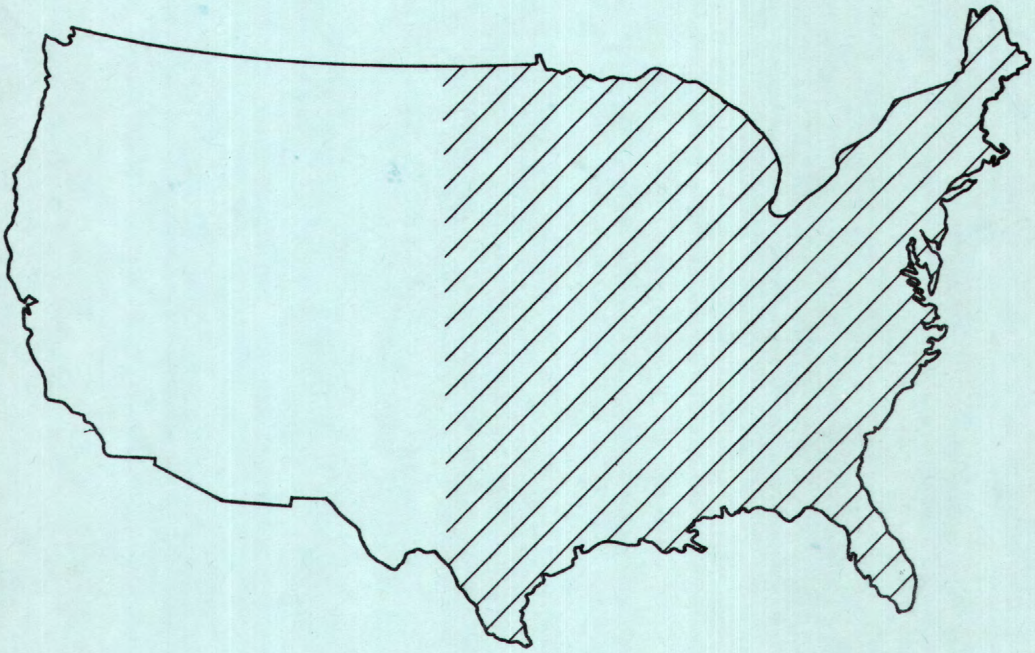
REVIEW OF BURIED CRYSTALLINE ROCKS OF EASTERN UNITED STATES IN SELECTED HYDROGEOLOGIC ENVIRONMENTS POTENTIALLY SUITABLE FOR ISOLATING HIGH-LEVEL RADIOACTIVE WASTES



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By R. W. Davis

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WILLIAM P. CLARK, Secretary

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ILLUSTRATIONS
(Plates are in pocket)

The report, "Review of buried crystalline rocks of Eastern United States in selected hydrogeologic environments potentially suitable for isolating high-level radioactive wastes," released as Water Resources Investigations Report 84-4091, was prepared as part of the U.S. Geological Survey's Hazardous Waste Hydrology Program.

Copies of the report are available for inspection at the U.S. Geological Survey, Water Resources Division, District Office in Louisville, Kentucky, and may be purchased at cost from the Open-File Services Section, U.S. Geological Survey, Western Branch of Distribution, P. O. Box 25425, Denver Federal Center, Denver, Colorado 80225.

REVIEW OF BURIED CRYSTALLINE ROCKS OF EASTERN UNITED STATES IN SELECTED HYDROGEOLOGIC ENVIRONMENTS POTENTIALLY SUITABLE FOR ISOLATING HIGH-LEVEL RADIOACTIVE WASTES

by R. W. Davis

ABSTRACT

Among the concepts suggested for the deep disposal of high-level radioactive wastes from nuclear power reactors is the excavation of a repository in suitable crystalline rocks overlain by a thick sequence of sedimentary strata in a hydrogeologic environment that would effectively impede waste transport. To determine the occurrence of such environments in the Eastern United States, a review was made of available sources of published or unpublished information, using the following hydrogeologic criteria:

1. The top of the crystalline basement rock is 1,000 to 4,000 feet below land surface.

2. The crystalline rock is overlain by sedimentary rock whose lowermost part, at least, contains ground water with a dissolved-solids concentration of 10,000 milligrams per liter or more.

3. Shale or clay confining beds overlie the saline-water aquifer.

4. The flow system in the saline-water aquifer is known or determinable from presently available data.

All of these hydrogeologic conditions occur in two general areas: (1) parts of Indiana, Ohio, and Kentucky, underlain by part of the geologic structure known as the Cincinnati arch, and (2) parts of the Atlantic Coastal Plain from Georgia to New Jersey.

INTRODUCTION

Background

The U.S. Department of Energy (DOE) has the responsibility for the selection of sites for disposal of high-level radioactive wastes produced by commercial power reactors. The U.S. Geological Survey has been advising and assisting the DOE in the earth-science aspects of this task. With its own Congressional appropriations, the Survey has been conducting independent research designed to complement and augment the DOE's program. Specific areas of research include methods for identifying suitable geohydrologic environments for waste disposal, for characterizing these environments, and for defining the geohydrologic processes that would affect the integrity of the environments. Part of this research program has been to evaluate host rock types such as granitic rock, western Cretaceous shales, and anhydrite. Another part has involved using the Basin and Range province of the southwest to investigate the concept of identifying potentially suitable geohydrologic environments on the basis of their possessing multiple natural barriers to waste transport (Schneider and Trask, 1983).

The present study is a preliminary evaluation of the feasibility of applying a strategy for high-level waste disposal proposed by Bredehoeft and Maini (1981) and subsequently recommended for further consideration by the National Academy of Sciences (National Research Council, 1983).

The area covered by this report is the eastern half of the United States--approximately east of the 94th merdian. The decision to focus the study on the Eastern United States was prompted by provisions of the Nuclear Waste Policy Act of 1982 (Public Law 97-425, 1983) which requires the Federal government to consider a regional distribution in the siting of repositories. Most of the potential sites now under consideration for the first repository are located in the west.

Waste-Disposal Problems

Various rock types have been considered as potential host media for isolating high-level radioactive wastes from the human environment. Crystalline rocks, which are defined in this report as crystalline igneous rocks and some metamorphic rocks such as gneiss, have been regarded favorably because they are strong, readily mined, and have favorable thermal properties for dissipating heat from the wastes. In addition, where they are massive and relatively free of fractures, they have a very low permeability.

This property is particularly significant because ground-water flow would be the dominant means for transporting wastes from a repository below the water table.

A particularly difficult problem with crystalline rocks is predicting the direction and rate of ground-water flow in fractures. The difficulties stem from an inadequate understanding of the geometry of the fracture systems, deficiencies in the theory for modeling the flow, and the inadequacy of field methods for measuring the fracture properties.

To overcome this difficulty, Bredehoeft and Maini (1981) proposed that wastes be placed in repositories in crystalline rocks blanketed by sedimentary rocks whose ground-water flow characteristics are well understood (fig. 1). One of the main advantages to this strategy is that ground-water flow from the fractures in the crystalline rock would join with the flow in the overlying cover of sedimentary rocks which could be investigated and modeled by conventional, well-understood theory and technology.

This strategy for emplacing wastes in buried crystalline rocks would be part of a broader concept, suggested earlier (Bredehoeft and others, 1978), of using a series of multiple barriers (natural and engineered) to nuclide migration. The intent of this concept was to offset to some extent the inability to predict the hydrologic and geologic properties of rocks associated with potential repository environments. The natural barriers would include specified hydrodynamic, geochemical, and geologic characteristics. Among the natural barriers that would occur in a suitable buried crystalline rock environment is a flow system in the sedimentary rock blanket with a long path and extremely low flow rate to the biosphere; and the presence of nonpotable water in the sedimentary rocks, which would minimize the possibility of future human intrusion.

OBJECTIVE

The objective is to determine if areas exist in the Eastern United States where buried crystalline rocks occur in hydrogeologic environments that could provide specified natural barriers to radionuclide transport from hypothetical deep repositories. Another desirable property of the environment would be to minimize the likelihood of human intrusion of the repository.

The following criteria were used to delineate the occurrence of areas where hydrogeologic conditions are considered suitable:

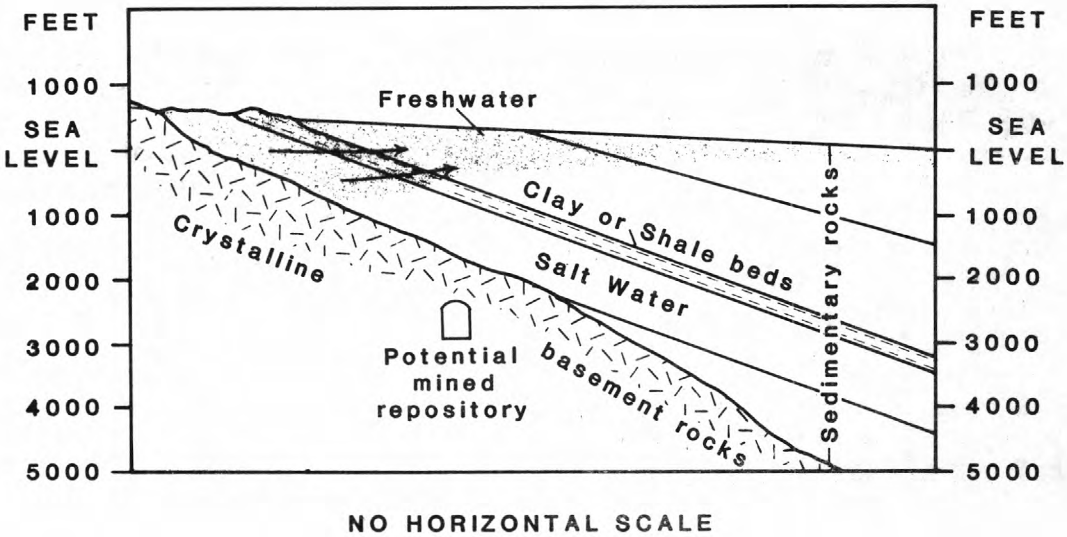


Figure 1.-- Hypothetical hydrogeologic cross section of the Atlantic Coastal Plain illustrating a situation in which a crystalline basement rock repository might be built below a blanket of sedimentary rocks. The ground-water flow characteristics within the sedimentary cover can be defined and predicted utilizing well-established techniques as well as theory.

1. The depth to the top of crystalline rock should be at least 1,000 feet and not more than 4,000 feet below land surface. The minimum depth was chosen because, in most of the study area, water below this depth would be saline (see item 2). The maximum depth limit is related to cost and safety, being near the practical limit for deep mining and the emplacement of heat generating wastes.

2. The basal part of the sedimentary rock aquifer overlying the crystalline rock should contain saline water. For the purposes of this report, saline water refers to water containing more than 10,000 mg/L (milligrams per liter) of dissolved solids. Water with this concentration of dissolved solids is not considered to be an underground source of drinking water (U.S. Congress, 1980, p. 45,502) and is unusable for most purposes. It is of interest to note that Federal regulations permit the injection of waste water in strata containing more than 10,000 mg/L of dissolved solids, provided water of better quality is not degraded by the injection.

3. A confining bed of clay or shale should be present directly over the saline-water aquifer to restrict upward movement of waste nuclides.

4. The characteristics of the flow system in the saline-water aquifer over the crystalline rock should be known reasonably well, or be determinable from presently available data.

METHODS OF STUDY

The study was restricted to a review of published materials and available unpublished sources of information.

Of primary significance was the occurrence of a potentially suitable host rock at the appropriate depth interval. Consequently, information was assembled initially on these two criteria, and it indicated four areas where the basement rocks are mostly crystalline and generally at the chosen depth. The four areas are: the Atlantic Coastal Plain; the area south and west of the Adirondack Mountains in New York; the Cincinnati arch area in parts of Indiana, Kentucky, and Ohio; and the Mid-Continent area extending from Michigan and Minnesota to Arkansas.

Data were taken mainly from the following sources:

Atlantic Coastal Plain:
North Carolina to New York--Meisler, 1980.
South Carolina to Florida--Brown and others, 1979.
Alabama--Ellard, 1977, and R. W. Lee, U.S. Geological Survey, Atlanta, Georgia, written commun., 1983.
Western New York and Adirondack Mountains area: Waller and others, 1978.
Cincinnati arch area: ORSANCO, 1976.
Mid-Continent area: Numerous State and U.S. Geological Survey reports and atlases, and H. L. Young, U.S. Geological Survey, Madison, Wisconsin, written and oral commun., 1983.

Data on the depth to crystalline rocks were compiled from comparison of two maps of the altitude and type of basement rocks (Bayley and Muehlenberger, 1968, and American Association of Petroleum Geologists and U.S. Geological Survey, 1967). Both maps appeared to be similar except in northern Florida where the map by Bayley and Muehlenberger is considered more accurate.

Because the scale (1:5,000,000) of the latter map was more convenient, it was used to delineate areas where the basement rocks are in the depth range of interest.

In order to establish a generalized depth below land surface for the basement rocks, regional topographic maps were scanned to determine the generalized altitude(s) that most nearly represents the position of the land surface. This generalized altitude was used as the datum plane to determine depth below land surface.

Because the gently sloping land in the Atlantic Coastal Plain lies only slightly above sea level, sea level was used as the datum plane in that area. A common altitude in much of the interior of the eastern United States is 1,000 feet so it was used as the datum plane.

To delineate information on a map (plate 2), data on water salinity were plotted together with the occurrence (or absence) of shale or clay confining beds above the basal part of the sedimentary rock aquifer.

LITHOLOGY OF BASEMENT ROCKS

The basement rocks in the eastern United States are of numerous types. Those of the interior, within a triangle formed by points in New York State, Minnesota, and Kentucky, are Precambrian, crystalline, igneous and metamorphic rocks (plate 1).

The rocks that underlie earliest Cretaceous or Jurassic formations in the Atlantic Coastal Plain are generally considered to be basement rocks. The basement rocks in much of the Atlantic Coastal Plain are crystalline, Piedmont-type, igneous and metamorphic rocks. However, sedimentary rocks and intrusive and extrusive igneous rocks of early Mesozoic age, deposited in down-faulted basins, are also considered to be basement rocks in parts of the region. In parts of Florida, Paleozoic sedimentary rocks are considered to be basement.

Two maps of basement rocks of the Atlantic Coastal Plain by Chowns and Williams (1983) and Wentworth and Mergner-Keefer (1983), show the lithologies as interpreted from well-boring data and aeromagnetic and gravity data. The delineation of basement rock types from geophysical data is a matter of individual interpretation. In areas where drilling data are sparse or absent, the geophysical data may be reinterpreted differently at a later time when additional drilling is done.

Large areas of the coastal plain are shown to be underlain by buried Mesozoic fault-bounded basins. The areas shown in Georgia and South Carolina are based on an interpretation of drilling data supplemented by geophysical data. The occurrence of the basins from North Carolina to New Jersey are also inferred from drilling information supplemented by geophysical data, but there has been much less drilling in this segment of the coastal plain. Consequently, it is even possible that in places the buried Mesozoic basins in the North Carolina/New Jersey segment do not exist or are much smaller than shown, based on drilling data compiled after publication of the two maps mentioned above (D. L. Daniels, U.S. Geological Survey, Reston, Virginia, oral commun., 1983).

OCCURRENCE OF CRYSTALLINE ROCKS IN SPECIFIED HYDROGEOLOGIC CONDITIONS SUITABLE FOR ISOLATING RADIOACTIVE WASTES

The initial phase of the study revealed four broad regions where crystalline basement rocks occurred from 1,000 to 4,000 feet below land surface. That phase provided the foundation for delineating areas where the remaining selected hydrogeologic conditions could be found (plate 2). The analysis by regions and subregions follows.

Atlantic Coastal Plain

A large area of the Atlantic Coastal Plain is underlain by basement rocks that are 1,000 to 4,000 feet below land surface (plates 1 and 2). The delineation of areas where ground water in the aquifers overlying the basement rocks contains more than 10,000 mg/L dissolved solids reduces the area of consideration to a strip near the coast from North Carolina to New Jersey and a smaller area in northern Florida and southern Georgia. Barrier clay beds are present above the basal saline aquifer, but where clay beds were deposited in near-marine or non-marine environments they may not be laterally continuous.

The lithologic characteristics of the basement rocks, as interpreted from geophysical and deep-drilling data, are shown on plate 1. The map shows a few areas underlain by Piedmont-type crystalline rocks. In much of the region from North Carolina to New Jersey; however, the basement appears to be composed of rocks deposited in the early Mesozoic basins. In an area in Florida and Georgia the basement is composed of Paleozoic sedimentary rocks.

Four areas in the Atlantic Coastal Plain appear to meet most of the four selected hydrogeologic criteria (plates 1 and 2). The largest of these, underlain by Piedmont-type igneous and metamorphic rocks, is in the southern and eastern part of a strip from near Wilmington, New Hanover County, North Carolina to Norfolk, Virginia. This area however, may be larger than shown. As noted earlier, in places the Mesozoic basins in this segment of the Coastal Plain, shown on plate 1 (from Wentworth and Mergner-Keefer, plate 1), may not exist or may be much smaller than shown, based on drilling data collected after the cited map was compiled.

The fresh ground-water-flow system in North Carolina (overlying ground water with a salinity of 10,000 mg/L of chloride) is being studied and modeled by the Atlantic Coastal Plain Regional Aquifer-System Analysis Group in the Survey. In the model, ground water containing more than 10,000 mg/L chloride (about 18,000 mg/L dissolved solids) is considered as not moving or moving so slowly that it has no effect on the overlying ground-water-flow system containing relatively fresh water (M. D. Winner, Jr., U.S. Geological Survey, Raleigh, North Carolina, oral commun., 1983). The model, though not directly related to the saline-water-flow system, should be helpful in understanding the hydrology of the area delineated on plates 1 and 2. The model is calibrated to have an upward movement of water from the deeper aquifers near the North Carolina-South Carolina border. This upward movement is necessary because of the high hydraulic pressures in this area and southward that were noted earlier by Peek and Register (1975). A generalized hydrogeologic section through the area is shown in figure 2. Ground-water salinity is interpreted from Meisler (1980).

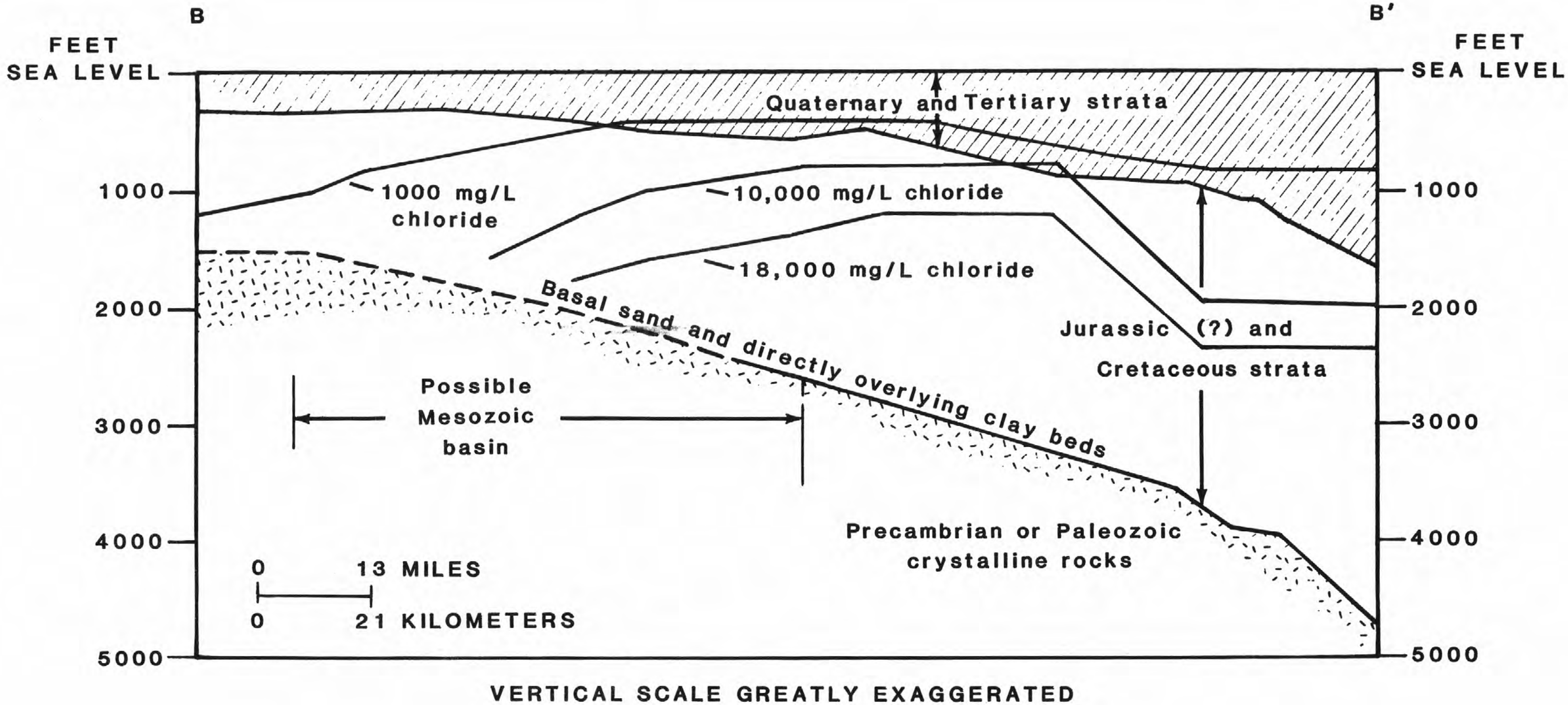


Figure 2.-- Generalized geologic section and approximate lines of equal chloride concentration through line B-B', on plate 2, in North Carolina. Modified from Brown and others(1979) and Meisler(1980).

Three smaller areas, all underlain by Piedmont-type igneous and metamorphic rocks (plate 1), appear to meet most of the hydrogeologic criteria. One area is eastern Long Island, New York; however, there are no reliable data on the salinity of the basal aquifer (Meisler, 1980, p. 6) and the water may not contain as much as 10,000 mg/L dissolved solids (plate 2). Another area is in parts of five counties in New Jersey and Delaware near the head of Delaware Bay. The third is in part of Dodge County in south-central Georgia. The hydrology of the overlying sedimentary rocks of these three areas is currently being studied by Regional Aquifer-System Analysis Groups of the Survey.

The criteria on depth and salinity are met in parts of Florida and Georgia, but the basement rock types are varied. They consist of shale and sandstone of Paleozoic age and the "volcanic-terrane rocks (Precambrian (?) felsic volcanic rocks on plate 1) are tuffaceous sedimentary rocks, felsic volcanic rocks, and granite plutons" of Precambrian (?) age (Chown and Williams, 1983, p. 9-14). The rocks in the early Mesozoic basins are arkosic sandstones interbedded with red shales and clay (red beds) and intrusive and extrusive igneous rocks. Geophysical data were used to supplement the small amount of drilling data in delineating the Mesozoic basins. For this reason, as noted earlier, the extent and existence of these basins is uncertain. The granitic rocks shown in the area where the basement occurs at 1,000 to 4,000 feet have been reached by only a few wells. (Chown and Williams, 1983, plate 1).

Western New York State and Adirondack Mountains Area

An area in western New York and the Adirondack Mountains region, underlain by crystalline Precambrian igneous and metamorphic rocks, falls within the specified depth criterion. Although the basal Cambrian sandstone contains saline water, it is overlapped by Ordovician carbonate rocks with no intervening shale beds to serve as hydraulic barriers. The ground-water-flow system is unknown. In addition, the Adirondack Mountains area contains numerous faults (Waller and others, 1978) which could have an adverse effect on the ability of rocks in this area to isolate radioactive wastes. This area does not appear to adequately meet the hydrogeologic criteria.

Cincinnati Arch Area

A large area in parts of Ohio, Indiana, and Kentucky meets the specified hydrogeologic criteria. The basement is composed of Precambrian igneous and metamorphic rocks. The basal Mount Simon Sandstone (Cambrian) in this area contains saline water and its use as a wastewater injection interval has been studied by the Ohio River Valley Water Sanitation Commission (ORSANCO) with the assistance of a grant from the Survey. In most of this area the Mount Simon Sandstone is overlain by shale or siltstone facies of the Eau Claire Formation which ranges in thickness from about 600 feet in eastern Indiana to about 400 feet near its limit as a confining bed in western Ohio. The porosity of the Mount Simon is reported to range from about 5 to 15 percent (ORSANCO, 1976). East of the edge of the confining bed, the Eau Claire grades into carbonate rocks of the Rome Formation (Janssen, 1973, p. 10). These carbonate rocks may not constitute an adequate barrier bed to prevent upward migration of contaminants. The report by ORSANCO presents geologic data on the Mount Simon, but no data on the flow system. A hydrogeologic section through the northern part of the area is shown in figure 3. Data on ground-water salinity are from ORSANCO (1976, tables 9 and 11).

Clifford (1973) described the flow system, or the propensity for flow, in a report on the hydrology of the Mount Simon Sandstone in Indiana and Ohio. His data were mostly from drill-stem tests of beds containing saline water. He converted values for the pressure head to feet of head of fresh water for comparison. A copy of his map of the generalized flow system is shown in figure 4. The direction of flow, although it may be extremely slow, appears to be up the dip of the beds on the Cincinnati arch toward its crest. The velocity of water in the Mount Simon does not exceed 6 inches per year, or about 1 mile per 10,000 years, according to Clifford (1973).

Intuitively, the movement of water up the dip of the saline aquifer appears unreasonable and no explanation has been found for this in the literature. It is possible that glacial loading by about a mile-thick section of ice during Pleistocene glaciation disturbed the pressure head so significantly that it has not adjusted to the preglaciation configuration. A careful review of Clifford's drill-stem data and the analysis of more recent data may result in a revision in the proposed flow pattern.

Janssens (1973) presents data on the lithology of the basement crystalline rocks in Ohio. He notes a change from predominantly high grade metamorphic rocks in the east, to lower grade metamorphic rocks and igneous rocks in the west. The contact between the two rock types is drawn from Toledo to Scioto County in Ohio by Janssens. He considers this change in lithology to be the Grenville front, as used in Canadian terminology. It is somewhat different from the Grenville front as shown by Rudman and others (1965, p. 899) who based their data on radiometric age dating.

Mid-Continent Area

Buried Precambrian crystalline rocks underlie a large part of the Mid-Continent area extending from Michigan and Minnesota to Arkansas. These rocks are overlain by a basal sandstone of Cambrian age, except locally over buried hills. In Missouri and Arkansas the basal sandstone is called the

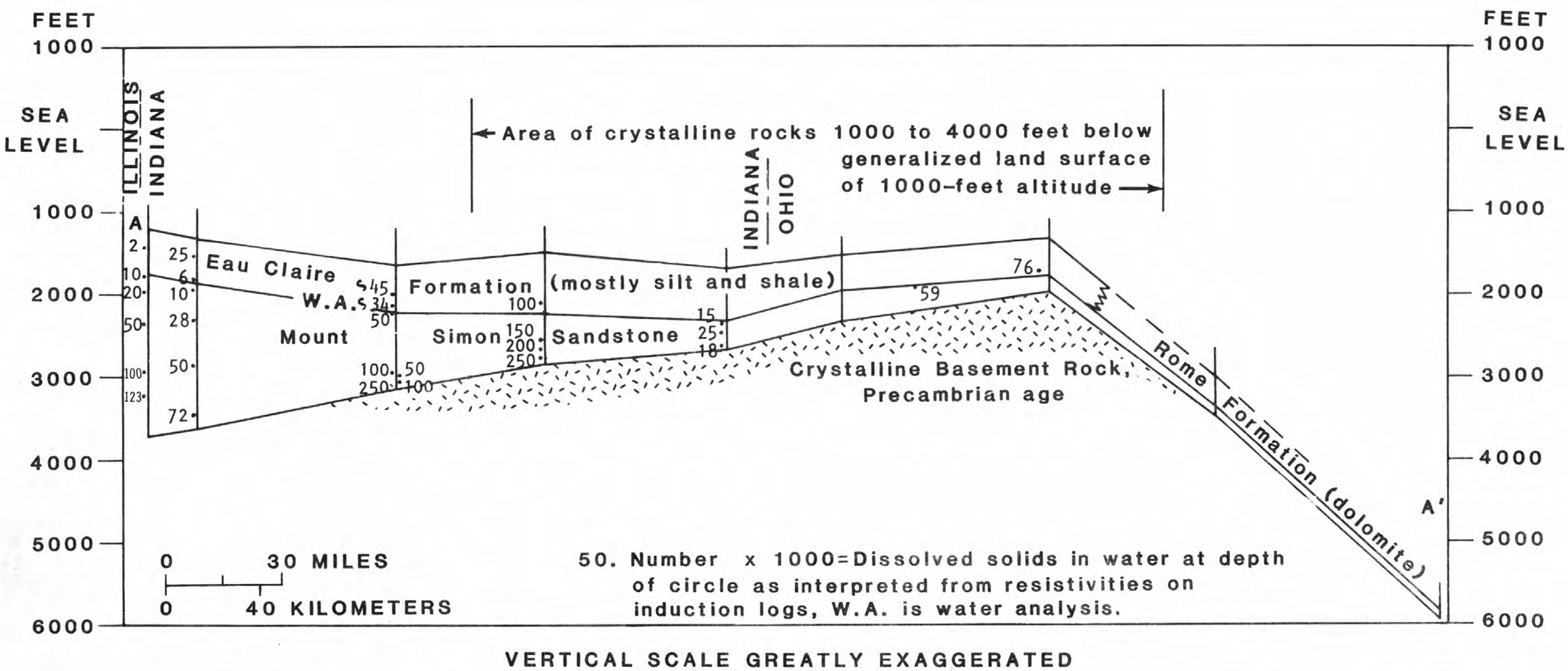
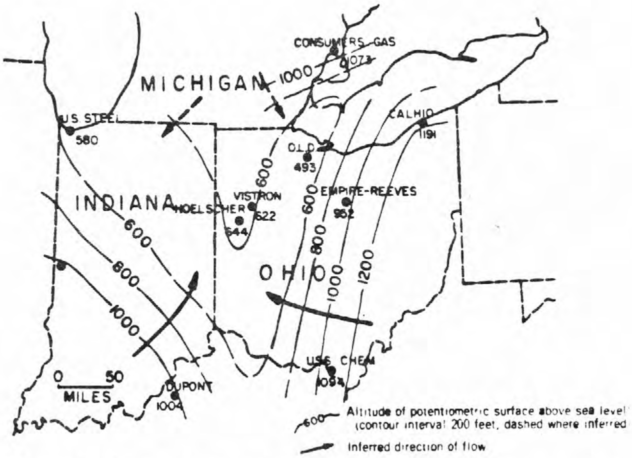
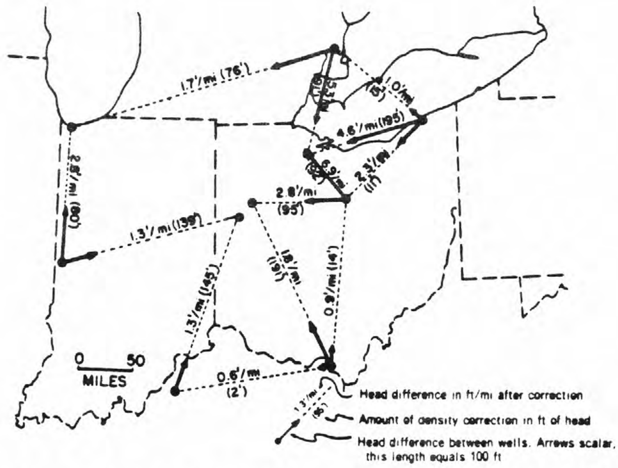


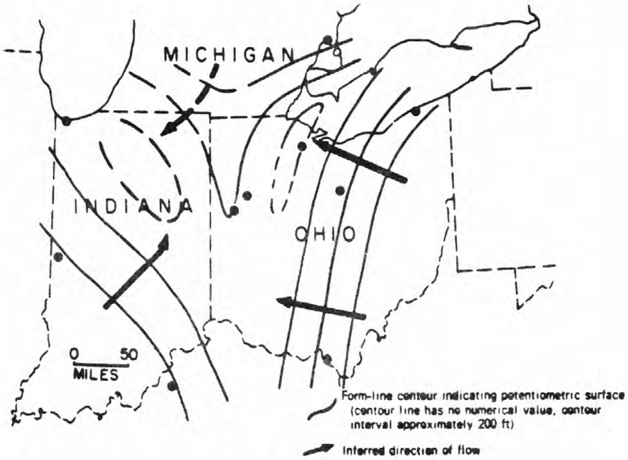
Figure 3.-- Hydrogeologic section through line A-A', on plate 2, in Indiana and Ohio, showing crystalline basement rocks, overlying sandstone aquifer, and silt-shale confining bed. Modified from ORSANCO(1976).



A Potentiometric surface of Mount Simon Sandstone; not corrected for density variation.



B Density corrections between pairs of wells and resulting head differences.



C Form-line contour map showing potentiometric surface of Mount Simon Sandstone corrected for density variation.

Figure 4.-- Flow system of ground water in the Mount Simon Sandstone in the Cincinnati arch area, from Clifford, 1973. Published with permission of the American Association of Petroleum Geologists.

Lamotte Sandstone; elsewhere in the area the basal sandstone is called the Mount Simon Sandstone. In Missouri, Arkansas, and southwest Illinois the basal sandstone is overlain by carbonate rocks of the Bonneterre Dolomite; elsewhere the basal sandstone is overlain by sandstone, siltstone, shale, and dolomite of the Eau Claire Formation. The sand content of the Eau Claire increases northward.

The quality of water in the basal sandstone varies from fresh, to saline, to stratified fresh and saline. Because of the diversity of the geology and hydrology, the Mid-Continent area is subdivided into smaller units for discussion.

Ozark Uplift

The Ozark uplift in Missouri and Arkansas is a modified dome centered in Missouri. The geologic formations above the Precambrian crystalline rocks dip outward in all directions from this center. The water in the basal sandstone overlying the basement rocks is fresh in most of Missouri. In the southwest corner of the State it is fresh to depths of about 2,000 feet (U.S. Geological Survey, 1967, p. 288); however in adjacent Crawford County, Kansas, wells of similar depths in the basal sandstone yield water containing more than 10,000 mg/L dissolved solids (Abernathy, 1941, p. 227). Northwest from the Ozark uplift in the Forest City basin area, all ground water below a depth of about 250 feet is of poor quality or saline (O'Connor, 1971, p. 48).

Southward, in northern Arkansas, freshwater is obtained from a deep Ordovician sandstone, the Gunter Sandstone Member of the Gasconade Formation; however, little data are available on water quality of the deeper basal Cambrian sandstone. Lamonds (1972, sheet 1) states that in the central and southern part of his study area in northern Arkansas (near 36' north latitude) the water in the Gunter (and also deeper aquifers) is probably highly mineralized. Unfortunately, data are lacking on water quality in the basal sandstone in this area. In contrast with this interpretation, in Butler County, southeast Missouri, Gann and others (1976), in a geologic section, show fresh water in the basal sandstone about 2,300 feet below land surface.

Water in the basal sandstone in north-central Missouri is of poor quality but contains less than 10,000 mg/L of dissolved solids and therefore does not meet the definition of saline water used in this report (L. F. Emmett, U.S. Geological Survey, Rolla, Missouri, written commun., 1983).

To summarize, in the Ozark uplift area the quality of water in the basal sandstone is variable and not sufficiently known in some areas. However, the lack of shale beds above the basal sandstone (the Bonneterre Dolomite overlies the basal sandstone) is probably of considerably more importance than the variability of water quality in judging the extent to which this area meets the hydrogeologic criteria. The dolomite does not have the low permeability of a shale or clay, consequently it would not provide a barrier to radionuclide movement.

Illinois and Michigan basins

Buried crystalline rocks occur at the appropriate depths along the west edges of the Illinois and Michigan basins (plate 1). These basins are structural depressions with geologic formations above the Precambrian rocks dipping inward from all sides. The Illinois basin is centered near southern Illinois, and the Michigan basin is centered in the lower peninsula of Michigan.

Saline water is reported in the basal sandstone in the eastern part of Missouri (Gann and others, 1971 and 1976), the western and northern parts of Illinois (Bergstrom, 1968, p. 4-9, and H. L. Young, U.S. Geological Survey, Madison, Wisconsin, written commun., 1983), easternmost Wisconsin (Ryling, 1961), and the upper peninsula of Michigan (Vanlier and Deutsch, 1958, p. 50-52).

Water in the older formations in the Illinois part of the Illinois basin is saline (ORSANCO, 1976, map 7) as is the water in older formations in the Michigan basin (McGuinness, 1963, p. 420-424).

It appears that the basal sandstone strata in the two basins contain saline water downdip from near the edge of the basins. Near the edge, a fresh-water wedge extends downdip into the basin above the saline water. The distance the wedge extends downdip appears to be a function of the amount of dip of the beds. At Chicago, Ill., where the dip is slight, the wedge extends much farther basinward than it does just north of St. Louis, Mo., where the dip of the beds into the basin from the Ozark uplift is steep.

The presence of fresh and saline waters in the same aquifer overlying the basement violates one of the hydrogeologic criteria of this study; that is, the water in the aquifer above the basement rocks must be saline and unusable.

Wisconsin, Minnesota, and Iowa

These States are in the recharge area of the basal Cambrian sandstone and younger Ordovician sandstones. Together, they form the Cambrian-Ordovician aquifer which is used extensively for water supply. In Wisconsin the basal sandstone is known to be saline only in the east, near Lake Michigan. In Minnesota the basal sandstone is not known to contain saline water (Feth and others, 1965).

The flow path of water in the upper part of the Cambrian-Ordovician aquifer in Iowa is southeastward toward the Illinois basin (Horick and Steinhilber, 1978). The flow path of water in the lower part, the deeper basal sandstone, is assumed to be similar. Assuming that the water quality variations are similar in the two aquifers, the quality of water in the basal sandstone aquifer probably deteriorates in the southeast and southwest corners of the State. Both southern corners of the State are on the edges of basins containing saline water, the Illinois basin to the southeast and the Forest City basin to the southwest. There may be a fresh-water wedge in the updip parts of the basal aquifers in both areas. Little is published on the water quality of deep aquifers in either area. In Iowa the basal sandstone is overlain by carbonate rocks in the southwest and by shale of the Eau Claire Formation in the southeast. The shale is about 250 feet thick in Des Moines County at the Illinois-Iowa State line (ORSANCO, 1976, map 8), and appears to extend about 30 miles into Iowa, but its extent is poorly documented.

Data on the extent of impervious barrier strata above the basal sandstone aquifers, and on the quality of contained ground water are so meager that, for the purposes of this study, it is concluded that the conditions do not meet the hydrogeologic criteria.

CONCLUSIONS

Based on a review of published literature and available unpublished materials, there appear to be two areas in the eastern United States where buried crystalline rocks occur in hydrogeologic environments that could provide all the specified natural barriers to radionuclide transport from hypothetical deep repositories. They are in parts of Indiana, Ohio, and Kentucky on the west flank of the geologic structure known as the Cincinnati arch, and in several parts of the Atlantic Coastal Plain from Georgia to New Jersey. The lithologic character of the deeper basement rocks in the part of the Atlantic Coastal Plain from North Carolina to New Jersey was interpreted from a small amount of drilling data supplemented by geophysical data. These interpretations are subject to change as additional drilling data become available. Parts of this area, presently assumed to be underlain by Mesozoic sedimentary basins, may actually be underlain by crystalline rocks that may also meet the specified hydrogeologic criteria.

SUGGESTIONS FOR FURTHER STUDY

Owing to the time limitations on conducting this review, it was necessary to confine the analysis to readily available sources of information. Following are several areas worthy of additional study if the buried crystalline rock concept is to be investigated more specifically.

1. Review new drilling and geophysical data that were not available to the authors of the references used in this study, to better define areas which appear to be underlain by suitable host rocks in hydrogeologic environments favoring the isolation of radioactive wastes.

2. Compile additional data on the variations of salinity of the aquifers above the crystalline rocks. Thickness of the saline-water zone and movement of water between the saline- and freshwater zones, especially in the Atlantic Coastal Plain, need to be better defined.

3. Define the integrity and thickness of the low-permeability strata overlying the crystalline rocks, using geophysical and lithologic logs, seismic profiles, and core testing data.

4. Evaluate the flow system of the Mount Simon Sandstone in the Cincinnati arch area from oil and gas drilling data, gas-storage data, and test data from waste-disposal injection wells, to supplement the study made by Clifford (1973). In addition, the validity of Clifford's data and interpretations should be checked because of the unique ground-water flow pattern which resulted from his investigation.

5. Obtain data on the occurrence, thickness, hydrologic properties and other characteristics of deeply weathered basement rock, the saprolite, above the solid crystalline rocks of the basement.

6. Evaluate the lithologic and other physical properties of the unweathered crystalline basement rocks to assess the competency of the rocks to contain radioactive wastes.

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