CENOZOIC AND MESOZOIC AQUIFER SYSTEMS OF THE ATLANTIC COASTAL PLAIN*

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INTRODUCTION

An aquifer system is defined as "a heterogeneous body of intercalated permeable and less permeable material that acts as a water-yielding unit of regional extent" (American Geological Institute, 1974, p. 34). In a broad sense, the entire sediment mass of Cenozoic and Mesozoic age, that lies along the Atlantic Coastal margin and which consists of lens-like layers of chiefly unconsolidated sediment, may be considered one aquifer system. In a more restricted sense and for practical descriptive and operative purposes, component chronostratigraphic units (lenses) of the sediment mass, offset and stacked one above the other, may be considered to represent individual aquifer systems that, to a greater or lesser extent, are hydraulically interconnected. They are so considered in this summary, because they are material units, characterized by lithologic heterogeneity and variable permeability, that act as water-yielding units of regional extent. Moreover, they have practical utility - boundaries of chronostratigraphic units can be determined, and the external and internal geometry of the units can be mapped in the subsurface by conventional geologic methods (Brown and others, 1972).

Geothermal energy may be generated in the crust, either radiogenically or by mechanical-thermal energy conversion, as when igneous intrusions are present at shallow depths in the crust (Grose, 1971) and/or as when mechanisms such as stress, shear-strain, and friction are operative in the crust (Roy and others, 1972). Component parts of the vertical succession of aquifer systems, that comprise a sediment mass overlying the crust, may have potential either as geothermal reservoirs or reservoir seals. To a considerable degree, the geothermal potential of an aquifer system depends not only upon its proximity to a crustal heat source, but also upon its position within the sediment mass and its position relative to other aquifer systems that may be present, and the nature of, thicknesses, volumes, relative permeabilities, and thermal conductivities of its component materials.

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In areas such as the Atlantic Coastal Plain, where suspected crustal heat sources have not yet been fully documented, the geothermal potential of aquifer systems may, in the absence of a known heat source, and in part, be quantified, on the basis of geologic information, for comparative, region-wide, screening purposes. The basic geologic information required is (1) that which defines the regional structural-stratigraphic framework and the manner in which it controls the position and composition of aquifer systems present in the sediment mass, and (2) that which delineates aquifer systems and their component parts.

STRUCTURAL-STRATIGRAPHIC FRAMEWORK

Anything more than a cursory introduction to the geothermal potential of the Atlantic Coastal Plain's aquifer systems demands some degree of familiarity and specific knowledge of the area's overall structural-stratigraphic framework and the manner in which that framework controls the ground-water storage and distribution system. Two basic structural-stratigraphic concepts are currently applied to the Atlantic Coastal Plain; one old and one new. They have little in common.

Benson (1976) describes the old concept as follows:
"The historical concept of the subsurface geology of the Atlantic Coastal Plain Province suggests a wedge of sediments of Mesozoic and Cenozoic age that dips uniformly toward the southeast. The sediments were thought to comprise a series of units, unbroken by faults, with uniform or gradually increasing thickness, as they extend seaward beneath the continental shelf to the continental slope where they crop out beneath the sea. The basement surface upon which the sediments were deposited likewise was considered a uniformly seaward-sloping erosional surface developed on crystalline rocks of Precambrian and Paleozoic age that crop out in the Piedmont Province of the eastern United States."

This is a concept in which the depositional dip of layers of the sediment mass is considered essentially uniform, unidirectional, and concordant with the present-day dip of the underlying basement surface.

In accordance with this simple model of a structural-stratigraphic, monoclinal system for the Atlantic Coastal Plain, permeable stratigraphic units (formations), delineated in outcrop and projected into and through the subsurface as gently-dipping, compositionally-constant layers, have been defined, by numerous investigators, as aquifers. Many or most of these have been considered to have regional extent (Sinnott and Cushing, 1978). Although oversimplified, the resultant hydrologic model is one in which ground water in the sediment mass is considered to travel significant distances from an outcrop area and in the direction of the continental shelf (from the northwest toward the southeast). It is presumed to travel through gently-dipping (15-20 ft/mi) permeable layers (aquifers) interspersed with other less-permeable layers (confining beds) having the capacity to leak water, at various rates, into the more permeable layers. At varying distances, either inland or seaward of the shoreline, both the permeable and less-permeable layers are considered to contain saline water.

A new concept of the structural-stratigraphic framework of the Atlantic Coastal Plain was developed (Brown and others, 1972) as part of a detailed subsurface study of the geometry of the sediment mass, and the manner in which it controls permeability distribution in the area extending from Long Island, N.Y. through North Carolina. The new concept is that the basement underlying the coastal plain consists of a mosaic of fault-bounded blocks and that differential horizontal and vertical movement of the blocks relative to each other, controlled both the depositional and subsequent erosional patterns recognized in Mesozoic and Cenozoic sediments on the Atlantic Coastal Plain. The areal distribution, thickness, and composition of chronostratigraphic units comprising the sediment mass represent a response to structural configurations generated by relative movement of fault-bounded blocks during and/or after their deposition. The basic structural configuration produced at any one time by the relative movement of blocks is that of graben, half-graben, horst systems. Based upon changes in the alinements and geometry of successive chronostratigraphic units, two such systems, characterized by different alinements and that alternate in their occurrence, are judged to have controlled both the deposition and subsequent erosion of Mesozoic and Cenozoic sediments. Depositional troughs, alined differently in each of the two systems (NE-SW and N-S, respectively), are angularly discordant with respect to each other. In terms of both their external geometry (location, shape and thickness) and internal geometry (composition, depositional strike and dip, facies gradient, energy levels of deposition, etc.), chronostratigraphic units, deposited when one system was operative, exhibit angular discordance with respect to those deposited when the other system was operative. Thus, permeable, tabular or lenticular bodies of sand (aquifers), associated with one group of chronostratigraphic units, have a different orientation and properties than those associated with the other group of chronostratigraphic units. The differences include patterns of intrinsic permeability distribution (zonation) characteristic of each group of units and which is chiefly dependent upon the composition and distribution of their component facies. Intrinsic permeability distribution patterns recognized in one group of chronostratigraphic units have different alinement and distribution from those recognized in the other group.

For purposes of comparing some basic elements of the new and historical concepts of the Atlantic Coastal Plain's structural-stratigraphic framework, the new concept is one in which the depositional dip of layers or lenses within the sediment mass is considered nonuniform, instead of uniform, multidirectional, instead of unidirectional, and, in large part, discordant, instead of concordant, with the present-day dip of the underlying basement surface. Unlike the historical concept that attempts to explain the evolution of the sediment mass by means of a forced-fit of its component stratigraphic parts so as to establish agreement with a preconceived structural model, the new concept uses the intrinsic geometry of the sediment mass to derive a mutually-satisfying, structural-stratigraphic model of coastal plain evolution.

Except locally in the Atlantic Coastal Plain, the concept of permeable stratigraphic units (formations), designated as aquifers in the outcrop area and projected significant distances into and through the subsurface as unidirectional, gently-dipping, compositionally-constant layers, is not supported by geologic fact.

AQUIFER SYSTEMS

Given the "new" concept for purposes of evaluating the geothermal potential of aquifer systems in the Atlantic Coastal Plain, additional geologic information is required that permits delineation of aquifer systems and determination of the areal extents, compositions, volumes, and relative permeabilities of their component parts.

Both on the basis of the types and amounts of necessary information available, the region can be divided into two segments: a northern one, extending from Long Island, N.Y. through North Carolina, and a southern one, that includes South Carolina and Georgia. Pertinent geologic information is relatively abundant in the northern segment and sparse in the southern segment. In the northern one, the maximum depth to the top of the basement surface is about 10,000 feet below mean sea level, in the vicinity of Cape Hatteras, N.C. (Brown and others, 1972, pl.5). In the southern one, the maximum depth to the top of the pre-Cretaceous surface is about 7,000 feet below mean sea level in Seminole County, Ga. (Brown and others, 1978, pl. 3A).

For descriptive and operative purposes, the regional sediment mass can be divided into those parts that contain Mesozoic and Cenozoic sedimentary rocks, respectively. In the northern segment, the volume of Mesozoic sedimentary rocks is about 17,900 mi^3 and that of Cenozoic about 5,800 mi^3. The maximum thickness of Mesozoic sedimentary rocks is about 7,100 feet (Dare County, N.C.) and that of Cenozoic about 2,900 feet (Dare County, N.C.) (Brown and others, 1972). In the southern segment, the volume of Mesozoic sedimentary rocks is about 20,000 mi^3 and that of Cenozoic about 11,300 mi^3. The maximum thickness of Mesozoic sedimentary rocks is about 5,200 feet (Seminole County, Ga.) and that of Cenozoic about 3,000 feet (Camden County, Ga.) (Brown and others, 1978).

Northern Segment - Atlantic Coastal Plain

In the northern segment, the sediment mass, extending from the basement surface to the land surface, has been mapped in some detail (Brown and others, 1972). Seventeen regional chronostratigraphic sequences, comprising nine of Mesozoic age and eight of Cenozoic age, were delineated in the subsurface by means of a series of structure maps and a series of isopach-lithofacies-permeability-distribution maps. For each sequence, the series of maps shows the configuration of its surface, its thickness, its facies composition, and the distribution (zonation) of its intrinsic permeability. By definition, each sequence or chronostratigraphic unit also is an aquifer system, because it represents a material unit, characterized by lithologic heterogeneity and variable permeability, that acts as a water-yielding unit of regional extent. Therefore, the maps drawn to show the external and internal geometry of chronostratigraphic units that comprise the sediment mass also show the external and internal geometry of aquifer systems that comprise the sediment mass. For purposes of evaluating their geothermal potential, the areal extent and volume for each lithofacies and each intrinsic permeability zone have been calculated for each aquifer system mapped. The maps previously constructed for each system (Brown and others, 1972), together with the calculated values derived from these maps for each system, provide a quantitative basis for evaluating reservoir and reservoir-seal potential (geothermal potential) of individual aquifer systems and for comparing that of different systems. Quantitative evaluation and comparison can be made in terms of the spatial distribution of aquifer systems relative to each other and to the underlying basement surface. Comparison can also be made in terms of the compositions, areal extents, volumes, and relative permeabilities of their component parts. The calculated, map-derived values, for the areal extent and volume of each lithofacies and each relative intrinsic permeability zone in each aquifer system, are combined and summarized (Tables 1 and 2) for 14 of the 17 aquifer systems present in the sediment mass. These systems were selected for their areal extent and thickness and/or depth of burial. They are judged to be of possible interest in a reconnaissance program of geothermal exploration. The aquifer systems listed in the tables are identified and arranged according to the identification and arrangement of their time-equivalent counterparts in the geologic sequence (see Brown and others, 1972, pl. 2). The oldest aquifer system is shown in the column to the left and the youngest in the column to the right.

Southern segment - Atlantic Coastal Plain

In the southern segment the types and amounts of data needed to evaluate the geothermal potential of aquifer systems, either qualitatively or quantitatively, are sparse. A wide assortment of publications describe local geohydrologic conditions and documents the fact that large quantities of ground water are stored in and transmitted through different segments of the sediment mass, chiefly in its upper part. However, point-source data in local areas have not generally been collated for purposes of drawing regional subsurface maps that illustrate both the spatial distribution and facies composition of chronostratigraphic units and their counterpart aquifer systems. Therefore, and except perhaps in local areas, it is not possible to determine the areal extent, thickness, volume, and permeability of bodies of sand or shale that would need to be considered in evaluating the geothermal reservoir or reservoir-seal potential of aquifer systems.

The spatial distribution of chronostratigraphic units, and their counterpart aquifer systems, in a part of the Mesozoic segment of the sediment mass, were mapped for purposes of evaluating waste-storage potential in the deep subsurface and of delineating, areally and volumetrically, the component parts of each aquifer system that contained either usable or non-usable ground water. (Brown and others, 1978). In that report, usable ground water was defined as that which contained less than 10,000 mg/L dissolved solids. Basic data from that report are combined and summarized in table 3. When used in conjunction with the maps of aquifer systems in that report, these data may be useful for purposes of evaluating the geothermal potential of aquifers in the deep subsurface.

Table 1. Cenozoic Aquifer Systems, Atlantic Coastal Plain, North Carolina to Long Island, New York

	Midway aquifer system	Sabine aquifer system	Claiborne aquifer system	Jackson aquifer system	Oligocene aquifer system	Middle Miocene aquifer system
Total volume[1]	971	217	1,062	263	261	1,661
Total area[2]	34,500	16,730	28,860	8,445	6,800	30,205
Lithologic facies						
Sand: 75-100%						
Volume	82.1	50.8	22.7	9.6	5.1	8.1
Area	4,775	3,140	2,175	310	345	1,580
Sand: 50-75% Shale: 25-50%						
Volume	260	20.8	98.8	135	7.6	197
Area	11,900	1,295	5,200	2,775	280	4,200
Shale: 50-75% Sand: 25-50%						
Volume	211	16.9	103	56	-	966
Area	7,125	1,720	4,575	1,400	-	15,125
Shale: 75-100%						
Volume	188	72.2	78.8	61.2	-	425
Area	5,450	7,300	4,150	3,550	-	8,275
Limestone: 25-50% Clastics: 50-75%						
Volume	118	25.3	7.2	0.1	12.5	55
Area	2,800	1,645	435	31	375	840
Limestone: 50-75% Clastics: 25-50%						
Volume	44.4	24.1	70.5	0.9	37.8	9.8
Area	1,100	1,225	1,225	290	1,100	175
Limestone: 75-100%						
Volume	67.5	6.9	681	0.2	198	0.1
Area	1,350	405	11,100	89	4,700	10
Relative intrinsic permeabilities						
Very high						
Volume	-	-	-	-	198	-
Area	-	-	-	-	4,700	-
High						
Volume	0.6	-	681	-	-	9.4
Area	95	-	11,100	-	-	115
Moderately high						
Volume	13.7	0.9	7.9	7.5	42.4	58.8
Area	1,150	230	655	195	1,400	1,100
Moderate						
Volume	74.7	51.3	18.9	3.3	12.9	4.8
Area	4,300	3,025	1,650	500	405	1,390
Moderately low						
Volume	390	43.5	173	135	7.7	197
Area	15,800	2,625	6,755	2,800	295	4,200
Low						
Volume	238	42.2	103	56	-	966
Area	6,555	3,150	4,550	1,400	-	15,125
Very low						
Volume	254	79.1	78.2	61.2	-	425
Area	6,600	7,700	4,150	3,550	-	8,275

[1]Volume - mi^3

[2]Area - mi^2

Table 2. Mesozoic Aquifer Systems, Atlantic Coastal Plain, North Carolina to Long Island, New York

	Aquifer system H	Aquifer system G	Aquifer system F	Aquifer system E	Aquifer system D	Aquifer system C	Aquifer system B	Aquifer system A
Total volume[1]	4,662	3,124	5,321	888	900	1,215	1,099	711
Total area[2]	29,220	28,495	55,455	22,835	24,885	35,685	31,650	28,555
Lithologic facies								
Sand: 75-100%								
Volume	20.4	9.4	81	18.3	38.5	104	35	69
Area	795	475	1,125	820	1,325	3,375	980	2,700
Sand: 50-75% Shale: 25-50%								
Volume	643	71.7	974	70.8	176	338	101	181
Area	7,730	2,125	10,975	2,125	6,320	10,250	3,650	6,400
Shale: 50-75% Sand: 25-50%								
Volume	3,785	2,552	3,855	126	548	618	293	324
Area	19,610	22,100	29,200	5,125	13,600	15,400	10,500	11,850
Shale: 75-100%								
Volume	40	444	408	539	124	155	656	124
Area	460	3,550	4,050	12,240	3,450	6,660	16,075	6,635
Limestone: 25-50% Clastics: 50-75%								
Volume	96.2	46.9	3	103	13.5	-	14	11.8
Area	360	245	105	2,050	190	-	445	815
Limestone: 50-75% Clastics: 25-50%								
Volume	77.4	-	-	30.9	-	-	-	1.2
Area	265	-	-	475	-	-	-	155
Limestone: 75-100%								
Volume	-	-	-	-	-	-	-	-
Area	-	-	-	-	-	-	-	-
Relative intrinsic permeabilities								
Very high								
Volume	-	-	-	-	-	-	-	-
Area	-	-	-	-	-	-	-	-
High								
Volume	14.9	9.4	-	0.9	1.2	21.5	-	-
Area	665	475	-	187	100	465	-	-
Moderately high								
Volume	-	-	84	0.7	36.9	22.5	4.6	1.1
Area	-	-	1,225	48	1,175	1,675	265	190
Moderate								
Volume	644	62.7	716	16.4	189	259	58.4	70.9
Area	7,725	1,805	7,775	590	6,550	8,425	2,380	2,715
Moderately low								
Volume	83.1	2,561	3,854	153	540	181	158	179
Area	395	22,420	39,220	5,500	12,910	5,500	5,080	6,200
Low								
Volume	3,880	46.9	259	178	8.9	576	222	324
Area	19,975	245	3,180	4,255	700	12,970	7,850	11,850
Very low								
Volume	40	444	408	539	124	155	656	136
Area	460	3,550	4,055	12,255	3,450	6,650	16,075	7,600

[1]Volume - mi^3

[2]Area - mi^2

Table 3. Mesozoic Aquifer Systems, Atlantic Coastal Plain, Georgia and South Carolina

	Aquifer system H(?)	Aquifer system G(?)	Aquifer system F	Aquifer system E	Aquifer system D	Aquifer system C	Aquifer system B	Aquifer system A
Total volume[1]	583	872	4,875	852	4,496	2,648	3,146	3,410
Total area[2]	4,678	6,257	60,000	30,725	48,090	55,590	50,050	50,450
Percentage of aquifers containing usable ground water								
Volume	0	0	57	48	89	76	87	90
Area	0	0	73	55	85	84	86	88
Aquifers containing usable ground water								
Volume	0	0	2,795	409	4,023	2,009	2,735	3,061
Area	0	0	43,681	17,072	40,850	46,714	42,818	44,626
Aquifers containing non-usable ground water								
Volume	583	872	2,080	443	473	639	411	349
Area	4,678	6,257	16,319	13,653	7,240	8,876	7,232	5,824

[1]Volume - mi^3

[2]Area - mi^2

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