________________

Approval Date _____________________

A-2 -- OUTLINE OF SCOPE AND CONTENT OF A FEASIBILITY REPORT TO ACCOMPANY AN APPLICATION TO DRILL AND TEST A WELL

I. WELL LOCATION

A. General map and description of well location showing cultural and geographic features and boundaries of property owned or leased by the applicant.

B. Detailed plat showing proposed injection well site and locations of all types of existing wells within two miles of injection well site. Plat should also include all wells penetrating the proposed injection horizon and its confining beds, within five miles.

C. Records of wells shown in detailed plat, including ownership, available subsurface information, and well-plugging data.

II. GEOLOGY AND GEOHYDROLOGY

A. Structural geologic features in the immediate and general vicinity of the well location. Provide a surface geologic map.

B. Geologic and engineering description of subsurface rock units

1. General types and characteristics including a geologic column
2. Potential injection horizons and confining beds with reference to: lithology; thickness; areal distribution; porosity; permeability; reservoir pressure and temperature; chemical characteristics of reservoir fluids; formation breakdown or fracture pressure; hydrodynamics.

C. Geohydrology of fresh-water aquifers at the site and in the vicinity with respect to depth; thickness; general character; and usage.

D. Mineral resources and their occurrence at the well site and in the immediate area such as: oil and gas; coal; brines; and any other deposits of significance.

E. Seismicity -- Location and intensity of earthquakes recorded in area.

III. RESERVOIR RESPONSE AND WASTEWATER MIGRATION

A. Estimated pressure build-up with time (at the well bore and at 100, 1,000, and 10,000 feet from the well bore)

B. Predicted rate and direction of wastewater movement.

IV. PROPOSED WELL DESIGN, CONSTRUCTION AND TESTING PROCEDURES

A. Drilling, coring, and testing program
B. Casing and tubing -- size, grade, type, weight, setting depth
C. Cement -- type including additives and amount
D. Other subsurface equipment
E. Well-head equipment.

A-2 continued

A-2 continued

V. PROPOSED SURFACE EQUIPMENT

A. Holding tanks, flow lines, filters and pumps

B. Flow, pressure and other monitoring devices

C. Other equipment or control devices

VI. CHARACTERISTICS OF UNTREATED WASTES

A. Industrial process from which waste is derived

B. Physical and chemical description of waste -- including variations

C. Volume -- including variability in rate of production

D. Compatibility with subsurface fluids

VII. ALTERNATIVE DISPOSAL METHODS

A. Description of alternative disposal strategies

B. Comparison of alternatives with respect to both economic and environmental considerations, and justification for decision to use underground injection.

VIII. PROPOSED PRE-INJECTION WASTE TREATMENT

A. Settling

B. Filtration

C. Chemical Treatment

D. Concentration or Dilution

E. Other

IX. PROPOSED OPERATING PROGRAM

A. Injection schedule including average and maximum rates, and estimated yearly total for each year through projected well life.

B. Injection pressures including average and maximum

C. Monitoring techniques

X. PROPOSED CONTINGENCY PLAN IN EVENT OF UNANTICIPATED WELL FAILURES

A-3 -- WELL DRILLING AND COMPLETION RECORD

I. WELL OWNER

1. Name ______________________________

2. Address ______________________________

3. City ______________________________

II. WELL DRILLING OR WELL CONVERSION PERMIT NUMBER ______________

III. LOCATION DESCRIPTION (if different than in original application)

____

____

IV. DRILLING AND CORING RECORD

1. Date drilling commenced ______________________________
(month) (day) (year)

2. Date drilling completed ______________________________
(month) (day) (year)

3. Chronological drilling record (submit on separate sheet)

4. Well* Cored From ______ft. to ______ft. Recovery ______ft.
From ______ft. to ______ft. Recovery ______ft.

Cores were: ___ Lab analyzed ___ Described

5. Drilled total depth ________ft.

6. Plugged-back total depth _________ft.

V. CASING AND CEMENT

	Hole Size	Casing Size, Weight and Grade and type	Depth Set	Amount of Cement	Type of Cement
Surface					
Intermediate					
Injection					
Liner					

* List cores and samples submitted to State on a separate sheet

A-3 continued

VI. LOG INFORMATION

Check drilling logs compiled:

☐ Driller's log ☐ Sample log ☐ Drilling time ☐ Others: __________

Check other logs run:

☐ Gamma ray-neutron ☐ Temperature ☐ Caliper ☐ Cement bond

☐ Resistivity ☐ S.P. ☐ Others: ____________________

VII. TESTING DATA (attach copies of original charts, diagrams, data sheets, and interpretations of results)

Type test	Duration of test	Zones tested From To	Amounts, kinds, and pressures of fluids produced or injected during test
	hrs.	ft.- ft.	
	hrs.	ft.- ft.	
	hrs.	ft.- ft.	

VIII. STIMULATION ACTIVITIES (attach copies of original data sheets and interpretations of results)

Zones treated	Treatment: Perforated, acid treated, etc.	Details of treatment: Kinds and amounts of materials, rates, pressures, dates, etc.

The information given is a correct record of the well and all work done.

______________________ ______________________ ______________

(Signature) Representing (company) Date

To be submitted within 30 days after completion of construction and testing, along with copies of all logs, field and laboratory test data, drilling and core samples, and formation fluid samples. Construction and testing to be construed as casing and cementing and preliminary injectivity testing of well. The names, company affiliations and qualifications of geologists and engineers participating in construction, evaluation, and testing of the well should be included with the completion report.

A-4 -- OUTLINE OF A SUMMARY RECORD TO ACCOMPANY REQUEST TO USE A WELL

I. GEOLOGIC DESCRIPTION OF SUBSURFACE ROCK UNITS

A. Geologic column of rock units penetrated

B. Observed characteristics of injection horizons and confining beds

1. Lithology
2. Thickness
3. Porosity
4. Permeability and/or formation acceptance rate during testing
5. Reservoir temperature and pressure
6. Chemical characteristics of reservoir fluids
7. Formation breakdown or fracture pressure. Include well logs, core analyses, injectivity test data, water analyses, etc., used in determining 1 through 7, or refer to previously submitted logs and data.

C. Observed characteristics of fresh water aquifers

1. Depth to fresh water (include date, location, and method of determining)
2. Thickness and character of fresh water bearing strata
3. Fresh water quality (include date, location, and depth of sampling and chemical analyses)

D. Description of any mineral resources encountered during drilling

II. DRILLING AND CONSTRUCTION OF WELL

A. Drilling, construction and testing history

B. Materials of construction (if different than originally proposed)

III. SURFACE EQUIPMENT (if different than originally proposed)

IV. PREINJECTION WASTE TREATMENT PROGRAM (if different than originally proposed)

V. OPERATING AND MONITORING PROGRAM (if different than originally proposed)

VI. CONTINGENCY PLAN (if different than originally proposed)

A-5 -- MONTHLY OPERATIONAL INFORMATION AND RECORD

I. OPERATING PERIOD

Month __________ Year ________

II. WELL OPERATOR

1. Name ______________________________
2. Address ______________________________
3. City ______________ State ______________
4. Phone number ______________________________
5. Permit number ______________________________

III. SUMMARY OF OPERATIONAL DATA

A. Injected Volumes

1. Maximum daily volume specified in permit __________ gal/day
2. Maximum daily volume during operating period __________ gal/day
3. Present average daily volume __________ gal/day
4. Total volume injected to date _________ gal.

B. Injection Rate

1. Maximum injection rate specified in permit __________ gpm
2. Maximum injection rate during month __________ _______ gpm
3. Average injection rate during month _________________ gpm

C. Injection Pressure

1. Maximum well-head injection pressure specified in permit ________ psi
2. Maximum well-head injection pressure during month __________ psi
3. Estimated average well-head injection pressure during month _______ ps

IV. DETAILED OPERATIONAL DATA (supply detailed well operating record to accompany this report).

V. INSTRUCTIONS

A. Each operator of an injection project shall furnish information on this form not later than the 10th day of the month following the month reported
B. If several wells are utilized, report each one separately.
C. Fill in reverse side of form relative to daily injection practices.
D. Continuous recording charts will be made available upon request.
E. All operational problems, changes in injection system or wastes are to be reported when they occur.

A-5 continued

INJECTION WELL OPERATING RECORD

1. CONTINUOUS OPERATING PERIOD					2. INJECTION RATE (GPM)		3. PRESSURE (PSI)				4. FLUID INJECTED (GAL.)	
Start		End		Length of Period (days & hrs.)			Well-Head Injection			Casing Tubing Annulus	Operating Period	Total Cumulative
Date	Time	Date	Time		Aver.	Max.	Max.	Min.	Estimated Average			

NOTE: Report items 2 and 3 for each day of operating periods that exceed one day.

A-6 -- APPLICATION FOR PERMIT TO PLUG AND ABANDON A WELL

I. Well operator:

1. Name ____________________
2. Address ____________________
3. City ____________________
4. Waste injection well permit number ____________________

II. Detailed description of proposed plugging procedure (attach additional sheets if necessary) ____________________

____

____

III. Planned date and time of plugging: ____________________

IV. Present well status:

1. Total volume of waste injected ____________________
2. Present injection rate ____________________
3. Present injection pressure (well-head) ____________________
4. Present well shut-in pressure ____________________

V. Plugging operations will be conducted by:

1. Name of Company ____________________
2. Address ____________________
3. City ______________ State ______________

____

Signature of Authorized Representative of Operator Date

____

____

1. Application for a permit to plug and abandon shall be filed at least 30 days in advance of planned date of operation.

2. The planned date and time of plugging should be specific and the operation must be witnessed by a representative of the ____________________
(State regulatory agency)

A-7 -- PLUGGING INFORMATION AND ABANDONMENT AFFIDAVIT

I. WELL OPERATOR:

Name ______________________________

Address ______________________________

Waste injection well permit number ______________________________

II. DESCRIPTION OF PLUGGING: (add additional sheets if necessary)

Plug materials -- type and volume	Depth From - To (feet)

III. FINAL STATUS

Total volume of waste injected __________ as of ______________ (date)

Final well shut-in pressure ______________________________

Estimated horizontal extent of injected waste ______________

____

IV. ASSOCIATED WORK

Pits and excavations filled ( ) yes

Equipment and debris removed ( ) yes

Permanent monument emplace ( ) yes

A-7 continued

A-7 continued

Executed this __________ day of __________, 19 ___,

State of __________________________ County of ____________________________

____
(Signature of affiant)

____
(Typewritten name and title)

On this __________ day of __________, 19 ____, before me appeared ______________________________, known to me to be the person whose name is subscribed to the above instrument, who being by me duly sworn on oath, states that he is authorized to make the above report and that he has knowledge of the facts stated therein, and that said report is true and correct.

SEAL

My commission expires _______________________

____
(Notary Public)

Plugging witnessed by ____
Authorized state representative

ORSANCO INJECTION-WELL REGISTRY

In an earlier report to the Commission (Cleary/Warner, 1969) this question was posed: Should ORSANCO be charged with the establishment and maintenance of a registry of data on injection wells in the eight-state district for the purpose of providing a central file for such installations in the Ohio basin and disseminating such information for reference needs and public record?

The advisory committee responded affirmatively to this proposal at one of its initial meetings. In turn, the U. S. Geological Survey found merit in supporting the initiation of such an undertaking and made available a $35,000 research grant to ORSANCO for this purpose.

At this writing it can be reported that such a registry is virtually complete and is being readied for publication. It encompasses a record of all injection-well systems that have been installed in the eight states from 1941 to the present; however, most of these were developed only within the past decade. Details are compiled on 50 wells, of which 32 are active and 18 are in categories of standby, development or abandoned. There are 26 well systems within the topographic boundaries of the ORSANCO district.

The information compiled includes preliminary and well completion data, operational information, description of malfunctions that could be documented and plugging reports on abandoned wells. Additionally, numeric data on pressures, volumes, injection rates, total accumulation and composition of wastewaters is included. Furthermore, the wells are tabulated in categories related to depth, formation, thickness of injection intervals, conversions and those having unusual characteristics or special uses.

To assure continued maintenance and usefulness of the injection-well registry the advisory committee recommends that the appropriate agency in each of the eight states should provide the Executive Director of ORSANCO with copies of:

The application for a construction permit for each new well.

Each drilling or construction permit issued or notice of other action taken.

Completion reports filed for each well.

Requests for permission to operate a wastewater injection well.

The operating permits issued or notices of other action.

An annual summary for each operating well, including the total volume of wastewater injected, the range of injection rates and pressures, and any change in wastewater character and well status.

Records for each well abandoned, including the application for a permit to abandon, the permit itself, and the well-plugging information.

Copies of each of the above listed documents should be sent to the Executive Director within 30 days of their receipt or issuance by the regulatory agency. In turn, the Executive Director should periodically issue a report informing each of the member states of current activities in underground disposal. All records should be available for public inspection at the headquarters of the Commission.

INFORMATION DEFICIENCIES

Looking toward improvement of regulatory activities the advisory committee recommends that efforts should be made to expand procedures for testing and observation of injection wells.

At present it cannot be said that the testing of existing wells has been sufficient to permit appropriate analysis of the original condition of the injection reservoirs and adjacent strata. Neither has monitoring of the operating wells been detailed enough to permit analysis of the changes that have occurred during operation. State regulatory agencies should be able to specify testing and operating procedures that will supply the needed information and require that the companies comply.

A parallel area of attention is the accumulation and interpretation of information from deep oil and gas test wells for those stratigraphic intervals that are of most interest for wastewater injection. Many deep oil and gas test wells have been drilled into and through potential wastewater injection zones. However, when oil or gas "shows" are not encountered the formations are not usually cored or tested for their fluid content and natural pressure. Whenever possible, more reservoir information should be obtained from deep wells of all kinds. This can be accomplished by encouraging the companies that drill such wells to cooperate in obtaining the needed information as a public service. Depending on the cost to the company, some public funds may need to be invested to offset part of these costs.

Monitoring of local and regional effects of wastewater injection on the geologic environment should be encouraged. This should be initiated in areas where the maximum disturbance is anticipated. Studies also are needed to better define the relationship between earthquake occurrence and wastewater injection and to develop methods for predicting the potential hazard of earthquake stimulation by injection.

Information should be collected on the relative merits and limitations of the various materials and operating procedures used in injection systems in the ORSANCO states with a view toward incorporating these findings in evaluation of future installations.

Examination of methods that might be employed to minimize the amounts of wastewater injected through existing and future wells likewise should be undertaken.

Geological and Technological Evaluation

Recommended administrative procedures for regulation of wastewater injection wells have been outlined. Attention will now be focussed on the geological and technological aspects to be considered in preparing and evaluating proposals, and for guiding the construction, operation and abandonment of injection systems.

This discussion is primarily oriented toward conditions prevailing in the Ohio Valley. The geologic and hydrologic aspects of the ORSANCO region are broadly delineated. Details regarding a specific location can be developed only by reference to data assembled by state and federal agencies and from private consultants. For example, Illinois and New York have published papers dealing with the geologic aspects of subsurface disposal in various parts of those states. (Bergstrom, 1968; Kreidler, 1967). A description of potential areas for subsurface industrial-waste disposal in New York has also been published by McCann and others (1968).

Reviews of the technical aspects of deep-well injection that apply generally are available. A selected list of references to these earlier publications has been provided at the end of this report.

GEOLOGY AND GEOHYDROLOGY

The suitability of a particular site within the ORSANCO drainage district for subsurface waste injection depends primarily on the geological conditions and the hydrology of underground waters in the vicinity.

Examination of a site begins at the regional level, then is narrowed to the vicinity of the site and finally focuses upon the immediate location of the well. Outlined in Table 1 are factors to be considered in site evaluation at the regional and local levels. This tabulation contains the same information as appears in the outline for a feasibility report to accompany an application to drill and for testing an injection well.

Only regional geologic and hydrologic framework for the ORSANCO district are outlined. It is not practical to attempt to report on such a large geographic area in sufficient detail to provide an analysis of the local geology. Such an analysis must be made for each proposed injection system unless an existing installation is so closely located as to provide this information.

The regulatory agency in each of ORSANCO states may not always have the information or the personnel to adequately develop and evaluate the geologic aspects of injection proposals. But each of the ORSANCO states does have agencies with geologic information on file and staffed with men trained in the geologic fields to assist in the development and evaluation of proposals.

TABLE 1 -- Factors to be Considered for Geologic and Hydrologic Evaluation of a Site for Subsurface Waste Injection

Regional geologic and hydrologic framework

Physiography and general geology; structural; stratigraphic; groundwater; mineral resources; seismicity; hydrodynamics.

Local geology and geohydrology

A. Structural geology
B. Geologic description of subsurface rock units
    1. General rock types and characteristics
    2. Description of injection horizons and confining beds

        Lithology; thickness and vertical and lateral distribution; areal distribution; porosity (type and distribution as well as amount); permeability (same as areal distribution); reservoir temperature and pressure; chemical characteristics of reservoir fluids; formation breakdown or fracture pressure; hydrodynamics.

    3. Groundwater aquifers at the site and in the vicinity

        Depth; thickness; general character; amount of use and potential for use.

    4. Mineral resources and their occurrence at the well site and in the immediate area.

        Oil and gas (including past, present and possible future development); coal; brines; other.

GENERAL GEOLOGIC FEATURES OF THE OHIO VALLEY

The physiographic provinces shown in Fig. 1 reflect the underlying geologic features of importance in the Ohio Valley. In Table 2 are listed the physiographic units of the valley and vicinity with a description of their characteristics, principal rock units, and general geologic structure. The descriptions in Table 2, and the information on Figs. 1, 2 and 3, show the close relationship between the physiographic units and the geologic features. For example, the boundaries of the Blue Ridge physiographic province, the Valley and Ridge province, and the Coastal Plain province are essentially the same as boundaries of geologic features shown in Fig. 3, and it is therefore convenient to discuss them as geologic units.

Consolidated rocks within the Ohio River drainage basin range in age from Precambrian to Tertiary; Precambrian rocks are the oldest and tertiary the youngest (Fig. 2). These consolidated rocks are overlain by unconsolidated Quaternary-age glacial deposits in the northern part of the basin and by alluvium in the major stream valleys. A few feet of soil usually masks these geologic deposits at the immediate surface. Precambrian igneous and metamorphic rocks lie beneath the covering of younger sedimentary rocks everywhere in the Ohio basin and because they are essentially nonporous and impermeable form the so-called "basement." Precambrian rocks lie at the surface in the bulge that extends from the southeast side of the basin into the Appalachian Mountains of West Virginia, Virginia and North Carolina.

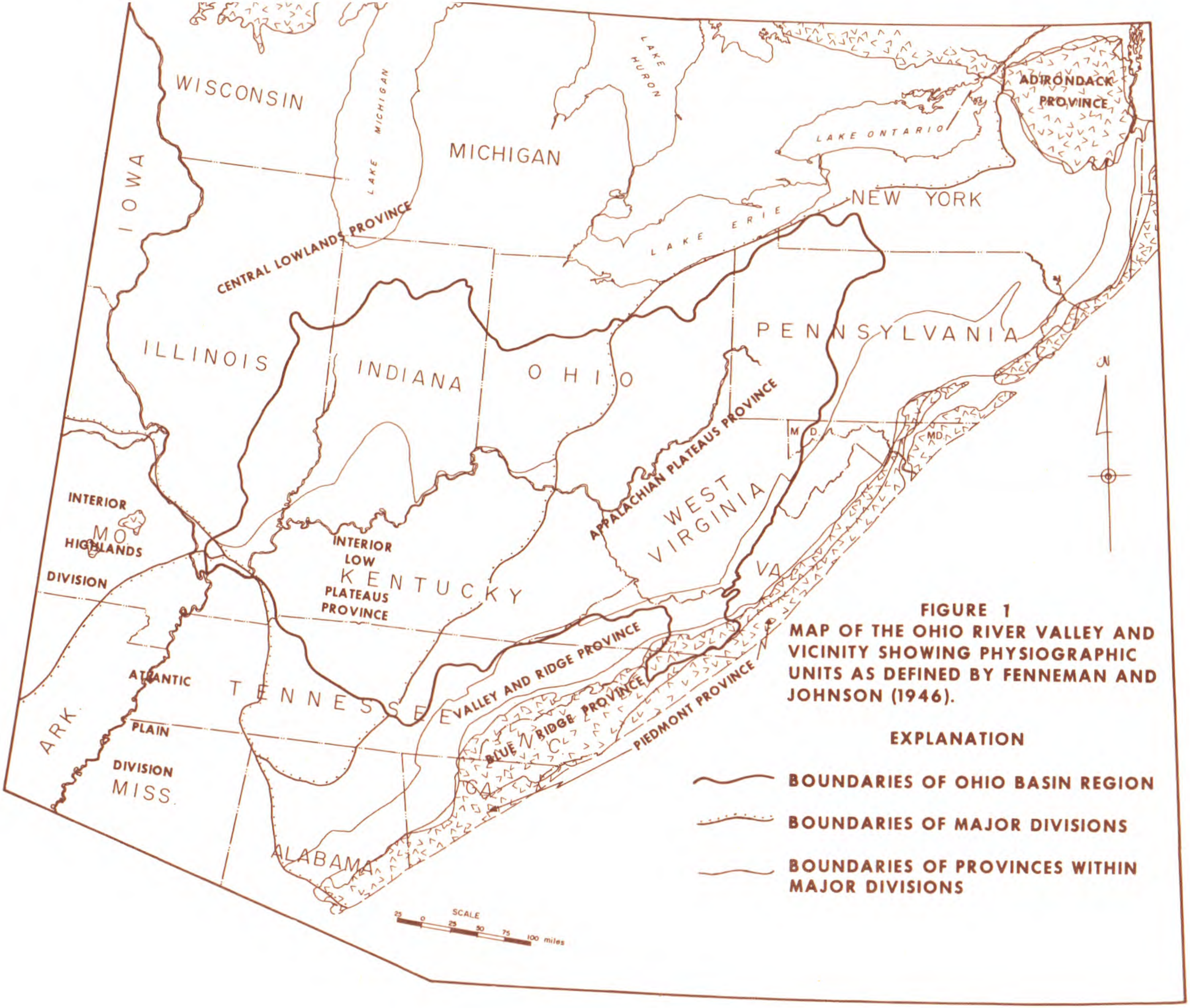


FIGURE 1
MAP OF THE OHIO RIVER VALLEY AND VICINITY SHOWING PHYSIOGRAPHIC UNITS AS DEFINED BY FENNEMAN AND JOHNSON (1946).

TABLE 2 -- Physiographic Units of the Ohio Valley and Their Characteristics

Physiographic unit	General physiographic characteristics	Principal rock units	General geologic structure
1. Appalachian Highlands Division			
a. Piedmont Province	Rolling hills, gentle slopes low to moderate relief	Paelozoic, metamorphic and igneous crystalline rocks	Intense faulting and folding and intrusion by igneous rocks
b. Blue Ridge Province	Mountains, steep slopes, deep valleys, moderate to high relief	Precambrian and Paleozoic metamorphic and igneous rocks	As in a.
c. Valley and Ridge Province	Ridges with steep slopes and moderate to high relief. Broad valleys with areas of low rounded hills. Valley and ridge pattern controlled by geologic structure	Sedimentary rocks of Cambrian through Pennsylvanian ages. Total thickness 25,000 to 40,000 feet	Sedimentary rock beds are everywhere tilted and folded into prominent anticlines and synclines and are cut by many large faults
d. Appalachian Plateaus Province	Dissected plateaus, steep slopes, moderate to strong relief. Drainage pattern is random	Sandstone and shale with coal, limestone and conglomerate of Devonian through Permian age, but primary Pennsylvanian and Mississippian. Older sedimentary rocks are not exposed. Total thickness of sedimentary rocks ranges from 5,000 feet in west to 20,000 feet in east	Considerable folding and faulting along the boundary of the Valley and Ridge province. Nearly flat lying beds further west with more gentle folds and few faults

TABLE 2 (cont'd.) -- Physiographic Units of the Ohio Valley and Their Characteristics

Physiographic unit	General physiographic characteristics	Principal rock units	General geologic structure
2. Interior Plains Division			
a. Central Lowlands Province	Gentle slopes, low to moderate relief, random drainage pattern	Sedimentary rocks of all types;but limestone and shale predominate. Exposed rocks are of Ordovincian to Pennsylvanian age. Quaternary age glacial deposits may cover bedrock. Total thickness of sedimentary rock 3,000 to 5,000 feet	Beds nearly flat lying with broad arches and basins. Little faulting except in Kentucky River, Rough Creek and associated fault zones
b. Interior Low Plateaus	As in a.	As in a., except no glacial deposits	
3. Atlantic Plain Division			
a. Coastal Plain Province	Low hills, flood plain and delta low to moderate relief	Poorly consolidated Cretaceous and Tertiary sedimentary rocks, may be overlain by Quaternary alluvium. The thickness increases southward from a few hundred feet in the north	Cretaceous and Tertiary sedimentary beds dip gently to the south and unconformably overlie Precambrian rocks

The configuration of the Precambrian basement in the Ohio basin is shown in Fig. 4, which is a contour map of that surface with sea level as a datum. The total thickness of the sedimentary rock cover at any point can readily be estimated by subtracting the altitude of the Precambrian surface as determined from Fig. 4

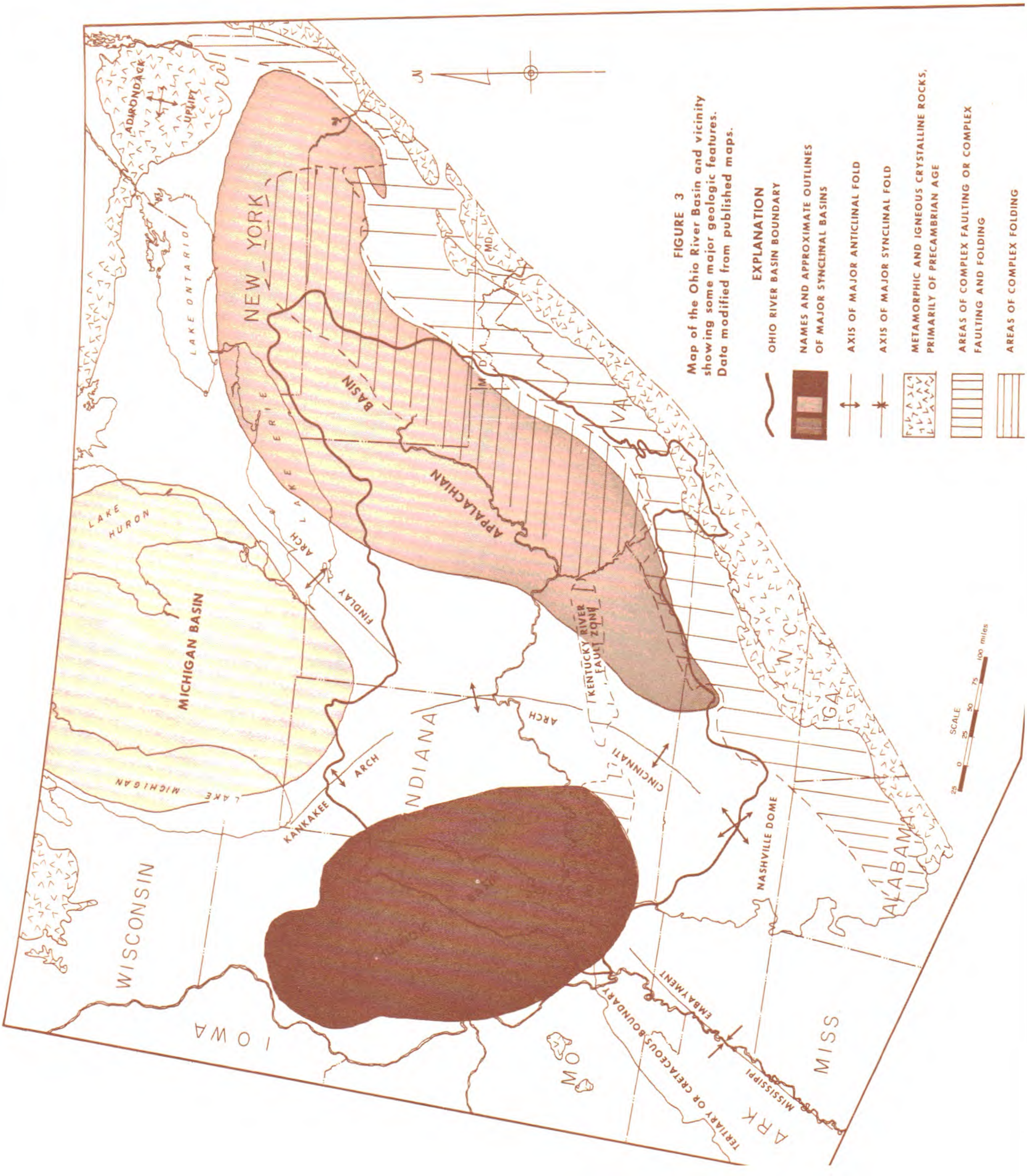


FIGURE 3

Map of the Ohio River Basin and vicinity showing some major geologic features. Data modified from published maps.

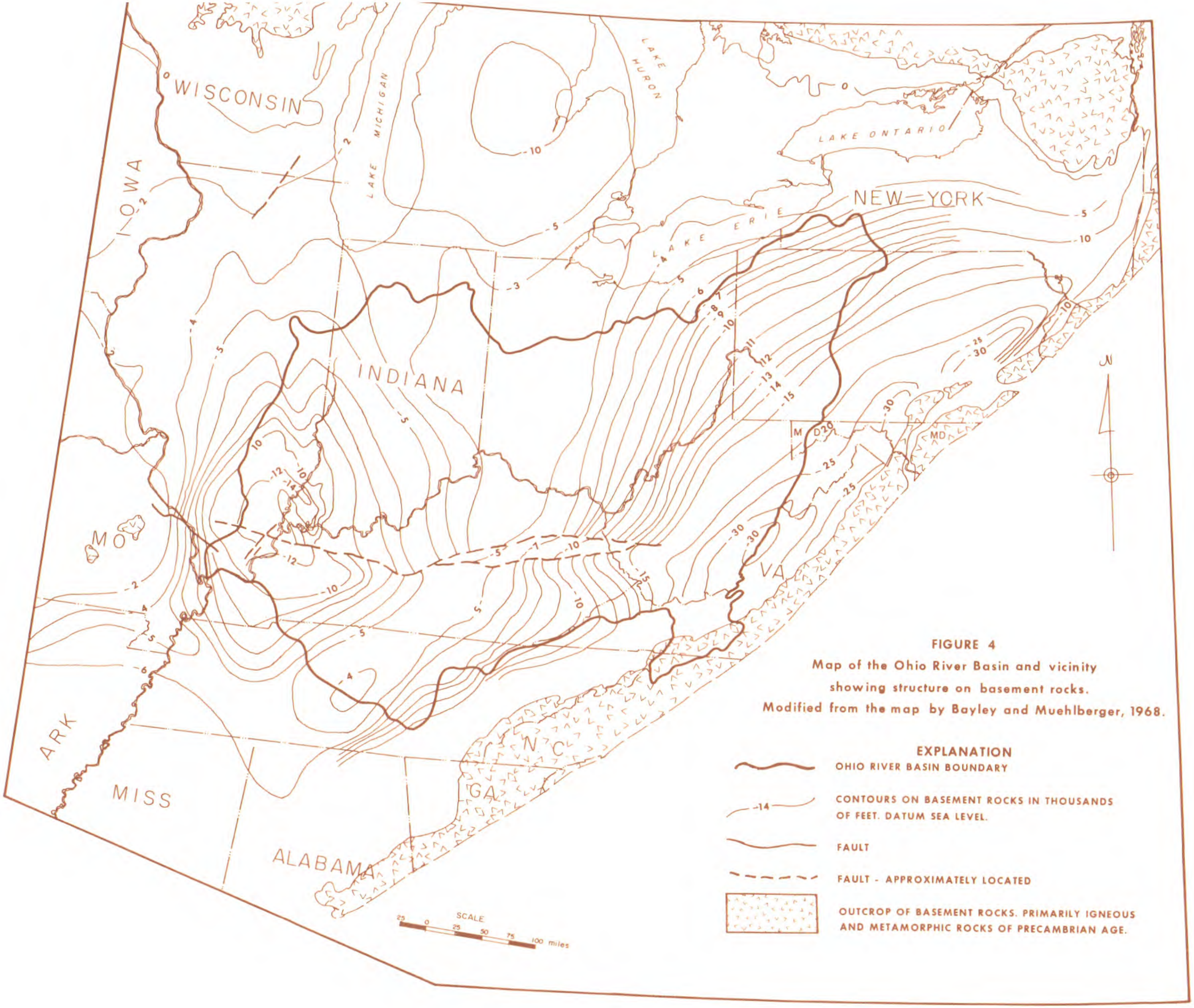


FIGURE 4

Map of the Ohio River Basin and vicinity showing structure on basement rocks. Modified from the map by Bayley and Muehlberger, 1968.

to form arches, domes and basins. In the basins the sediments are thicker and Pennsylvanian and Mississippian age rocks lie at the surface, whereas the sedimentary cover over the uplifts is thinner and older rocks are exposed. The basins and arches have undergone several periods of deformation and they have had some smaller folds and faults superposed on them. The various major structural geologic features of the interior provinces are discussed below.

Cincinnati Arch

The Cincinnati arch and its continuations separate the Appalachian basin from the Michigan and Illinois basins. Near Cincinnati, Ordovician rocks lie nearly flat on its crest and about 4,000 ft. of Ordovician and Cambrian sedimentary rocks cover the Precambrian basement. These sediments dip gently northwest and southeast from the crest of the arch beneath progressively younger beds. Sediments are about 2,000 ft. thick over the crest of the Findlay arch and about 5,000 ft. thick over the Nashville dome. The sediments are not generally disturbed by faulting of much consequence, except in the area of the Kentucky River fault zone. Minor folds trend northwest across the main structure of the Nashville dome on its southside and may reflect the presence of fractures at depth.

The anticlinal area between the Illinois and Appalachian basins is also generally favorable for underground disposal. Sedimentary rock sequences are, however, thinner in the interbasin areas and the number of potential injection intervals is thus limited.

Illinois Basin

The Illinois basin (Fig. 3) is an oval area containing a thickness of 12,000 to 14,000 ft. of sedimentary rocks at its center. The basin is a relatively gentle downwarp and beds dip toward the center of the basin at rates of one degree or less, except where local deformation has caused greater tilting.

The Illinois basin is divided into two parts by the southward trending anticlinal ridge (LaSalle anticline) that extends through much of the length of the basin. The location of this feature is reflected by the southward indenting of the structure contours in Fig. 5. Subsidiary folds and faults associated with the LaSalle anticline and other unrelated folds and faults complicate the structure of the Illinois basin.

The Illinois basin is a generally favorable area for deep-well disposal, since it is underlain by a relatively thick sequence of sedimentary rocks with potentially suitable injection intervals.

Rough Creek Fault Zone

In southern Illinois, western Kentucky, and adjacent areas, the Paleozoic rocks are extensively disturbed by faulting in a 175-mile long area. A series of east-west trending faults along the north border of this area form the Rough Creek fault zone (Figs. 3 and 5). A series of northeast trending faults

GENERALIZED STRATIGRAPHIC COLUMN WITH OIL AND GAS RESERVOIRS WEST VIRGINIA

GEOLOGIC SYSTEMS AND SERIES		TERMINOLOGY USED ON 1968 STATE GEOLOGIC MAP	FORMER TERMINOLOGY (W. VA. GEOLOGICAL SURVEY COUNTY REPORTS) IF DIFFERENT	OIL AND GAS "SANDS" (DRILLERS' TERMS)
PERMIAN		DUNKARD GROUP		CARROLL MINSHALL MURPHY MOUNDSVILLE COW RUN LITTLE DUNKARD BIG DUNKARD
PENNSYLVANIAN	? UPPER	MONONGAHELA GROUP		BURNING SPRINGS GAS AND LOWER GAS
		CONEMAUGH GROUP		HORSE NECK SALT SANDS (1st, 2nd, 3rd)
	MIDDLE	ALLEGHENY FORMATION		PRINCETON RAVENCLIFF
	LOWER	POTTSVILLE GROUP		MAXON LOWER MAXON LITTLE LIME
MISSISSIPPIAN	UPPER	MAUCH CHUNK GROUP		BLUE MONDAY BIG LIME KEENER BIG INJUN
	MIDDLE	GREENBRIER GROUP		SQUAW WEIR BEREA
	LOWER	MACCRADY FORMATION POCONO GROUP		GANTZ
DEVONIAN	UPPER	HAMPSHIRE FORMATION CHEMUNG GROUP	CATSKILL	FIFTY FOOT THIRTY FOOT GORDON STRAY GORDON FOURTH FIFTH BAYARD
		BRALLIER FORMATION	PORTAGE	ELIZABETH WARREN FIRST WARREN SECOND CLARENDON (TIOGA) SPEECHLEY BALLTOWN (CHERRY GROVE) RILEY BENSON ELK (PORTER) KANE BROWN SHALE — YIELDS GAS IN OHIO, KY. AND SO. W. VA.
	MIDDLE	HARRELL SHALE (MILLBORO SHALE)	GENESEE	
		MAHANTANGO FM. (MILLBORO SHALE)	HAMILTON	
		MARCELLUS FM (MILLBORO SHALE)		
		ONESQUETHAW GROUP: ONONDAGA LS., HUNTERSVILLE CHERT, NEEDMORE SHALE	HUNTERSVILLE	"CORNIFEROUS" YIELDS GAS IN PA. AND NORTHERN W. VA.
	LOWER	ORISKANY SANDSTONE		ORISKANY SAND GAS IN MD., NY., OHIO, PA AND W. VA.
		HELDERBERG GROUP		HELDERBERG YIELDS GAS FROM SEVERAL PA. AND W. VA. WELLS "BIG LIME" OF OHIO
SILURIAN	UPPER	TONOLOWAY FM.	BOSSARDVILLE (CAYUGAN (SALINA) SERIES)	
		WILLS CREEK FM (BLOOMSBURG FACIES)	RONDOUT (CAYUGAN (SALINA) SERIES)	NEWBURG SAND IMPORTANT GAS SAND IN WEST VIRGINIA
		WILLIAMSPORT FM. (BLOOMSBURG FACIES)	BLOOMSBURG (CAYUGAN (SALINA) SERIES)	LOCKPORT DOLOMITE OIL IN KY., GAS IN OHIO AND W. VA. "NEWBURG DOLOMITE" OF OHIO
	MIDDLE	MC KENZIE FM.	NIAGARA (NIAGARAN SERIES)	KEEFER SANDSTONE GAS IN OHIO, E. KY., AND SW. W. VA. (BIG SIX SAND)
		ROCHESTER SHALE KEEFER SANDSTONE ROSE HILL FORMATION	CLINTON (NIAGARAN SERIES)	
	LOWER	TUSCARORA SANDSTONE	WHITE MEDINA	CLINTON GAS SAND OF OHIO AND W. VA. MEDINA GAS SAND IN N.Y. SOME OIL IN N.Y. AND OHIO.
ORDOVICIAN	UPPER	JUNIATA FORMATION	RED MEDINA	
		OSWEGO FORMATION	GRAY MEDINA	
		REEDSVILLE SHALE	MARTINSBURG	TRENTON-BLACK RIVER. YIELDS OIL IN ONTARIO, N.Y., MICH., C. KY., NE TENN., AND SW. VA. SHOWS OF OIL AND GAS IN DEEP WELLS IN CENTRAL BASIN. "GLENWOOD" HORIZON AT BASE
	MIDDLE	TRENTON GROUP: MARTINSBURG FM., NEALMONT LS.	CHAMBERSBURG / MOCCASIN	
		BLACK RIVER GROUP	CHAZY / STONES RIVER	CHAZY-STONES RIVER. YIELDS OIL IN SOUTH CENTRAL KENTUCKY "ST. PETER" GAS AND OIL IN OHIO AND KENTUCKY
		ST. PAUL GROUP: NEW MARKET LS., ROW PARK LS.		
	LOWER	BEEKMANTOWN GROUP: PINESBURG STATION DOL., ROCKDALE RUN FM., STONEHENGE LS.	KNOX	KNOX DOLOMITE OIL IN EASTERN KENTUCKY ROSE RUN SAND
CAMBRIAN	UPPER	CONOCOCHEAGUE FORMATION	KNOX	TREMPEALEAU OIL AND GAS IN OHIO
	MIDDLE	ELBROOK FORMATION		
	LOWER	WAYNESBORO FORMATION		ROME SANDSTONE OIL IN E. KY
		TOMSTOWN DOLOMITE		OIL IN EASTERN KENTUCKY
	?	CHILHOWEE GROUP: ANTIETAM FM., HARPERS FM., WEVERTON-LOUDOUN FORMATION		
		CATOCTIN FORMATION		
PRECAMBRIAN		CRYSTALLINE ROCKS		

TABLE 3

(From: West Virginia Geological Survey)

that lie south of the Rough Creek zone and, in part, cut across it are included in the faulted area shown in Fig. 3. Faults in this disturbed zone have displacements of up to 3,500 ft. In the southern part of the area faults contain veins of the mineral fluorite and numerous bodies of igneous intrusive rocks have invaded the sedimentary beds.

To the east, in Kentucky, the Rough Creek zone breaks up into discontinuous fractures. Further east along the same trend the previously mentioned Kentucky River fault zone occurs as a continuation of this disturbed belt.

The major fault zones that have been mentioned are not necessarily entirely unsuitable for underground disposal but their suitability is greatly limited because of their structural geologic complexity and because injection zones and confining beds are offset by faults and perhaps extensively fractured.

Other Interior Provinces

Because so little of the Ohio Valley is involved, the Michigan basin and the Mississippi embayment will not be discussed in detail.

The area of the Ohio basin that is underlain by the Mississippi embayment is considered to offer little possibility for underground disposal because the deeper rocks that contain potential disposal intervals are likely to be disturbed by the same type of structural features that occur in the fault zone immediately to the north.

STRATIGRAPHIC GEOLOGY

A satisfactory injection horizon may be defined as one with sufficient porosity, permeability, and areal extent to accept injected fluids at safe pressures without hazard to natural resources. Thick sequences of sedimentary rock usually contain sandstones, limestones, or dolomites with these characteristics. Such rocks are fluid-saturated in the subsurface and, below the present level of fresh water circulation, contain saline water in the pores. This interstitial saline water is not suitable for most purposes and only occasionally contains enough dissolved materials to be comercially valuable.

It is generally desirable for shale or other impermeable confining strata to overlie and underlie the injection horizon to prevent the vertical escape of injected waste. Absolute confinement may not always be essential, as sufficient protection may be provided by a series of thick permeable formations that can safely accommodate the relatively small volumes of waste liquids involved.

As previously mentioned, the total thickness of sedimentary rocks in the Ohio Valley ranges from zero to a maximum of about 30,000 ft. These sediments range in age from Cambrian to Tertiary. Rocks of interest for underground disposal are from Cambrian to Pennsylvanian in age.

In Fig. 10 are shown the relationships of some of these sedimentary rocks in a cross section that extends from eastern Illinois to western Pennsylvania; in Fig. 11 are shown similar relations from northwest to southeast Ohio. These two cross sections are shown to provide some concept of the regional distribution to be found among some of the rock units of the Ohio Valley. It is informative to realize, for example, that the Trenton Limestone is found in the subsurface throughout virtually the entire Ohio Valley area and beyond. This point is further illustrated by Fig. 5, which is a contour map on the top of the Trenton Limestone.

Other geologic units such as the Mt. Simon Sandstone are also widely distributed and are recognized by the same name. On the other hand, many of the geologic units are only locally recognizable and their names are only locally applied. The original cross sections from which Figs. 9 and 10 were constructed provide examples of much more detailed correlations of some of the geologic units found in the subsurface in the Ohio Valley. In Table 3 is listed the terminology used for rock units in West Virginia. The variability in terminology indicated in this table offers an example of the problems involved in understanding and discussing subsurface geology on a regional basis.

Indicated in Figs. 5, 6, 10 and 11 are the depths at which the various geologic horizons occur. It is clear, for example, from Figs. 5 and 10 that formations of Ordovician and Cambrian age are too deeply buried to be of interest as disposal horizons in the central parts of the Illinois and Appalachian basins.

Other useful cross sections and structure contour maps are available from the geological surveys of the various states and from the U. S. Geological Survey. This information, supplemented by the data from nearby wells, makes it possible for a qualified geologist to predict with reasonable accuracy the geologic conditions to be encountered in much of the Ohio Valley.

For purposes of deep waste injection, it is convenient to discuss the sedimentary rock units of the Ohio Valley in different groupings than are ordinarily used in geologic reports. The groupings used in this study are shown in Fig. 12. The Cambrian-Ordovician, Silurian-Devonian, and Mississippian-Pennsylvanian sequences contain the majority of the potential injection horizons whereas the Devonian and Ordovician shale sequences are primarily useful as confining units. The top of the basement sequence of crystalline igneous and metamorphic rocks defines the lower limit of possible injection zones. Cretaceous and Tertiary rocks are present only in a very small portion of the southwest corner of the area and are, therefore, not discussed. Each of the other sequences is described below.

Basement Sequence

The basement sequence consists of igneous and metamorphic rocks that usually have virtually no permeability and porosity and do not, therefore, contain potential injection intervals. Basement-sequence rocks in the Ohio Valley and vicinity are of Precambrian and Lower Paleozoic age. Within the Ohio Valley, basement rocks are probably entirely of Precambrian age in the subsurface and include only a few Cambrian age metamorphic rocks in the area of basement exposure in the southeast side of the area (Fig. 2).

Igneous and metamorphic crystalline rocks normally have virtually no injection potential and drilling ceases soon after passing into them. However, injection at the Rocky Mountain Arsenal near Denver, Colorado, was entirely into fractured and sheared Precambrian crystalline rocks during the operation of that well from 1962-66. It has also been reported that a part of the liquid injected into the deeper of the two injection wells at Hammermill Paper Company, Erie, Pennsylvania, has gone into fractured or sheared Precambrian rocks. The presence of zones of permeability was not anticipated prior to drilling of the two wells mentioned and basement rocks cannot be considered as having potential for injection disposal in the Ohio Valley except in rare instances.

Cambrian-Ordovician Sequence

Rocks of the Cambrian-Ordovician sequence overlie basement rocks in the Ohio Valley in all but the small area of Virginia and North Carolina where basement rocks are exposed (Fig. 2). Cambrian rocks are exposed only in that area of the Valley and Ridge province immediately adjacent to the exposed basement rocks. In the remainder of the Ohio Valley, the oldest exposed rocks are Ordovician and a minimum of about 3,000 ft. of Cambrian-Ordovician sedimentary strata cover Precambrian rocks. Throughout much of the valley these basal sediments provide the only available injection intervals because overlying rocks have been removed by erosion. Rock types in the Cambrian-Ordovician sequence include limestone, dolomite, shale and sandstone, generally in about that order of relative abundance.

The Trenton Limestone and equivalent rocks lie at the top of the sequence. Contours on the top of the Trenton are shown in Fig. 5. In areas where the top of the Trenton lies more than about 5,000 ft. below sea level, the basal Cambrian-Ordovician sequence is too deep to be of practical interest for disposal purposes in most cases, although it is still well within drilling reach.

A generalized stratigraphic section of the Cambrian-Ordovician sequence from a deep well in Cattaraugus County, New York, is shown in the following tabulation.

Generalized Sequence of Trenton and Older Rocks from a Deep Oil Well in Northwestern Cattaraugus County, New York (From Flagler, 1966)

Rock Unit Age	Rock Unit Name	Thickness (ft.)	Character
Ordovician	Trenton-Black River Groups	780	limestone and dolomite
Cambrian	Little Falls Formation	19	gray to green dolomite
	Theresa Formation	653	dolomite, sandy dolomite and sandstone
	Potsdam Formation	173	sandstone with streaks of dolomite and shale
Precambrian	Basement Sequence		gneiss

Rock unit names in the section are ones used in New York and immediately adjacent areas, except for the Trenton and Black River names, which are widely used.

The sequence is composed mainly of limestone and dolomite in this well and in the adjacent Ohio Valley area. A considerable amount of sandstone may be present in the Theresa Formation. The Potsdam Formation, which is equivalent to the Mt. Simon Formation, is primarily sandstone.

Available data indicate some possibility of disposal into each of the horizons, but good permeability and porosity are not consistently present in any part of the sequence. The Theresa Formation appears to be the most generally promising interval, but locally other units or none at all may be suitable. Overlying Ordovician shales provide good vertical confinement provided unplugged oil or gas wells do not penetrate the shales.

The top of the Trenton lies about 4,800 ft. beneath the ground surface in this well and is deeper than this toward the southwest into the Appalachian basin portion of the Ohio Valley. The cross section in Fig. 10 correlates these rocks from within the northern part of the Appalachian basin into the northern part of the Illinois basin. The combined Trenton and Black River Groups remain nearly constant in thickness from east to west but other rock units thicken considerably, particularly the sandstones at the base. The thickness of sediments covering these rocks also varies as the cross section proceeds from the Appalachian basin onto the Cincinnati arch and then into the Illinois basin.

As in New York, all of the rocks in the stratigraphic interval are potential disposal zones throughout the extent of the cross section. The relative adequacy of each zone varies with geographic location. The suitability of the Mt. Simon Formation increases greatly from east to west as its thickness increases. The Eau Claire contains much more sandstone in some areas than in others and has generally better potential in areas where it is thickest. Zones of porosity and permeability occur at or near the top of the Trenton and in the Cambrian limestones and dolomites below the Trenton-Black River Groups, but such zones are not consistently present.

The nomenclature shown on the west (left-hand) side of Fig. 10 has been widely used throughout northern Ohio, Indiana, and Illinois for these rocks, but a variety of other names are used in Kentucky and Tennessee as shown in the table on the following page. The Trenton Limestone and equivalents, which lie immediately over the Black River, are not shown in the tabulation. In Kentucky, the Trenton consists of the Lexington Limestone, which lies on the Tyrone, and the Cynthiana Limestone.

As of 1963, only 50 oil and gas test wells had been drilled as deep as the top of the Copper Ridge and only 9 to Precambrian basement in Kentucky, so the amount of information concerning the deep formations is very limited. Available data indicate that intervals through the entire Cambrian-Ordovician sequence have potential for underground disposal. However, the necessary combination of thickness, porosity and permeability is not consistently present in any one of the units.

Upper Ordovician Sequence

Throughout most of the Ohio Valley, the limestone and dolomites of the Trenton and Black River Groups are overlain by a shale or shale-limestone sequence of upper Ordovician age. This unit is over 2,000 ft. thick in the northern Appalachian basin but thins to about 200 ft. in thickness in the northern Illinois basin (Fig. 10). It is not present in parts of central Tennessee.

Rocks of this sequence are divided into the Utica, Lorraine, and Queenston Formations in western New York; and the Eden, Maysville and Richmond in Ohio, Kentucky, and central Tennessee. The name Maquoqueta Shale is applied in the Illinois basin and vicinity, and the Martinsburg Shale is applied in the Illinois basin and vicinity, and the Martinsburg Shale and Sequatchie Formation occupy this interval in West Virginia.

The shale or interbedded shale-limestone lithology of the sequence provides vertical confinement for the underlying rocks in much of the Ohio Valley and in particular across the Cincinnati, Waverly and Kankakee arches where these beds frequently separate fresh and saline water-bearing rocks. The Ordovician shale sequence is not generally a promising disposal horizon, but in the northern Appalachian basin, where it is over 2,000 ft. thick, sandstones such as the Oswego, which occurs at the base of the Queenston Shale, offer some potential.

System	Group	Subgroup	Nomenclature used by McGuire & Howell in Kentucky	Thickness	General rock types in Kentucky	N.E. Tennessee, S.W. Virginia (group)	N.E. Tennessee, S.W. Virginia		Ohio & U. Miss. Valley
M. ORDOVICIAN	BLACK RIVER		TYRONE OREGON CAMP NELSON	400-1000'	LIMESTONE	CHICKAMAUGA	EGGLESTON HARDY CREEK BEN HUR WOOLWAY HURRICANE BRIDGE MARTIN CREEK		PLATTEVILLE
M. ORDOVICIAN	CHAZY	WELLS CREEK-ST. PETER	JOACHIM DUTCHTOWN ST. PETER EVERTON	0-800	DOLOMITE, SHALE, AND SANDSTONE	CHICKAMAUGA	ROB CAMP POTEET DOT		GLENWOOD ST. PETER
L. ORDOVICIAN	KNOX GROUP	BEEKMANTOWN	NEWALA	0-1000+	DOLOMITE	BEEKMANTOWN	MASCOT KINGSPORT	PRARIE DU CHIEN	SHAKOPEE
L. ORDOVICIAN	KNOX GROUP	BEEKMANTOWN	LONGVIEW	0-1000+	DOLOMITE	BEEKMANTOWN	LONGVIEW	PRARIE DU CHIEN	NEW RICHMOND
L. ORDOVICIAN	KNOX GROUP	BEEKMANTOWN	CHEPULTEPEC ROSE RUN SS	350-750	DOLOMITE WITH SANDSTONE AT BASE	BEEKMANTOWN	CHEPULTEPEC SANDSTONE BEDS	PRARIE DU CHIEN	ONEOTA MADISON SS JORDAN SS
CAMBRIAN			COPPER RIDGE	700-1500	DOLOMITE		COPPER RIDGE		TREMPLEALEAU FRANCONIA
CAMBRIAN			CONASAUGA	50-320	LIMESTONE		MAYNARDVILLE NOLICHUCKY MARYVILLE ROGERSVILLE RUTLEDGE PUMPKIN VALLY		DRESBACH
CAMBRIAN			ROME	250-4560+	SANDSTONE, SILTSTONE, SHALE, LIMESTONE AND DOLOMITE		ROME		EAU CLAIRE
CAMBRIAN			SHADY	0-160	DOLOMITE		SHADY-TOMSTOWN		EAU CLAIRE
CAMBRIAN			BASAL SAND	80-300	SANDSTONE		ERWIN		MT. SIMON
Pe									

CORRELATIONS OF CAMBRIAN, LOWER ORDOVICIAN, AND EARLY MIDDLE ORDOVICIAN FORMATIONS MODIFIED FROM McGUIRE AND HOWELL, 1963)

Silurian-Devonian Sequence

A heterogeneous sequence of Silurian and Devonian rocks overlies Ordovician strata throughout the basin areas of the Ohio Valley. The Silurian-Devonian sequence is not present across the Cincinnati arch and the Nashville dome because it was either not deposited in this area or because it has been removed by erosion (Fig. 6). The principal sedimentary rock types within the Silurian-Devonian sequence include limestone, dolomite, shale, sandstone, salt, anhydrite and gypsum.

The sequence has a thickness of over 4,000 ft. in the north-central portion of the Appalachian basin, but thins toward the margins of the basin, particularly southwest toward the Cincinnati arch. Westward from the Cincinnati arch, the thickness increases to about 1,500 ft. in the central Illinois basin. Northward, the thickness increases to over 7,000 ft. in the central Michigan basin. The top of the Silurian-Devonian sequence lies at depths of greater than 7,000 ft. in the central Appalachian basin and greater than 5,000 ft. in the central Illinois basin.

In the Appalachian basin of New York, the Silurian-Devonian sequence consists of the sandstones and shales of the Medina and Clinton at the base, the remainder of the sequence being primarily limestone, dolomite and evaporite beds with lesser amounts of shale and sandstone. Subdivisions used in western New York are shown below. The character and thickness of this sequence and some of the names applied to it change rapidly when traced laterally.

Generalized Silurian-Devonian Sequence in Western New York

Rock Unit Age	Rock Unit Name	
Devonian		Onondaga Limestone
		Oriskany Sandstone
Silurian		Salina Group
		Lockport Group
	Clinton	Rochester Shale
		Irondequoit Limestone
		Reynales Limestone
		Neahga Shale
	Medina	Thorold Sandstone
		Grimsby Sandstone
		Cabot Head Shale
		Whirlpool Sandstone

The sandstones of the Clinton and Medina are replaced by interbedded sandstones and shales in western New York, western Pennsylvania and eastern Ohio and by limestones west of central Ohio, as shown in Fig. 10. The names change with the lithology and the Clinton and Medina of New York are the Brassfield and "Niagaran" limestones and dolomites in western Ohio.

In that area of the northeast Ohio Valley where disposal into Devonian and Silurian rocks is indicated as most likely to be feasible (Fig. 9), the Clinton-Medina interval is from 200 ft. thick in the west to 1,200 ft. thick in the east. The sandstone content ranges from nearly 100 percent in the east to very little in the west.

The 3,000 ft. of carbonates, evaporites and shales that comprise the Silurian-Devonian sequence above the Clinton in south-central New York thins to about 1,200 ft. at the eastern end of the cross section of Fig. 10 and continue to thin toward the west. This is almost entirely because of variation in the thickness of the Salina Group. The total Lockport to Onondaga unit thins toward the southwest also and is not present in southeastern Kentucky and most of Tennessee.

One significant sandstone unit, the Oriskany sandstone, occurs in this interval just below the Onondaga Limestone. The Oriskany is not present everywhere, and when present it is often impermeable. It does, however, have potential as a disposal interval in areas of the northern Appalachian basin, and was the original disposal interval in the Jones and Laughlin well at Aliquippa, Pennsylvania.

The Silurian-Devonian sequence is composed of about 500 to 1,000 ft. of dolomite and limestone in the Illinois basin. One set of rock unit names that is applied to this sequence in the northern Illinois basin is shown below. Other names are also used.

Subdivisions of the Silurian-Devonian Carbonate Sequence
in the Northern Illinois Basin

<table>
<tr><th colspan="2">Rock Unit Age</th><th>Rock Unit Name</th></tr>
<tr><td colspan="2" rowspan="2">Devonian</td><td>Grand Tower Dolomite</td></tr>
<tr><td>Cedar Valley Limestone</td></tr>
<tr><td rowspan="3">Silurian</td><td rowspan="2">Niagaran</td><td>Racine Limestone</td></tr>
<tr><td>Joliet Limestone</td></tr>
<tr><td>Alexandran</td><td>Alexandran Series Limestones</td></tr>
</table>

Silurian and Devonian age limestones and dolomites do not generally have sufficient porosity and permeability for disposal purposes in the Illinois basin, but locally there are zones in this sequence that would be satisfactory.

Devonian Shale Sequence

Throughout the Zone I and Zone II portions of the Illinois and Appalachian basins shown in Fig. 9, Devonian Shales overlie the Silurian and Devonian strata previously discussed.

Within Zones I and II in the Ohio Valley portion of the Appalachian basin, the Devonian shale sequence is a wedge-shaped mass that ranges from a minimum of about 400 ft. thick in the west to over 7,500 ft. thick in the east. In the west, the sequence is almost entirely shale but numerous sandstones appear toward the east as shown in Fig. 10.

In Figure 10, the basal 100 feet or so of the shale sequence is termed the Hamilton Shale and the remainder the Ohio Shale. These beds are largely grey to black shale. As the sequence thickens toward the east the percentage of black shale decreases and sandstones, siltstones, and red-colored sediments become abundant and the nomenclature becomes complex. As many as thirty sandstone units have been named in the Devonian oil fields of Pennsylvania and perhaps equally as many in West Virginia. These sandstone beds are generally lenticular and individual ones cannot be traced far.

In the western part of Zone II within the Appalachian basin the Devonian shale sequence is a series of shales that provide confinement for underlying potential disposal zones. In the eastern part of Zone II and in Zone I, the sequence provides confinement and has many sandstones that are potential disposal zones. However, the large number of oil and gas wells drilled into these sandstones in Pennsylvania and West Virginia limits their potential considerably.

The New Albany shale of the Illinois basin is a black shale with some lenses of limestone in the lower part. It ranges in thickness from 50 ft. in the north to over 400 ft. in the south, but it is generally 100 ft. thick or less. The New Albany shale provides a convenient marker bed to separate Devonian and Mississippian strata (the uppermost part of the New Albany may be Mississippian in age), and also acts as a somewhat limited hydrologic barrier between them.

Mississippian-Pennsylvanian Sequence

Mississippian and Pennsylvanian age rocks are present at the surface throughout most of the major synclinal basin areas of the Ohio Valley, but have been removed by erosion from parts of the Cincinnati arch and its continuations (Fig. 2). Up to about 1,000 ft. of Permian age rocks overlie Pennsylvania age strata in the central part of the northern Appalachian basin, but are not present elsewhere and are grouped with Pennsylvanian age rocks.

The sequence is composed primarily of shale, siltstone, sandstone, and conglomerate with lesser amounts of limestone and coal. The combined vertical thickness of Mississippian and Pennsylvanian strata reaches about 3,000 ft. in the north central Appalachian basin and 5,000 ft. in the central Illinois basin. This thickness of rocks immediately limits the possibilities of underground disposal in those areas to Mississippian and lower Pennsylvanian strata and to areas where the sequence reaches half its maximum thickness or more.

A generalized geological column of the Mississippian-Pennsylvanian sequence in Roane County, West Virginia, is shown in the table on the following page. The groups shown are ones recognized throughout the portions of southwestern Pennsylvania, western West Virginia and southeastern Ohio where disposal into Mississippian and lower Pennsylvanian strata is most likely to be feasible. Many of the Mississippian and lower Pennsylvanian sandstone units have physical characteristics satisfactory for waste disposal, but the large number of abandoned and active oil and gas wells that penetrate these rocks greatly restricts their potential as disposal units.

The thickness of Mississippian and Pennsylvanian rocks increases toward the southeast in the Appalachian basin and the total thickness of Mississippian rocks alone aggregates as much as 4,500 ft. in Greenbriar County, West Virginia. In southern West Virginia, eastern Kentucky and southwestern Virginia, Mississippian strata alone range in total thickness from 1,000 to 6,000 ft. One set of rock unit names that has been used in that area is shown below. Each rock unit appears to have some potential for underground disposal, since they have each produced gas in this area.

Generalized Geological Section of Mississippian Rocks in Southern West Virginia, Southwestern Virginia, and Eastern Kentucky

(Constructed from data by Wilpolt and Marden, 1959)

Rock Unit Age	Rock Unit Name		Thickness	Principal Rock Type
MISSISSIPPIAN	PENNINGTON GROUP	Bluestone Formation	300-1,000	Shale, sandstone, limestone, and twin coal beds
	PENNINGTON GROUP	Princeton Formation	0-250	sandstone
	PENNINGTON GROUP	Hinton Formation	300-1,700	red shale and siltstone
	Bluefield Formation		200-1,950	calcareous shale, some limestone and sandstone
	Greenbriar Limestone		250-850	limestone and dolomite

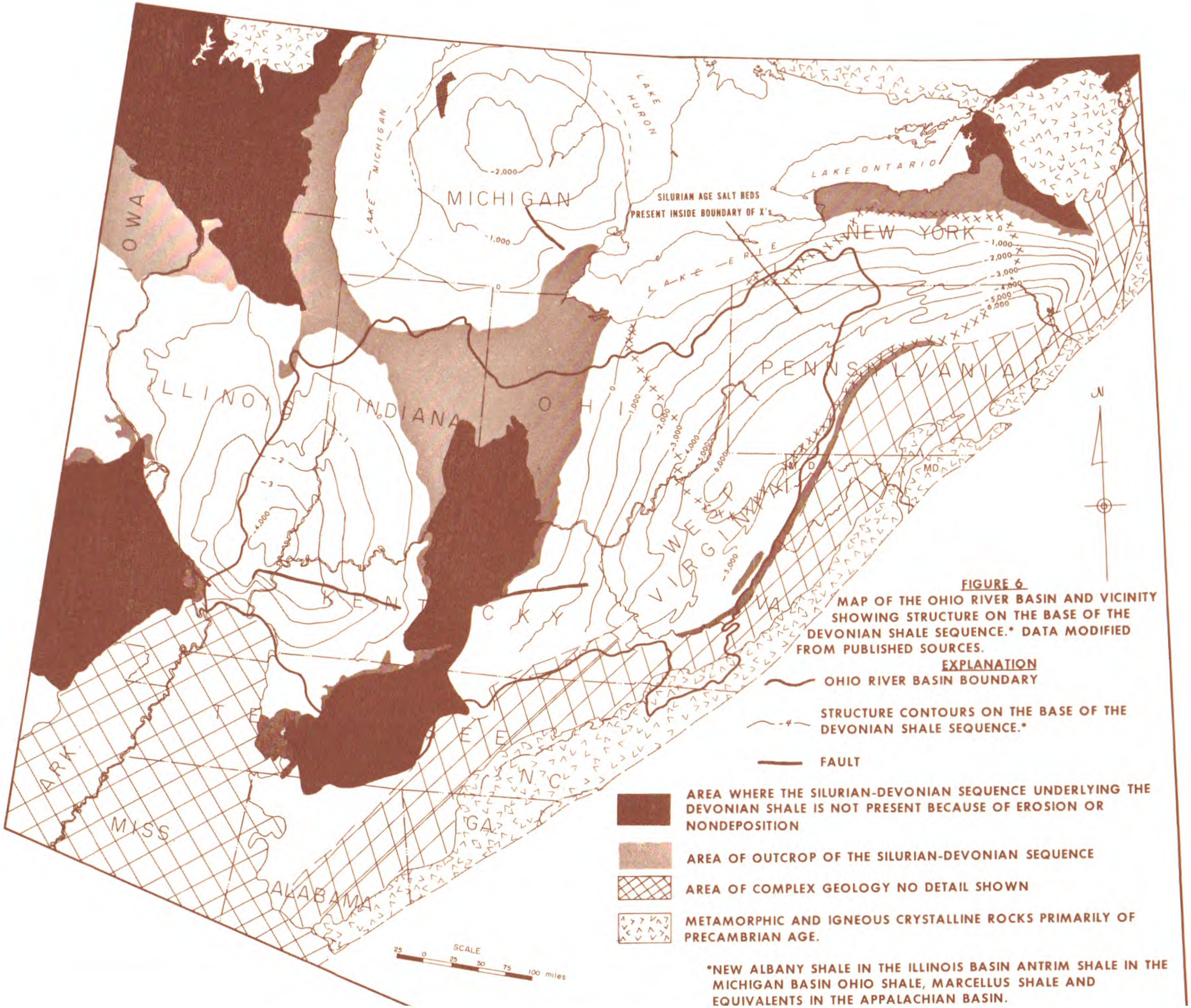


FIGURE 6
MAP OF THE OHIO RIVER BASIN AND VICINITY SHOWING STRUCTURE ON THE BASE OF THE DEVONIAN SHALE SEQUENCE.* DATA MODIFIED FROM PUBLISHED SOURCES.

AGE	GROUP	ROCK TYPE	APPROX. THICKNESS	DRILLERS TERMS FOR SANDSTONES AND OTHER MARKER BEDS
PERMIAN	DUNKARD		0-350'	WASHINGTON COAL
PENNSYLVANIAN	MONONGAHELA		250'	CARROLL SAND PITTSBURGH COAL
	CONEMAUGH		650'	MINSHALL SAND MURPHY SAND MOUNDSVILLE SAND FIRST COW RUN (DUNKARD) BIG DUNKARD UPPER FREEPORT COAL
	ALLEGHENY		250'	BURNING SPRINGS SAND GAS SAND LOWER GAS SAND HORSENECK SAND
	POTTSVILLE		700'	SALT SANDS MAXTON SAND
MISSISSIPPIAN	MAUCH CHUNK		65'	LITTLE LIME PENCIL CAVE
	GREENBRIER		135'	BIG LIME
	POCONO		450'	KEENER SAND BIG INJUN SAND SQUAW SAND BEREA SAND

LEGEND

Generalized geological columnar section of Mississippian, Pennsylvanian and Permian rocks, Roane County, W. Va.

In the Illinois basin, Mississippian strata reach a maximum total thickness of about 3,500 ft. in the southeast and thin toward the northwest. The lower portion of the Mississippian System, which reaches a maximum thickness of 2,000 ft., includes strata of the Kinderhook and Osage-Meramec (Valmeyeran) Series. Kinderhook and Osage rocks are principally shale and calcareous siltstone with some beds of fine sandstone and siliceous limestone. The Meramec Series includes, in ascending order, the Salem Limestone, the St. Louis Limestone, and the Ste. Genevieve Limestone.

There are occasional sandstone beds in the Osage Series which have potential as disposal intervals, but the principal units of interest are the limestones of the Meramec Series. These limestones may have fracture or solution porosity and permeability or may have porous and permeable oölitic or sandy intervals. The Ste. Genevieve Formation is a particularly prolific oil producing unit in the Illinois basin and contains potable water in a narrow band along the Ohio and Mississippi rivers.

The Chester Series includes the Mississippian rocks above the Ste. Genevieve Formation. This interval reaches a maximum thickness of 1,400 ft. in the southeastern Illinois basin and consists of alternating limestone-shale and sandstone-shale intervals, many of which are oil producing. Some of the individual sandstones of the Chesterian Series are the Palestine, Waltersburg, Tar Springs, Cypress, and Bethel sandstones. The Tar Springs and Cypress sandstones are principal aquifers used as sources of brine in the secondary recovery of oil.

Pennsylvanian age rocks of the Illinois basin attain a maximum thickness of about 2,500 ft. in Edwards County, Illinois, and consist principally of shale, sandstone and siltstone, with lesser amounts of limestone and coal. Pennsylvanian age rocks occur at the surface and contain potable water to depths as great as 900 ft. Below the potable water, Pennsylvanian age sandstones contain saline water and some oil accumulations. These sandstones are potential disposal horizons, but are of generally low permeability and may be of limited areal extent.

In Fig. 9 is shown the area within the Illinois basin where Pennsylvanian, Mississippian, or older strata may be suitable for disposal purposes. Two disposal systems in extreme southwestern Indiana are used for injecting wastes into sandstones of Mississippian age.

GROUNDWATER GEOLOGY

A primary consideration in the appraisal of an injection proposal is the protection of potable groundwater. In this regard the question arises: Which groundwaters are potable and to be protected and which are of low enough quality (high salinity) to be used for disposal purposes?

Groundwaters containing less than 1,000 mg/l of dissolved solids will be protected except under unusual circumstances. Water containing less than 500 mg/l is presently considered to be acceptable for potable water to be used by interstate carriers (U. S. Public Health Service, 1962), and formerly (U. S. Public Health Service, 1946) if such water was not available, water containing 1,000 ppm of dissolved solids was considered acceptable. The minimum salinity may be set at a level higher than 1,000 mg/l of dissolved solids to provide a margin of safety. Water with several times this dissolved solids content is now used in some geographic areas and may be more widely used in the future.

Illinois agencies have determined that groundwater containing less than 10,000 mg/l should be protected. As previously mentioned in the discussion of the New York regulations, groundwaters in that state have been classified, based on quality. According to the New York classification, water having a total dissolved solids content of 1,000 mg/l or less is considered to be fresh. Waste injection is prohibited in aquifers containing water with a dissolved solids content of 2,000 mg/l or less.

In Fig. 7 is shown the approximate depth to aquifers containing greater than 1,000 mg/l of dissolved solids in the Ohio Valley and adjacent areas. This map gives a very broad indication of the depth range to which surface casing must extend in order to close off aquifers containing potable water. It also shows that there are no saline water-bearing aquifers to be used for disposal in portions of the eastern Ohio Valley. If waters containing more than 1,000 mg/l of dissolved solids are considered fresh, then larger areas of the Ohio Valley would be unsuited for underground disposal, and the depth to the fresh water-saline water interface would be extended. A more detailed map of the fresh water-saline water interface in Kentucky has been prepared by Hopkins (1966), and the saline groundwater resources of Ohio have been studied by Sedam and Stein (1970).

The details of groundwater occurrence that should be examined in considering underground disposal at a specific location can be obtained from various published reports and from state and federal agencies.Deutsch and others (1965) and Wyrick (1968) describe groundwater resources of the Ohio Valley and Appalachia, respectively, and reference the available published reports on groundwater occurrence in these areas.

MINERAL RESOURCES DISTRIBUTION

The occurrence of oil, gas, coal, mineralized brines, and occasionally other less abundant minerals require consideration in preparing and evaluating injection proposals. Oil, gas and coal are widely distributed and important resources in the Ohio Valley and mineralized brines are also of economic importance to a number of industries.

Of the mineral resources, oil and gas most frequently require consideration because of their abundance and because rock units that contain them are often physically well suited for waste injection. In Fig. 8 the relative intensity of oil and gas field development in the Ohio Valley area is shown. Intense development of oil and gas resources does not necessarily preclude injection disposal. However, the potential for such disposal will, within certain areas, be greatly limited because of oil and gas development. For example, in the Lima-Indiana oil field area shown in Fig. 8, nearly 75,000 wells were drilled during the late 1800's and early 1900's. These oil wells are now abandoned and many of their locations are unknown.

Because of the inadequate plugging practices used at the time when the Lima-Indiana field was abandoned, it is now not possible to contemplate injection into the Trenton Limestone or any of the horizons above the Trenton in that area. Injection into the deeper Mt. Simon Formation, which lies well below the Trenton, is still possible as is illustrated by the Sohio Petroleum Company injection well at Lima, Ohio. It is not practical to list all of the situations similar to this that exist in the Ohio Valley. However, matters such as this must be considered individually at the time when underground disposal is actually contemplated at a specific location.

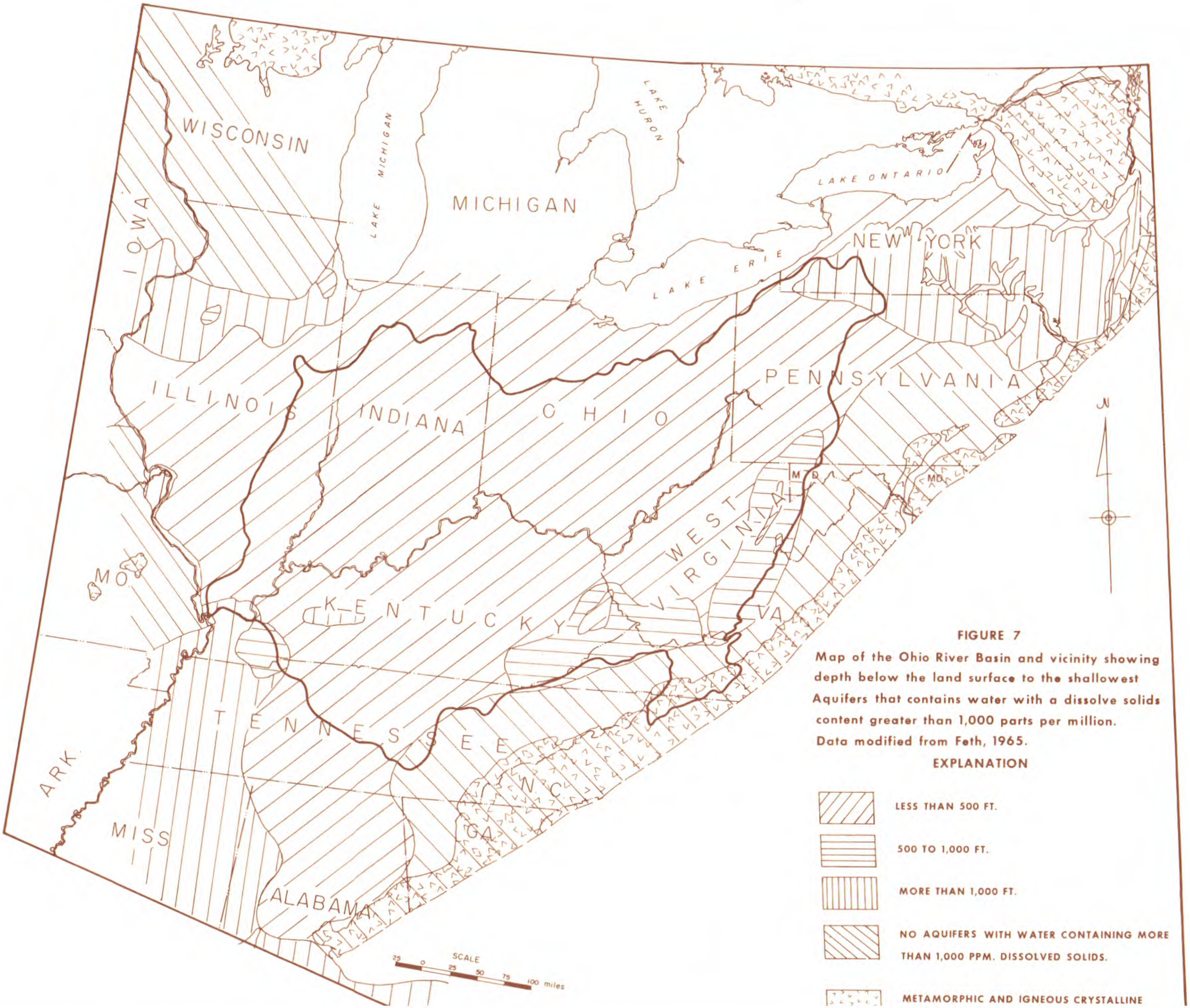


FIGURE 7

Map of the Ohio River Basin and vicinity showing depth below the land surface to the shallowest Aquifers that contains water with a dissolve solids content greater than 1,000 parts per million. Data modified from Feth, 1965.

EXPLANATION

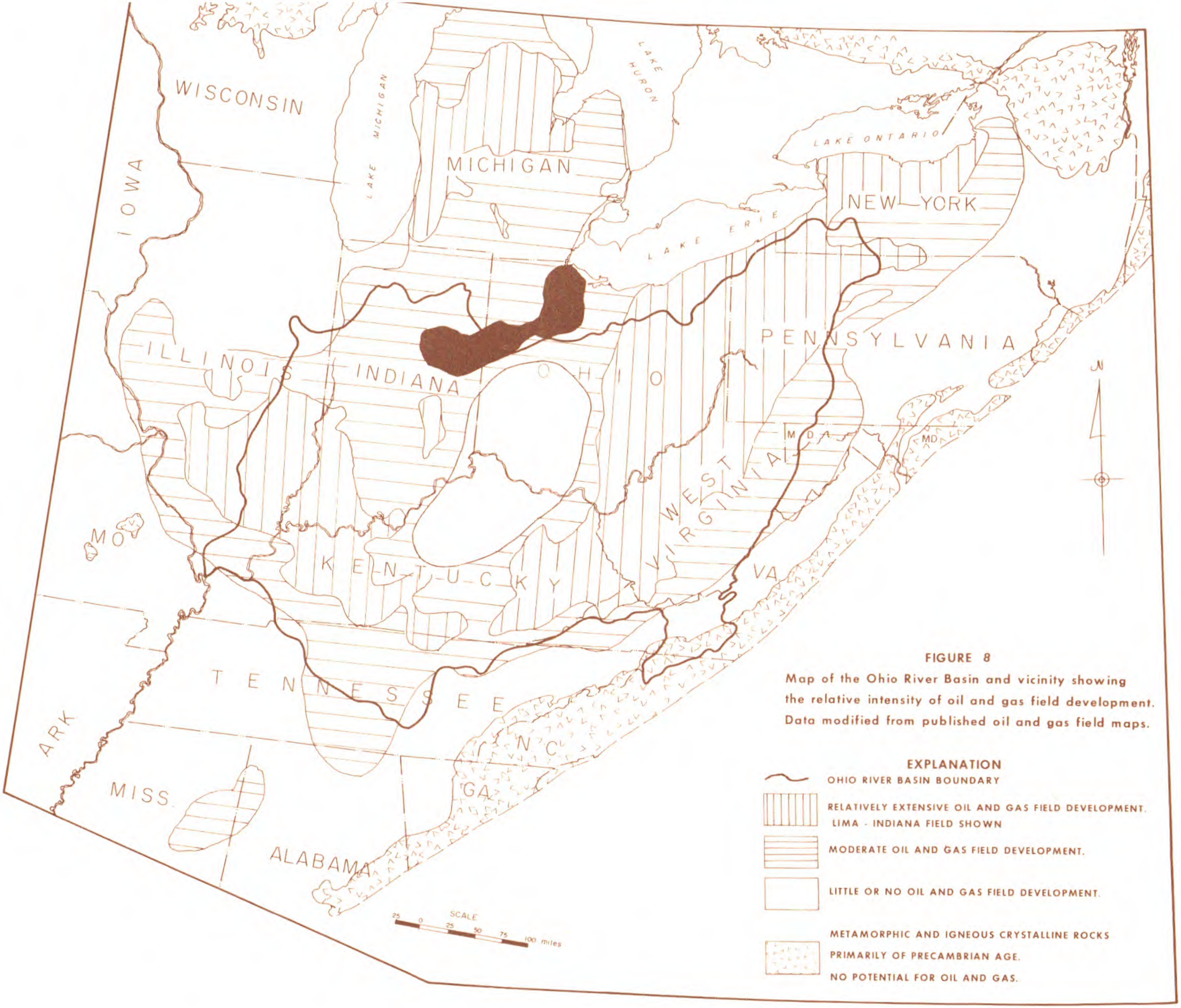


FIGURE 8

Map of the Ohio River Basin and vicinity showing the relative intensity of oil and gas field development. Data modified from published oil and gas field maps.

Coal is also a very abundant resource in the Ohio Valley, as illustrated by the fact that about 77 percent of the bituminous coal produced in the United States in 1964 was mined in the area. Coal resources are in the Pennsylvanian age rocks of the Appalachian and Illinois basins. It is necessary to insure adequate casing and cementing of wells in areas where coal is now being mined to prevent possible contamination just as in the case of groundwater. This is recognized in coal-producing states, where special well construction regulations apply to oil and gas wells when they are drilled in coal-producing areas. Such regulations would also be expected to be applied to disposal wells, perhaps even in a more stringent form.

Underground bituminous coal mines that have been developed to date have been primarily above stream drainage level in the Appalachian basin because of the increased cost of extracting coal as the mines become deeper. However, as the shallower coal resources are exhausted, the mines are becoming deeper and will eventually reach depths where injection disposal may be possible. Some mines are already approaching such depths, for example, the Island Creek Coal Company-Republic Steel Corporation mine in Buckhannon County, Virginia, the deepest coal mine in North America, is 1,350 ft. deep. With this possibility in mind, it will be necessary to consider the presence of deep coal reserves, as well as oil and gas, in evaluating injection proposals.

Some natural subsurface brines and salt formations also require protection. Natural brines and brines obtained by dissolving solid salt with water circulated from the surface are used as sources of salt and chemicals by industries in the Ohio Valley. The Silurian age Salina Formation (Fig. 10) contains natural, solid-salt beds; these are mined by conventional underground mining methods and also by circulation of water from the surface which dissolves the salt and is returned to the surface for use. The extent of salt beds in the Salina Formation is shown in Fig. 6. Other formations used as sources of brine in the Ohio Valley are the Silurian age Clinton, which is used in eastern Ohio, and the Pennsylvanian age Salt Sands, which have been used in the Charleston, West Virginia, area.

SEISMICITY APPRAISAL

The past history of earthquake activity in an area must be considered because an earthquake might potentially damage injection well facilities or alter geohydrologic conditions. In addition, because of the possibility that injection into the Denver Rocky Mountain Arsenal well may have induced earth tremors (Healy and others, 1968), the susceptibility of an area to such induced seismic activity should be examined.

Within and near the Ohio Valley Region, two localities stand out as having been affected by significant earthquakes during recorded time. Three of the most intense earthquakes that have been recorded in this country were centered near New Madrid, Missouri, and occurred in December 1811, and January and February 1812. All three of these earthquakes were of greater intensity than any that have occurred in California, including the 1906 San Francisco earthquake. A total area of at least 2,000,000 square miles was shaken and significant topographic changes occurred, including the formation of Reelfoot Lake, Tennessee. Because the epicenter area was largely a wilderness, few lives were lost. The area of southeast Missouri and areas of adjoining states is still an active one and more than one hundred earthquakes have been reported there since 1812.

An earthquake occurred November 9, 1968, near Broughton, Hamilton County, Illinois, about 100 miles northeast of the epicenter of the New Madrid earthquakes. The intensity was about 7 (modified Mercalli scale) as compared to an estimated intensity of 12 for the New Madrid earthquakes. These values are equivalent to 5.5 and 8.1 on the Richter scale. Preliminary reports from the oil and gas industry (Heigold, 1968) reveal that subsurface hydrologic changes and minor damage to well facilities occurred.

A second area in the Ohio Valley where relatively intense earthquakes have been recorded is in western New York. Here earthquakes with intensities of 8 were recorded in 1929 and 1944. These two earthquakes were centered near Attica and Massena, New York, respectively. Changes in groundwater conditions reportedly occurred in 1929. A less intense 1966 earthquake was also centered near Attica, New York.

Data from a recently published map depicting the degree of seismic risk is reproduced in Fig. 14. These data agree with the above discussion and indicate that there is a possibility of major earthquake damage in the extreme southeast and northeast portions of the Ohio Valley and of moderate to minor damage elsewhere in the area.

There is no known precedent for regulatory policy and requirements that will take seismic risk into account. Tentative suggestions are:

(1) Special attention should be given to standby facilities in areas where major or moderate earthquake damage is considered possible; and

(2) Injection wells should not be constructed at sites where major earthquake damage is considered possible and where subsurface faults occur that could shift and cause damage to well casing.

HYDRODYNAMIC FACTORS

The usual discussion of subsurface disposal conveys the impression to the reader that the naturally occurring fluids in deep aquifers are in a static state. For many purposes this can be assumed to be the case in the Ohio Valley area. However, deep subsurface fluids are naturally in motion, although slowly, and the fact that they are moving should be considered in managing subsurface disposal.

An initial attempt to analyze the patterns of fluid movement in deep aquifers of the Illinois basin has been made by Bond (1972). However, at present, there is not enough information to allow satisfactory examination of hydrodynamic factors in most of the Ohio Valley area, particularly in the case of the deep Cambrian-age strata that account for most of the injection wells that have been constructed to date. If accurate initial fluid pressure data are obtained from wells that are drilled in the future eventual determination of the regional patterns of fluid movement in the deep subsurface of the Ohio Valley, may be possible.

It will also be necessary to obtain accurate data on injection rate and pressure during the operation of injection systems to determine the local and regional effect of these systems on the injection horizons.

SUMMARY OF GEOLOGIC AND HYDROLOGIC CONSTRAINTS

The geology and groundwater hydrology of the Ohio Valley have been broadly considered in view of the potential for subsurface waste injection in the area. Implications of the previous discussion are partly summarized in Fig. 9. Here is indicated the relative feasibility of deep-well disposal as constrained by the thickness of sedimentary rocks, geologic structure, and the presence of saline water-bearing aquifers. Areas underlain only by metamorphic and igneous crystalline rocks provide virtually no potential for subsurface disposal of liquid waste. Areas where subsurface waste injection is indicated as being of limited feasibility are those where:

No aquifers containing more than 1,000 mg/l of dissolved solids are available, as indicated in Fig. 7;

The saline-water-bearing sedimentary sequence is less than 1,500 ft. thick;

Structural geologic conditions are considered sufficiently complex to cause great uncertainty about subsurface hydrology.

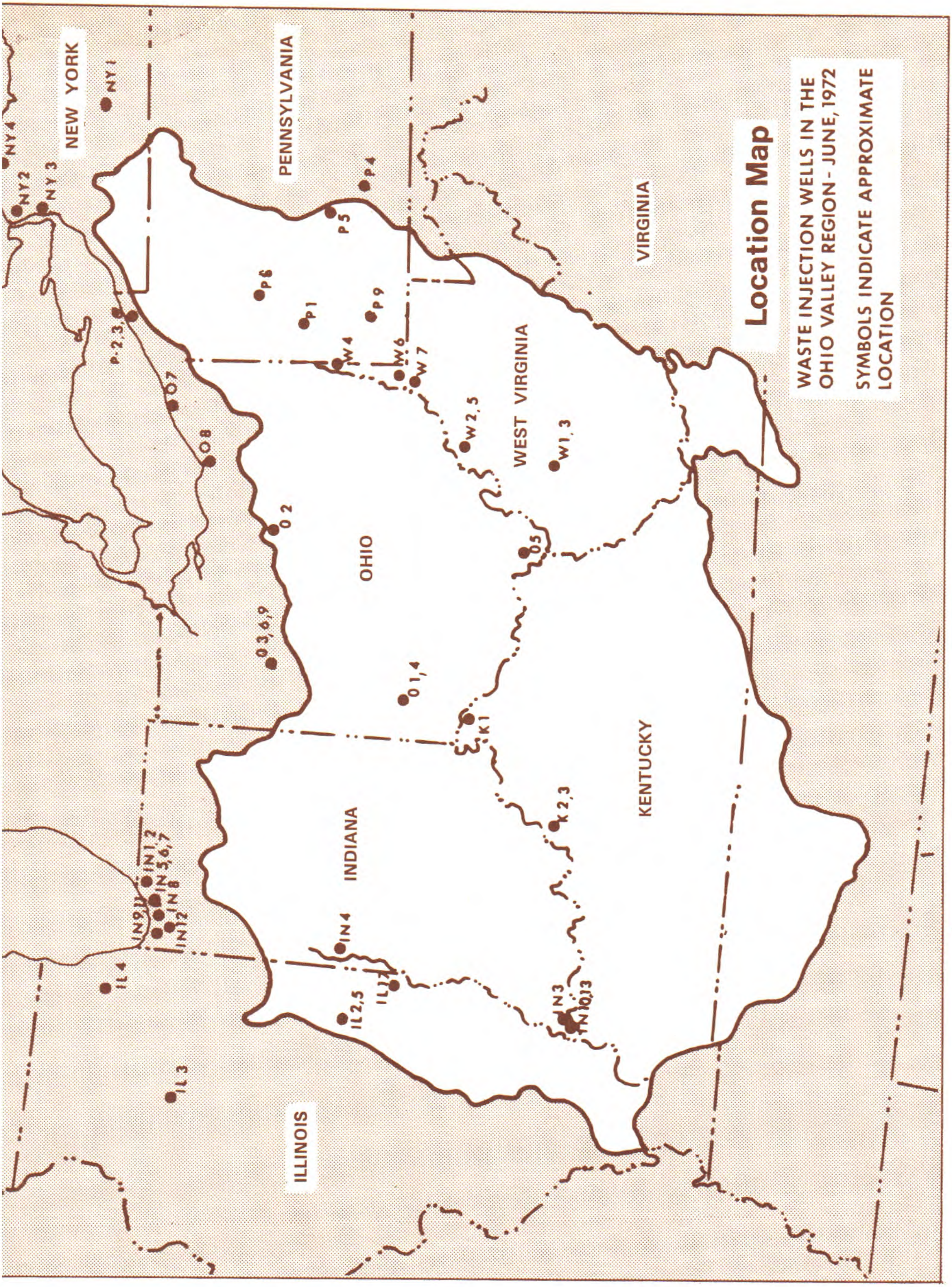
Within the areas where the above limitations do not apply, feasibility of waste injection is shown as being most likely in one or more of the stratigraphic sequences indicated in Fig. 9. In Zone I, disposal feasibility is shown as being most likely in Pennsylvanian, Mississippian, or older rocks. There is at least 1,500 to 2,000 ft. of Mississippian-Pennsylvanian sedimentary rock present containing water with 1,000 mg/l or more of dissolved solids in Zone I. In Zone II, there is at least 1,500 to 2,000 ft. of Silurian-Devonian rock present containing saline water and in Zone III there is at least 1,500 to 2,000 ft. of Ordovician and Cambrian sedimentary rock present containing saline water.

While Fig. 9 offers broad geographic guidelines, it cannot be used to specify where subsurface injection may or may not be permitted. For example, in constructing the map aquifers with water containing more than 1,000 mg/l were considered as having waste-disposal potential, whereas, at least in Illinois and New York, the dissolved solids content would have to be greater (10,000 mg/l and 2,000 mg/l, respectively) before an aquifer could be considered for waste injection. Some other limitations of the map are:

It does not consider the presence of unplugged abandoned wells or the locations of mineral resources.

The fact that 1,500 ft. or more of saline water-bearing sedimentary rock is present does not assure that a suitable porous and permeable injection horizon or a suitable confining interval will be present.

Areas of relatively high seismic risk are not excluded for use because evaluation of the hazard of earthquake damage and earthquake mitigation are considered to be related to specific well location and depth.


Location Map
WASTE INJECTION WELLS IN THE OHIO VALLEY REGION - JUNE, 1972
SYMBOLS INDICATE APPROXIMATE LOCATION
NEW YORK
PENNSYLVANIA
OHIO
WEST VIRGINIA
VIRGINIA
KENTUCKY
INDIANA
ILLINOIS
NY 1
NY 2
NY 3
NY 4
P 1
P 4
P 5
P 8
P 9
P 2,3,6
O 1,4
O 2
O 3,6,9
O 5
O 7
O 8
W 1,3
W 2,5
W 4
W 6
W 7
K 1
K 2,3
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IN 3,6,7
IN 4
IN 8
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IN 12
IN 10,13
IL 2,5
IL 3
IL 4

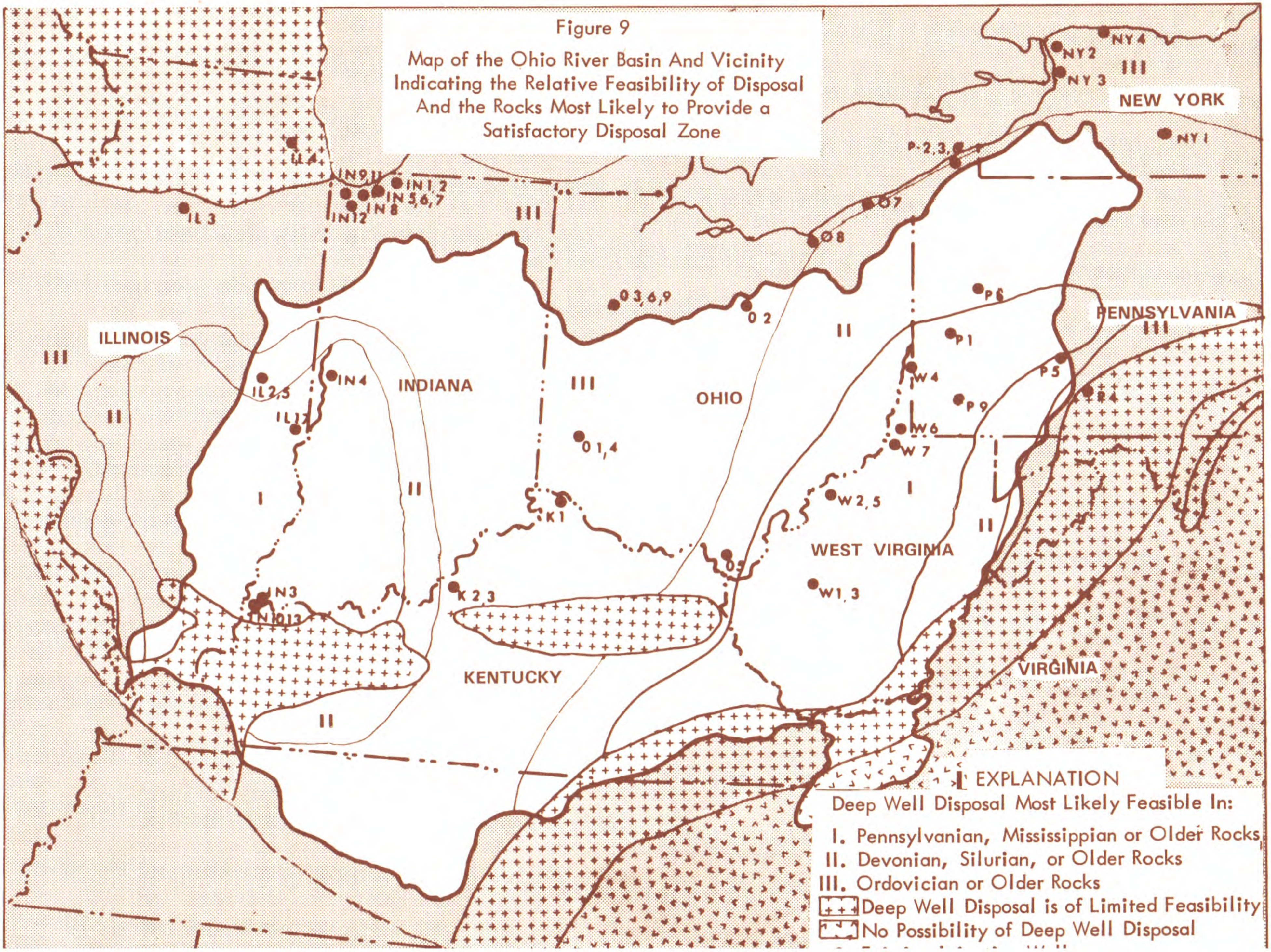

Figure 9

Map of the Ohio River Basin And Vicinity Indicating the Relative Feasibility of Disposal And the Rocks Most Likely to Provide a Satisfactory Disposal Zone

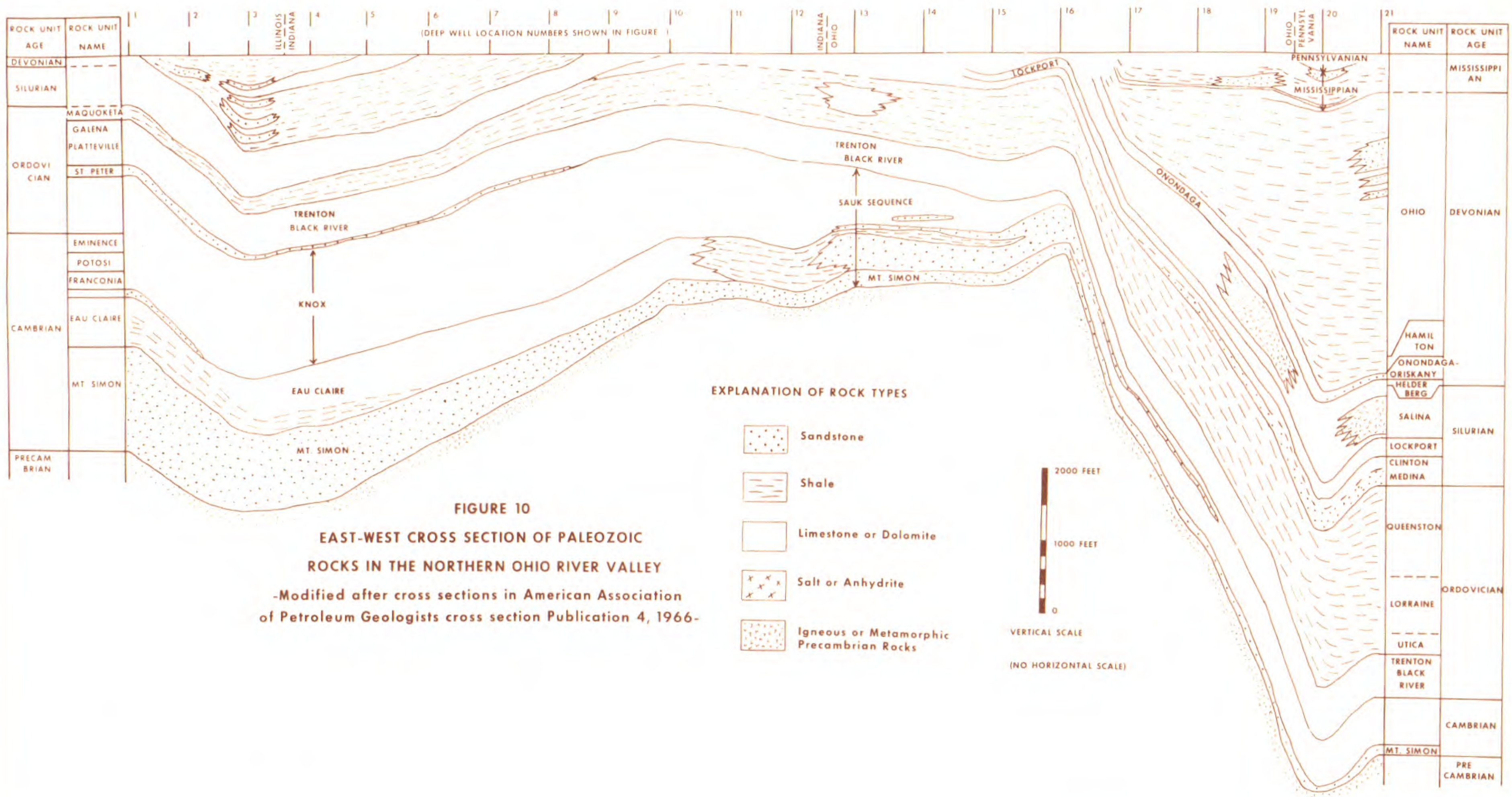

FIGURE 10

EAST-WEST CROSS SECTION OF PALEOZOIC ROCKS IN THE NORTHERN OHIO RIVER VALLEY

-Modified after cross sections in American Association of Petroleum Geologists cross section Publication 4, 1966-

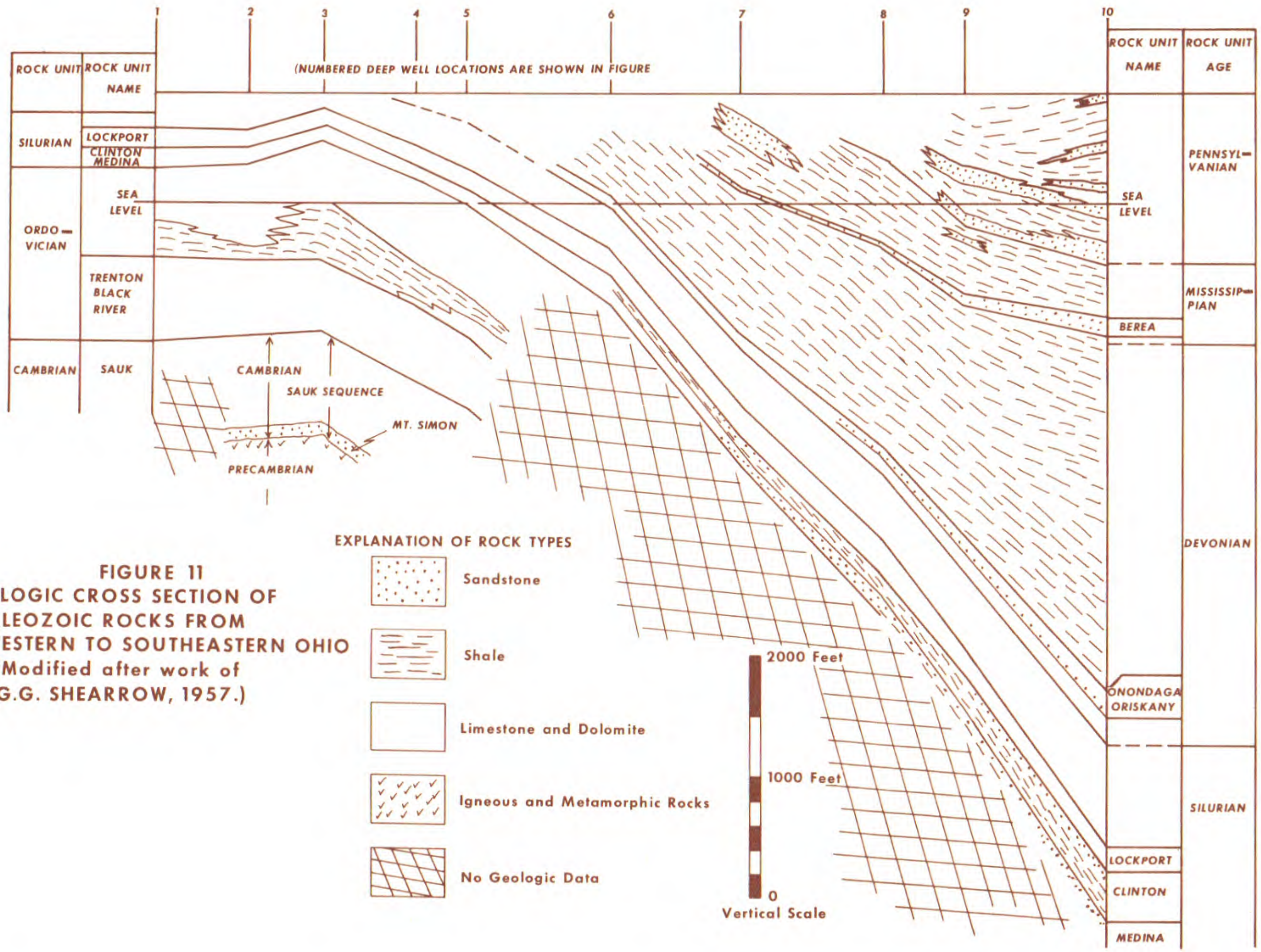

FIGURE 11
GEOLOGIC CROSS SECTION OF PALEOZOIC ROCKS FROM NORTHWESTERN TO SOUTHEASTERN OHIO
(Modified after work of G.G. SHEARROW, 1957.)

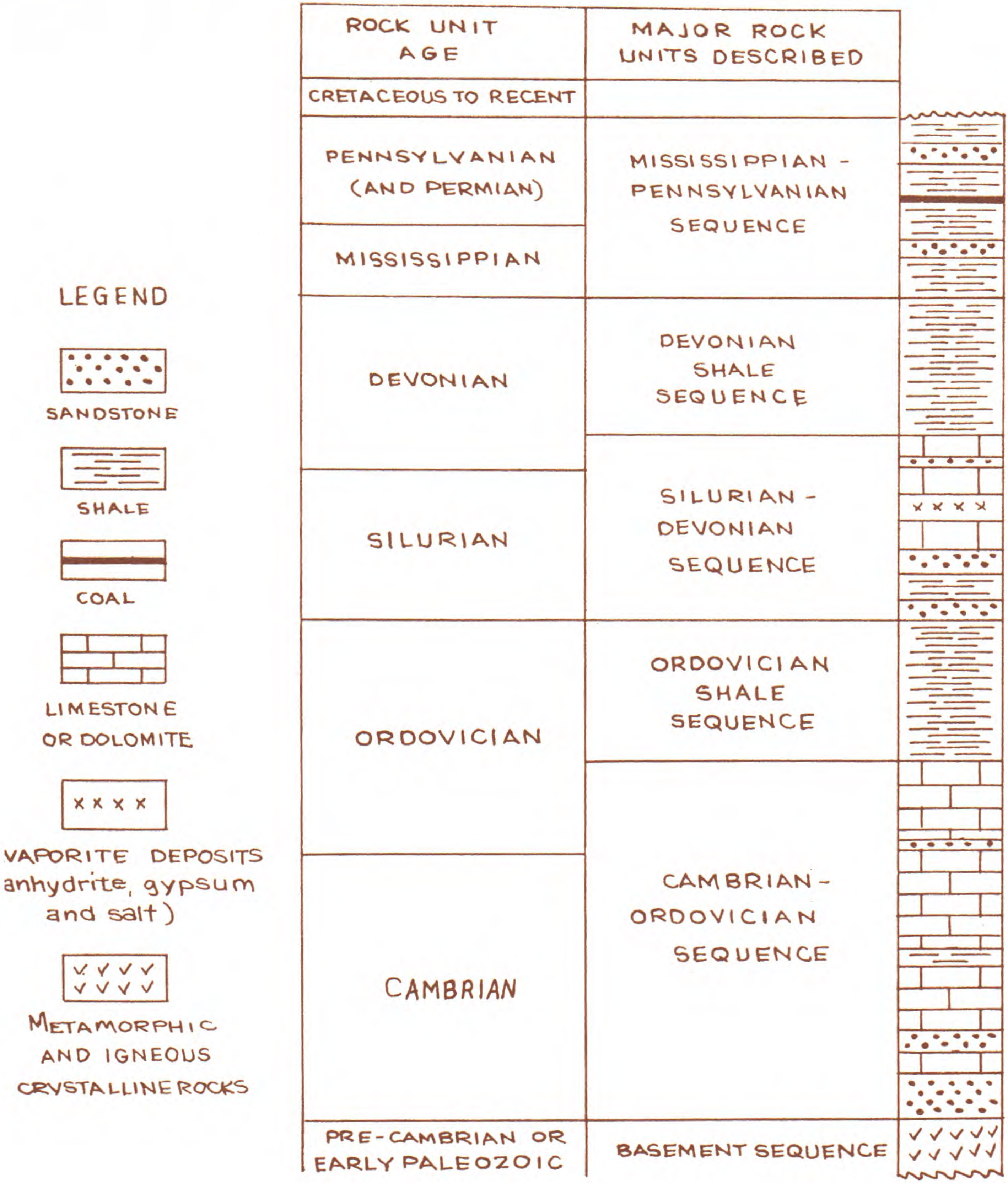

FIGURE 12

Diagramatic composite geological column of rock sequences in the Ohio River basin

Careful examination may show that geologic structural conditions will permit disposal within portions of the areas shown to have generally complex structures. However, there are places where local geology precludes subsurface disposal.

The above points are emphasized to discourage use of this report, and Fig. 9 in particular, to make specific decisions on the geologic and hydrologic aspects of individual proposals for subsurface waste injection. The information will be found useful only in establishing a framework for decisions.

Well Design, Construction, and Testing

The variability of geologic situations and the characteristics of wastes precludes establishment of rigid specifications for injection-well construction. Each injection system requires individual consideration. Certain general requirements, however, can be outlined.

Construction of well facilities for an injection system includes drilling, logging and testing, and completion activities. A hole must first be drilled, logged, and tested before it can be ascertained that it should be completed as an injection well. The completion phase includes: Installation and cementing of the casing; installation of tubing; and other related procedures such as perforating or slotting the casing and stimulating the injection horizon. Generally, it is necessary to install and cement at least some of the casing during drilling.

Drilling programs should be designed to permit installation of the necessary casing strings with sufficient space around the casing for an adequate amount of cement. Samples of the rock formations penetrated should be obtained during drilling, and it may be necessary to have formation cores or water samples at horizons of particular importance to provide necessary geologic and hydrologic data. Complete logging and testing of wells intended for injections should be required. Such data should be filed with the appropriate state agencies.

In Table 4 is summarized the information desired in subsurface evaluation of the disposal horizon and the methods for obtaining this information.

TABLE 4 -- Summary of Information Desired in Subsurface Evaluation of Disposal Horizon, and Methods Available for Evaluation

Information desired	Methods available for evaluation
Porosity	Cores, electric logs, radioactive logs, sonic logs
Permeability	Cores, pumping or injection tests, drill stem tests, electric logs
Fluid pressure in formations	Drill stem tests, water level measurements
Water samples	Cores, drill stem tests, pumping tests

Continued

Table 4 continued

Geologic formations intersected by hole	Drill time logs, drilling samples, cores, electric logs, radioactive logs, caliper logs
Thickness and character of disposal horizon	Same as above
Mineral content of formation	Drilling samples, cores
Temperature of formation	Temperature log
Amount of flow into various horizons	Injectivity profile

Design of a casing program depends primarily on well depth, character of the rock sequence, fluid pressures, type of well completion, and the corrosiveness of the fluids that will contact the casing. Where fresh groundwater supplies are present, a casing string (surface casing) is usually installed to below the depth of the deepest groundwater aquifer immediately after drilling through the aquifer (Fig. 13). One or more smaller diameter casing strings are then set, with the bottom of the last string just above or through the injection horizon, the latter determination depending on whether the hole is to be completed as an open hole or gravel-packed or is to be cased and perforated.

The annulus between the rock strata and the casing is filled with a cement grout. This is done to protect the casing from external corrosion, to increase casing strength, to prevent mixing of the waters contained in the aquifers behind the casing, and to forestall travel of the injected waste into aquifers other than the disposal horizon.

Cement should be placed behind the complete length of the surface casing and behind the entire length of the smaller diameter casing strings also, or at least for a sufficient length to provide the desired protection. It is suggested that at least one inch of annular space be allowed for proper cementing. Casing centralizers, other equipment, and techniques such as stage cementing can give added assurance of a good seal between the strata and the casing and should be encouraged where applicable.

Temperature logs, cement logs and other well-logging techniques can be required as a verification of the adequacy of the cementing. Cement can be pressure-tested if the adequacy of a seal is in question.

Neat portland cement (no sand or gravel) is the basic material for cementing. Many additives have been developed to impart some particular quality to the cement. Additives can, for example, be selected to give increased resistance to acid, sulfates, pressure, temperature, and so forth.

It is recommended that waste be injected through separate interior tubing rather than the well casing itself. This is particularly important when corrosive

Continued

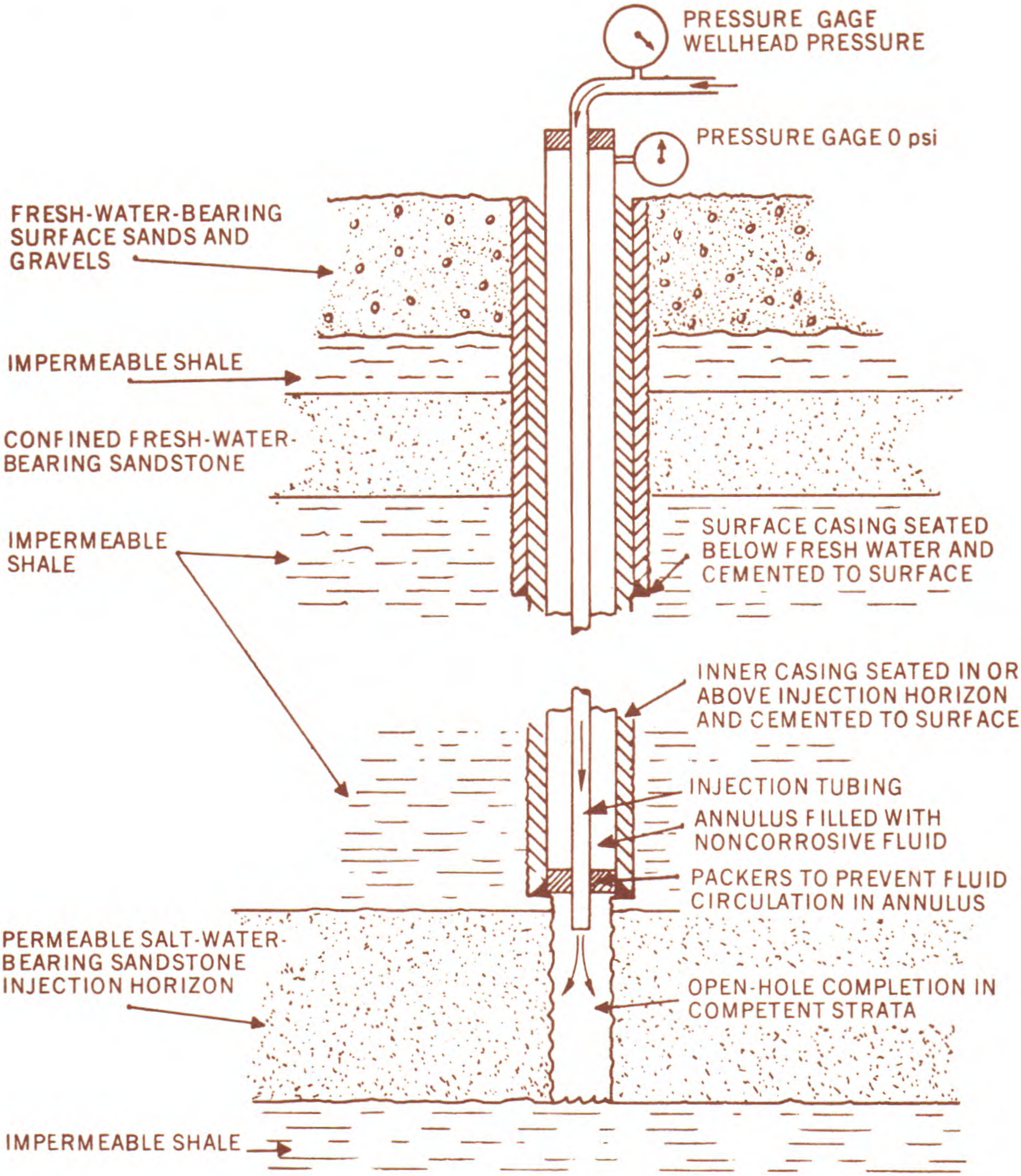

Figure 13. Schematic diagram of a waste injection well completed in competent sandstone

wastes are being injected. A packer can be set near the bottom of the tubing to prevent corrosive wastes from contacting the casing. Additional corrosion protection can be provided by filling the annular space between the casing and the tubing with oil or water containing an added corrosion inhibitor.

It is frequently desired to increase the acceptance rate of injection wells by chemical or mechanical treatment of the injection zone. Careful attention should be given to stimulation techniques such as hydraulic fracturing, perforating and acidizing to insure that only the desired intervals are treated and that no damage to the casing or cement occurs.

The type of well-head equipment can be a consideration in cases where the build-up of high back-pressure is a possibility. In such cases, the well head should be designed to "bleed-off" back flows into holding tanks or pits before pressures reach a hazardous level. High back-pressures can be developed by chemical reactions in the formation. This possibility was recognized in designing the E. I. duPont de Nemours well at New Johnsonville, Tennessee. In this case, a ferric-chloride solution is being injected into dolomite and limestone which could cause an excessive build-up of carbon dioxide gas pressure.

Surface Equipment

Surface equipment includes holding tanks and flow lines, filters, other treatment equipment, pumps, monitoring devices, standby facilities.

Surface equipment associated with an injection well should be compatible with the waste volume and physical and chemical properties of the waste to insure that the system will operate as efficiently and continuously as possible. Experience with injection systems has revealed the difficulties that may be encountered due to improperly selected filtration equipment and corrosion of injection pumps.

Surface equipment should include well-head pressure and volume monitoring equipment, preferably of the continuous recording type. Where injection tubing is used, it is advantageous to monitor the pressure of both the fluid in the tubing and in the annulus between the tubing and the casing. Pressure monitoring of the annulus is a means of detecting tubing or packer leaks. An automatic alarm system should signal the failure of any important component of the injection system. Filters should be equipped to indicate immediately the production of an effluent with too great an amount of suspended solids.

Characteristics of Untreated Wastes

A foremost consideration in evaluating the feasibility of deep-well injection is the character of the untreated wastewater. In Table 5 are listed the factors that are pertinent.

Waste volumes should be small. No arbitrary limit can be specified, but quantities greater than a few hundred gallons per minute are generally too great for injection into a single well in the Ohio Valley. Review of industrial processes may reveal possibilities for minimizing the volume of wastes for injection through such means as improved waste management practices or by exclusion of waste streams that can be handled by other means.

For example, Armco Steel Corporation of Middletown, Ohio, originally contemplated injecting 700 gpm of concentrated spent-pickling liquor along with dilute rinse water from pickling operations into a well. Testing of the first well, which was drilled in 1967, indicated that only the concentrated pickling liquor could be economically injected. The remaining dilute rinse water will be treated by neutralization and other processes.

TABLE 5 -- Factors to be Considered in Evaluating the Suitability of Untreated Wastes for Deep-Well Disposal

A. Volume

B. Physical Characteristics

1. Specific Gravity
2. Temperature
3. Suspended solids content
4. Gas content

C. Chemical Characteristics

1. Chemical constituents
2. pH
3. Chemical stability
4. Reactivity

    a. With system components
    b. With formation waters
    c. With formation minerals

5. Toxicity

D. Biological Characteristics

Waste liquids with a high content of dissolved inorganic solids are among the most commonly considered feasible for injection disposal. Industries have also favored injection of waste liquids containing organic or inorganic chemicals that are objectionable in trace amounts in surface waters, as well as highly concentrated organic chemicals that are resistant to biological degradation.

Wastes containing suspended solids as the major contaminants are not normally suitable for injection. However, wastes of this type are being injected, without prefiltration, into a highly porous and permeable limestone formation by the Dow Chemical Company at Midland, Michigan.

Commonly mentioned problems related to waste characteristics are listed in Table 6. Examples of the occurrence of some of these problems and methods used for solving them are included in the description of existing wells.

TABLE 6 -- Operational Problems Related to Waste Character

Problem of Concern	Means of Evaluating	Means of Controlling Undesirable Effects
REACTION		
Wastes and formation minerals	Laboratory tests and observation of system	Preinjection waste treatment
Wastes and formation water	Laboratory tests	Preinjection waste treatment or a buffer zone
Autoreaction of waste at formation temperature and pressure	Laboratory tests	Preinjection waste treatment
Wastes and system components	Laboratory tests and observation of system	Preinjection waste treatment, addition of corrosion inhibitors to waste, and use of corrosion-resistant materials
MICROORGANISMS		
	Laboratory tests and observation of system	Preinjection waste treatment and addition of biocides
SUSPENDED SOLIDS		
	Laboratory tests and observation of system	Preinjection waste treatment or formation treatment
ENTRAINED OR DISSOLVED GASES		
	Laboratory tests and observation of system	Chemical or mechanical degasification

Operating Program

The operating program for an injection system should conform with the geological and engineering properties of the injection horizon and the volume and chemistry of the waste fluids.

Injection rates and pressures must be considered jointly, since the pressure will usually depend on the volume being injected. Pressures are limited to those values that will prevent damage to well facilities or to the confining formations. The maximum bottom-hole injection pressure is commonly specified on the basis of well depth. It may range from about 0.5 to 1.0 psi per foot of well depth depending on geologic conditions, but seldom is allowed to exceed about 0.8 psi per foot of depth.

Well-head pressure and waste injection rate should be continuously measured if injection tubing is used, the casing-tubing annulus should be pressure monitored. Other types of monitoring include: Measurement of the physical, chemical and biological character of injected fluids, on a periodic or continuous basis, and periodic checking of the casing and tubing for corrosion, scaling, or other defects.

Experience with injection systems has shown that an operating schedule involving rapid or extreme variations in injection rates, pressures or waste quality can damage the facilities. Consequently, provisions should be made for shut-off in the event of hazardous flow rates, pressure, or waste quality fluctuations.

Observation wells can be constructed to monitor the pressure or water quality changes that occur in the injection horizon or in the overlying groundwater aquifers. Such wells have not been widely required but are an additional precaution that can be provided.

Contingency Plan

A plan should be developed by the well operator and approved by the state regulatory agency for an alternative waste management procedure if the injection well should become inoperative or need to be shut down. Such a plan requires the availability of standby facilities, which could be a standby well, holding tanks or ponds, or a waste treatment plant.

Abandonment of Wells

Each state in the ORSANCO district has an agency charged with supervising the abandonment of oil and gas wells and these agencies have developed regulations for well plugging and abandonment.

Such regulations often provide for the segregation of water-bearing intervals with cement and the plugging of other intervals with "mud or other equally non-porous materials." It is recommended that waste injection wells be plugged from bottom to the surface with cement to provide all possible segregation of aquifers.

The pulling of casing, which is sometimes allowed during the abandonment of oil and gas wells, should be entirely forbidden in the case of waste-injection wells. In addition, oil and gas well abandonment regulations sometimes provide for the cutting off of the surface casing below the ground, the intent being to prevent interference with farming or other uses. In contrast to this practice, it is suggested that a permanent surface monument be established at the location of waste-injection wells at the time they are abandoned, so that there will be no future doubt concerning the well location.

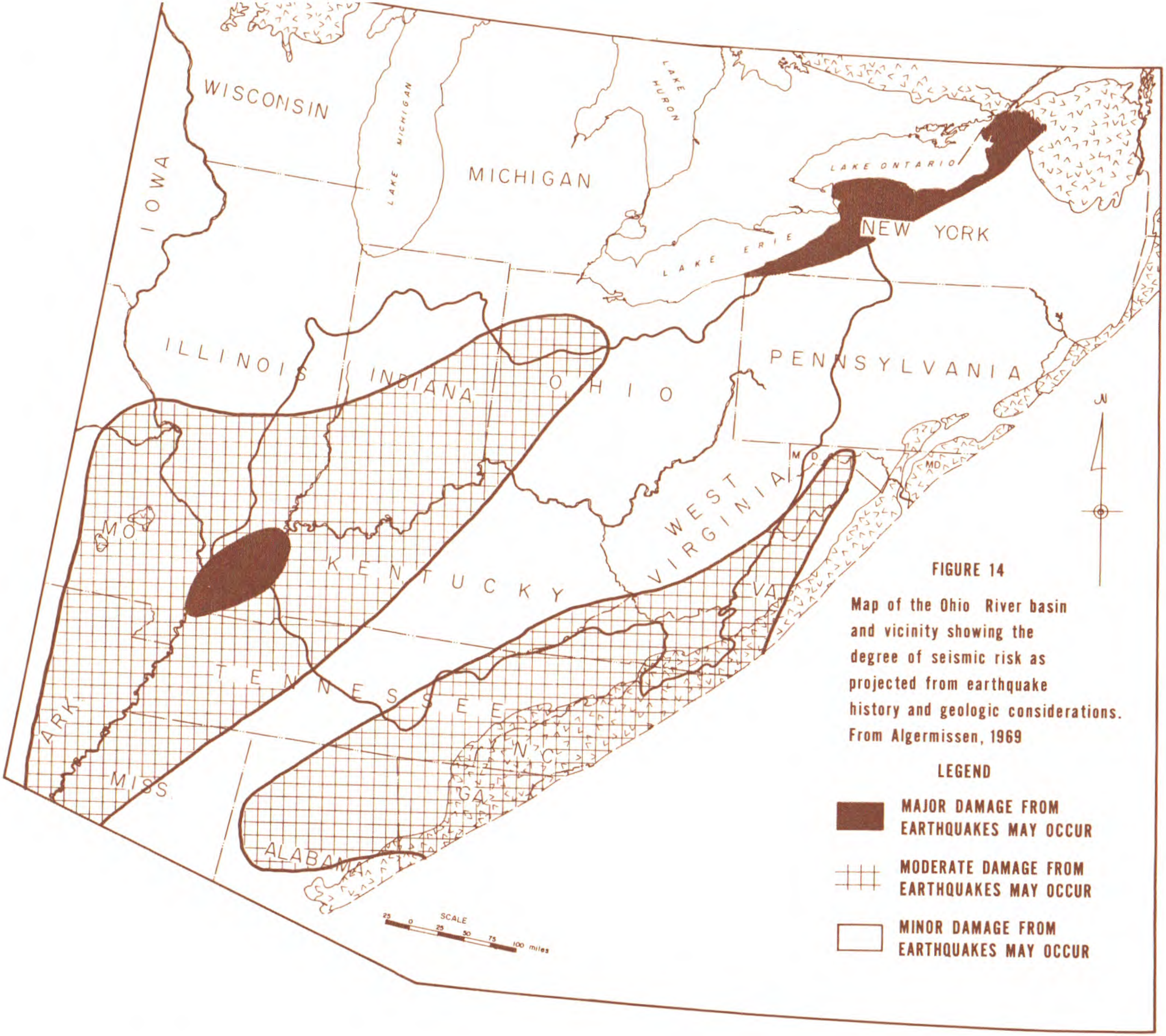

FIGURE 14

Map of the Ohio River basin and vicinity showing the degree of seismic risk as projected from earthquake history and geologic considerations. From Algermissen, 1969

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