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SALINITY DISTRIBUTION AND GROUND-WATER CIRCULATION BENEATH THE COASTAL PLAIN OF DELAWARE AND THE ADJACENT CONTINENTAL SHELF

BY

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Johan J. Groot

INTRODUCTION

The possibility of salt-water encroachment into the aquifers of the Coastal Plain of Delaware from saline-water bodies (Chesapeake and Delaware Canal, Delaware Bay, Atlantic Ocean) has received considerable attention (e.g., Sundstrom *et al*., 1967, 1971, 1976; Woodruff, 1969). These authors have shown that, so far, little encroachment has taken place.

It is also known that a large body of highly saline water occurs at depth beneath the Coastal Plain (Upson, 1966; Back, 1966; Brown and Reid, 1976) and the adjacent continental shelf, but no reports have been published about its origin and shape, and the salinity distribution and flow pattern within it. Yet, this saline-water body has a bearing on the development of fresh-water resources throughout Delaware, the feasibility of constructing injection wells for the disposal of liquid wastes, and radioactive waste disposal in the crystalline rocks beneath the Coastal Plain sediments, and upon the occurrence or migration of hydrocarbons (Bredehoeft and Maini, 1981). It is, therefore, important to study this body of saline water.

ACKNOWLEDGMENTS

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GENERAL GEOLOGIC FRAMEWORK

The Atlantic Coastal Plain is only a small part of a very large geologic feature, the Atlantic continental margin, which extends from Newfoundland to Florida, and includes four physiographic provinces: the emerged coastal plain, the submerged continental shelf, the continental slope, and the continental rise. From the hydrogeological point of view, the main features of the margin are the presence of a very thick wedge of sediments (Fig. 1) deposited upon a subsiding crystalline basement and the altitude of sea level which has fluctuated considerably during the period of deposition.

During the Triassic Period, downfaulting of basement rocks occurred and the grabens created were gradually filled with nonmarine sandstones and shales, which are probably present in the subsurface of Sussex County (Anderson, 1948). In the early Jurassic subsidence began to form the Baltimore Canyon trough. It initially received carbonate sediments and some evaporties as suggested by geophysical investigations and the occurrence of a thick sequence of salt in one of the exploratory wells drilled offshore (Benson, 1979). With the progressive deepening of the trough during the Cretaceous and Tertiary, deposition of clastic and carbonate rocks, mostly of marine facies, continued with little interruption.

On the landward side of the trough, where the wedge of sediments thins considerably, deposition was greatly affected by sea-level fluctuations. Consequently, the landward side is characterized by sediments of nonmarine to shallow-marine origin, and deposition was interrupted several times by relatively short periods of non-deposition or erosion (due to low relative sea levels), resulting in unconformities.

The hydraulic and hydrochemical properties of aquifers depend greatly on the environment of deposition of the geologic formations in which they occur and on their post-depositional history. In general, nonmarine sediments are characterized by rapid changes in lithology, and ground-water reservoirs in these deposits are often of limited extent or have rapidly changing hydraulic properties. Initially, at least, they contain fresh water which may be displaced by

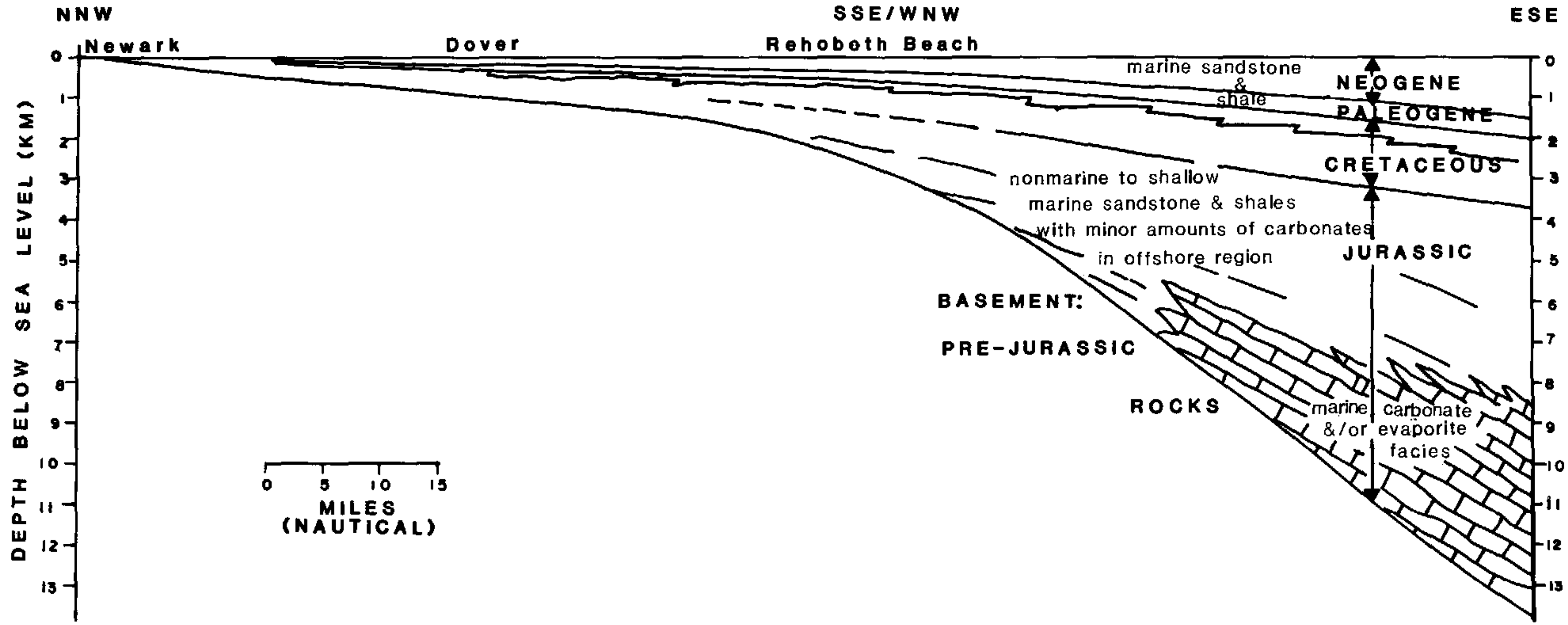


Figure 1. Diagrammatic cross section of the inner margin of the Baltimore Canyon trough through Delaware. (Source: modified after Benson, 1980).

saline water during a relative sea-level rise. Marine sediments are usually more homogeneous and contain saline water at the time of their deposition.

Post-depositional changes affecting ground-water reservoirs are changes in hydraulic properties due to compaction and cementation resulting in diminishing porosity and permeability, and hydrochemical changes due to leaching of minerals present in the sedimentary deposits through which the ground water flows. In general, therefore, the most deeply-buried sediments have the least favorable hydraulic and hydrochemical characteristics.

The geologic formations and aquifers that underlie the State of Delaware (the landward side of the trough; see Pickett, 1976) and are briefly described in Table 1. This table relates the formations to all known aquifers, and also indicates their approximate transmissivities (T), storativities (S), and chemical qualities in terms of total dissolved solids (TDS).

SALINITY DISTRIBUTION

General Observations

It has been found that ground water of meteoric origin generally evolves, during its flow from recharge area to discharge area, from the bicarbonate water with low total dissolved solids (TDS) to a chloride-dominated high-TDS water (Cheboratev, 1955). The completeness of this hydrochemical evolution depends on the distance the ground water travels and its residence time. Generally, bicarbonate water is young, i.e., a few years or a few decades old, and chloride-dominated water is old, its age being thousands or perhaps millions of years.

Many, if not all, deep sedimentary basins contain chloride-dominated high-TDS ground water in their deeper parts, even those in which there are no obvious sources of high chloride concentrations. For instance, brines occur in the Illinois basin in which there are neither evaporites (except some anhydrite) nor the possibility of salt water encroachment (Chave, 1960; Bredehoeft et al., 1963). Even Even if the source of sodium chloride was connate water (of sea water salinity), a considerable concentration of salts would be required to obtain salinities reportedly as high as

TABLE 1. Geologic formations and aquifers in Delaware

TIME UNITS	LITHOLOGIC UNITS	LITHOLOGY	HYDRAULIC PROPERTIES			TDS (mg/1)
			GENERAL	T(gpd/ft)	S	
HOLOCENE	Estuarine, lagoonal and barrier beach deposits	Silts and clays with organic matter, and sands	Sands form aquifer of limited extent	-	-	-
PLEISTOCENE	COLUMBIA GROUP:					
	Staytonville unit	Mottled gray and brown silt and clayey sand				
	Omar Formation	Interbedded gray quartz sand and silt	Generally good to excellent aquifer depending on saturated thickness	Variable, up to 170,000	0.15	<100 to 250
	Columbia Formation	Yellow and reddish-brown quartz sand, some gravel				
	Beaverdam Formation	Generally well-sorted quartz sand, some gravel				
PLIOCENE(?)	Bryn Mawr Formation	Red and brown quartz sand with clay, silt and some gravel	Not a significant aquifer	-	-	-
MIOCENE	CHESAPEAKE GROUP:					
	Pocomoke aquifer	Gray, silty, medium to coarse sand	Aquifer in SE Sussex County	10,000 - 11,000	6.6×10^{-3}	<100 to 1,000
		Blue and gray silt	Aquitard			
	Manokin aquifer	Gray, silty, medium to coarse sand	Important aquifer	40,000	5×10^{-4}	<100 to 250
		Blue and gray silt	Aquitard			
	Frederica aquifer	Fine to coarse sand	Important aquifer in Milford	10,000 - 12,000	3×10^{-4}	<100 to >1,000
		Blue and gray clay	Aquitard			
	Federalsburg aquifer	Fine to medium sand	Minor aquifer	9,400	3×10^{-4}	<100 to >1,000
		Blue and gray clay	Aquitard			
	Cheswold aquifer	Gray, medium to coarse sand and shells	Important aquifer	11,000 - 32,800	3×10^{-4}	<100 to >1,000
		Blue and gray silt and clay	Aquitard			
OLIGOCENE	Rocks of this age not present in Delaware					
EOCENE	Piney Point Formation	Fine to medium sand, glauconitic. Grading into silt and clay	Important aquifer in Kent County	6,000 - 41,000	3×10^{-4}	200 to >1,000
	Nanjemoy Formation	Sandy, clayey, glauconitic silt	Aquitard			
PALEOCENE	RANCOCAS GROUP:					
	Vincentown Formation	Green, gray and reddish-brown fine to coarse sand, some silt	Aquifer	14,000 - 19,200	1.9×10^{-4} to 2.8×10^{-4}	<100 to >500
	Hornerstown Formation	Green, gray and reddish-brown silty sand, glauconitic				
UPPER CRETACEOUS	Mt. Laurel Formation	Gray, green and brown glauconitic quartz sand, some silt	Minor aquifer			
	Marshalltown Formation	Dark greenish-gray, glauconitic fine to medium sand, some silt	Minor aquifer	1,800	2.5×10^{-4}	<100 to >10,000
	Englishtown Formation	Gray and brown micaceous sand	Minor aquifer			
	Merchantville Formation	Dark gray to blue glauconitic sandy silt and silty fine sand	Aquitard			
	Magothy Formation	White medium to coarse sand and black clay	Aquifer	4,000	6×10^{-5}	<100 to >10,000
	Potomac	Variegated clays and quartz sands	Upper and lower sands Important aquifer	4,000 - 12,000	5×10^{-4} to 6×10^{-5}	<100 to >100,000
LOWER CRETACEOUS & JURASSIC (?)	Formation					
TRIASSIC	-----	Sandstone and shale	No data			
PALEOZOIC & PRECAMBRIAN(?)	Wissahickon Formation Cockeysville Marble Baltimore Gneiss James Run Formation Wilmington Complex	Schist, gneisses, marble, gabbro	Minor aquifer	Generally < 2,000	10^{-4}	< 250

Sources: Cushing et al., 1973; Sundstrom and Pickett, 1971; Talley and Hahn, 1978.

150,000 milligrams per liter (mg/l). Brines may be the result of solution of chloride minerals where evaporites are present in deep basins, but where such deposits are scarce or absent, high-chloride ground water must be of different origin.

Any explanation of the occurrence of brines in sedimentary basins has to account for these features: (1) generally, but not always, salinity increases with depth; (2) brines having salinities several times greater than that of sea water are common; (3) the chemical composition of brines varies little over large areas (White, 1957); and (4) brines occur in basins with and without evaporites.

As early as 1947 de Sitter suggested that brines were formed by the passage of water through fine-grained sediments that behave as semi-permeable membranes. White (1957) thought that the characteristics of the brines and their distribution pointed to water of connate origin with salts being concentrated by processes which involve the selective separation of water and salt in compacting shales.

Neglia (1979, p. 575) found that the "...degree of salinity of water expelled from the shales decreases through geologic time as compaction increases," and that toward "...the end of the compaction process an almost fresh water... will flow out." He stated that "...compacted shales behave as ideal membranes, whereas partially compacted shales behave as non-ideal membranes." In both cases, however,

> ...the salinity of the outflowing water will be less than the salinity of the incoming water therefore, the salt concentration in an aquifer below a partially compacted shale will increase gradually during geologic time. Thus, the presence of brines in the upper part of the geologic column testifies that a large volume of water has preferentially migrated toward a particular area of the sedimentary basin. The presence of low-salinity water at great depth, however, proves that the compacted shales are releasing the last water adsorbed on the clay surfaces. (p. 576).

Although the process involved in creating brines in the subsurface does not appear to be understood in detail, there can be little doubt that it is significant in at least those basins where evaporites are scarce or absent.

The compaction of fine-grained sedimentary rocks results in the expulsion of quantities of water which have to migrate from the deeper part of a basin (where compaction is greatest) to the shallower edges, because water that migrates to permeable sedimentary rocks will move most easily in a near-horizontal direction as horizontal permeability is generally much greater than vertical permeability. At the same time, if one or both edges of an elongated basin are above sea level, fresh water of meteoric origin will tend to move toward the center of the basin. A basin in this condition is hydrodynamically active with movements both of fresh and saline water.

Salinity Distribution Beneath the Delmarva Peninsula and the Adjacent Continental Shelf

Data regarding the salinity distribution in those areas and aquifers in which TDS exceeds 500 mg/l are scarce because water well drillers have little reason to explore ground-water sources of poor quality. Evidence of highly saline ground water does exist however, mainly in the form of geophysical logs of deep holes, usually drilled for exploratory purposes either by the oil or water-well industry. Because only a few such holes with adequate logs exist in Delaware, several have been examined from locations on the Eastern Shore of Maryland, Cumberland County, New Jersey, and the continental shelf. Self-potential (SP) logs were used to interpret chloride concentrations, and the Cl^- (chloride) figures were used to estimate TDS content. As the SP curve is affected by many factors, including porosity, bed thickness, and temperature of the formation fluids, its interpretation in terms of Cl^- concentration is subject to errors. In addition, there is no simple fixed relationship between Cl^- concentration and TDS. Consequently, both Cl^- and TDS concentrations presented in this report are only approximate. However, where possible, the Cl^- concentration determined from the SP curve and by chemical analyses of water samples was compared; the two methods gave comparable results. Thus, although precise salinity data are scarce, the available information is sufficient to provide a schematic presentation of the salinity distribution in the area.

The salinity distribution in onshore and offshore wells (for locations see Fig. 2) is shown in Figures 3 and 4, Figure 5 represents the vertical chloride distribution in three deep wells located in the Eastern Shore of Maryland and two stratigraphic test wells in the Baltimore Canyon

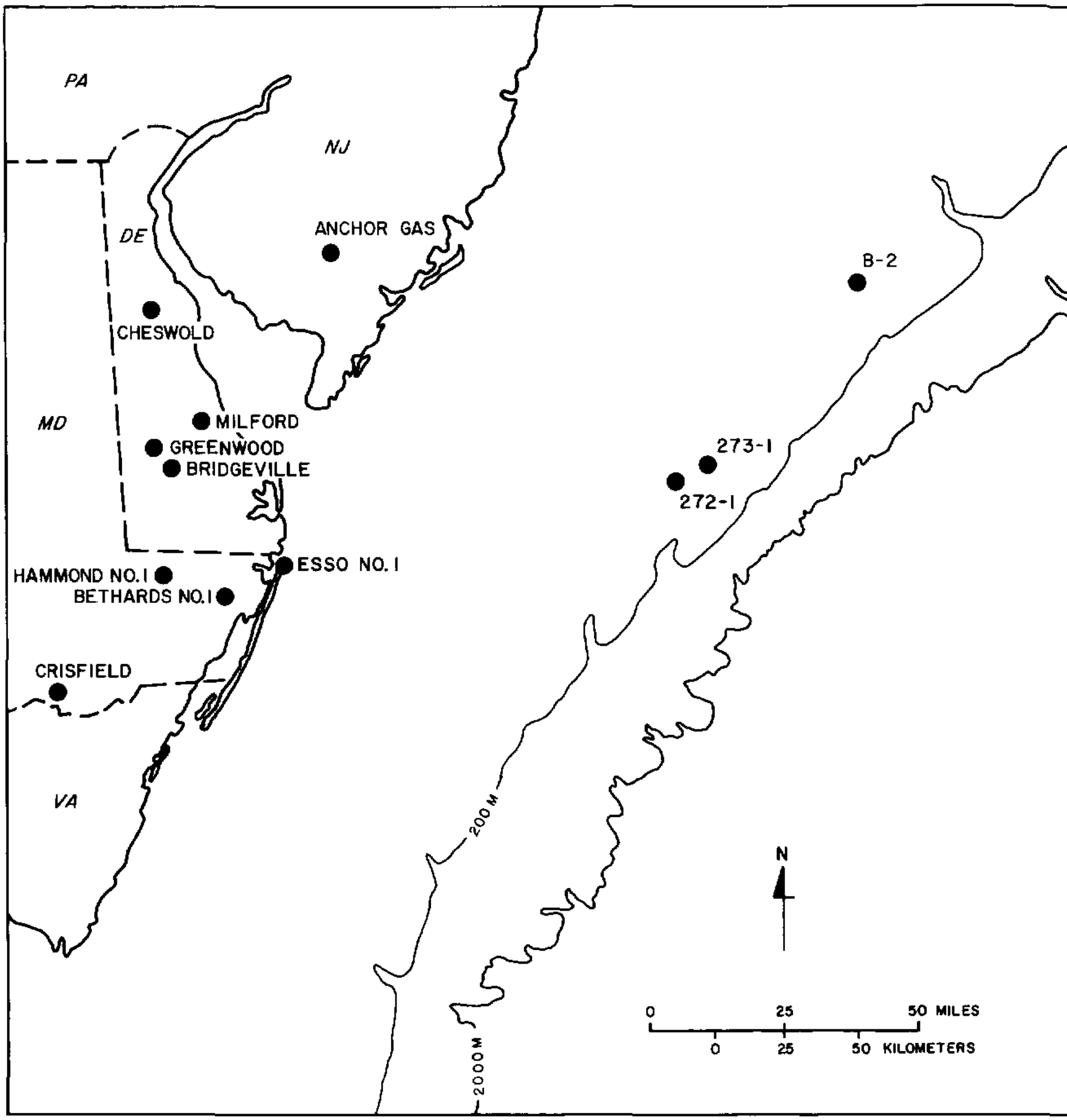
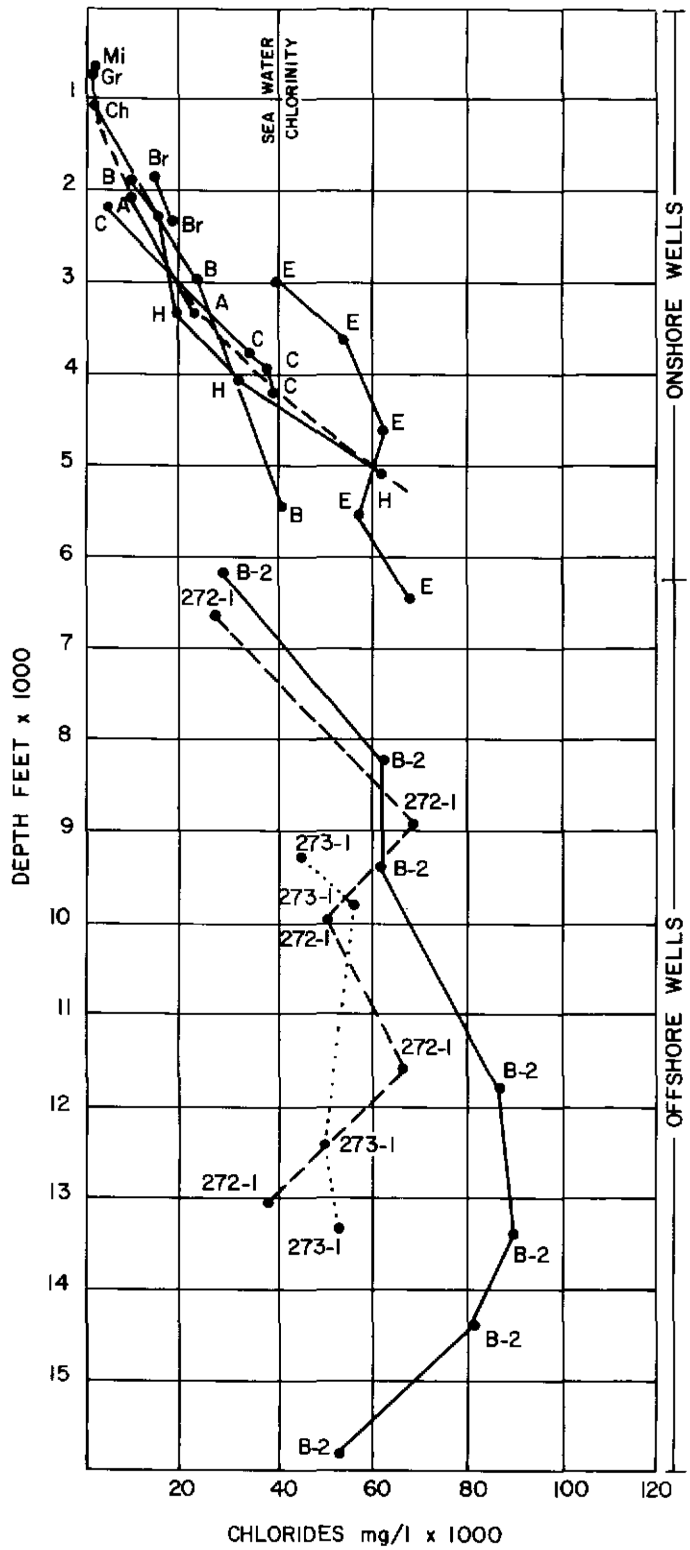


Figure 2. Map showing location of wells used in interpretations of ground-water salinity.



LEGEND

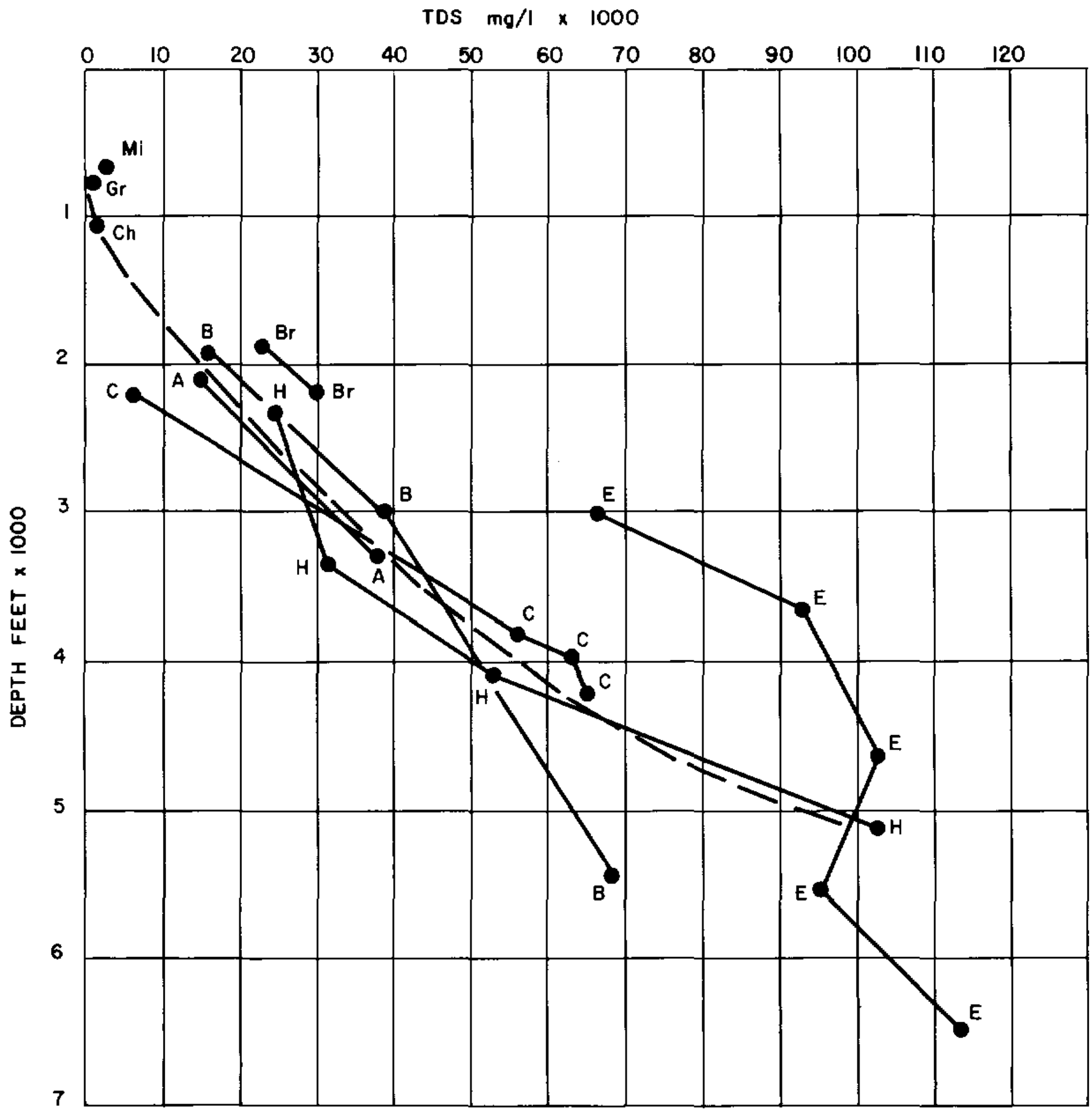
A Anchor Gas, N.J.
B Bethards No. 1, Md.
Br Bridgeville
C Crisfield, Md.
Ch Cheswold, De.
E Esso No. 1, Md.
H Hammond No. 1, Md.
Gr Greenwood, De.
Mi Milford, De.
B2 COST B2
272-1 Shell
273-1 Shell

Notes:

(1) For well locations see Figure 2.

(2) The points representing chloride concentrations in each well have been connected to facilitate viewing chloride changes with depth. The lines do not necessarily indicate concentrations between points.

Figure 3. Chloride concentrations (mg/l) versus depth in onshore and offshore wells.



FOR LEGEND SEE FIGURE 4

—— GENERAL TREND OF SALINITY

Figure 4. Distribution of TDS versus depth.

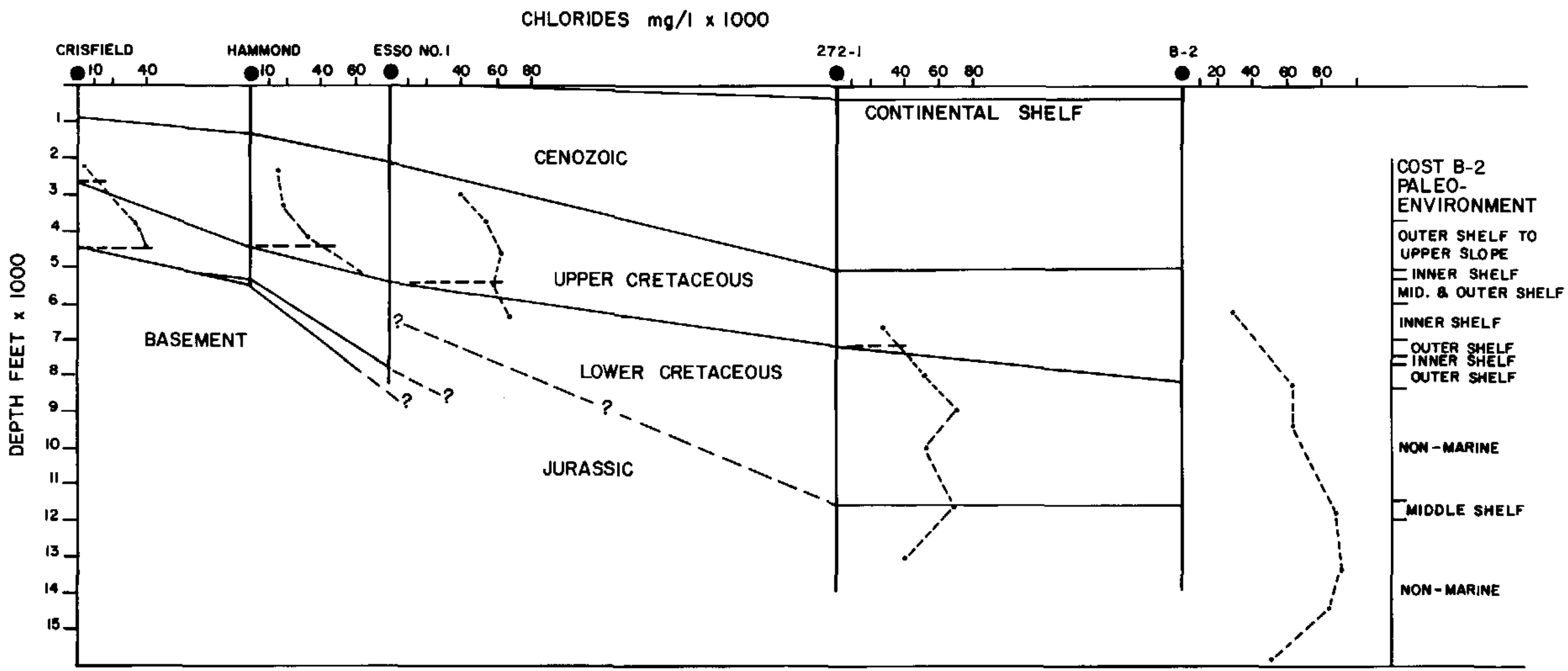


Figure 5. Chloride distribution versus depth in some wells on the Eastern Shore of Maryland and the Baltimore Canyon trough.

trough. Figure 6 is a schematic presentation of the salinity distribution (in terms of TDS) beneath the Delaware Coastal Plain and the adjacent continental shelf.

Figures 3 and 4 show that salinity increases with depth, except in the deepest parts of wells 272-1 and COST B-2. Low salinities (TDS $\leqq$ 10,000 mg/l; Cl^- $\leqq$ 5,000 mg/l) are found up to a depth of about 1,500 - 1,700 feet. Below that depth, the Cl^- concentration in Coastal Plain aquifers increases at a rate of approximately 12,000 to 13,000 mg/l per 1,000 feet; below the Outer Continental Shelf (in wells 272-1 and COST B-2), the chloride concentration increase is less consistent; it averages about 6,500 mg/l per 1,000 feet. Below the Coastal Plain, a salinity of 35,000 mg/l TDS (sea water salinity) is found at approximately 3,000 feet, and a TDS of about 50,000 to 60,000 mg/l occurs at about 4,000 feet, with the exception of the Esso #1 well in which higher salinities occur. It appears that (1) salinity is primarily related to depth, regardless of aquifer, geologic formation, and environment of deposition (see Fig. 5); (2) that a fresh water/salt water interface does not exist; and (3) that nearly one-half of the volume of sediments below the Coastal Plain of Delaware is saturated by ground water of sea-water salinity and by brines. Finally, it may be noted that close to areas where aquifer recharge occurs, salinity increase with depth is less than elsewhere in the Coastal Plain; for instance, in the Crisfield well, TDS is only about 8,000 mg/l at a depth of 2,200 feet, whereas in other wells, farther away from the recharge area of the Potomac Formation, it is more than double that salinity. Fresh water (TDS $\leqq$ 500 mg/l) is generally found up to a depth of 300 to 800 feet, except in central and northern New Castle County, where it occurs in the entire sequence of sediments (Fig. 7).

Although some of the older sediments in the Baltimore Canyon trough are of nonmarine origin, most of the Cretaceous and younger deposits were laid down in a shallow marine environment and therefore contained sea water at the time of their deposition. Moreover, the whole sedimentary sequence beneath the Coastal Plain of the Delmarva Peninsula and the adjacent shelf was inundated by the sea, which must have resulted in saline-water infiltration during various phases of transgression, for instance during the early and middle Miocene, and perhaps several times for short periods during the Pleistocene. On the other hand, a partial flushing out of saline water by fresh water during regressions must have occurred during post-Potomac/pre-Magothy time, during the late Eocene-Oligocene, post middle Miocene, and during the latest

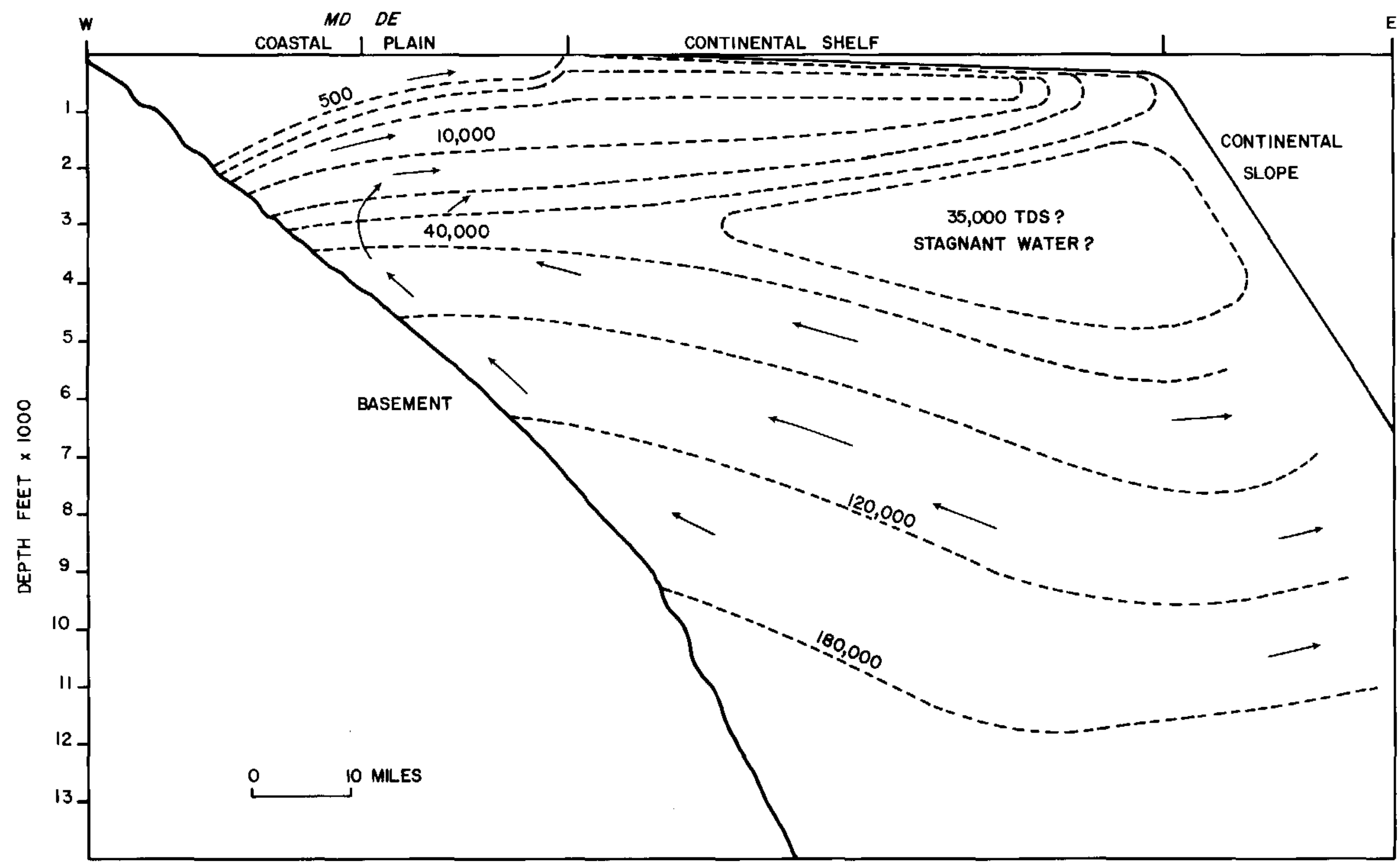


Figure 6. Schematic presentation of salinity distribution and ground-water flow.

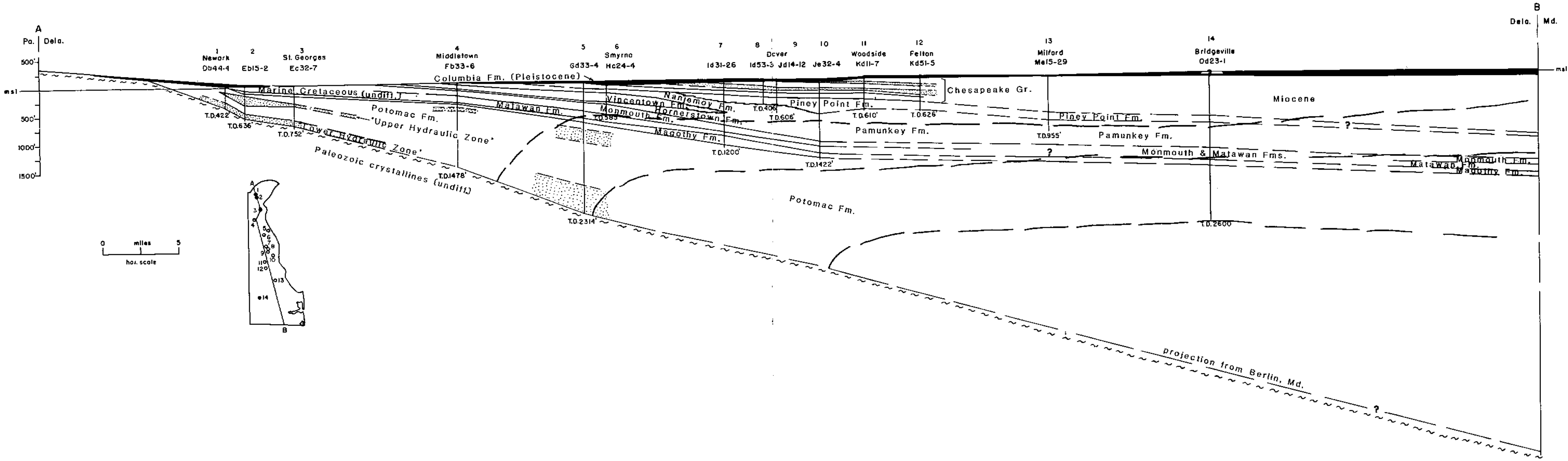


Figure 7. Geologic cross-section of Delaware and approximate depth of 500, 10,000, and 35,000 mg/l TDS. Adapted from Woodruff, 1969.

part of the Pliocene, and several times during the Pleistocene (R. N. Benson, personal communication). This complex history of salt-water intrusion alternating with fresh-water flushing was probably limited to the upper part of the sedimentary sequence. However, the salinity distribution in Coastal Plain wells (located in the shallow western edge of the deep basin) does not indicate this complexity; in fact, the salinity increase with depth is more consistent in the Coastal Plain wells then it is in the two deep offshore wells investigated (Fig. 3).

In spite of alternating phases of intrusion and flushing, there is no lack of sea water entrapped in the sediments of the basin; the question is only whether brines occurring at depths exceeding 3,000 feet must be attributed to solution of evaporites, "ionic filtering," or both. The presence of evaporites has been demonstrated, but their extents and thicknesses are unknown. Therefore, it is impossible to determine whether or not they are a major source of the brines.

Compaction of shales has undoubtedly occurred, or is a continuing process; thus, it is reasonable to assume that brines produced by shales behaving as semi-permeable membranes are present. The tendency of salt concentrations to diminish somewhat at about 12,000 to 13,000 feet in wells B-2 and 272-1 (Fig. 3) suggests that the compaction of shales at this depth has progressed to the stage that water of relatively low salinity is expelled (Neglia, 1979), but the available data are too few to draw firm conclusions.

The Baltimore Canyon trough is, in the hydrodynamic classification of Coustau et al. (1975), a juvenile basin, one that is characterized by sedimentation and compaction, and increasing salinity with depth. Fluids expelled from fine-grained sediments migrate centrifugally. This movement is slow, and is measured, according to Coustau et al., in terms of millimeters per year. The trough may be in an advanced phase of the juvenile stage of hydrodynamic development, with shales at great depth perhaps releasing less saline water than before and fresh water of meteoric origin occurring in shallow aquifers at the landward edge of the trough. At depth, however, aquifers are still in the centrifugal stage, i.e., saline ground water moves slowly in a generally westerly direction, whereas meteoric water flows in the opposite direction (Fig. 6).

In aquifers in which ground-water density varies little, the horizontal component of flow is perpendicular to the potentiometric contours of that aquifer. Where density differences do occur, the potentiometric contours should be adjusted to represent fresh-water heads in order to determine direction of flow. Because density depends on salinity and temperature, this adjustment can only be made when both these factors are known.

The sands of the Potomac Formation are examples of aquifers containing water of great density differences. The necessary data to obtain fresh-water heads in the Potomac "upper sand" at two sites, an actual well at Bridgeville, and an imaginary well at Rehoboth, are listed below:

	Bridgeville	Rehoboth
Water level (ft. sea-level datum)	+ 6	0 (estimated from Figure 8)
Depth of sand (ft)	1,720	2,600
TDS	24,000	30,000 (estimated from Figure 4)
Temperature (°F)	75	86 (based on geo-thermal gradient)
Density (ρ)	1.016	1.018

Fresh-water head $H^{1.00} = H^{obs} + L\ (\rho - 1)$ (Bond, 1972), where $H^{1.00}$ is fresh-water head, H^{obs} is head actually observed, L is the length of the observed water column, and ρ is water density.

For Bridgeville

$$H^{1.00} = 6 + 1{,}726(1.016 - 1)$$

$$H^{1.00} = 33.6 \text{ feet}$$

For Rehoboth

$$H^{1.00} = 0 + 2{,}600(1.018 - 1)$$

$$H^{1.00} = 46.8 \text{ feet}$$

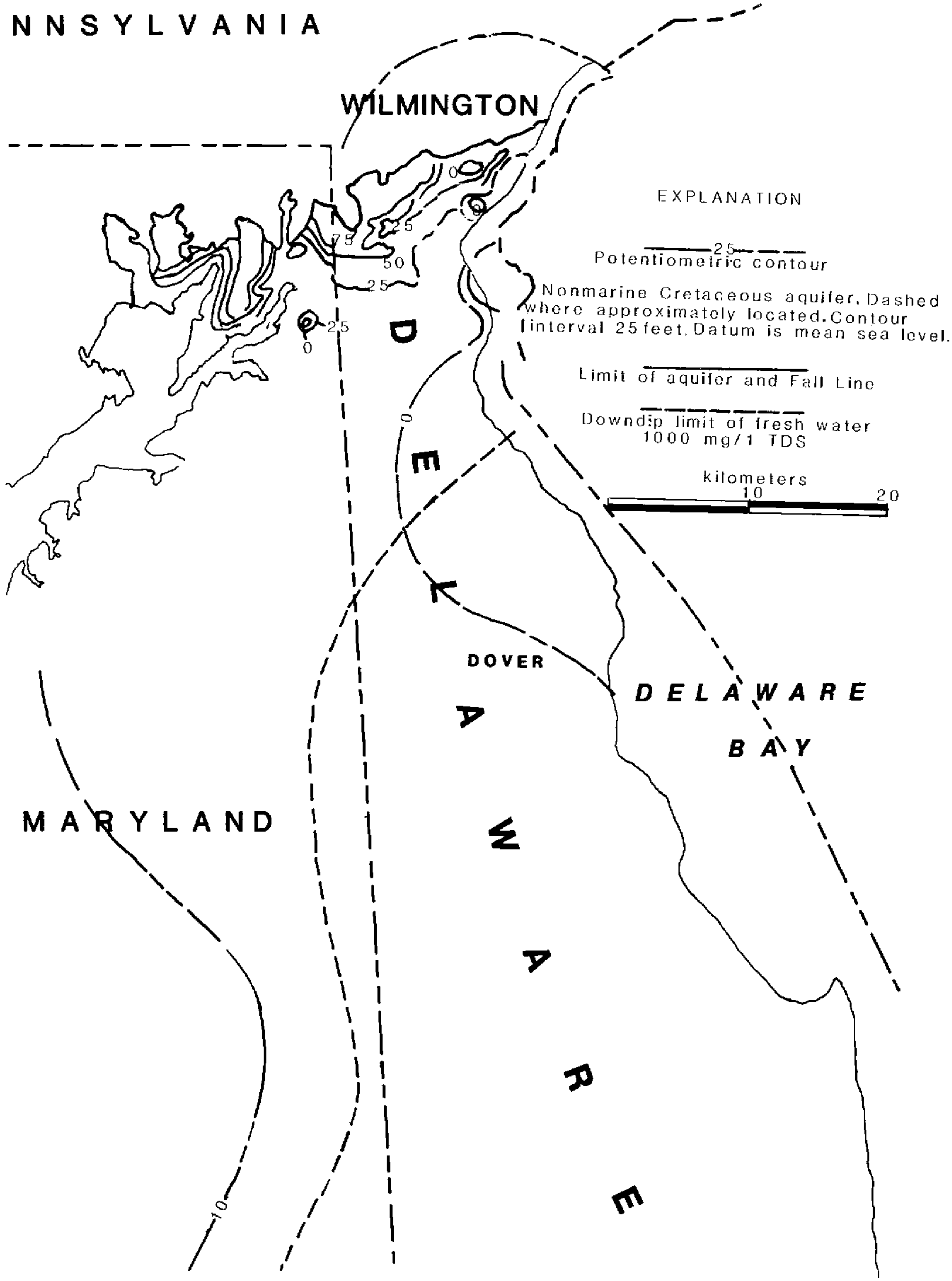


Figure 8. Potentiometric surface of the Potomac Formation from Cushing et al. (1973).

It should be noted that the figures used in this calculation are mostly based on estimates, and the result - indicating westward movement of ground water in the upper part of the Potomac Formation in Sussex County, in the opposite direction of that suggested by the unadjusted potentiometric contours - must be viewed with some caution. The result does, however, agree with the hydrodynamic concepts of Coustau et al. (1975) and Magara (1978).

Hubbert (1969) noted that when fresh water flows above saline water in an aquifer, the interface between the two is tilted. When stratified water of variable density flows through an aquifer, it can be considered to have an infinite number of tilted interfaces in which the angle of tilt decreases with depth. The interface will tilt upward in the direction of flow. The vertical salinity distribution shown in Figure 6 suggests a salinity distribution (or density distribution, ignoring the effect of temperature) which would cause a westward migration of ground water below Delaware at a depth of 3,000 feet and more, and a seaward motion somewhere above that level; ground water of the Potomac upper sand is expected to move upward in the region of the Delaware-Maryland state line, as indicated by the arrows. Thus, the westward movement of ground water at depths below 3,000 feet is suggested both by the vertical salinity distribution and fresh-water heads.

Figure 6 indicates the presence of a body of low-salinity ground water at depths of 300-650 ft/sld, below the continental shelf. This relatively fresh water was found by the U. S. Geological Survey (Hathaway et al., 1976) off the coast of New Jersey and Maryland. Its origin is meteoric; in Wisconsin time sea level was 300 feet lower than it is at present, and the continental shelf received recharge by precipitation. Such a body of fresh water is expected to occur beneath the Delaware part of the continental shelf also. Its presence has, however, little or no bearing on the movement of brines in the deep subsurface.

Rate of Ground-Water Movement

The average linear ground-water velocity is calculated from the following formula:

$$V = \frac{K \times I}{\mu}, \text{ where}$$

K is hydraulic conductivity
I is hydraulic gradient, and
μ is porosity.

Although the porosity of sedimentary rocks varies considerably, its range is within one order of magnitude. A reasonable figure for sandstone is 20 percent. Hydraulic conductivity, however, has a range of ten orders of magnitude for different sedimentary rocks, depending on grain size distribution and degree of cementation. Freeze and Cherry (1979) give a range of 10^{-8} to 10^{-4} cm/sec for sandstones, and 10^{-4} to 1 cm/sec for clean, unconsolidated sand. Shales have a hydraulic conductivity as low as 10^{-11} cm/sec.

Hydraulic gradients can also vary several orders of magnitude, particularly in aquifers from which large quantities of water are withdrawn. Where that is not the case, hydraulic gradients of 10^{-4} to 10^{-5} may be considered reasonable.

In the Rehoboth-Bridgeville area, the fresh-water head difference in wells in the upper part of the Potomac Formation was calculated to be about 13.2 feet or 4.0 m (page 16). The distance between the wells is about 45 km, and the hydraulic gradient is approximately 9×10^{-5}. Considering that the depth of the aquifer is relatively shallow, an above-average hydraulic conductivity for sandstone, 10^{-5} cm/sec, is assumed. If porosity is 20 percent, ground-water velocity would be about 1.5 mm/year (0.06 in/yr).

It should be noted, however, that there may be areas where steeper hydraulic gradients occur and where unconsolidated sands have good permeability. If so, ground-water velocity could be greater by several orders of magnitude, althougy it seems doubtful that it would be measured in more than meters per year, except under the influence of pumping.

Even though saline ground-water velocity is low, the expulsion of water from shales and the westward motion of ground water have occurred for more than 100 million years, a long enough period to account for the migration of fluids over a distance of 150 to 200 km (93 to 124 miles).

Salinity Distribution and Ground-Water Supplies

Brines occur at depths great enough not to be a threat to fresh water supplies, but water having a salinity of

500 mg/l or even less is found at depths of 500 to 750 feet (see Fig. 7) beneath the Coastal Plain of Delaware. Such slightly brackish water poses a potential threat to fresh-water supplies because (1) at such shallow depths hydraulic conductivity is usually considerably larger than that found in the deep part of a sedimentary basin, and (2) under the influence of pumping hydraulic gradients steepen greatly, thus resulting in much higher ground-water velocities than those thought to occur at depth.

For the purpose of illustration, assume that a well is developed in southern New Castle County in an aquifer of the Potomac Formation, having a transmissivity (T) - 8,000 gpd/ft, a thickness of 50 feet, and thus a hydraulic conductivity of 160 ft/day. Continuous pumping causes a cone of depression having a radius of 60,000 feet and a drawdown of 200 feet; thus an average hydraulic gradient of about 3×10^{-3} is created. If the porosity of the aquifer is 20 percent, then the average velocity of ground water flowing to the well is

$$V = \frac{3 \times 10^{-3} \times 160}{0.2} \text{ ft/day}$$

$$= 2.4 \text{ ft/day; or } 876 \text{ ft/year.}$$

Thus, a well with the characteristics mentioned above, located 5 miles from ground water having a salinity of 500 mg/l, will begin producing water of that quality after 30 years of pumping.

This calculation indicates that, provided that data regarding hydraulic coefficients and chemical quality are available in sufficient detail, saline water intrusion can be avoided.

SUMMARY AND CONCLUSIONS

In the Coastal Plain of Delaware and the adjacent continental shelf ground-water salinity generally increases with depth; total dissolved solids reach 35,000 mg/l at a depth of approximately 3,000 ft (sld) and TDS may exceed 100,000 mg/l at a depth of 5,000 feet.

The origin of the brines present in the deep subsurface may either be solution of evaporites occurring in the Baltimore Canyon trough or it may be related to shales behaving as semi-permeable membranes; it appears likely that both of the processes are responsible for the occurrence of the brines.

It is thought that the brines have migrated from the center of the Baltimore Canyon trough toward its edges, one of which is the Coastal Plain. The rate of movement is considered to be in the order of millimeters per year; such slow movement is probably due to small hydraulic gradients and low hydraulic conductivities of the sedimentary rocks in the deeper parts of the trough.

At relatively shallow depths (500 to 750 feet) in the Coastal Plain, brackish water occurs in unconsolidated sands of several geologic formations which have high permeabilities; if wells are drilled in such sands close to where brackish water occurs, steep hydraulic gradients can be created by pumping and the rate of ground-water movement can be in the order of several hundred feet per year. Under such conditions no wells should be constructed within several miles of the presence of brackish water (the 250 mg/l isochlor), if drinking water quality is required.

RECOMMENDATION

It is recommended that the salinity distribution and the direction and rate of ground-water movement beneath the Coastal Plain and the adjacent continental shelf be studied in greater detail in order to provide adequate data for the protection of fresh ground-water resources from saline water encroachment.

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