FEASIBILITY STUDY OF EAST COAST TRIASSIC BASINS FOR WASTE STORAGE

Interim Report —

DATA AVAILABILITY

73-15

by

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SUMMARY

The Triassic deposits of the East Coast are continental clastics of alluvial, lacustrine, and paludal origin preserved in negative, fault-bounded structures, the exact origin of which is not fully understood. The basins are preserved in discontinuous strips from Nova Scotia to Georgia in the older Appalachians of the Atlantic Coast and extend ocean-ward beneath younger coastal plain sediments for an unknown distance.

In most cases, the continental clastics were derived locally from the basin margins, were deposited in alluvial fans at basin scarps and river mouths, and were redistributed by longitudinal streams and lake currents. The coarse rocks near the basin edge lens and intertongue with, and grade basinward rapidly into, finer grained and more tabular bodies. Evaporites, coal, chert, and tufa record swamps and saline lakes and indicate deposition in closed or restricted basins for part of Triassic time.

The percentage of interbedded volcanic rocks increase from Virginia northward and coal is more prominent from Virginia southward. The basins are extensively blockfaulted, causing most estimates of thickness based on average dip to be 50 to 100 percent high.

The composition and textural range of the outcropping Triassic rock suite are probably known, but the stratigraphy of the deeper parts of the basins is not known because it has not been sampled. The exact structural model is not known; therefore, the correct depositional model is in doubt. Conclusions about subsurface geology, pore-water chemistry, and hydrodynamic relations cannot be made with certainty until the sedimentary model is understood.

Rapid transport of granitic, gneissic, and sedimentary debris over short distances has created poorly sorted, dirty, and dense feldspathic sandstones, conglomerates, and siltstones -- chiefly arkose and high- and low-rank graywacke -- with inherent low porosity. Locally, high and sustained hydraulic energies in the depositional environments of Triassic time were sufficient to produce better sorted and cleaner sandstones and conglomerates. In some places, post-depositional overgrowths on detrital minerals and recrystallizaiion of matrix and cement in the feldspathic Triassic rocks have produced very dense, tough rock with interlocking crystal texture and low porosity. For the most part, however, the rocks are less cemented.

There have been few wells drilled deeper than 1,000 feet and there are practically no aquifer test data. The available data indicate that fractures account for most of the secondary pore space, and possibly solutional openings for some of the porosity. Most hydrologists have found decreasing yields in the 400- to 600-foot depth range which indicates that most fractures at this depth are tightly closed. Thin, saline, artesian aquifers exist down to at least 2,000 feet.

Intrusive diabase and basalt flows generally act as hydrologic barriers near the surface, and will probably also prove to be effective barriers in the deep subsurface.

Permeabilities of samples of Triassic rock range from 0.06 X 10^{-5} $(\mu m)^2$ to 2,100 X 10^{-5} $(\mu m)^2$. Porosities are generally well below 10 percent. Reported transmissivities range from 0.00005 ft^2/day in fine sandstone in the buried Dunbarton basin to 20,300 ft^2/day for the Brunswick Formation.

Ground-water yields are considerably greater in the basins north of Culpeper, Va. than to the south. Whether the explanation is one of difference in recharge, aquifer lithology, degree of regional fracturing, or a combination of causes has not been determined.

Very few chemical data are available for water from deep aquifers. Most water samples have been taken from a discharge point at the top of the well and represent a mixture of all contributing aquifers. Data from 3 wells 2,000 to 4,000 feet deep showed a range in TDS (Total dissolved solids) from 6,000 to 46,000 mg/l (milligrams per liter).

Water from wells 400 to 1,000 feet deep generally had TDS below 1,000 mg/l. The vertical change in chemical facies with increasing depth or length of flow path is generally sodium bicarbonate to sodium calcium magnesium bicarbonate to sodium calcium magnesium sulfate to calcium suf-fate to sodium chloride. Regionally, the calcium magnesium bicarbonate sulfate facies dominates in the basins north of Culpeper, Va., except in Maryland where calcium bicarbonate predominates. In North Carolina and South Carolina, sulfate is generally absent, and water is mostly of a sodium calcium magnesium bicarbonate type and a few rare calcium chloride types. Sodium chloride types apparently predominate at depth in all basins.

The regional change in water chemistry may reflect the regional change in the mineralogy of the source rocks or the areal variation in depositional environments. The presence of evaporites, tufa, chert, and coal suggest closed lakes and playas deposits, the mineralogy of which would be reflected in the chemistry of the ground-water leachate.

The intra-basin flow system is presumed to be from the basin margins toward the major longitudinal and trunk streams, modified by such intra-basinal barriers as faults, intrusive diabase, basalt flows, and impervious sedimentary rock layers. The increase of sulfate and TDS near major streams supports this conclusion. The effective circulation depth is not known.

There is great variation in geographic coverage, type, and quality of the few geophysical logs available from the Triassic. The few good logs are limited almost entirely to the buried basins of the Coastal Plain. Even there, few density logs have been run.

Bulk densities from logs of one well in Maryland and one in Virginia indicate a range of 2.50 to 2.80 grams per cubic centimeter for the shales and sandstones penetrated.

Both regional gravity and magnetic maps show a close, but not unique, correlation of Triassic sedimentary rocks with areas of low magnetic intensity and negative gravity anomaly. Residual gravity anomaly profiles in the Deep River basin suggest the basement to be slightly shallower than estimated and the Triassic wedge to be extensively block faulted.

The central East Coast Piedmont experiences 10 to 13 low intensity earthquakes per decade on the average. A geographic plot of epicenters shows few if any in or near Triassic basins. Rather, the epicenters have a pronounced east-west trend transverse to the Triassic basins.

Subsurface data are fragmentary, isolated, and incomplete for any one basin site, making inter- and intra-basin comparisons questionable on anything other than a qualitiative basis.

INTRODUCTION

Location and Description

Triassic rocks are distributed along the Atlantic Coast for 1,500 miles from about 30° north latitude to 43° north latitude in the United States and as far north as the Bay of Fundy in Nova Scotia at about 45° north latitude. They appear as half graben or tilted graben structures arranged in isolated en echelon fashion (fig. 1) and are confined mostly to a piedmont belt composed of Precambrian to early Paleozoic rocks. The width of the outcrop belt of Triassic rocks is about 100 miles, but known deposits exist for at least another 100 miles eastward beneath the sedimentary blanket of Coastal Plain and Continental Shelf deposits.

All of the Triassic troughs have been filled with extremely coarse to fine-grained continental clastics. In some basins they are interbedded with basalt flows, pyroclastics, coal, and fresh-water limestones. Most Triassic deposits have been intruded by sheet-like diabasic masses subparallel to bedding and by diabase dikes along post-depositional faults and cross fractures.

Fig. 1.--Map showing distribution of Triassic rocks along the Atlantic Coast.

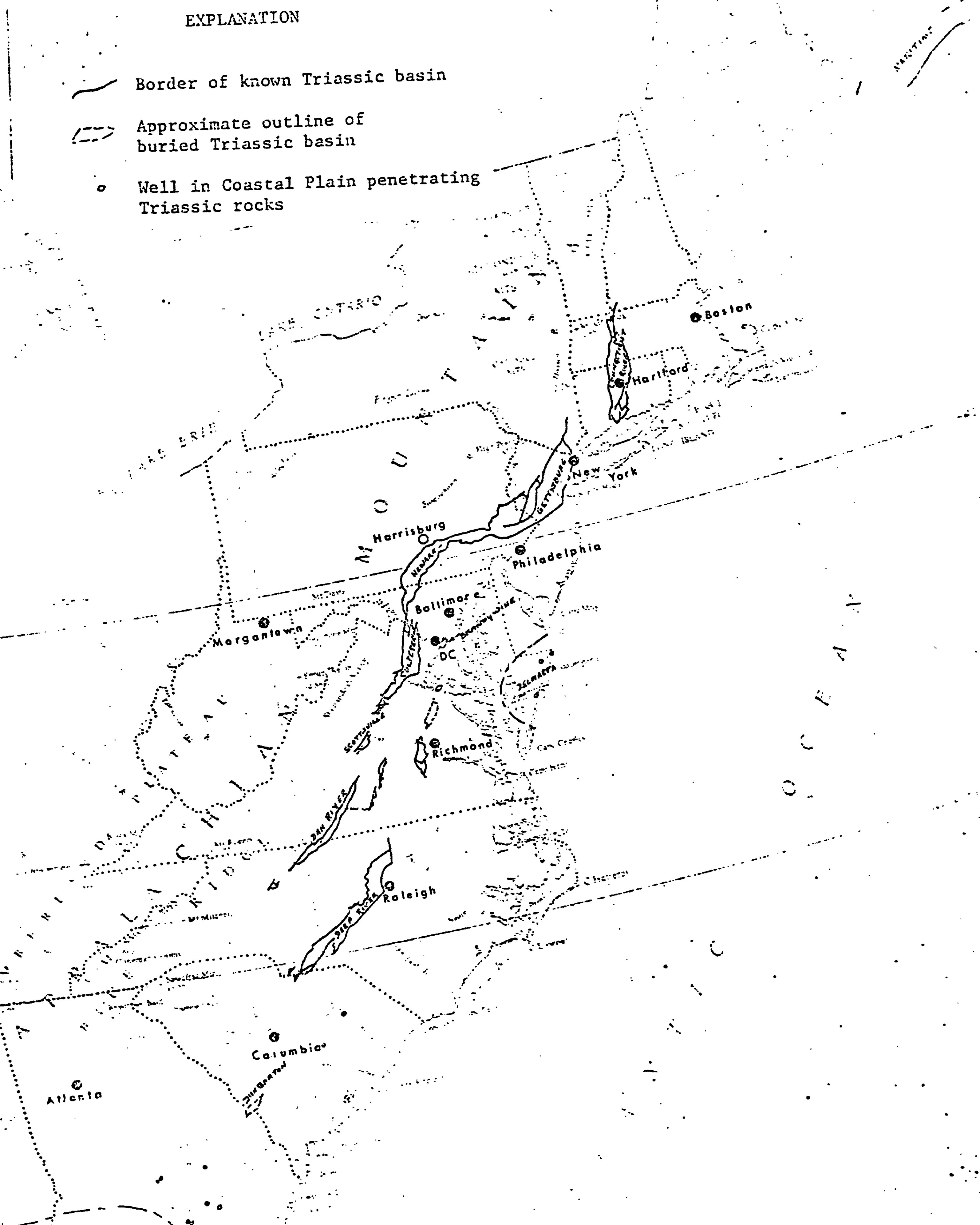


Figure 1.--Distribution of Triassic rocks along the Atlantic Coast.

Purpose and Scope

The ultimate purpose of this study is to determine the suitability of Triassic rocks of the eastern United States as loci for the subsurface emplacement and storage of liquid wastes. The initial or short range object of this study was to determine the general availability of the stratigraphic, structural, hydrologic, geophysical, rock mechanical, seismic, and geochemical data for each of the Triassic basins. All these types of data are necessary for proper and dependable waste disposal evaluation. Most of this report is devoted to the initial object -- a summary of our present knowledge of the East Coast Triassic; a tabulation of the data available from files of the U. S. Geological Survey, state surveys, and industry and all published sources; and to mechanical and hydraulic test on a few core samples. The study was also designed to make recommendations, where sufficient data are available, concerning the potential of any one or more basins for waste storage, the advisability of further research, and possible sites for detailed study.

Acknowledgements and Direction

This study was made under the general supervision of Joseph T. Callahan, Chief, Branch of Ground Water; Leonard A. Wood, Coordinator of Waste Disposal Research; and Frank H. Olmsted, Staff Geologist, ACR. P. M. Brown, J. A. Miller, Research Geologists, U. S. Geological Survey, gave advise on technical problems. The project is part of a much larger cooperative effort by the U. S. Geological Survey and DARPA (Defense Advanced Research Projects Agency of the Department of Defense) in waste disposal research throughout the United States.

The project effort benefited materially through cooperation from several universities, state geological survey and water-resource agencies, water-well companies, and oil and gas industries. In particular, Dr. James L. Calver of the Virginia Division of Mineral Resources; Mr. Stephen G. Conrad, North Carolina Department of Earth Resources; Mr. Frank Jacobeen, Washington Gas Light Company; Mr. William Overbey, Morgantown Research Laboratory, U. S. Bureau of Mines; Dr. Arthur Socolow, Pennsylvania Geological Survey; and officials of Cities Service, Chevron, and Gulf oil companies aided the investigation by submitting data, giving technical assistance, or performing tests.

Data Needs

The kinds of data needed to evaluate the potential of the East Coast Triassic for storage of waste liquids are listed below-but not necessarily in order of priority.

1. Internal and external geometry of the Triassic deposits to determine the geographic extent and reservoir volume of candidate rocks as well as their location relative to sensitive man-made structures or useable mineral and water resources;
2. Porosity and intrinsic permeability of candidate reservoir rocks and enclosing rock seals to determine possible injection rates and volumes;
3. Chemistry and physical character of host fluids and gases to determine their compatability with potential injection fluids and gases;
4. Formation resistivity factors of typical Triassic lithologies to evaluate host water chemistry from geophysical logs;
5. Seismic history of immediate area of Triassic grabens to determine earthquake risk to reservoir rocks;
6. Rock strength of and local residual stress on representative candidate rock types to determine safe injection pressures in order to avoid unintentional hydrofracturing;
7. In situ pore pressures at suitable disposal depths to help determine the volume of waste that can be emplaced;
8. Head distribution of aquifers to first define 3-dimensional flow patterns and then to identify possible membrane phenomena and such physical barriers as faults, dikes, and clay-rock seals; and
9. Thickness of the fresh-water part of the ground-water flow system.

Data Availability

Despite the fact that the geology of the Triassic of the East Coast has been intensively studied -- at some places in the East Coast since the early 1800's -- genuine, measured facts about the subsurface are practically non-existent below 400 feet. The project literature search -- U. S. Geological Survey basic data, numerous interviews with state, federal, and petroleum-industry project officials -- and current data analysis reveal that most data types needed for evaluation of the Triassic rocks are available at one place or another along the East Coast. They are, however, fragmentary, isolated, and incomplete for any one site making inter- and intra-basin comparisons questionable on anything greater than a simple qualitative basis.

Data concerning the internal and external geometry of the Triassic basins come mostly from a multitude of geologic reports containing two-dimensional surface bedrock maps and hypothetical cross sections based on attitudes and displacement of known faults and dikes, various author's personal stratigraphic interpretations, and projection of measured strikes and dips. Records of wells which have penetrated the complete Triassic section do give point data on the subsurface floor, but geologists' logs, geophysical logs, cores, etc., are rare.

Porosity and permeability data from Triassic rocks below 1,000 feet are available for wells at only three sites. All are from different basins -- the Savannah River Plant wells in the Dunbarton basin of South Carolina and Georgia, U. S. Bureau of Mines core holes in the Deep River basin of North Carolina, and two exploratory wells in the Brandywine, Maryland basin.

Chemical analyses of water from more than 400 wells deeper than 400 feet were available for this study. However, all these samples were taken at the top of the well and are, therefore, composite samples of all producing zones in the well. Only four analyses of ground water are available from specific zones below 1,000 feet in wells drilled in Triassic rocks.

Some geophysical logs are available (Patten and Bennett, 1963), but many of the logs needed to determine porosity and pore-fluid chemistry are unavailable.

Seismic events occur frequently on the East Coast but are mostly of low magnitude and go unnoticed without sensitive detection equipment. The East Coast Piedmont has experienced historic earthquakes with magnitudes between 4 and 5 Meus, however. (Meus or $M_{8.5}$ is the magnitude of P body waves having velocities in the 8.3 to 8.7 Km/sec range typical of eastern United States.) The availability of data to evaluate the earthquake risk to stored wastes in individual Triassic basins has not yet been determined.

Rock strength tests have been made recently on a core from the Deep River, North Carolina basin for the purpose of estimating the fracture point of reservoir rock. These are the only such tests known for Triassic rocks. No regional or local in-situ residual-stress measurements are available.

Deep subsurface circulation patterns for Triassic water are unknown. Head measurements for the deeper aquifers are available for only a few widely isolated wells.

GEOLOGY OF THE EAST COAST TRIASSIC BASINS

The Triassic basins along the inner edge of the Atlantic Coastal Plain from Nova Scotia to Georgia are a series of tilted, elongated, sediment-filled troughs of Triassic (Newark) age. Everywhere the continental clastics are tilted toward a major border fault and are greatly similar, especially in their prevailing maroon color. The Triassic rocks are block faulted and gently folded in all the troughs. Locally, reversals of dip are sometimes noted near border faults or large intrusives. Usually the Triassic sediments are intruded by diabase (Dolerite) dikes and sills and are interbedded with extensive basalt flows in some places.

The exposed troughs are confined to the Precambrian crystalline and early Paleozoic meta-sedimentary rocks of the Piedmont and New England Upland, except where they are in juxtaposition with the Cambro-Ordovician carbonates of the Great Valley in western Maryland and south central Pennsylvania. The Newark-Gettysburg, Richmond, and Deep River basins (fig. 2) are overstepped by younger Coastal Plain sediments. Eastward other basins extend beneath the Coastal Plain and the Continental Shelf sediments for an unknown distance.

Summary of Literature

The presence of Triassic rocks in the eastern United States has been recognized since the early 1800's. The geographic extent of the exposed basins was fairly well delineated by the 1850's. They have been studied extensively since that time -- especially the Triassic of the Connecticut Valley. Krynine (1950) reported that there were well over 1,200 papers in existence about East Coast Triassic.

Fig. 2.--Map showing general geology and regional structure along the Atlantic Coast.

Despite all this geologic study, most of the papers contain data only from the easily accessible surface outcrops and much speculation about the subsurface geology. The deepest subsurface data were obtained from coal exploratory holes in the Deep River, Dan River, and Richmond basins and wildcat oil wells in Connecticut, New Jersey, Maryland, Pennsylvania, and Virginia.

This investigation has depended heavily on those works listed in the selected references at the end of this report, especially the early works of Russell (1892), Hobbs (1901), and Emmons (1852) and the more recent work of Reinemund (1955), Krynine (1950), Klein (1962, 1963, 1968, 1969), de Boer (1967), Thayer and others (1970), Sanders (1960, 1962, 1963, 1968, 1971), Glaeser (1966), and McKee and others (1959). The last named is a paleotectonic treatment of the Triassic of the United States and comes closest to being a similar investigation. It contains maps of the then known extent of Triassic basins, locations of subsurface data points, and an extensive bibliography.

Geologists still vigorously disagree on the exact tectonic origin and depositional environment of the Triassic. According to Krynine (1950), Benjamin Silliman recognized the intrusive origin of the traprock and described the sandstones and "traps" of the Connecticut Valley between 1806 and 1837. I. C. Russell, who began his studies in New Jersey, is largely responsible for first bringing together the then current knowledge of the Triassic of the East Coast. Russell (1892) also proposed the "broad-terrane hypothesis" to explain the geographic extent and the observed structural attitude of the Triassic basins.

According to this hypothesis the separate basins were erosional remnants of a once much larger estuarine depression along the East Coast having a warm humid climate. Dana (1883), a contemporary of Russell, objected to the single estuary theory, citing the presence of conglomerates along the borders of the individual basins as evidence of their separate origin. Although he did not fully reject the estuarine origin of separate basins, he noted the fluvial nature of the Triassic sediments. However, he felt that isolated cobbles and pebbles in finer sediments were good evidence for ice rafting, therefore adopting a glacial climate for the Triassic.

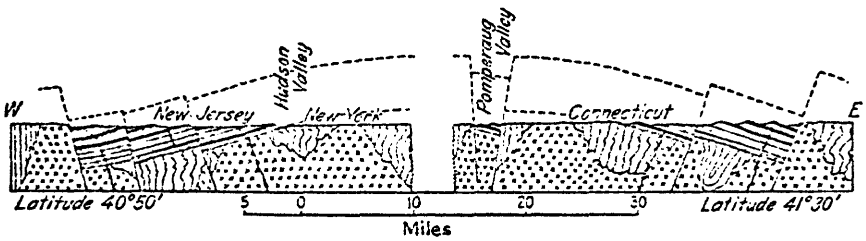
William Davis's 1898 report on the Triassic of Connecticut was the culmination of 20 years of detailed study. He proved the extrusive character of most of the trap bodies and used them to unravel the stratigraphy of that basin. In so doing, he discovered that the Triassic basin was faulted into blocks of variable length and width which were then rotated to the east. He recognized only one period of faulting, and attributed the estimated sediment thickness of 10,000 feet for the Connecticut Triassic to continued synclinal subsidence. He agreed with Russell that the climate during deposition was mild. Hobbs (1901) did a very detailed study of the Pomeraug Valley and differed with Davis on the method by which the Triassic had been faulted and fractured. Hobbs attempted to show how such complicated faulting and fracturing could be produced by a shear couple caused by recurrent compression from a N 80° W direction.

Barrell (1908) apparently was the first to postulate a relationship between semi-arid climate and the origin of the red pigment in the sediments. He is also credited with proposing that Triassic sedimentation had been controlled by the depression of a wedge-shaped block along an eastern border fault.

Longwell (1922 and 1928) further refined the complicated structural picture of the Connecticut Triassic. He was also a proponent of the Broad-terrane hypothesis (fig. 3). W. L. Russell (1922) confirmed Barrell's proposition that there was recurrent movement along an eastern normal border fault during deposition. G. W. Bain (1932), however, proposed overthrusting rather than normal faulting along the eastern border.

It is to Krynine (1950) that we are indebted for a detailed consideration of the petrology, depositional environment, paleoclimate, and paleogeography of Triassic alluvial fans. After an exhaustive treatment of the many climatic indicators preserved in the sedimentary record, he concluded that a savannah-type climate having a uniform temperature of approximately 80° F, a marked dry season lasting at least one fourth of the year, and an annual rainfall exceeding 50 inches in the valley and 60 or more inches in the highlands best explained the character of the observed sediments. Thus, desiccation marks, and crystal casts of halite, glauberite, and gypsum found in the sediments are not incompatible with the associated arkose deposits, red soils, and lakebeds if high temperature, steep fault scarps, and high rainfall interrupted by a pronounced dry season occurred. Krynine demonstrated by heavy mineral distribution that distinct alluvial fans extended at least 2,000 feet westward from the eastern fault scarp and that their source was within 3 to 10 miles east of that fault. Krynine postulated that all sedimentary material came from the acid granitic rocks east of the eastern border fault and that all petrographic types found in Connecticut could be explained by various admixtures of arkose, clay, and cement which in turn were controlled by three structural factors: (1) The type of source rock available, (2) the type of detritus locally deposited, and (3) the type of chemical matter introduced.

Fig. 3.--Idealized cross section illustrating the broad-terrane hypothesis for the origin of Triassic basins.



Idealized section suggesting the probable structural relations of the Triassic basin of Connecticut and that of Pennsylvania and New Jersey. The western part of the section follows the line of latitude 40° 50′ and is about 50 miles south of the line of the section in Connecticut. Moreover, a section about 35 miles long is omitted in the center. In Connecticut the Triassic strata dip eastward toward a great fault, and in New Jersey and Pennsylvania they dip westward against another great fault. As here interpreted, these basins were on opposite sides of a great low arch. It is not certain that the Triassic sediments ever extended entirely across the arch. Triassic sandstone, dotted; trap rock, black; old metamorphic rocks, wavy lines or crosses. After C. R. Longwell.

Figure 3.--Idealized cross section illustrating the broad-terrane hypothesis for the origin of the Triassic basins.

Reinemund (1955) found the Deep River coal field of North Carolina to be part of a southeast tilted and downfaulted trough-shaped block of Triassic rocks similar to the Connecticut basin. According to Reinemund, the source of the basal conglomerate in this basin was a short distance to the northwest, but most of the overlying sediments were derived from the southeast, beyond the eastern boundary fault. After deposition ceased, these sediments were broken by tensional cross fractures, were later cut by longitudinal faults, and were then intruded by basic magma along bedding planes and open cross fractures. However, he did not recognize a graben structure southwest of the Colon cross structures (Conley, 1962).

McLaughlin (1959) found that the basal conglomerate in Bucks County, Pa., also came from the side opposite the major fault, in this instance to the south, with much of the succeeding detritus coming from the north and northwest. In particular, he not only recognized the stratigraphic units as contemporaneous, but also noted that the coarse-grained fan deposits graded outward toward the center of the trough into finer and finer deposits. He proposed that after intrusion and solidification of diabasic dikes and sheets, the accumulated rocks were then broken into several great fault blocks and tilted to the northwest. He further reasoned that block-faulted mountains with considerable relief could have been formed at this time if the dislocations were very rapid.

Glaeser (1966) studied source, dispersal, depositional environment, and diagenesis of the Triassic sedimentary rocks of Pennsylvania, much of which is very pertinent to this investigation.

He also found deposition was from both margins of the basin and concluded that poor sorting and high feldspar and rock mixtures near the southern edge both indicated short transportation and a southern limit of sedimentation near the present southern outcrop edge. He postulated that some of the pod-shaped conglomerates are of mudflow origin and suggested that there were areas in the depositional environment where highly efficient sorting took place as evidenced by some of the exceptionally clean, matrix-free sandstones and conglomerates in the Stockton and New Oxford Formations (fig. 4).

Sanders (1960, 1962, and 1963) has written extensively on the tectonic history, structure, and paleogeography of the Triassic of the northeastern states. Sanders favored the broad-terrane concept with deposition of 30,000 feet of continental sediment in a rift valley 50 to 70 miles wide created by tensional collapse of the Appalachians. Longitudinal arching of the rift valley explained to him the present day outcrop belts and the oppositely dipping symmetry. He recognized four discrete episodes of tectonic activity. All sedimentation and igneous activity occurred in the first; the graben floor was arched by longitudinal folding, drainage was reversed, and basins were separated in the second; second-generation subsidence and development of transverse folds took place in the third; and transverse folds were offset by faulting and dolerite dikes injected in the fourth and final episode. Reinemund (1955) believed transverse faulting occurred after intrusion of diabase because these dikes are offset by the transverse faults.

The Triassic rocks of the maritime provinces of Canada were closely scrutinized by Klein (1962) who found the continental clastics there to have a greater range of compositional variety than Krynine (1950) listed for those in Connecticut.

Fig. 4.--Generalized stratigraphic correlation chart of the East Coast Triassic.

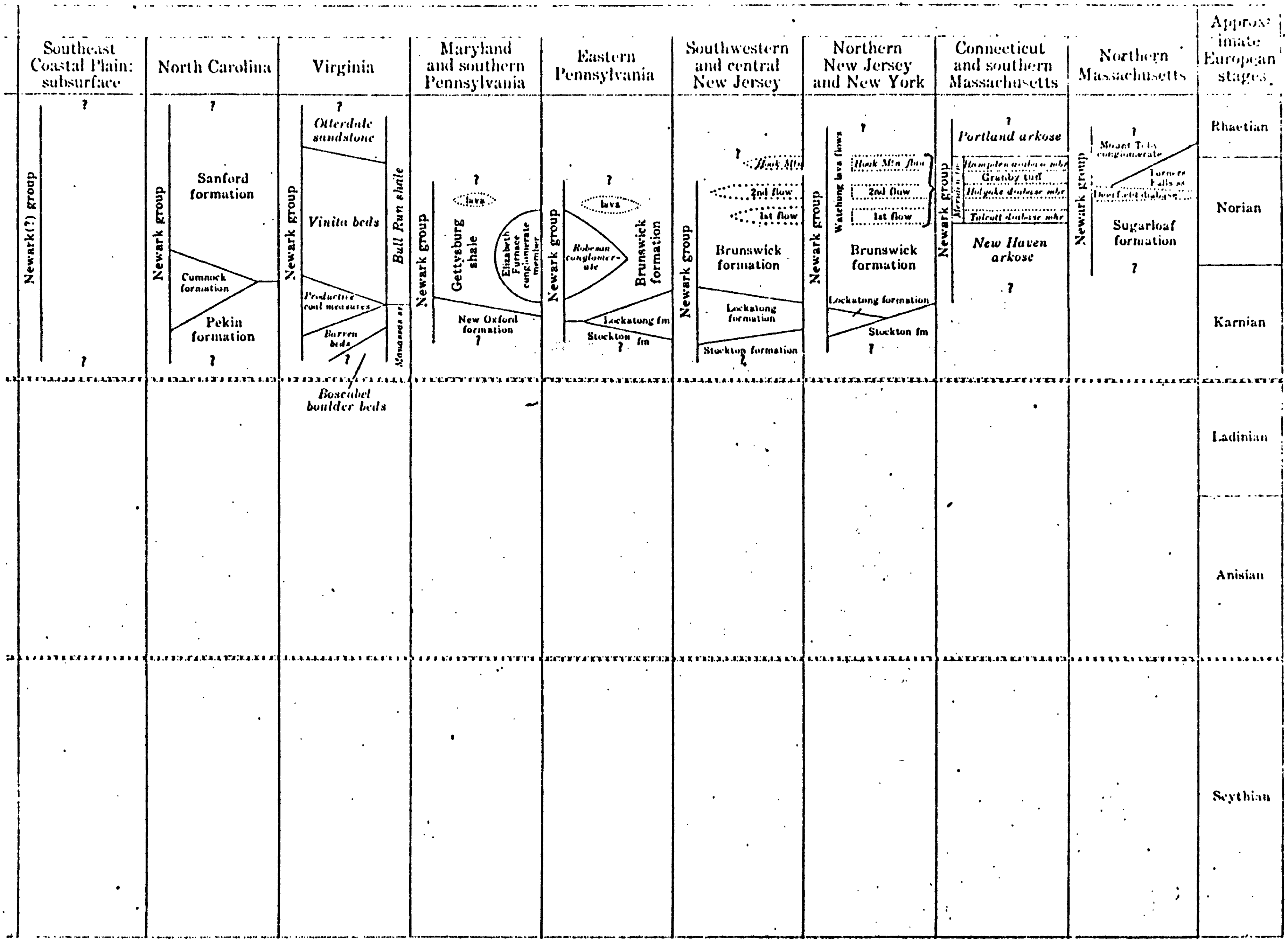


Figure 4 .--Generalized stratigraphic correlation chart of the East Coast Triassic (after McKee and others, 1959).

Klein found a close correlation between type of sediment and source area of the parent rock. Pre-Mississippian sedimentary rocks generated low-rank graywacke; Paleozoic granites generated arkose, impure arkose, and high-rank graywacke; and Pennsylvanian sedimentary rocks generated orthoquartzites. He concluded that provenance control of sediment type is more important than the diastrophic or tectonic control favored by Krynine. Klein also found abrupt lateral changes in thickness of strata, stratification, and composition in the continental sediments. The Maritime basin is fault-bounded on the northwest, but sediments were demonstrated to have been derived locally from all sides of the basin. In a later paper, Klein (1969) summarized recent studies of paleocurrent and inclination of thermal-remanent-magnetism (TRM) data that shed further light on the paleogeography of the Triassic of the East Coast. One plank of the broad-terrane hypothesis advanced by Russell (1878, 1880), accepted by Longwell (1922, 1928), and expanded by Sanders (1963) has been the lateral equivalency of three basalt flows in the Connecticut basin with three in the New Jersey portion of the Newark-Gettysburg basin. Studies by de Boer (1967) of thermal remanent magnetism in the basalt flows in these two basins show that three distinct volcanic events, the Talcott, Holyoke, and Hamden, occurred in Connecticut (fig. 4) and all lava flows in New Jersey are of the same age as the middle or Holyoke outpouring.

Further, recent work in New Jersey by Abdel-Monem and Kulp (1968), who have developed some refined paleocurrent tracing techniques in New Jersey, and the previously cited work of Glaeser (1966), demonstrate that the Newark-Gettysburg basin received sediment from the north, west, and south.

Further literature search by Klein (1969) revealed that the works of McLaughlin (1959), Johnson and McLaughlin (1957), McLaughlin and Gerhard (1953), and Glaeser (1966) in the Newark-Gettysburg basin; Fritts (1963), Van Houten (1962, 1964), Lehmann (1958), Sanders (1968), and Klein (1968) in the Connecticut Valley; Prouty (1931), Reinemund (1955), and Leith and Custer (1968) in North Carolina; and Stose and Stose (1946) in Maryland all contained data which indicate by directional paleocurrent surveys or other evidence that the sediments were locally derived and the basins were geographically separate (fig. 5). However, the over-all tectonic pattern of Sanders and previous workers may be generally correct.

Klein (1969) further pointed out that, if we accept a sedimentary model which received sediment from all sources marginal to the basin, the accepted distribution of sedimentary facies of basin-marginal alluvial-fan deposits into flood-plain deposits and then into basin-center lacustrine deposits may be wrong. If the structural margins are different, he stated, then the facies distribution will be different. Identification of the correct sedimentary model for the Triassic is critical to this investigation, and the problem is further discussed in a subsequent section.

Tectonic Origin

The red continental clastics of the eastern United States Triassic have traditionally been accepted as a post-orogenic suite deposited in fractures in the earth's crust formed during tensional collapse of the Appalachians.

Fig. 5.--Map showing regional dispersal patterns, eastern North America.

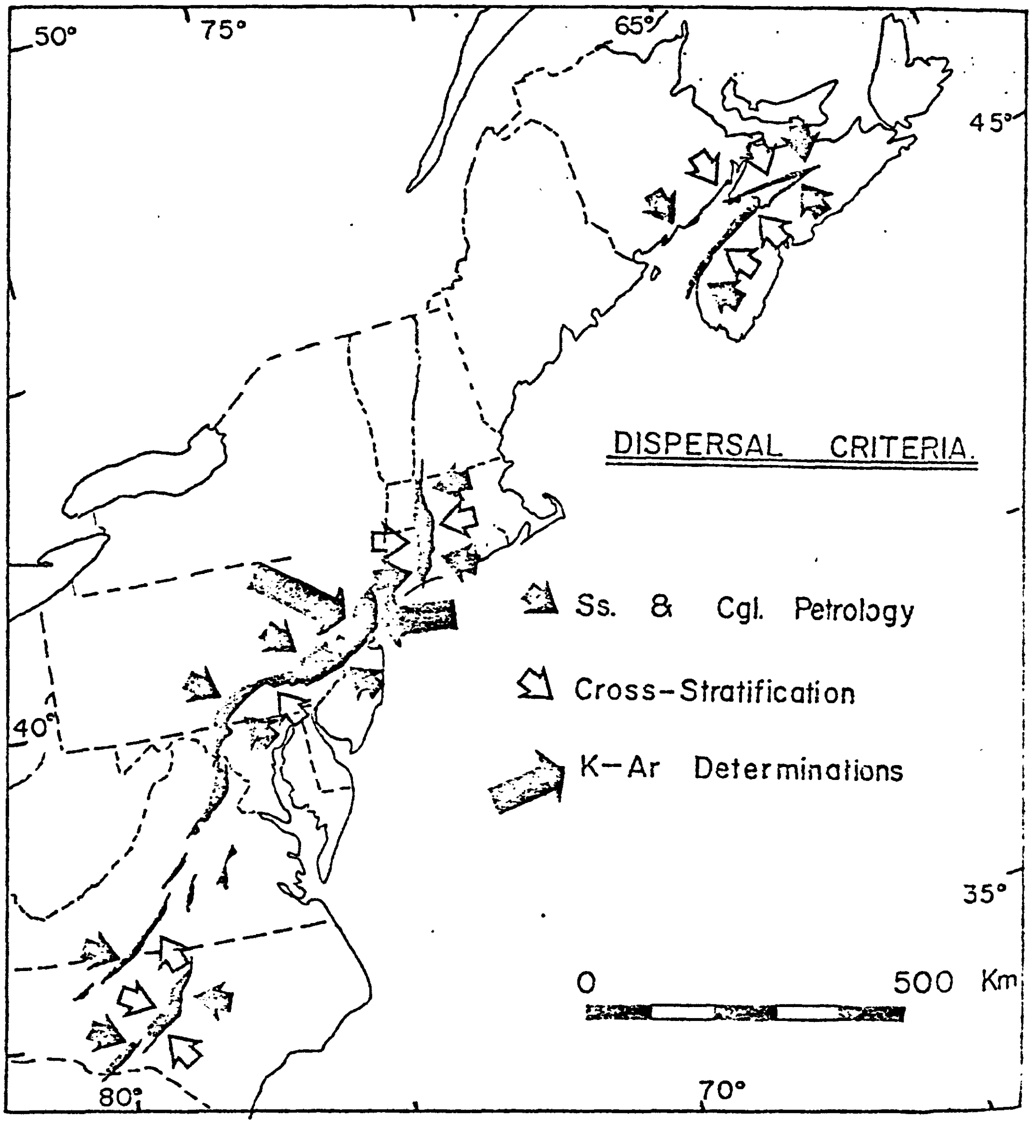


Figure 5.--Triassic regional dispersal patterns, eastern North America. After Klein, 1969.

Recent oceanographic research has upset previous popular notions of the character of the ocean floor by documenting the existence of a rugged Atlantic medial ridge along which basaltic mantle is upwelling (fig. 6) and creating new crust. See Bullard, et. al. (1965), Heezen (1960), LePichon and Fox (1971), Phillips and Forsythe (1972), and many others. The "rift" discovery has raised some very fundamental questions about the earth and has caused reevaluation of many time-honored concepts. One result has been rebirth of continental-drift theory to explain several observed phenomema -- in particular, the absence of sediment older than Jurassic on the Atlantic Ocean floor, the decreasing age of the oceanic crust as the medial ridge is approached, and the discordant locations for the earth's poles as shown by Paleomagnetic data from rocks of the same age on different continents.

The onset of rifting along the medial Atlantic Ridge is calculated to have taken place approximately 200 million years ago, and 190 and 202 million-year-old (Phillips and Forsyth, 1972) volcanic rocks along the present-day Atlantic seaboard, i. e. Triassic, are believed to be associated with the initial rifting. Indeed, some of the Triassic volcanic rocks of the East Coast are tholeiitic basalts of the type now being extruded along the mid-Atlantic Ridge. Note the similarity of tectonic models being drawn for the mid-Atlantic rift (fig. 6) and the structural models drawn by some for the East Coast outcrop zone of Triassic rocks (fig. 3).

Cook (1961) has postulated rising convection currents in the mantle as a cause of graben subsidence at the crustal surface. When convection ceases, the resulting isostatic adjustment may cause linear arching of the type postulated by Sanders (1963) in his "broad-terrane" explanation.

Fig. 6.--Tectonic model of mid-Atlantic ridge rift zone.

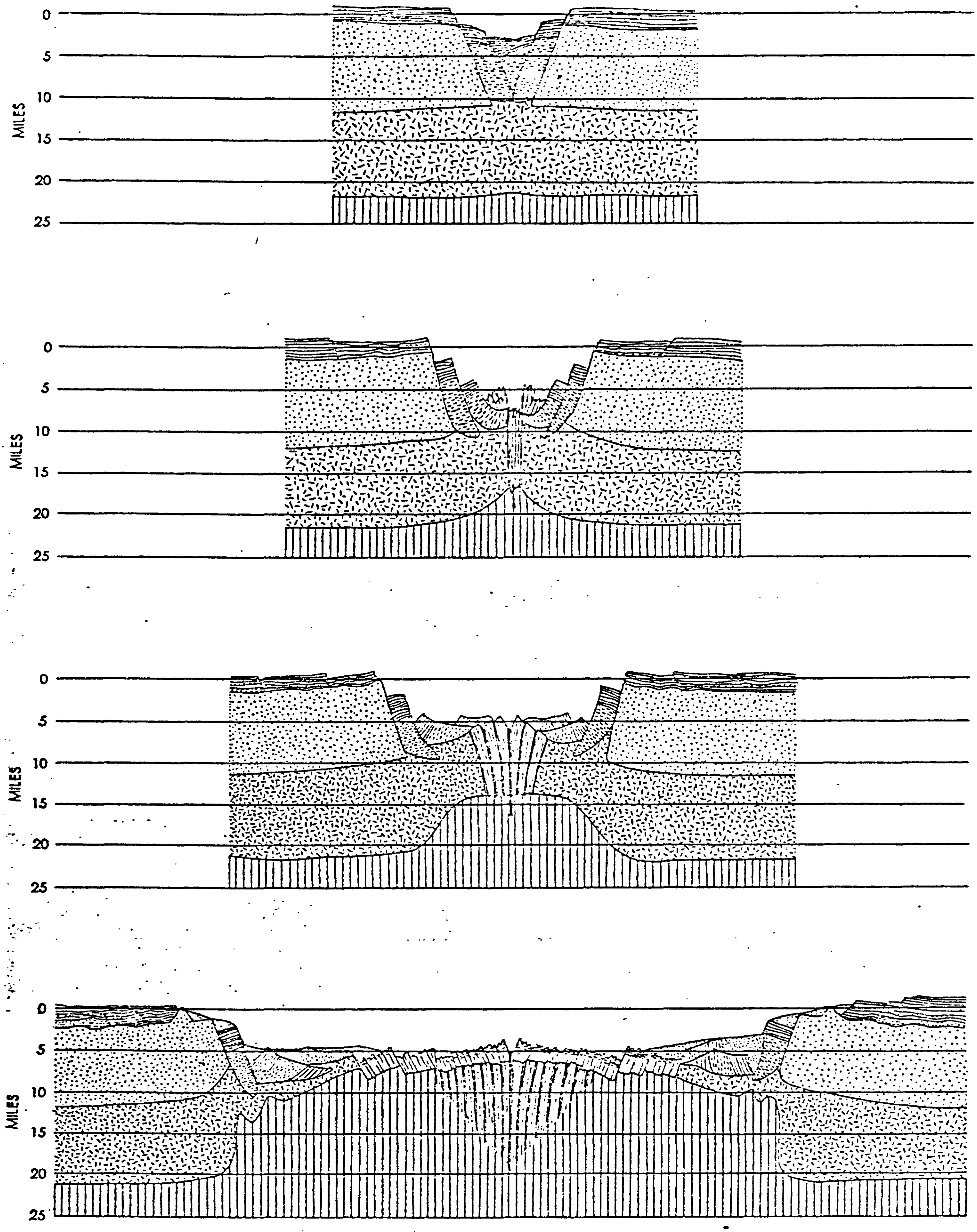


Figure 6.--Tectonic model of mid-Atlantic Ridge rift zone. After Heezen, 1960.

EVOLUTION OF OCEAN BOTTOM according to the expanding-earth hypothesis is represented by these diagrams. Top layer of material is sedimentary rock of continents. Below it is continental crust. Beneath that is the type of material that makes up the crust of the oceans. Bottom layer (*vertical hatching*) is the earth's mantle. In top diagram continents are close together; rift between is just opening up. Next, material from mantle comes through rift, creating mid-ocean ridge seen in third diagram. Bottom diagram represents Atlantic Ocean bottom as it is today, with ridge and rift in center and continents at far right and left.

Taphrogeny, which is the transcurrent faulting caused by compressional forces generated by the normal rotation and precession of the earth, is gaining increasing attention as a tectonic force capable of fracturing the crust and forming grabens and half grabens of large magnitude (Brown, Miller and Swain, in press).

Whatever the tectonic cause of the Triassic rents in the Precambrian crystalline and early Paleozoic metasedimentary rock floor along the Atlantic seaboard, it is tempting to believe that continental drift is involved. Paleomagnetic measurements of volcanic rock in North America (Phillips and Forsyth, 1972; LePichon and Fox, 1971; and Tanner, 1963) indicate that the equator was nearly parallel with and located just east of the present-day coast during Triassic time (fig. 7) and that the North American continent shifted counterclockwise and to the north during this period. Such an equatorial position during the Triassic is quite tenable with the savannah-type climate and lateritic weathering proposed by Krynine (1950). In addition, Tanner (1968) notes a reversal in strike-slip fault motion in the Appalachians during Mesozoic time. He also finds (Tanner, 1963) that paleoclimatic and paleomagnetic data indicate the hypothetical Appalachian Island Arc, during much of Paleozoic time, lay close to and parallel to the equator.

King (1961) and May (1971) have noted that the Late Triassic (?) diabasic dikes intruded world wide may indicate an early-Atlantic-opening stress pattern (figs. 8 and 9). If the pre-drift arrangements of the major continents are as shown, the other half of the eastern United States belt of Triassic rocks should be found in the Spanish Sahara along the northwest coast of Africa.

Fig. 7.--Paleomap of Lauraia and Gondwanaland at 200 M.Y. before present.

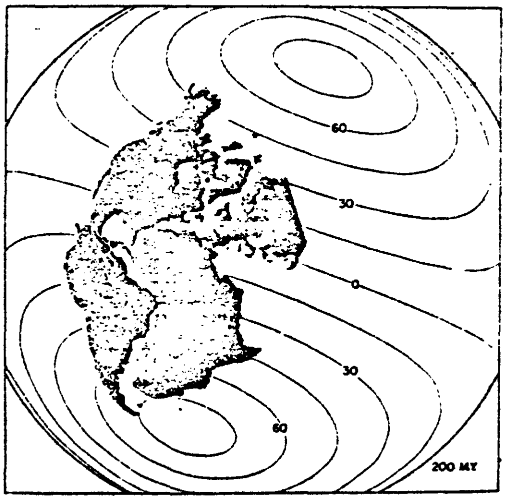


Figure 7.--Paleogeographic map of Laurasia and Gondwanaland at 200 M.Y. before present. After Phillips and Forsyth, 1972.

Fig. 8.--Map showing Triassic-Jurassic diabase dikes in eastern North America, West Africa, and northeastern South America.

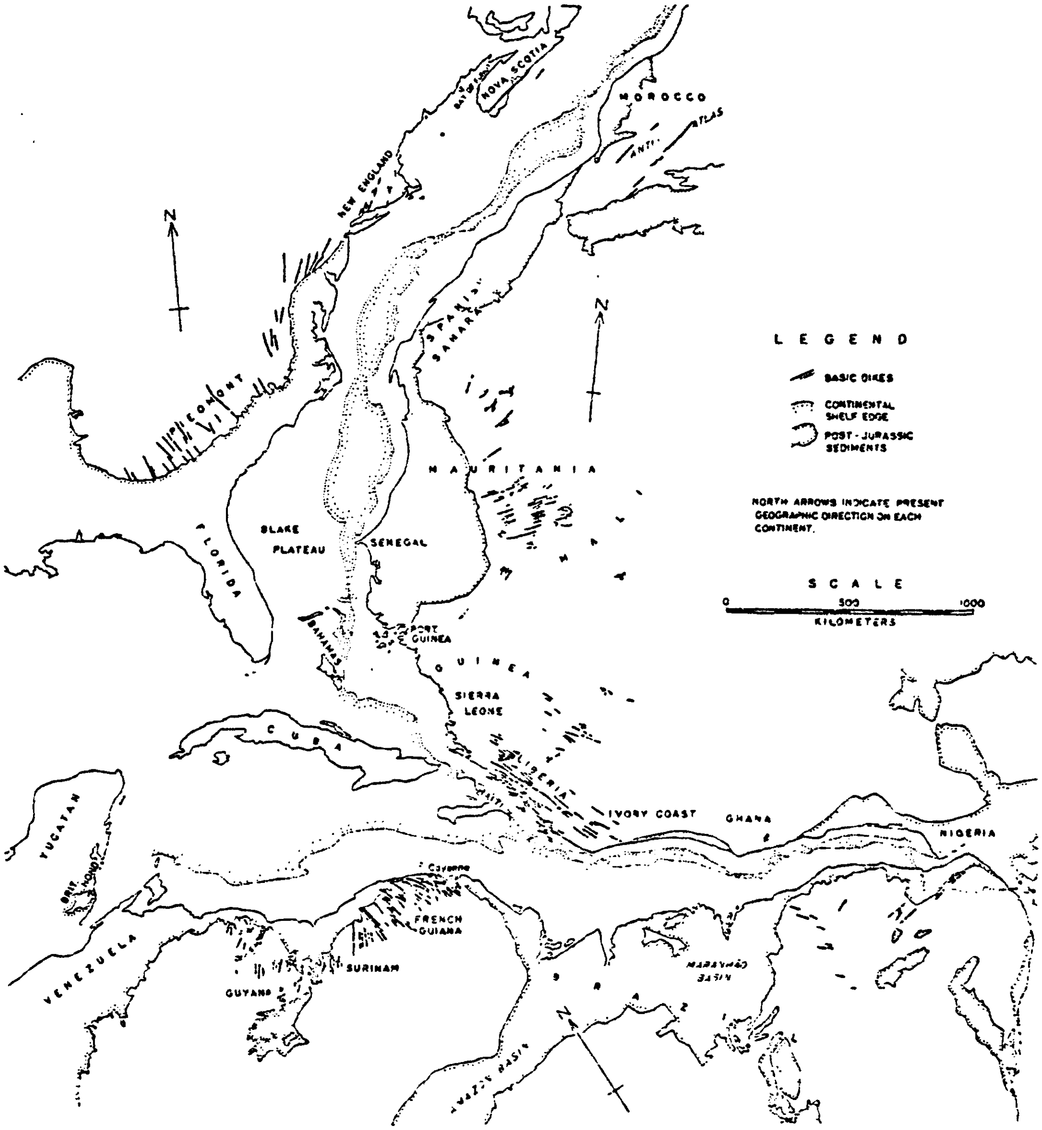


Figure 8.--Triassic-Jurassic diabase dikes in eastern North America, West Africa, and northeastern South America, with the continents restored to their relative position in the Triassic. After May, 1971.

Fig. 9.--Map showing trajectories of principal stress indicated by the pattern of Triassic-Jurassic dikes.

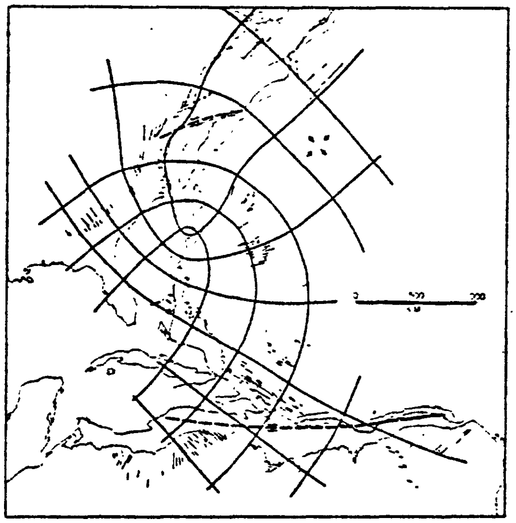


Figure 9.--Trajectories of principal stress indicated by the pattern of Triassic-Jurassic dikes. Lines normal to tensional stress are convex to the south. Lines normal to compressional stress are convex to the north. Heavy dashed lines are possible shear faults. After May, 1971.

Whatever the tectonic origin of the East Coast Triassic basins, it is quite evident from casual inspection of figure 1 or 2 that even the exposed basins are not a simple paired row of oppositely dipping half grabens. The known location of buried basins indicates that the subcrop area extends seaward at least as far as the eastward limit of the emerged coastal plain, and their extension onto the continental shelf is inferred from offshore seismic data. Vertical-magnetic-intensity maps of the East Coast show that the Triassic of the eastern United States occurs in a broad belt of low magnetic intensity. South of the Baltimore dome, this belt appears to swing eastward. It parallels but lies south of the Newark-Gettysburg basin in Pennsylvania, and passes beneath the buried Triassic basin at the Delaware-Maryland border on the Delmarva Peninsula. If Triassic rocks are related to this band of lower magnetic intensities, buried Triassic basins should show up as negative gravity anomalies. The expected area of subcrop of Triassic basins includes the continental shelf well east of Cape May, New Jersey, and northward on the continental shelf toward Nova Scotia. The small scale Bouguer gravity map (fig. 24) shows negative anamolies in this area.

Basin Filling

Geologic Character of Basin Margin Terrane

As stated previously, the East Coast Triassic basins are confined, for the most part, to the Piedmont complex and its geologic equivalents in New England and eastward beneath the Coastal plain. The presence of conglomerates, fanglomerates, and sandstones of high feldspar content and the immaturity of the Triassic sediments in general indicate short and rapid transport.

Krynine (1950) and almost all other workers found the composition of rock types presently exposed at or near the basin margins sufficient to explain all observed Triassic textural and mineralogic variations. The East Coast has been relatively quiet tectonically since Late Triassic time; therefore, the source rocks or modern basin-margin geology should be little changed. Exceptions occur where shallow-rooted structural and/or lithologic elements have been removed by erosion and deeper structures (such as granitic plutons) have been exhumed. The Piedmont and New England Upland complex from Georgia to Nova Scotia (Bayley and Muehlberger, 1968 and fig. 2) consists of Precambrian and lower Paleozoic metasedimentary and metavolcanic rocks which have been locally metamorphosed to schists and gneisses where intruded by felsic and subordinately mafic plutonic rocks. In addition, the northwestward salient of the Newark-Gettysburg basin is adjacent to and, in some instances, overlies the early Paleozoic carbonate section of the Great Valley.

If observations of previous workers concerning short transport distances are correct, it is reasonable to expect that the gross compositional varieties of any basin or part of a basin can be predicted from the basin-margin geology and the paleodrainage. Meyerhoff (1972) cites the presence of major Triassic alluvial fan deposits where Peekskill Creek, Susquehanna, Schuylkill, Lehigh, and Hudson Rivers cross the Newark-Gettysburg trough as evidence that Triassic drainage was not far different from modern. Glaeser (1971) regarded the Colorado River delta in the Gulf of California as a modern analogue of the Hammer Creek deposit of Pennsylvania.

Paleodrainage

The nature of the Triassic drainage patterns, both within and across the basins, seems an especially useful tool to unravel the distribution of the textural and compositional types and, thus, ultimately to identify the spatial distribution of possible reservoir rock.

Carlston (1946) found no evidence to indicate that modern major trunk streams previously crossed the Newark-Gettysburg basin. Instead, he postulated that all former drainage was interrupted and sedimentation was by short consequent streams of steep declivity along the northwest margin. He pointed out that all lithologic types definitely identified as Silurian and Devonian crop out today not more than 20 miles from the basin's edge and were most surely closer in Triassic time. Meyerhoff and Olmsted (1936) and Meyerhoff (1972) postulated that pre-Triassic streams which originated on a Permian cover, continued to flow southeastward in Triassic time because the association of conglomerate deposits in the Newark-Gettysburg basin with the present-day courses of the transverse streams is too close to be fortuitous. From extensive study of sedimentary properties, Glaeser (1966) found that basal sediments were derived dominantly from the south side of the basin followed by sedimentation from the north side mostly through a restricted (single?) opening between the Susquehanna and the Schuylkill Rivers. The evidence of possible sedimentation by short consequent streams from the north during the early history of the basin must surely be buried beneath several thousand feet of rock.

It is interesting to note that the Hammer Creek Formation, which is the coarse deltaic deposit occurring in the narrowest part of the Newark-Gettysburg basin, has an apparent counterpart with the Colon cross structure of the Deep River basin of North Carolina. The Colon is a 5 by 8 mile restriction between the Durham and Sanford basins. Two possible explanations come to mind: (1) the narrow outcrop width and probable shallow basement depth indicate greatest uplift and erosion in post-Triassic time along a basement positive structural element at these points. (The elevated coarse clastic sequences thus exposed are examples of the basal sediments in the remainder of these basins.) or (2) the crustal element along which these narrow sections are now elevated was alternately a negative or positive structural axis (Brown, Miller and Swain, in press) and, when expressed as a negative feature, determined the location of major transverse drainage in the Triassic. Conley (personal communication) believes that it is possible that there has been little movement in the Colon cross structure and that it has remained a shallow positive area.

Paleoclimate

Most investigators agree that the climatic indicators observed in the sedimentary record of the Triassic can be explained by climatic conditions proposed by Krynine (1950). Krynine visualized a savannah-like climate where the temperature was a constant 80° F or more, with rainfall of 50 inches or greater distributed into very distinct arid and wet seasons. These conditions, to him, satisfactorily explained the red lateritic soil debris, the fresh feldspar, the poor sorting, the rapid transport and quick burial, the evaporites and mud cracks, and, presumably, the black shale deposits and associated coal. However, no coal has been found in the Connecticut basin.

The association of coal with evaporites is difficult to understand. The evaporite bearing red shale sequence indicates warm temperature, oxdizing conditions in a closed basin system. Coal requires a source of plant debris, reducing conditions, and a long period of little or no tectonic activity for its quiet, sediment free accumulation and perhaps a complete change in climate on the basin floor. Perhaps the presence of coal is the one compelling argument for the vertical stratigraphic rather than lateral facies separation of the black shale from underlying or overlying oxidized red sediments. This writer found no sedimentary model described which accounts for the deposition of these two facies at the same time in the same basin.

Walker (1967a and 1967b), however, found that hematite-rich red color in red beds, particularly those associated with evaporites and aeolian sandstones, currently forms from the in situ weathering of iron-rich minerals in a hot dry climate. A later inspection of the savannah-type areas of the western Gulf of Mexico, which Krynine cited as an area where red hematitic color was being derived from erosion of red lateritic soils, revealed that the red lateritic soils were being transported and deposited by the rivers as a grayish brown alluvium. The occurrence of coal in a hot arid environment seems hardly tenable without a complete change in climate. Oxidation, if it occurred, took place after deposition.

The probable equatorial position of the East Coast Triassic has been previously cited from the paleomagnetic evidence; thus, the consistently warm temperature seems not to be a problem.

Triassic Sedimentary Suites

The Triassic basins contain intertonguing continental rocks of fluvial (river), lacustrine (lake), and paludal (swamp) origin. Although closed basin lakes must have become periodically quite saline, no rocks deposited in a brackish, estuarine or marine environment have been documented to date. Fluvial deposits consist mostly of the alluvial fans developed along trough margins and flood-plain and channel deposits that accumulated along transverse and longitudinal streams. Krynine (1950), Klein (1969), Thayer and others (1970), and Glaeser (1966) found that alluvial fans consisting of conglomerates and fanglomerates were distributed along the basin margins and graded outward toward the basin's center into progressively finer deposits to a point where they were apparently redistributed by longitudinal streams and/or wave action. Coarse conglomerates and fanglomerates are distributed along the modern basin margins, especially on the more downthrown side. Their presence records a local source area and contemporaneous movement along the major faults during sedimentation.

These alluvial fans are characteristically heterogeneous deposits which result from dumping the bed load of a high gradient, high energy, permanent or ephemeral stream at the base of a steep scarp or at the point where a major transverse stream entered the trough and began aggrading. Rapid lateral changes in grain size, thickness, texture, sorting, and stratification are commonplace. Sediment composition depends considerably upon the geology of the drainage area, and sorting is generally poor because the opportunity for reworking the alluvial fan sediment is also poor.

However, Glaeser (1966) found extensive areas of "clean" sandstones and conglomerates in the Stockton and New Oxford Formations which lack clay-size matrix. This he ascribes to "high mechanical activity" at the depositional sites. Additional investigation may show that these sandstones and conglomerates have accumulated along the entrance channels of the major transverse trunk streams; whereas, the conglomerates and sandstones exhibiting poor sorting and high matrix content have accumulated along and are confined to the intra-stream parts of the basin margins.

Lacustrine deposits are the finer grained fraction of the basin sediment that have collected below wave base. Such deposits characteristically have thin and rhythmic bedding, uniformly even stratification, oscillation ripple marks, and graded bedding. They are frequently dark colored because of reducing conditions in the depositional environment. Intertonguing with the alluvial-fan and lacustrine deposits, are the red, fine-grained, thin-bedded siltstones, shales, and mudstones that have accumulated on broad alluvial oxidizing mudflats, flood plains, and delta surfaces adjacent to river distributaries and lakes. They characteristically show desiccation marks, burrow casts, raindrop prints, current lineation, and ripple marks.

Conditions favorable for the formation of swamps and the accumulation of organic debris existed from time to time in most, if not all, of the basins as is shown by the thin coaly seams in the black-shale facies. Conditions particularly favorable for the formation of coal occurred in the Richmond, Danville, and Deep River basins where coal is thick enough to have been of commercial importance and was mined from colonial times until the middle part of this century. The black-shale facies of the Deep River basin contains substantial deposits of oil shale (Reinemund, 1955), and small amounts of oil were found when the Deep River coal field was cored in the 1940's.

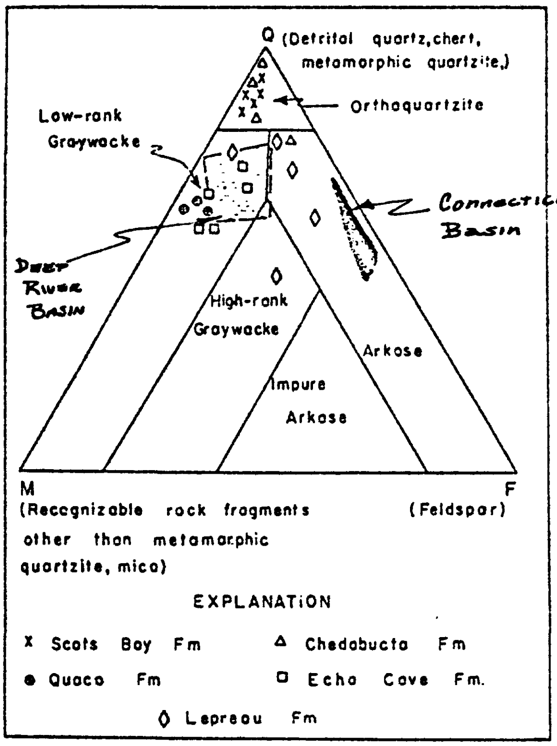
Some of the troughs contained closed lake systems where evaporation exceeded water input -- perhaps during the short arid season proposed by Krynine. In addition to mudcracks, casts of salt crystals, gypsum, and glauberite have been found in weathered outcrops in most of the basins. The minerals themselves have been found in fresher rock and core samples (Thayer and others, 1970; Klein, 1963; Krynine, 1950; Glaeser, 1966; Herpers and Barksdale, 1951). Thin-bedded limestones and chert of playa origin have been identified in the Triassic lacustrine facies of some basins, particularly the Durham section of the Deep River basin of North Carolina (Custer, 1967; Wheeler and Textoris, 1971) and Culpeper, Va., basin (Ellison, et al, 1971).

Regional Sandstone Petrology

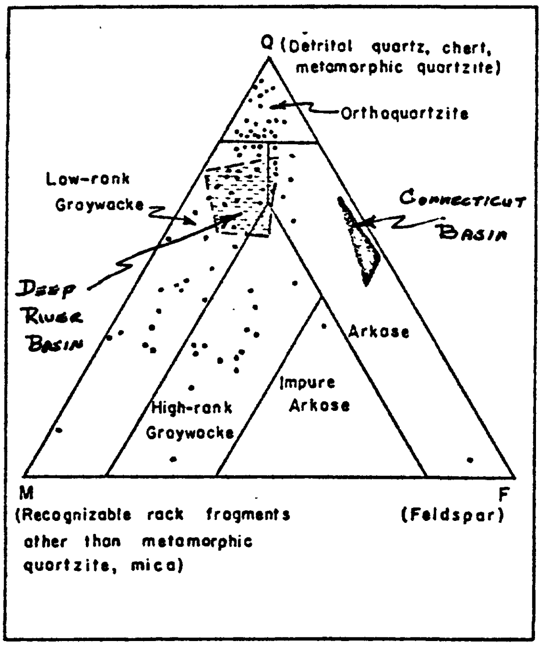
Textural sediment types found in the Triassic continental clastic suite include fanglomerates, conglomerates, sandstones, siltstones, shale, and argillite. The sandstones of this suite can be classed according to a scheme used by Krynine (1950) to illustrate different lithologic types. This classification can also be used to show regional compositional changes and their relation to regional geology. The compositional varieties used consist of combinations of varying proportions of three end members -- quartz, rock fragments, and feldspar -- to form orthoquartzite, arkose, impure arkose, high-rank graywacke, and low-rank graywacke. Klein (1962) adapted Krynine's scheme to compare compositional types found in Nova Scotia with those of the Connecticut Valley and the Deep River basin of North Carolina.

The results of Klein's grain count of 127 sandstone thin sections are summarized in the ternary modal plots of figure 10.

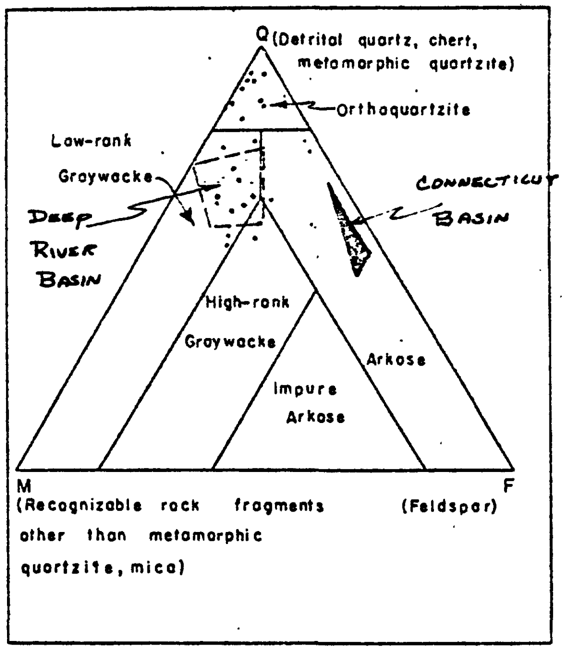
Fig. 10.--Ternary diagrams of sandstone compositions of the Maritime, Connecticut, and Deep River basins.



A. Sandstone composition of the Scots Bay, Chedabucto, Quaco, Echo Cove, and Lepreau formations after classification of Krynine (1948). Black area represents composition of Triassic of Connecticut (*after* Krynine, 1950, p. 84). Patterned area represents composition of Triassic of the Deep River Basin, North Carolina (*after* Reinemund, 1955, p. 52).



B. Sandstone composition of the Wolfville Formation according to classification of Krynine (1948). Area in black represents composition of Triassic of Connecticut (*after* Krynine, 1950, p. 84). Patterned area represents composition of Triassic of Deep River Basin, North Carolina (*after* Reinemund, 1955, p. 52).



C. Sandstone composition of the Blomidon Formation according to classification of Krynine (1948). Black area represents compositional field of Triassic of Connecticut (*after* Krynine, 1950, p. 84). Patterned area represents compositional field of Triassic of Deep River Basin, North Carolina (*after* Reinemund, 1955, p. 52).

Figure 10.--Ternary diagrams of sandstone compositions of the Maritime, Connecticut, and Deep River basins. After Klein, 1962.

The compositional range shown for the Maritime Provinces (fig. 10) is much greater than that found in either the Deep River or Connecticut basins, and is directly dependent on provenance. Rocks from Connecticut are all arkose, and those from North Carolina, which Reinemund termed "schist arenite", are mostly low-rank graywacke. Klein found the matrix of Maritime basin sandstones to consist of a quartz and muscovite-sericite hash, ranging from 0 to 33 percent, and the cement to be sparry calcite, ranging from 0 to 55 percent. All grain sizes from fine to very coarse were recognized. Although the orthoquartzites were texturally mature, most other compositions were texturally immature.

Krynine (1950, p. 71), discussing the sandstones of the Connecticut basin, states that "The Triassic sedimentary rocks have been derived exclusively from the granitic (and subordinatly schistose) rocks of the Eastern Highland." Krynine found the Newark Group in the Connecticut basin to be approximately 64 percent sandstone, 13 percent shale, 13 percent siltstone, and 10 percent conglomerate. The group as a whole was composed of about 58 percent quartz, 40 percent feldspar, and 2 percent mica. Usually, the matrix was mostly kaolin with subordinate amounts of gibbsite, serecite-illite past, and hematite. The cement was generally calcite.

The sandstone composition shown in part "a" of figure 10 for the Deep River basin is for samples from the coal field part of the basin and represents a restricted species. Sampling from other parts of the Deep River basin would undoubtedly show considerably more compositional spread.

Reinemund (1955) states that arkose is, ... "present almost exclusively in the Durham basin, north of the mapped area mainly in parts of the basin bordered by the Carboniferous (?) granite." He found that arkose grades longitudinally along the basin into schist-arenite by addition of debris from feldspar-deficient metamorphic rocks and laterally across the basin into argillaceous sandstones by addition of clay, mica, and other fine debris. Although sandstone here, too, reflects source-rock control, it makes up a smaller fraction of the total sedimentary column in the Deep River coal field partly because of a lack of suitable source rocks. Reinemund reports that the basal or Pekin Formation ranges from about 40 to 80 percent shale, siltstone, and claystone; the middle or Cumnock Formation (coal bearing) is about two-thirds shale at the type locality; and the upper or Sanford Formation ranges from 50 to 95 percent siltstone and claystone. Table 1 summarizes the lithologic distribution and types present in that area. The Deep-River-coal-field facies grades northward along the basin axis into a dominantly sandstone and conglomerate facies which may be similar in origin to the Hammer Creek Formation in Pennsylvania. Reinemund reports the character of the basic sandstone types of the Deep River coal field to be:

Arkose, Type 1

Composed of 80 percent quartz and feldspar from Carboniferous (?) granite sources. Cement is calcite but usually uncemented.

Arkose, Type 2

Composed of 80 percent quartz and feldspar from metamorphosed acid volcanic rocks. Cement is mainly quartz.

Table 1.--Summary of composition of rocks and distribution of lithologic types in the Deep River basin, North Carolina.

Table 1.--Summary of composition of rocks and distribution of lithologic types in the Deep River basin, North Carolina. After Reinemund, 1955.

A. —*Thickness and color of formations, and percentage distribution of conglomerate and fanglomerate, sandstone, siltstone, claystone, and shale in different parts of the Deep River basin*

Formation	Sanford basin (southwest end, vicinity of Carthage)						Sanford basin (north of Deep River fault between Gulf and Cumnock)						Colon cross structure (opposite Sanford water works)						Durham basin (south end, east side Cape Fear River)	
	Total thickness (feet)	Dark strata [1]	Congl. and fangl.	Sandstone	Siltstone	Claystone and shale	Total thickness (feet)	Dark strata [1]	Congl. and fangl.	Sandstone	Siltstone	Claystone and shale	Total thickness (feet)	Dark strata [1]	Congl. and fangl.	Sandstone	Siltstone	Claystone and shale	Total thickness (feet)	
Pekin	3,000 to 4,000	74	4	20	40	36	1,750 to 1,800	90	2	15	29	54	3,500 to 4,000	72	24	35	28	13	3,000 to 3,500	Formations not sufficiently exposed to permit detailed estimates of lithology in this area.
Cumnock	520	10	......	67	28	5	750 to 800	2	......	19	17	64	Not recognized in this area; grades into Pekin and Sanford formations						300 to 600	
Sanford	[2] 3,500 to 4,000	82	18	20	26	36	[2] 3,000	93	......	11	22	67	[2] 500 to 600	73	80	20	......	......	[2] 2,000 to 3,000	

[1] Percentages include red, reddish-brown, moderate or dark-brown and purple rocks. They do not include light-brown, yellow, gray or black rocks.
[2] Thickness does not include an undertermined quantity of rock removed by post-Triassic erosion.

B. —*Percentage composition and size frequency distribution of typical sandstones in the Deep River coal field*

Specimen No.	Composition: Principal constituents [1]							Heavy minerals [2]												Matrix [3]			Size frequency distribution size class in millimeters [4]								
	Quartz	Feldspar	Quartzite	Quartz-sericite schist	Micas-clays	Olivine-pyroxene	Heavy minerals	Magnetite	Ilmenite	Titanite	Apatite	Rutile	Zircon	Tourmaline	Spinel	Garnet	Epidote	Staurolite	Pyrite	Cement	Detritus	Color	16-8	8-4	4-2	2-1	1-½	½-¼	¼-⅛	⅛-1/16	Less than 1/16
1	46	23	10	4	14	1	2	×	×	×××	×	----	×	----	----	----	----	----	----	Quartz (partial).	Chlorite-micas.	Green	---	---	---	---	24	28	24	6	18
2	53	14	17	8	6	1	1	××	×	×	×	×	××	×	×	----	----	----	----	do	Hematite-chlorite-micas.	Brown	---	---	6	48	24	7	2	1	12
3	39	13	24	6	10	6	2	×	×	××	×	××	×	×	----	×	----	----	----	do	Hematite-sericite-olivine (?).	do	---	---	2	3	32	37	9	2	15
4	12	5	46	24	----	7	6	×××	×	××	×	×	××	×	----	----	×	----	----	None	Hematite-micas-quartz.	do	---	15	32	14	16	5	1	1	16
5	23	----	30	36	3	5	3	×××	××	×	×	----	----	----	----	----	----	×	----	Quartz	Quartz-iron ores-sericite.	do	---	---	12	35	16	13	2	1	21
6	41	4	27	----	21	5	2	××	××	×	×	----	----	×	----	----	×	----	×	do	Chlorite-hematite-quartz.	Greenish-brown	---	---	---	---	25	37	23	9	6
7	15	11	26	28	15	2	3	×××	×	××	×	----	----	×	----	----	×	----	----	Quartz (partial).	Hematite-micas-clays.	Brown	---	---	---	1	34	25	12	1	27

[1] Quartz percentages include grains and cement but not quartz in rock fragments.
Quartz-sericite schist percentages include quartz-biotite-magnetite schist and other rocks.
Micas-clays percentages include some oxides and some unidentified debris.
[2] Heavy minerals shown as follows: ××× = 50 percent or more of total heavy mineral percentage; ×× = 20 percent or more; × = less than 20 percent.
[3] Detritus includes principal constituents in size fraction less than 1/16 mm.
[4] Frequency distributions based on measurements of grain parameters and calculation of grain areas in typical thin sections. The distributions are therefore volumetric and are only approximate. Granular constituents are too friable to permit accurate frequency determinations by crushing and sieving.

Schist-Arenite (low-rank graywacke)

Composed of 80 percent or more of quartz and feldspar from granite and pre-Triassic metamorphic rocks (contains 10 to 75 percent metamorphic rock fragments). Cement is partly quartz but mostly uncemented.

Argillaceous Sandstone

Composed of less than 80 percent quartz and feldspar from granite and pre-Triassic metamorphic rocks. Cement is partly quartz with clay acting as a bond.

Glaeser (1966) has prepared an exhaustive petrological study of the sediments of the Newark-Gettysburg basin using 1450 samples from 520 outcrops. He has carefully examined the mineral composition and textural maturity of the sediments and has given particular attention to identification of the source rock, dispersal of the rock debris into and throughout the basin, and the environment of deposition. Glaeser used a modified form of Krynine's sandstone classification, wherein he combined rock fragments and feldspar together at one pole and used detrital mica at the pole where Klein and Krynine used feldspar. Unfortunately, direct comparison with figure 10 cannot be made without replotting part of his data. However, all of the textural and compositional varieties noted in the other basins, including limestone, are present in the Newark-Gettysburg basin. There are apparently extensive areas of "clean" sandstones and conglomerates of single and multiple modal classes which are products of high energy environments. In addition, there are nearly pure limestone and quartzite conglomerates.

The following summary of provenance and sediment dispersal is quoted from Glaeser (1966).

> "The Newark-Gettysburg basin represents a nearly complete record of sedimentation in the original basin. This view emerged from the following significant interpretive features:
>
> 1. Both margins of the outcrop belt are parallel to and relatively close to the original basin margins.
> 2. Sediments contained within the basin represent dual sources; a southern feldspathic one dominating in early influx stages, and a northern sedimentary low-rank metamorphic one dominating in later stages. The southern source lay parallel to the entire south margin of the basin and had relatively uniform relief throughout its extent. A westward change in provenance character is reflected in both compositional and textural variations in the Stockton and New Oxford. The northern source shed debris into the basin through a rather limited zone of influx.
> 3. Sediments from the southern source were dispersed toward the basin center normal to the margin. Once beyond the northern limits of the basin, detritus from the north was dispersed laterally parallel to the basin axis. Both sources influenced the character of basin-center Lockatong deposits.
> 4. Final filling of the basin is marked by local, north-border mudflow deposits of locally derived detritus from uplifts along a border fault.
> 5. The composition and texture of the coarse sediments indicate that they have been influenced very little by transportation, and that the sediments now observed are essentially the fragmented debris from the source areas."

The sequence of sedimentation in the basin appears to be: (1) Deposition of the laterally equivalent Stockton-New Oxford beds in overlapping alluvial fans parallel to the basin's southern margin down a paleoslope from a high-rank metamorphic source; (2) a shift to a predominantly low-rank metamorphic source from the north with sediments entering the basin at one restricted point to form the Hammer Creek deposit;

(3) axial dispersal along the basin forming the lateral facies equivalent of the Hammer Creek deposit -- the Brunswick and Lockatong lithosomes and the Gettysburg Formation; and (4) sedimentation culminating in coarse mud flows probably initiated by late fault movement along the northern margin.

Glaeser apparently did not calculate the various percentages of the compositional or textural varieties of the total sediment bulk. McLaughlin, (1959) states that there is a greater preponderance of shale to sandstone in the Bucks County and adjacent area than elsewhere. This is to be expected if the Brunswick of Bucks County is a down-basin, fine-grained derivation of the Hammer Creek. McLaughlin also states that, "Evidently conditions of sedimentation differed in some respect (in Bucks County) from those that prevailed in the greater portion of the Newark terrane." The implication is that Bucks County had the finest sediment in the basin and that sand predominated over shale elsewhere. Glaeser noted that there was no lack of fine-grained material, only that it was winnowed out into alternating and discrete beds.

Roundness of sand grains in the Stockton and New Oxford Formations tends to increase to the north, parallel to the southern margin. Sorting of the coarse sands and gravels in the Hammer Creek apparently increases both east and west along the axis of the basin from the point of sediment influx. It is interesting to note that the exposed limestone fanglomerate has very angular fragments and unsorted matrix, indicating its very local origin.

Another point of importance in establishing Triassic drainage and dispersal patterns is made by Meyerhoff (1972), who notes "Clasts of probable Pocono derivation and of definite Devonian and Silurian formations are dominant among the identifiable detritus from the northwest." Apparently all of the Triassic detritus was not from local sources.

The composition of the sandstones of the Newark-Gettysburg basin are composed mainly of quartz and feldspar minerals and reflect source geology modified by transport processes. The matrix, where it is present, consists of weathered feldspar or chlorite-sericite and sericite. Cement is predominantly calcite with subordinate amounts of hematite and quartz. Accessory minerals include tourmaline, mica, epidote, hematite, pyrite, rutile, and zircon. From inspection of Glaeser's areal plots of composition-texture types, it appears that arkoses are associated principally with basal Stockton and New Oxford Formations, with the Stockton having the greater feldspar content. The orthoquartzites are mostly associated with the Hammer Creek Formation — especially its outer fringes.

Toewe (1966) found that sediments along the northern edge of the Culpeper basin in Virginia consists of limestone conglomerate, quartz conglomerate, sandstone, shale, and pyroclastic rock. One basalt flow is present near the top of the section, and the entire section is intruded by diabasic dikes and sills. The limestone conglomerate is an unsorted mass of limestone fragments in a red matrix of quartz, feldspar, calcite, mica, chlorite, and clay. Fragment sizes range from one-fourth inch to several feet in diameter. Quartz conglomerate composed of rounded fragments of quartz and quartzite from one-fourth inch to 6 inches in diameter interfingers with coarse sandstone.

The light colored matrix of this conglomerate is coarse-grained sandstone of quartz, calcite, feldspar, chlorite, and epidote. Sandstones consisting mostly of quartz and feldspar are medium- to coarse-grained and are represented by arkoses, graywackes, and pure sandstones (orthoquartzites?). They interfinger with conglomerate and shale. The shales are mostly quartz, plagioclase, and mica; are thin bedded; and range from soft to very brittle. Pyroclastic rocks in the upper part of the section are uniformly fine-grained, very dense, and are principally of andesitic or trachytic composition.

The sedimentary suite in the Danville and Richmond basins seem to be similar. Intertonguing feldspathic sandstones and shales predominate; however, there are coarse unsorted conglomerates at the basin margins; and coal is present in a down-basin black-shale facies. There are no data on sorting or textural maturity. Basalt flows, and pyroclastics are not known to be present.

The buried Dunbarton basin of the central Savannah River area of South Carolina is estimated to be about 30 miles long and 5 or 6 miles wide (Marine and Siple, in preparation). Lithologies range from coarse, unsorted gneissic breccia or fanglomerate, to massive, calcareous argillite or claystone. The sandstones are gray-brown to maroon, fine to very-fine, graywackes. Siltstone and claystone make up most of the known section. Sorting appears to be poor. Basement rock in the vicinity of this basin is chlorite-hornblende schist, hornblende gneiss, and some quartzite.

Volcanism

Basalt flows and associated tuffs are interbedded with the middle and upper parts of the Triassic continental clastics from at least Culpeper, Virginia northward to Nova Scotia. Basalt, reported in the subsurface of eastern Georgia and northern Florida above the basement complex, may also be of extrusive origin. The great "trap" or basalt flows of New Jersey and southern New York form the famous Palisades along the lower Hudson River. At least eight distinct flows have been identified in the New Jersey-Connecticut area, but paleomagnetic measurements show that they are not laterally equivalent. Thickness of the middle lava flow in Connecticut is 300 to 500 feet. Dikes which might have served as conduits or feeders for the overlying volcanic flows and pyroclastics have not been positively identified within any of the Triassic basins. The flows, particularly in the Connecticut basin, have been sliced, offset, and repeated by numerous transverse (?) faults. Increasingly younger paleomagnetic dates of lava from south to north have caused deBoer (1967) to suggest a northeastward shift of volcanism in Triassic time. Perhaps volcanics were once widespread in the southern basins also, but have since been eroded away. Tuffs and tuffaceous sediments are felsic to mafic crystal tuffs, which are dense to somewhat porous.

Depth of Basin Filling

Much has been written in speculation about the original maximum and present-day thickness of deposition in the Triassic. Estimates of original thickness are complicated by selection of the correct sedimentary model -- whether the local or broad-terrane model is used to describe the former area of outcrop -- and by the amount assigned to removal by subsequent erosion. Estimates of present-day thickness also depend primarily upon the structural model selected. Early workers, who visualized a synclinal depression, estimated that the thickness was much less than it actually is. Failure to correct for repetition of strata from block faulting in the half-graben model has led to estimates that are too high.

Sanders (1963) proposed an original sediment thickness of at least 35,000 feet for his Connecticut-Newark-Gettysburg basin and stated that the unfaulted New Jersey portion of the Newark-Gettysburg basin gives an unambiguous answer of 30,000 feet for the present day thickness if the dip of measured strata is projected into the border fault. The following historical summary is quoted from Sanders:

> "Cook (1868) calculated the thickness of the Triassic strata in New Jersey to be 27,000 feet, but he arbitrarily reduced this number to 15,000 feet to compensate for presumed repetition on hidden strike faults. I. C. Russell (1880) calculated at least 25,000 feet and accepted this figure as valid barring hidden faults. Kummel (1898) calculated 20,300 feet, but reduced this by one-half to one-third to 11,800 to 14,700 because of faults (Kummel, 1899). Darton and others (1908) considered the New Jersey Triassic to be "at least 15,000 feet thick". Grabau (1921) accepted a figure of 14,000 to 18,000 feet. McLaughlin (1944, 1945) has demonstrated that the sections in the Delaware River Valley, which are repeated three times by faults, include only the lower half of the total column. The largest thickness present here is 15,000 feet."

Estimated depths for the Danville basin (Thayer and others, 1970) based on outcrop width and average dip were 5,000 feet for the narrowest part of the basin and 15,000 feet for the widest. However, eight gravity profiles normal to the axis of the basin yield depths ranging from 4,750 to 6,260 feet indicating either extensive block faulting or flattening of the dip in the subsurface toward the northwest boundary fault.

In the Deep River basin, Prouty (1931) estimated sediments in the Durham section to be 10,000 feet thick, in the Sanford section to be from 6,000 to 8,000 feet thick, and over the Colon Cross Structure to be from 4,000 to 5,000 feet thick. Zablocki (1959) from residual gravity anomaly profiles, calculated the minimum sediment thickness to be 6,500 feet in the Durham section, 2,000 feet over the Colon Cross Structure, 7,700 feet in the Sanford section, and 3,800 feet in the Wadesboro section. David M. Stewart (personal communication) has one seismic depth determination of 3,800 feet in the Durham section at a point also indicated by gravity determinations to be between 2,000 and 5,000 feet deep.

The surface of the Triassic rocks of the buried Dunbarton Basin of South Carolina and Georgia is from 1,000 to 1,2000 feet deep. Thus far, the maximum depth at which the crystalline basement floor has been penetrated is approximately 4,000 feet.

In almost all basins, there are a few deep wells which penetrate to the basement floor along the updip edge. Most of these wells are less than 2,000 feet deep. For example, a wildcat oil well in the Pomperaug outlier in Connecticut penetrated basement rock at a depth of 1,235 feet. No wells except one in the Dunbarton basin are known to have been drilled to basement adjacent to the major barder faults -- the deepest parts of the basins.

Stratigraphy

The stratigraphic names used in the various Traassic basins of the East Coast are correlated in figure 4. The continental clastics by nature thin, lens, and intertongue rapidly. Thus, there are few good temporal marker beds. The thin limestones, coal seams, and basalt flows are notable exceptions and work well in individual basins on discrete fault blocks. However, the gross sedimentary record is reasonable decipherable as a series of rock stratigraphic units or lithosomes representing separate but intertonguing environments of deposition.

There are correlation problems between basins. As previously mentioned, the erroneous correlation of basalt flows from the Newark-Gettysburg basin to the Connecticut basin is a case in point. The lithologies of the Atlantic Coast Triassic basins are remarkably similar. Most rock types discussed above, including volcanics, are present in every basin, and the vertical and lateral successions at any one point depend on marginal source rock and the basin depositional environment. The traditional, generalized, stratigraphic model used in all basins of the East Coast to explain vertical and lateral succession consists of basal coarse, usually arkosic, conglomerates and sandstones composed of the granitic or gneissic wash from the adjacent highlands. These are overlain by limy gray or red shales or finer grained black shales, which are locally coal bearing; and these are overlain in turn by arkosic sandstones, shales, and conglomerates. Fanglomerates or mud flows are usually found at the top of the section at the major fault borders. In the northern basins basalt flows and pyroclastics are found from the middle to the top of the section.

Fig. 11.--Hypothetical cross sections showing fault trough facies models.

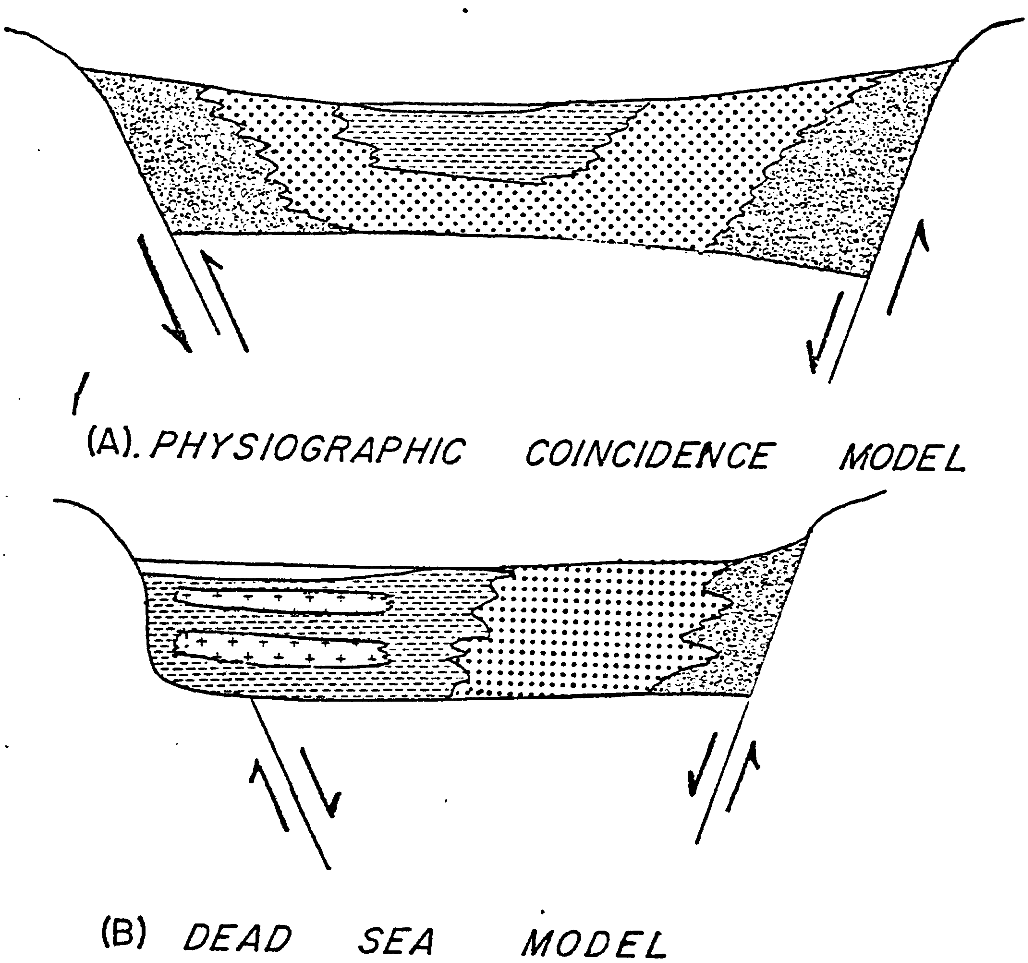


Figure 11.--Fault trough facies models. (A) Physiographic coincidence model (after Russell, 1878, 1880). (B) Half-graben model based on present-day facies distribution in the Dead Sea Graben. Reproduced from Klein, 1969.

Fig. 12.--Hypothetical cross section contrasting two possible sedimentary models to explain stratigraphy of tilted Triassic basins.

Klein (1969) implied that this stratigraphic model may be incorrect by pointing out that it has developed from our past conception of the structural model which produced the Triassic basin. That is, the broad-terrane hypothesis calls for deposition from both sides of a large classic graben, which is later arched along the axial portion to produce a series of oppositely dipping half grabens which are mirror images of one another. Klein also notes that the Dead Sea graben sediments are not symmetrically disposed in relation to the basin margins. See figures 3 and 11. The point is, if the structural and dispersal models are different from what we have traditionally supposed them to be, the sedimentary model will also be different.

Two further points are worthy of consideration. The traditional model has been drawn from surface observation. The subsurface lithologies of the basal, central, and deepest parts of the basins have been projected from their lateral updip equivalents modified only by the obvious assumption that conglomerates and fanglomerates should radiate outward from the faulted edge in fanlike fashion toward the basin center. Too, the literature is full of examples where the conglomerate of the updip edge (presumably in a basal position) is compared to conglomerates on the opposite basin edge at the top of the section. To this writer's knowledge, the basal and middle parts of the sedimentary record next to the major fault have been neither exposed nor studied.

If each of the wedge-shaped outcrop areas now preserved in the Piedmont represent remnants of tilted full grabens or block-faulted valleys, then it is just as reasonable to expect the sedimentary model to be as illustrated in the bottom profile of figure 12.

Here the fine-grained shale facies is in a medial position relative to infilling from both basin margins rather than middle in the vertical stratigraphic sense. Should the correct structural model be either a tilted full graben or a block-faulted valley wherein downthrow along the major fault is contemporaneous with sedimentation, the fine-grained facies should migrate toward the basin tilting fault as it moves upward stratigraphically. An asymmetric position for the fine-grained facies is not inconsistant with field observations. The basin sediments should be cyclic grading finer upwards in each cycle and recording discontinuous fault movement.

Structural Development

The exact order of events in the evolution of the Triassic basins of the East Coast is not yet known. However, there is sufficient data from the geologic record to infer the following sequence of major events:

1. Major crustal movement along pre-Triassic (?) faults to produce a graben, rift-valley, or block-fault valley in Late Triassic time,
2. Disruption of drainage and filling of basins from nearby marginal highlands on both sides. Sedimentation entered the basins through basin marginal alluvial fans and river-mouth deltas and was distributed by longitudinal or axial streams and shallow lakes,
3. Recurrent movement along the major fault concurrent with sedimentation interrupted by major periods of tectonic quiesence allowing the formation of evaporites in closed basins and coal in swamps. Cross faults possibly developed at this time and diabase was possibly intruded along these cross faults,
4. Estrusion of basalt flows and pyroclastics in the northern half of the East Coast,
5. Intrusion of thick sill-like diabasic rock into the middle and upper part of the sedimentary section sub-parallel to bedding,
6. Development of cross faults which offset border faults,
7. Development of late longitudinal tensional faults offsetting (?) cross faults and rotation of large blocks toward border fault,
8. Intrusion of mostly thin nearly vertical diabase dikes along cross faults in Late Newark or Early Jurassic time. See figure 8.

Present and Past Distribution of Triassic Basins

The present distribution of the Triassic basins on the East Coast is a function of all of the erosional and tectonic processes that have affected them since Triassic time. Their stated parallelism to the Appalachians is more apparent than real. The western edge of the Triassic rift belt progressively cuts across the Appalachian grain from south to north. The presence of basins beneath the younger Coastal Plain sedimentary blanket is documented by numerous well records (plate 1) and by offshore seismic evidence. If the Triassic basins were caused by an early Atlantic opening, then the outcrop pattern should be present as far east as the edge of the thick sial crust. There are undoubtedly more basins yet to be discovered.

The amount of Triassic sediment removed by erosion is not known. Proponents of the broad terrane hypothesis postulate that much more than half of the sedimentary and volcanic wedge has been removed by erosion. Most geologists of the separate-basin school postulate removal of much less than half, especially when they see evidence for the modern basin margins being very close to their depositional source areas.

Undoubtedly there were other basins which have since been completely eroded away either because of their shallowness or because of subsequent structural uplift in their outcrop area. Indeed, William White (personal communication) sees geomorphic evidence for uplift both northeast and southwest of the Newark-Gettysburg basin which may explain the modern greater width and thickness of this basin compared to those farther to the north and south.

Certainly, there are other linear, high-angle fault-bounded structures east of the Brevard Fault zone (Bayley and Muehlberger, 1968) which could have once contained Triassic sediments (Conley and Drummond, 1965). Woodward (1957) suggested that the strongly northeast trending Lackawanna or northern anthracite basin in Pennsylvania has a northwest bounding fault of Triassic age. Sanders (1963) proposed that the Taconic allochthon east of the Hudson River in eastern New York is a Triassic structure also bounded by a northwest fault.

The modern Triassic outcrop pattern appears to record the location of major crustal structural elements (fig. 13) in the Piedmont. Relative movement between these major crustal blocks has not only determined areas of non-sedimentation in Triassic time and maximum erosion in post-Triassic time, but has also undoubtedly greatly influenced drainage and sedimentation. Their existence and control of post-Triassic sedimentation is documented by Brown, Miller and Swain (in press). The suggested outline of these structural blocks and their extension onto the exhumed Piedmont is modified from that paper.

Buried Triassic Basins

The known location of buried basins and their possible area of subcrop beneath the younger sedimentary cover has been previously mentioned. An outline of their structural and sedimentary character is in order.

This writer has no evidence in hand which indicates that the buried basins are not all preserved in half-graben structures rather than by normal sedimentary overlap.

Fig. 13.--Map showing distribution of Triassic basins relative to possible crustal blocks.

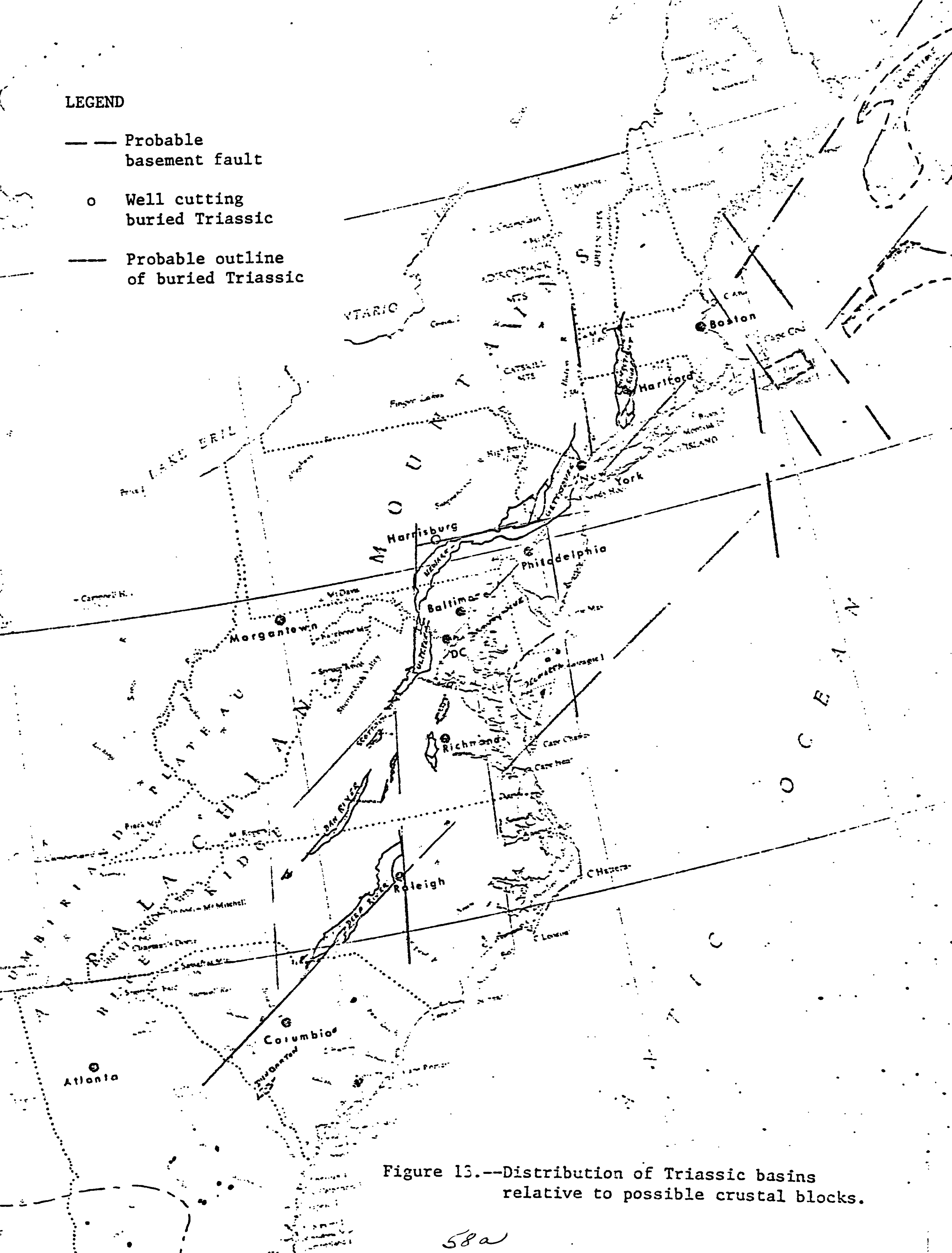


Figure 13.--Distribution of Triassic basins relative to possible crustal blocks.

The Dunbarton and Brandywine basins are definitely grabens or half grabens. Many of the other known and suspected buried basins are known only from a single well or widely scattered wells. Offshore seismic evidence has not yet been examined by this writer.

Cursory examination of available well cuttings, cores, geologic logs, and geophysical well-bore data from buried basins indicates no radical difference in lithologic types between the outcropping and buried Triassic sediments. However, the texture and bulk of the cuttings and cores examined indicated a preponderance of the finer fraction — siltstone, shale, and claystone or argillite.

Buried Triassic basins have been found from less than 1,000 feet to more than 6,000 feet beneath the Coastal Plain cover. Most wells penetrating buried Triassic have recorded more than 500 feet of sediment. The thickest section penetrated thus far has been 3,000 feet in the Dunbarton basin (Marine and Siple, in preparation).

Mineralization

Most of the rocks of the Triassic basins have been little affected by hydrothermal solutions, even near the diabase intrusives. The notable exceptions are in Pennsylvania where magnetite is a replacement deposit in lenticular beds of limestone conglomerate near diabasic intrusives and in New Jersey where copper mineralization occurs in the Triassic sediments near diabase dikes and flows. Elsewhere, veins of hornblende-diopside, prehnite, epidote, actinolite, albitite, and the zeolites are occasionally found in and adjacent to the diabase intrusives. Tourmalinization of fine-grained sandstones adjacent to faulted diabase occurs (Bain, 1959) near Nokesville, Virginia. Fracture coatings of malachite and azurite are common in Triassic rocks. Roberts (1928) has reported copper minerals from near Brentsville, Virginia. Barite occurs in the Triassic in association with chalcopyrite, azurite, malachite, and pyrite near faults and was mined as early as 1845 (Edmundson, 1938) in Virginia.

The greatest noticeable effect of the diabase intrusives is the conversion of the surrounding shales into a narrow band of grey, dense, knotted hornfels. The reduction of the red hematite into blue-grey or grey magnetite causes a striking color change which extends a few inches away from the smaller dikes to several hundreds of feet away from the larger ones.

Economic Resources

None of the above minerals have been sufficiently concentrated to be anything but collecting localities, except for barite, magnetite, and copper minerals. Thin layers of hematite in the Deep River basin of North Carolina containing 65-70 percent ferric oxide have been mined in the past (Kerr, 1875). Magnetite is mined near Cornwell, Pa., and barite has been mined in the past both in Virginia and Connecticut.

The Triassic sandstones have been used extensively in the past as a building stone, chiefly as a source of the well known Brownstone. The shales are especially suited to the manufacture of brick and light-weight aggregate, and there are plants near Manassas and Danville, Virginia and Durham and Sanford, North Carolina.

The diabase intrusives and basalt flows are used extensively throughout the Triassic outcrop area as a source of road material. A few quarries produce dimensional stone for buildings, mausoleums, and tombstones from the less fractured intrusives.

Coal of commerical importance occurs in the black-shale facies of the Richmond, Virginia; Deep River, North Carolina; and possibly the Danville, Virginia-North Carolina basins. No coal has been mined in these basins since the middle part of the century because of competition from lower sulphur coal from southwestern Virginia and West Virginia. In a few places, the coal in the Richmond basin is up to 12 feet thick, but it is usually much thinner.

It has been mined down to a depth of at least 722 feet (Woodworth, 1901). In the Danville basin, Triassic coal of poor quality crops near Walnut Cove, North Carolina. Coal in the Deep River basin occurs in the Cumnock Formation in two beds or benches generally less than 2 and 4 feet thick separated by 30 to 40 feet or grey shale, siltstone, and sandstone. The coal has been extensively cored and is known to occur below 2,000 feet. The estimated reserves are 110,000,000 short tons, half of which is believed to be recoverable (Reinemund, 1955). Occurring with the coal are beds of ferruginous, carbonaceous shale which yield small amounts of oil when heated (Vilbrandt, 1927). These oil shales also contain $Ca_2(PO_4)_2$ and $(NH_4)_2SO_4$ in quantities averaging 20 and 43 pounds per ton, respectively, and small amounts have been used in the production of fertilizer.

Undoubtedly, the greatest single resource of the East Coast Triassic is ground water. The Triassic aquifers are extensively developed from Culpeper, Virginia northward to the northern tip of the Connecticut basin in Massachusetts. This area coincides almost exactly with the greatest population density of the East Coast megalopolis indicating a possible causal relationship between population and ground-water development. However, according to the few data available, water yields tend to decrease southward from the Culpeper basin.

WATER-BEARING CHARACTER OF TRIASSIC AQUIFERS

A search of the literature of the East Coast Triassic and unpublished data reveal that very few wells have been drilled below 1,000 feet (table 2) and that there are essentially no test data available for the deep subsurface aquifers. The hydrology of the shallow aquifers and the significance of the few deep data are discussed below for their obvious clues to subsurface hydrology, the depth of potable water, and the degree of development of the fresh-water aquifers by man.

General Character

Short and rapid transport has created poorly sorted, dirty, and dense sandstones, conglomerates, and siltstones with low to moderate water yields. Not all Triassic rocks suffer from poor sorting, however. Exceptions exist where hydraulic energies have been sufficient during deposition to produce well sorted snadstones and conglomerates. Klein (1968), Glaeser (1966), and Conley (1962) all note well sorted sands in their respective areas of investigation.

The basins contain both basalt flows and intrusive dikes and sills. These diabase dikes and sills are generally fine textured and quite tough, dense, and competent. Small but dependable yields are obtained from wells in their weathered and jointed upper surfaces. The basalt flows, interbedded with the sediment, are present from at least the Culpeper, Va., basin northward. Their upper surfaces tend to be vesicular and as a whole, are apparently more brittle and more fractured than their intrusive counterparts.

Yields up to 400 gpm are reported in the multiple flows in New Jersey. However, producing zones have apparently not been systematically studied. Elsewhere, small but dependable yields are also obtained from their upper weathered surfaces.

Where unfractured, intrusive diabase and possibly basalt flows tend to act as barriers to the movement of ground water. Knowledgeable drillers take advantage of this fact by locating wells in the contact rock on the up-gradient side of the intrusive and extrusive rocks where water is trapped. There are no data that indicate these igneous bodies do not also act as barriers to water movement in the deep subsurface.

Porosity and Permeability

Porosity can be classed as primary or secondary depending upon its origin. Vesicles in igneous rocks and intergranular space in sediments created at the time of cooling are primary, and fractures, joints, and solution cavities are secondary. Primary intergranular porosity in sedimentary rocks is mostly dependent upon sorting of the clastic material. A rock made up of sand of a single size can have an initial porosity greater than 40 percent. Compaction, admixture of smaller sized particles, and growth of interstitial cement all combine to greatly reduce the percentage of pore space in rocks -- sometimes to zero.

Secondary porosity, consisting of fractures, joints, faults, and solution openings, results from tectonic and weathering forces acting on the rocks subsequent to deposition or solidification. The available evidence indicates that the secondary openings in Triassic rocks of the East Coast consist mostly of rock fractures.

Apparently, vertical joints, formed perhaps before complete induration of the Triassic rocks and perhaps widened by subsequent solution, form the aquifers. Partial solution of carbonate cement occurs in some of the calcareous shales and sandstones. There is also a possibility that some of the pyroclastics in the Leesburg, Virginia area have substantial primary or secondary porosity (Kadish, 1972, personal communication).

In Triassic rocks, fractures include the minute breaks created by the passive adjustment of the Triassic sedimentary wedge to external forces and those caused by topographic unloading as erosion proceeds; the nearsurface joints widened by growth of tree roots, freezing and thawing, and tensional release; and the major faults or fracture zones. Most fractures are apparently closed too tightly to be effective channels for the movement and storage of water below a depth of 400 to 600 feet. Hydrologists have generally found that below this depth the total yield of a well may increase, but the yield per foot of saturated aquifer penetrated decreases. Figure 14, which is a plot of yield versus depth for wells in the Brunswick formation of Pennsylvania, illustrates this point. A majority of investigators apparently believe there is essentially no primary porosity, and Wood (personal communication) feels that the decrease of yield with depth and the low storage capacity and high transmissivities of aquifers in eastern Pennsylvania indicate that all porosity is in secondary fractures. Perlmutter (1959) found that the Triassic rocks of southern New York are generally well cemented with most of the water occurring in bedding planes, joints, and irregular fractures.

Fig. 14.-- Graph showing relation of yield to depths of wells in the Brunswick Formation of Pennsylvania.

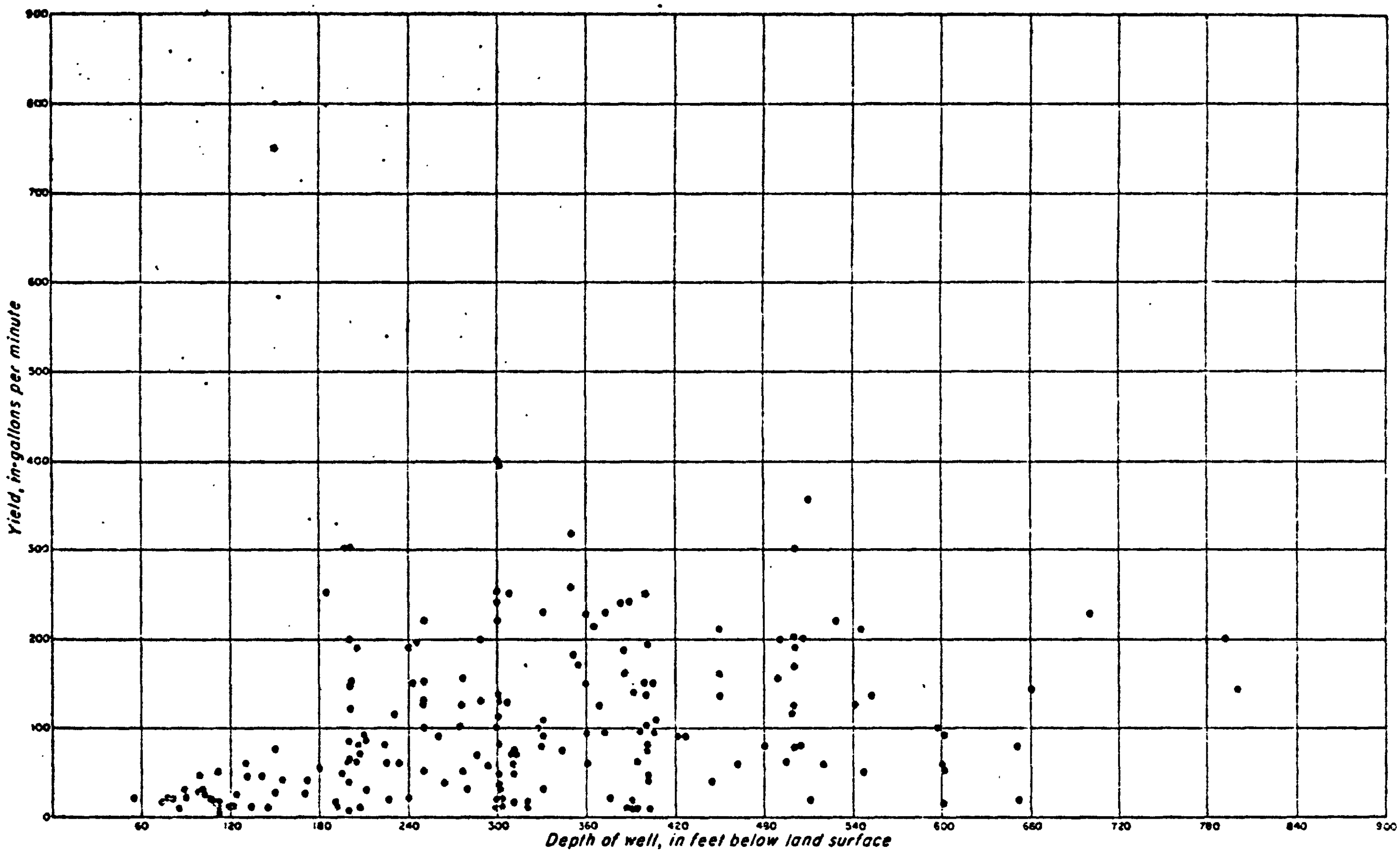


Figure 14.--Relation of yield to depth of wells in the Brunswick Formation of Pennsylvania. After Longwill and Wood, 1965.

However, in a few places the rocks were poorly cemented and "considerable water" occurred in the primary pore space. Physical properties of rock from his report, Table 3, show that the permeability of shallow samples is low and that porosity ranges from 1 to 21 percent. Carswell (in preparation) believes that the Brunswick Formation of New Jersey yields water from a three-dimensional network of joints, fractures, and irregular solution openings which decrease in size and number with depth. He found that few measurements had been made of the thickness and depth of the fresh-water circulation zone and the distribution of porosity and permeability in the Triassic of the eastern United States.

Rima (1955) concluded from flow-meter tests in the Lansdale, Pa., area that the aquifers could be divided into two classes. "A water-table aquifer that exhibits low permeability through a considerable thickness occurs to a maximum depth of 250 feet; below it is one or more artesian or semiartesian aquifers each generally less than 20 feet thick, which have a relatively high permeability, and occur to a maximum depth of about 600 feet." Data from a deeper wildcat oil well in the same area indicate that such thin permeable zones may not end at 600 feet.

Lesley (1891) shows the log of a well near Revere in eastern Burks County, Pa., whereon is noted that:

1. at a depth of 1,150 feet - "Here cased off the fresh surface water."

2. at a depth of 1,616 feet in 6 feet of sandstone - "Here cased off the salt water." — and just below at 1,624 feet -- "Here salt water again and plenty of it."
3. at 1,736 feet -- "cased well against salt water in Black Slate, at 1,736."
4. at 1,782 feet in 28 feet of coarser, brown sandstone -- "Cased off water successfully at 1,782."

The well was drilled to at least 2,084 feet.

The results of a 2,100-foot well drilled near Patterson, N. J., are recorded by Cook (1885). This well was drilled in Triassic shale and sandstone to 1,120 feet (table 2), where there was some trouble with "quick-sand" which was tubed off. The water at this point rose to within 17 feet of the surface. The water was found to have a total dissolved solids content of about 5,800 mg/1. The rock below 1,120 feet was found to be devoid of water down to 2,020 feet where the rock was more "granular and worked up into sand by the action of the tools". Strongly saline water (15,900 mg/1 total dissolved solids) at 2,050 feet rose to within 30 feet of the surface. Drilling was stopped at 2,100 feet, the tubing removed, and the well plugged back to 900 feet and completed as a fresh-water well.

In contrast, a well drilled to 4,000 feet (table 2) by the Winchester Repeating Arms Company in New Haven, Conn., in 1893 was dry except for surface seepage. The recently completed 4,212-foot test well in the Dunbarton basin of South Carolina and Georgia had a yield of 0.14 gpm (gallons per minute), which increased to 4 gpm only after penetration of the Triassic-Basement contact near the bottom of the hole.

The hydraulic anisotrophy of the Triassic sedimentary wedge has been demonstrated by Herpers and Barksdale (1951) and Vecchioli (1967). Drawdowns during pump tests in wells in New Jersey were much greater along strike than across strike.

Primary porosity in Triassic rocks is reduced by mineral growth or authigenesis. This process includes the replacement of minerals such as quartz and feldspar by other minerals such as sericite and calcite, the introduction of cement, and the production of feldspar and quartz overgrowths.

Sand-size and coarser grains in Triassic rocks are principally quartz, feldspar, mica, chert, and rock fragments. The matrix is uaually a paste of sericite, chlorite, and undifferentiated clays. Cements usually consist of quartz, calcite, and hematite in various combinations. Cement may be from at least 3 sources -- solution of grains at their points of contact during compaction or tectonic compression, introduction of material from outside the basin, and precipitation of minerals from interstital fluids. In this regard, Heald (1956) would favor a magmatic source for cement in the sandstones studied in the Connecticut basin. In regard to possible sources of cement, some of the Triassic border fault-zones, where identified, are occupied by siliceous mylonites (Conley and Drummond, 1965 and Goodwin, 1970).

Whatever the source of cement, authigenic overgrowths of feldspar and quartz and replacement of detrital grains by sericite and calcite are quite striking in Triassic rocks, especially as seen in thin section. Authigenesis of Triassic rocks frequently produces a very dense, tough rock with interlocking crystal texture and low porosity.

Permeability is the ease with which fluid flows through a rock and depends on the size, shape, and interconnection of rock pores. It is important to note that shales have high porosities, but the minuteness of their pores causes generally low permeabilities. The coefficient of permeability, P, as formerly used by the U. S. Geological Survey, is expressed as the number of gallons of water per day that will pass through 1 square foot of the aquifer material under a unit hydraulic gradient. The coefficient of permeability has generally been expressed in gallons per day per square foot. Intrinsic permeability, as now used, contains more consistent units and is a measure of the properties of the rock medium alone. Therefore, it is not dependent upon gradient or the viscosity of the fluid. The table of measured rock properties (table 3) contains data from a variety of sources. Permeabilities expressed in millidarcies and gallons per day per square foot have been converted to intrinsic permeability.

Transmissivity, Storage, and Specific Capacity

Transmissivity refers to the rate at which water is transmitted through a vertical section of a saturated aquifer of unit width under a unit hydraulic gradient. The storage coefficient of an aquifer is the volume of water an aquifer releases from or takes into storage for each unit of surface area of the aquifer per unit change in head. Transmissivity (T) data and coefficients of storage (S) used to measure the specific water bearing character of the Triassic aquifers are scarce to nonexistent everywhere except in the Newark-Gettysburg basin.

Care should be exercised in accessing significance of hydrologic data quoted in this report. Specific capacity is the yield in gallons per minute per foot of drawdown. It is not an exact indicator of the ability of an aquifer to transmit water because it is often affected by well losses, partial penetration, and hydrogeologic boundaries.

The anisotrophic tilted nature of the Triassic aquifers requires a special test design - a fact not always recognized or dealt with in the field. In addition, certain other assumptions have been made about the hydrology of the Triassic rocks at each test site that if incorrect will invalidate the calculations summarized below. The available data confirm previous tentative conclusions based on yield of wells in the Newark-Gettysburg basin that the best aquifers in this basin are the Stockton and Brunswick Formations, followed by the New Oxford Formation, and that the poorest is the Lockatong Formation. Transmissivities of the Stockton Formation range from 130 to 4500 ft^2/day with most being around 2600 ft^2/day. Transmissivities of the Brunswick Formation range from about 20 to 20,300 ft^2/day and average about 4,000 ft^2/day. The New Oxford Formation of south-central Pennsylvania and Maryland ranges from about 11 to 640 ft^2/day and averages about 260 ft^2/day. Transmissivities measured in the New Jersey part of the Newark-Gettysburg basin show marked differences at individual test sites depending upon whether the observation well is along strike or perpendicular to strike from the pumped well. Aquifer tests on two wells at Cromwell, Conn., show a range in transmissivity from 500 to 1200 ft^2/day in the shaly lower part of the Portland Arkose.

Specific capacities of wells in the Connecticut Valley range from 0.02 to 17.0 gpm/ft of drawdown. The average is 2.3 gpm/ft of drawdown, and the median is 0.72 gpm per ft of drawdown. Specific capacities of the Gettysburg Shale and the New Oxford Formation in Maryland range from 0.1 to 16 and 0.1 to 1.0 gpm/ft of drawdown, respectively, similar to those for Triassic rocks in Pennsylvania and New Jersey. The range in transmissivities for Maryland Triassic rocks is probably close to that of Pennsylvania, if the storage coefficients are similar. Only one transmissivity of 11,000 ft^2/day for the Gettysburg Shale is reported. Specific capacities for Virginia wells in the Culpeper basin range from 0.3 to 27 gpm per ft of drawdown, which is similar to those of Maryland and Connecticut. The average of 4.8 and the median 0.9. Aquifer data for other Virginia basins are unavailable. One specific capacity of 3.0 gpm per ft of drawdown is reported in North Carolina for a well in Stokes County.

Storage coefficients of 1.0×10^{-5} to 1.0×10^{-3} appear to be typical for the deeper Triassic rocks from Culpeper, Va., to Massachusetts. The similarity of the range in specific capacities throughout the area indicates that the hydrologic character of the rocks is the same.

Transmissivity data are not available for the Triassic rocks of the Deep River basin of North Carolina, the Danville basin of North Carolina and Virginia, and the Richmond and other miscellaneous basins of Virginia. The yields, however, are known to be lower than those of the Newark-Gettysburg and Connecticut basins -- perhaps considerably so. A very low transmissivity has been measured in one well in the buried Dunbarton basin of South Carolina and Georgia.

Marine and Siple (in preparation) calculated a transmissivity of 5×10^{-5} ft^2/day from a 7-year recovery test on a well bottomed in 30 feet of Triassic rock. The transmissivity of 1,366 feet of Triassic rock in another well in this basin was calculated to be 5.4×10^{-2} ft^2/day.

Although aquifer test data are lacking for the southern Atlantic States, there is an apparent striking change in ground water yield between the northern and southern states. North of Culpeper, Va., especially where the Triassic is blanketed with glacial outwash, sustained yields are quite good for consolidated rocks. The median specific capacity is about 1.0 gpm per ft of drawdown. South of Culpeper, yields are lower. Whether the explanation for the difference in yields is one of recharge, aquifer lithology, degree of regional fracturing, degree of cementation or a combination of causes has not been determined. Recharge from surficial glacial outwash may explain high sustained yields in New Jersey and Connecticut but not in Maryland and northern Virginia where glacial material is absent. Regional fracturing may control the distribution of secondary porosity, but it remains to be established that the Triassic rocks of the northern states are more highly fractured than those of the southern states. Regional change in distribution of lithologic types may control the distribution of primary porosity or the susceptibility of a rock to regional fracturing (rock competency).

Certainly, there appears to be a regional change in the overall lithologic make-up of the Triassic sediments, possibly caused by regional change in source rock, depositional environment, or both. Coal is present from central Virginia southward.

The literature suggests that the bulk of the sedimentary wedge is finer grained and less well sorted in the south. Most volcanism is confined to the northern states. There appears (from small scale maps) to be an increase in metamorphic and mafic igneous source rocks in the southern Piedmont. Certainly, there are no modern unmetamorphosed sedimentary-rock sources in the south such as occur all along the north border of the Newark-Gettysburg basin. Note that the line of apparent change is about 10 degrees south of one proposed location of the equator for 200 million years ago (Phillips and Forsythe, 1972).

WATER CHEMISTRY

The chemistry of the pore fluid of the target aquifer must be known in order to predict their compatibility with potential injected fluids. Knowledge of the subsurface water chemistry serves two other purposes important to waste storage evaluation. The water chemistry also defines the base of potable water and aids in determining the ground-water circulation pattern.

Deep Subsurface Samples

Very few chemical data are available from individual aquifers deeper than 1,000 feet. Available data include one sample from 2,050 feet at Patterson, New Jersey containing 15,900 mg/l total dissolved solids (TDS), one sample from 3,100 feet Triassic in King William County, Virginia with 46,000 mg/l TDS, and several samples from the Dunbarton basin of South Carolina and Georgia ranging in depth from 2,055 to 4,212 feet and from 5,950 to 13,000 mg/l TDS. Unfortunately, most of the available water-chemistry data are from samples collected at the well-discharge point. There is no possible way of determing the depth or individual water quality of the contributing aquifers.

Shallow Samples

Chemical analyses from wells between 400 and 1,000 feet deep (table 4) indicate that the chemical facies of waters from the Connecticut and the Newark-Gettysburg basins is essentially a calcium-magnesium bicarbonate-sulfate type except in Maryland where the dominant species is a calcium bicarbonate type (figs. 15-18).

Fig. 15.--Water-analyses diagram of ground water from the Connecticut Valley.

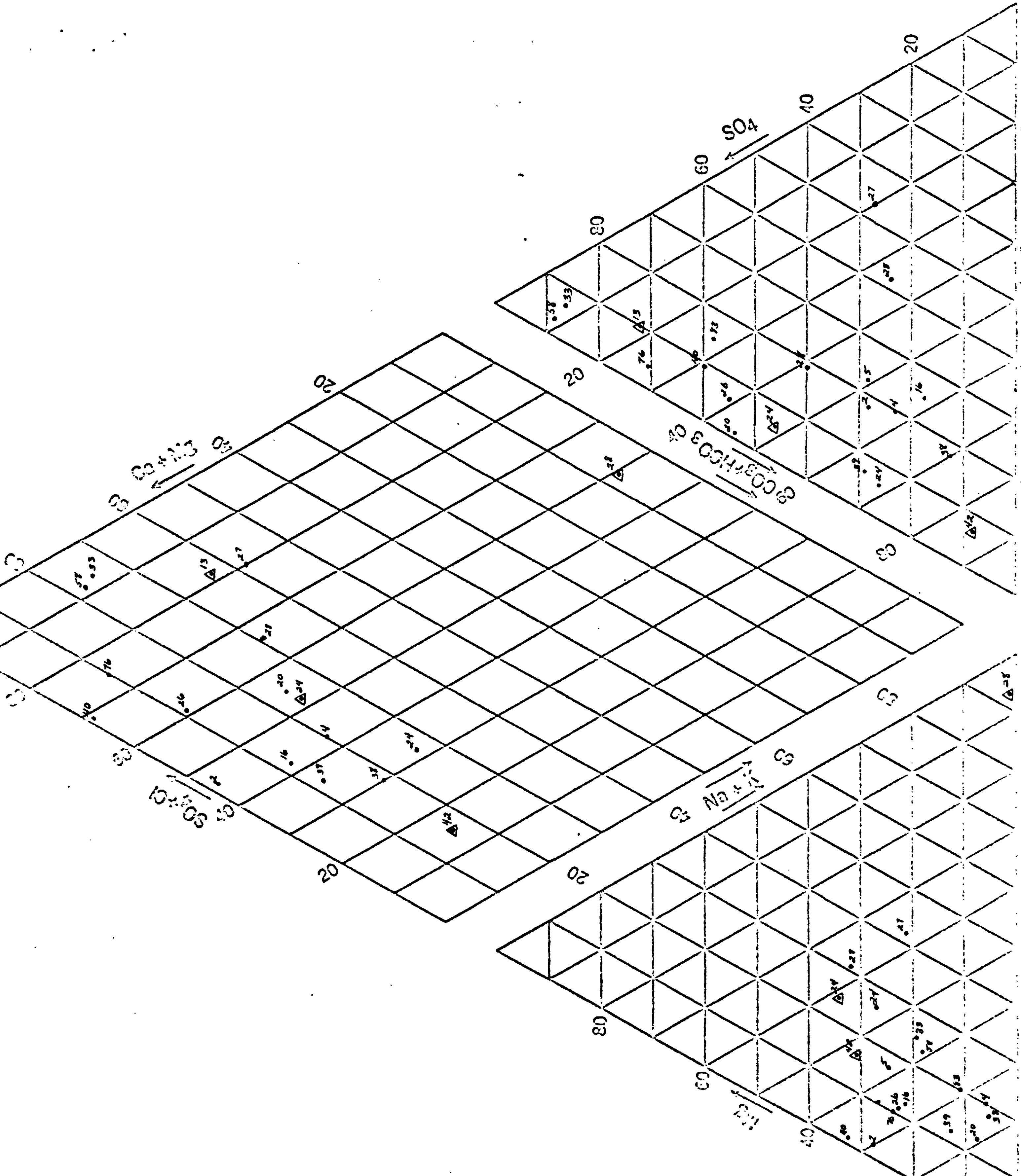


Figure 15.--Water-analyses diagram of ground water from the Connecticut Valley.

Fig. 16.--Water-analyses diagram of ground water from the Newark-Gettysburg basin in New Jersey.

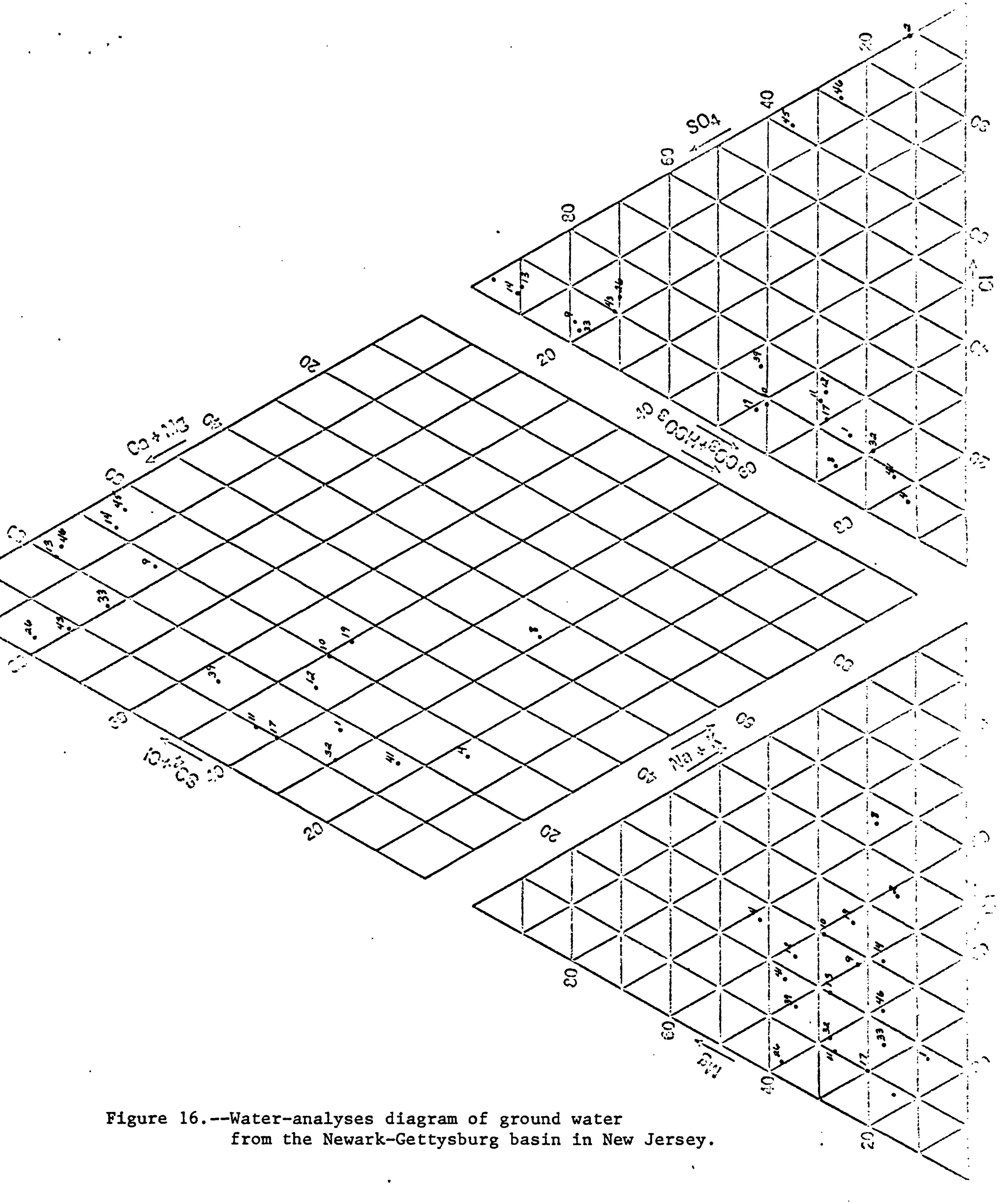


Figure 16.--Water-analyses diagram of ground water from the Newark-Gettysburg basin in New Jersey.

Fig. 17.--Water-analyses diagram of ground water from the Newark-Gettysburg basin in Pennsylvania.

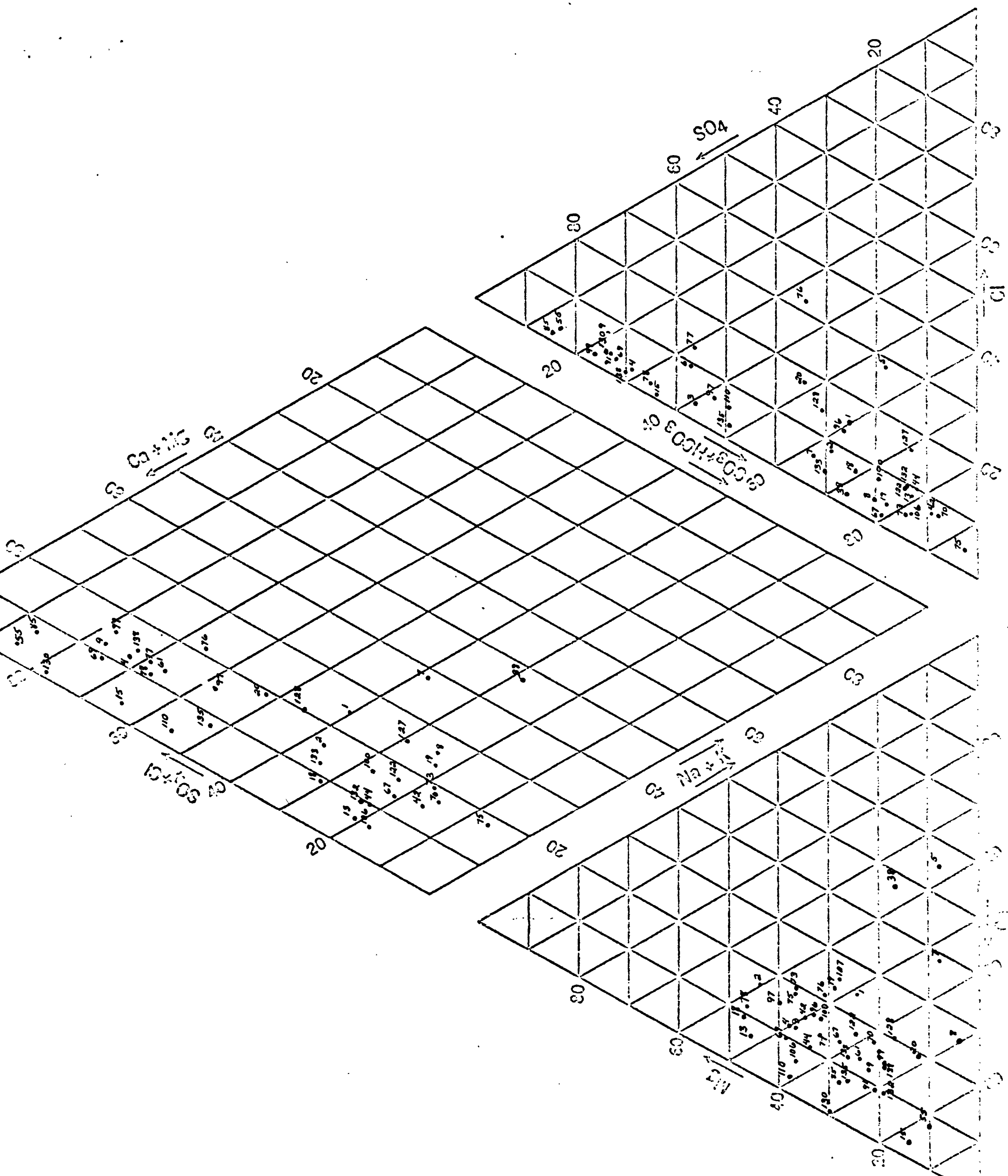


Figure 17.--Water-analyses diagram of ground water from the Newark-Gettysburg basin in Pennsylvania.

Fig. 18.--Water-analyses diagram of ground water from the Newark-Gettysburg basin in Maryland.

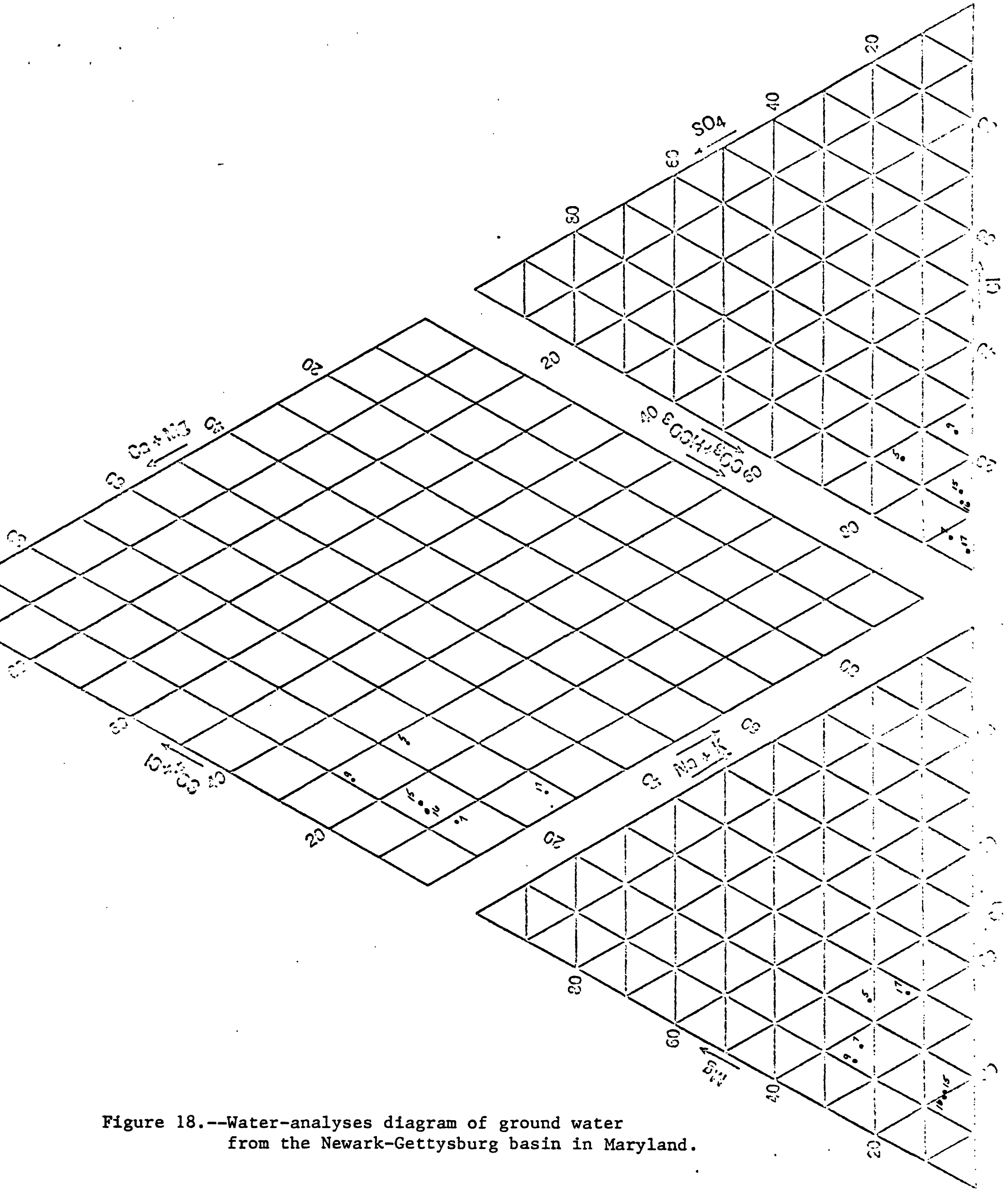


Figure 18.--Water-analyses diagram of ground water from the Newark-Gettysburg basin in Maryland.

Sodium is more plentiful in Connecticut and New Jersey; therefore, a few sodium bicarbonate types are represented. Seemingly, sodium bicarbonate water is restricted to the shallowest ground water. The deeper water in the northern area appears to be a calcium sulfate type, changing with increasing depth to a sodium chloride brine. Figure 19 is a graph of sulfate and carbonate plus bicarbonate versus dissolved solids in the Stockton Formation of eastern Pennsylvania (Rima, et. al., 1962). The graph shows that no bicarbonate is added after the water contains 200 mg/l TDS and that sulfate concentration increases sharply above 250 mg/l TDS. Holzer and Ryder (1972) also noted that in the Connecticut Valley, the character of the water changes from a calcium sodium bicarbonate type to a calcium sulfate type as the concentration of dissolved solids increased.

The presence of a calcium bicarbonate type water in Maryland (fig. 18) may reflect a change to a carbonate source rock, a decrease in evaporites in the sediments, increased flushing by circulating ground water, or the smallness of the sample size (fig. 18). The trilinear plots (fig. 20) of water from south of the Potomac River in northern Virginia resemble those of eastern Pennsylvania. Chemical data are unavailable from wells deeper than 400 feet for central and southern Virginia.

In North Carolina and South Carolina (fig. 21), sulfate is conspicuously absent as a major anion, and most of the deeper water sampled are sodium bicarbonate and sodium calcium magnesium bicarbonate types. Sodium chloride and rare, puzzling calcium chloride types are also present in the Triassic of North Carolina.

Fig. 19.--Graph showing the relation of carbonate plus bicarbonate and sulfate concentration to dissolved solids concentration.

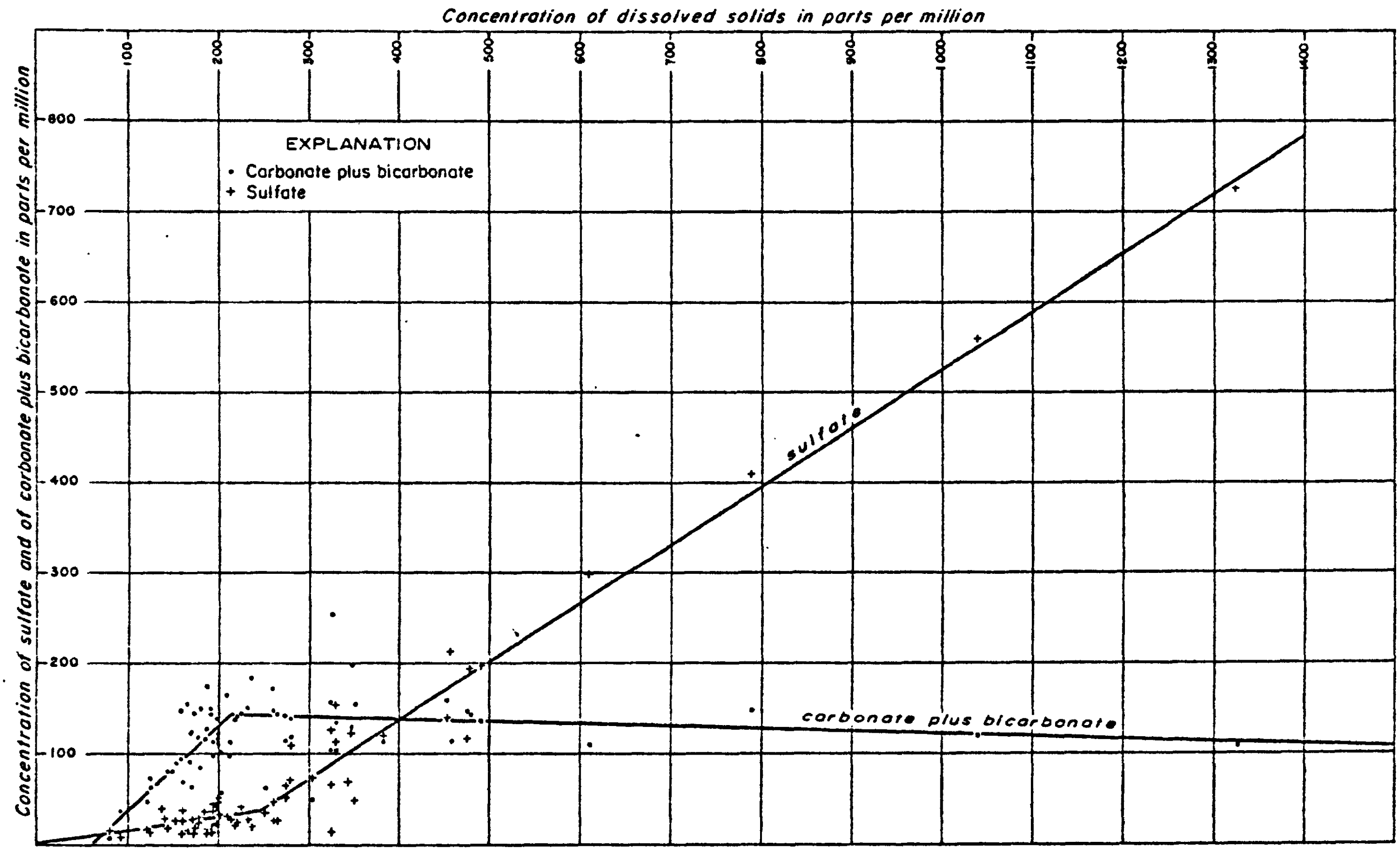


Figure 19.--Relation of carbonate plus bicarbonate and sulfate concentration to dissolved solids concentration. After Rima, and others, 1962.

Fig. 20.--Water-analyses diagram of ground water from the Culpeper basin of Virginia.

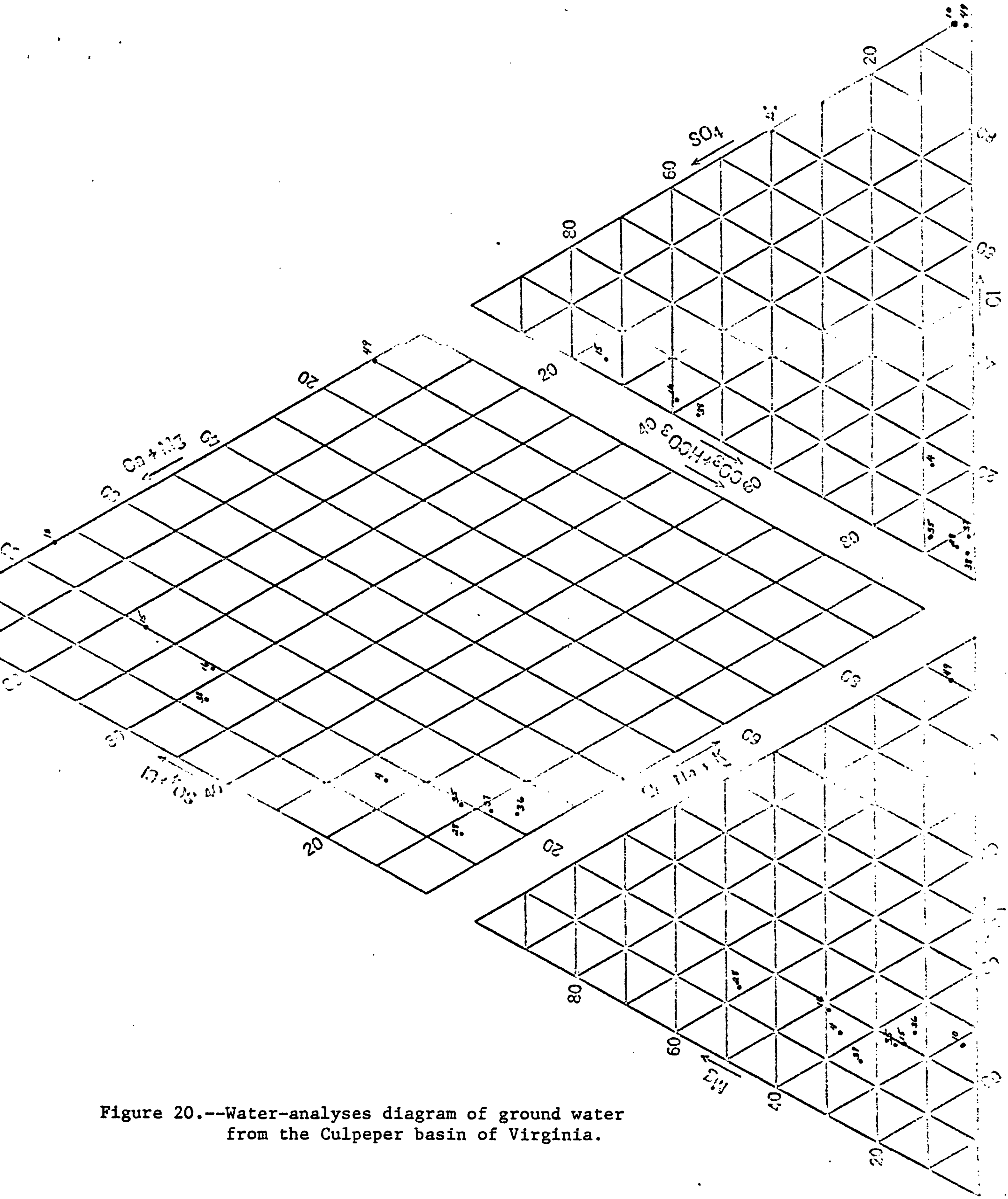


Figure 20.--Water-analyses diagram of ground water
from the Culpeper basin of Virginia.

Fig. 21.--Water-analyses diagram of ground water from Triassic basins in North Carolina and South Carolina.

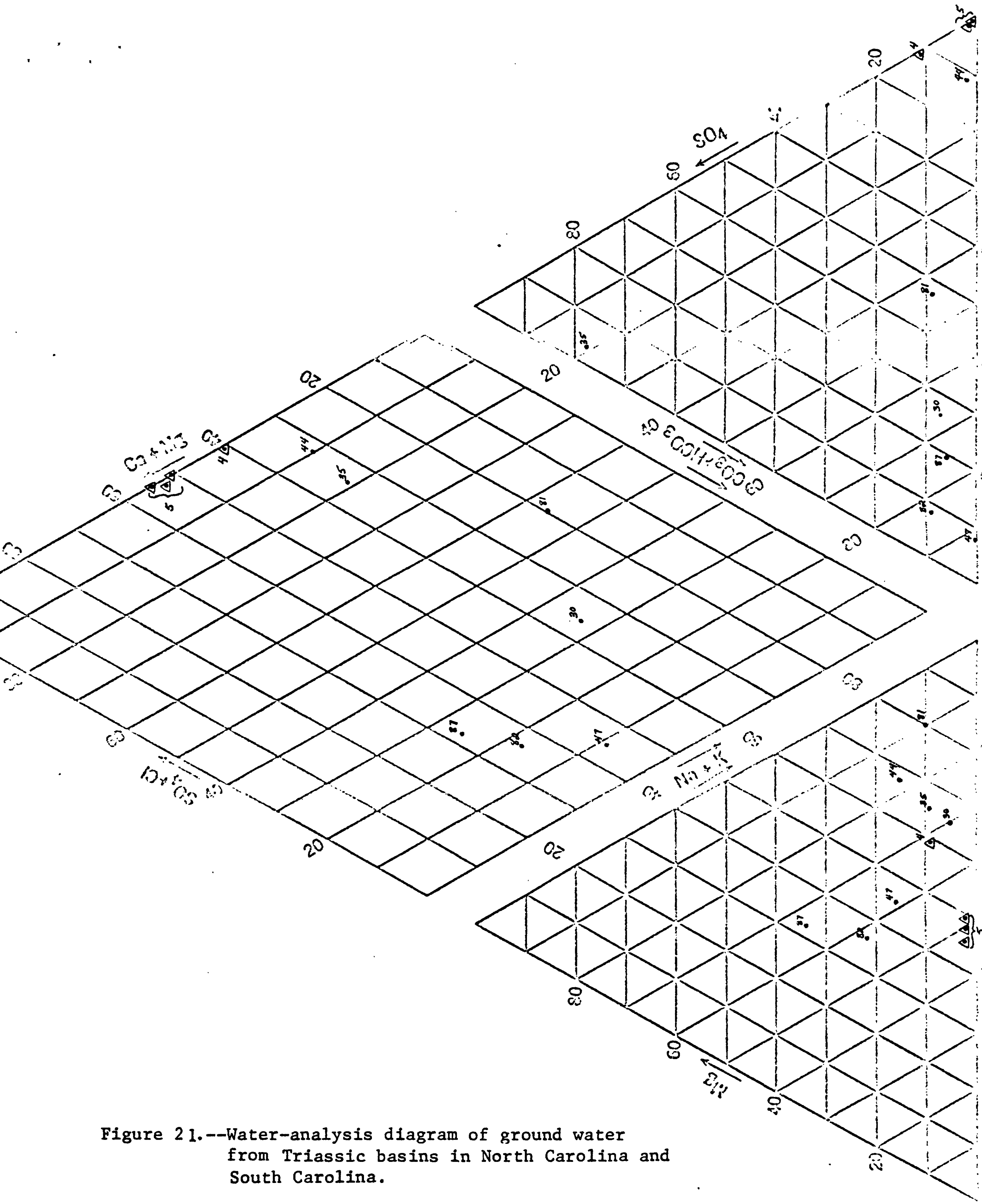


Figure 21.--Water-analysis diagram of ground water from Triassic basins in North Carolina and South Carolina.

The chemical constituents and their concentrations in ground water at any one locality and depth are dependent on such interrelated factors as mineralogy of host rocks, chemistry of water during deposition, ionic diffusion, membrane filtration and residence time. Residence time is primarily a function of the rate and depth of ground-water circulation -- which is in turn dependent on the physiography and transmissivity of the rocks.

The preponderance of calcium sulfate water in rocks of intermediate depth (200 to about 1,000 feet) may reflect either mineralogy of the parent rocks or depositional environment. According to the literature and a cursory inspection of small scale geologic maps of the United States, the source rocks for at least the northern basins are acidic to intermediate in composition. Potash, plagioclase feldspar, and mica are abundant in most Triassic sedimentary rocks. Albite (sodic plagioclase) cement increases near faults in Connecticut (Heald, 1956) and is presumed to be a late magmatic differentiate. Calcite ($CaCO_3$) cement is quite common. Thus, there is ample supply for sodium, calcium, and magnesium.

The major anions may be derived partly from the evaporate minerals reported in some Triassic sediments. Klein (1962), Emerson (1917), and Thayer (1970) have reported salt crystals in the Triassic. Gypsum plates were reported by Herpers and Barksdale (1951) at about 856 feet in the Celanese Corp. well in Newark, New Jersey. Wherry, in Bascom, and others (1931), reported mineral cavities in the Brunswick Shale such as might have been occupied by the mineral glauberite. Pyrite is found in the Springfield-Holyoke area of Massachusetts in calcareous shale. Thus, there is ample source material for the observed anions.

Possibly, the lower concentration of calcium in the deeper North Carolina Triassic water and its relative abundance as a chemical constituent farther north is related to the apparent increase in basaltic volcanic material in the northern sediments. However, it may only reflect increased sodic source rocks to the south.

The shallow calcium chloride waters in the Triassic of North Carolina are puzzling unless they are from a ground-water discharge zone undergoing a cation-exchange process wherein $CaCl_2$ is the end product of a calcic sediment flushed with a sodium chloride brine. Sea water invasion in the geologic past is an obvious possible source for the chloried anion; so is the mineral halite. The maximum landward extent of the sea strand in Mesozoic and Cenozoic time is not known. However, Coastal Plain sediments of Cretaceous age still overlap the Triassic in New Jersey, and Cretaceous and Tertiary sediments overlap the Triassic of central and southern North Carolina. Calcium chloride water also occurs in a low yielding 1,000-foot well in diabase in northern Virginia.

Subsurface Flow Systems

There are essentially no data in the literature concerning the depth, rate, and direction of subsurface water movement deep in the Triassic rocks. Otton (1970) estimated that the depth of "lethargic circulation" in the Triassic rocks may be 1,000 feet or more, based on the chemical analysis of water from one well in diabase near Herdon, Virginia. Indeed, the high TDS water may indicate that water in this diabase is isolated from that in the surrounding rocks, because a 1,000-foot well at nearby Dulles Airport yields 600 gpm or more of potable water from Triassic sandstones and shales. Carswell (1970) points out that ground water in the upper parts of the Newark basin (Rockland County, N. Y.) is of fairly good quality with sulfate ranging from 6 to 64 mg/l. In contrast, he finds that water in the lower part of the basin in New Jersey is highly mineralized and sulfate ranges from 87 to 966 mg/l. He reasons that the high sulfate concentrations may represent the quality of water in the longest and slowest path in the ground-water flow system.

Unless the basement rock is more permeable than the encapsulated Triassic, the expected ground-water discharge path should be to the major longitudinal and transverse rivers in each basin. Major faults and diabasic intrusives may serve as major barriers, dividing each basin into smaller sub-flow systems. The necessary hydraulic-head data and straddle-packer water samples necessary to define the flow system for a basin or part of a basin in any detail are not available. Figure 22 is a graph which shows that dissolved-solids content in water from Passaic County, New Jersey (Carswell and Roomey, 1970) decreases with elevation of both the top and bottom of wells. The graph hints at both depth and/or topographic (distance from discharge) control of dissolved solids.

Fig. 22.--Graph showing the relation of dissolved solids to the altitudes of wells tapping the Brunswick Formation.

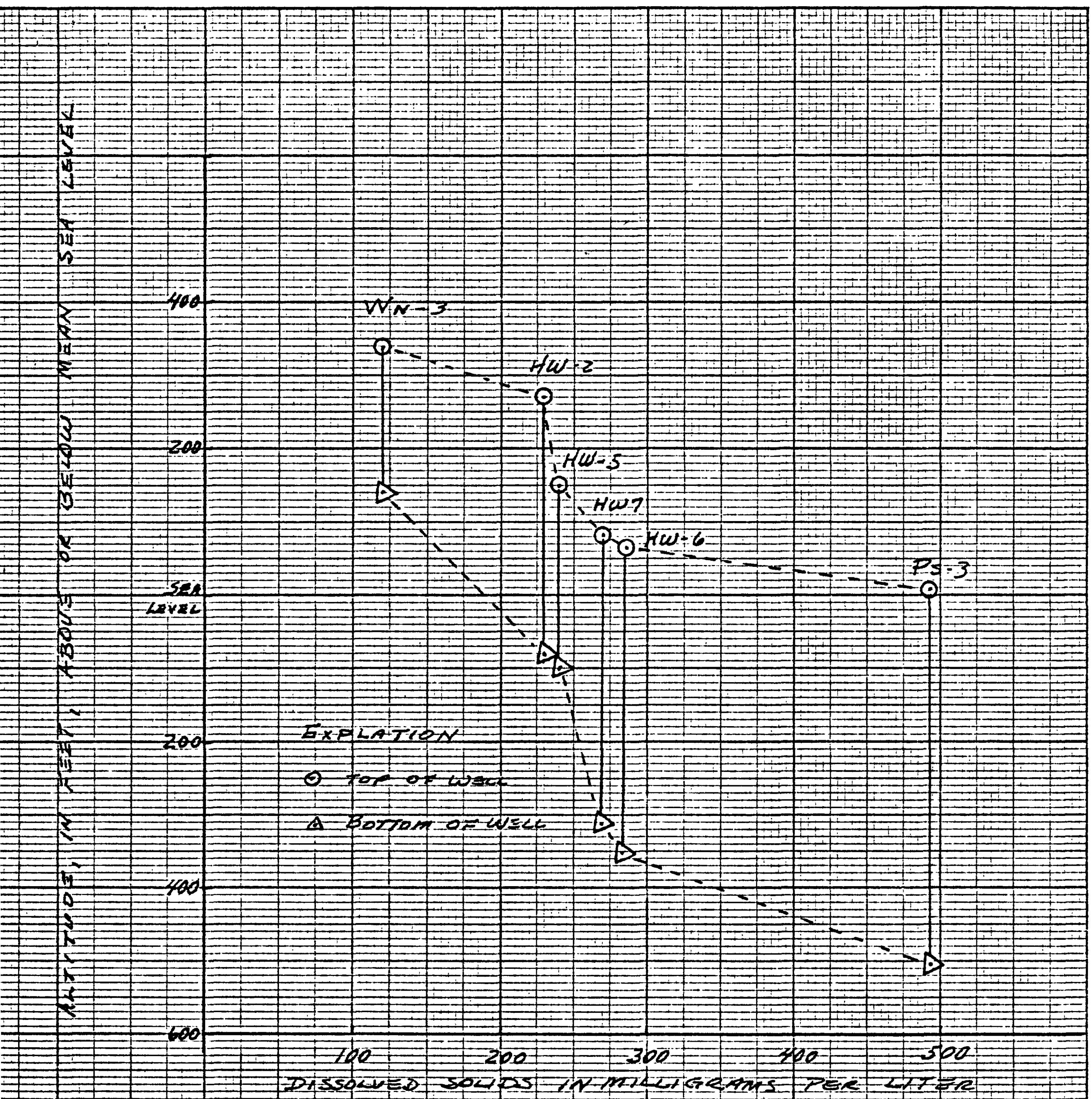


FIGURE 22 RELATION OF DISSOLVED SOLIDS TO THE ALTITUDES OF WELLS TAPPING THE BRUNSWICK FORMATION. AFTER CARSWELL AND ROONEY, 1970

Figure 23 is a topographic map of eastern Pennsylvania whereon the available sulfate data for wells deeper than 400 feet have been plotted. The resulting sulfate distribution map clearly shows a good relationship of highest sulfate in proximity to major streams. In the past, high sulfate content in ground water near streams in this area has been attributed to industrial pollution. It is just as plausible to expect sulfate content to be greatest along the ground-water discharge zones.

Fig. 23.--Map showing sulfate concentration in ground water from wells deeper than 400 feet in eastern Pennsylvania.

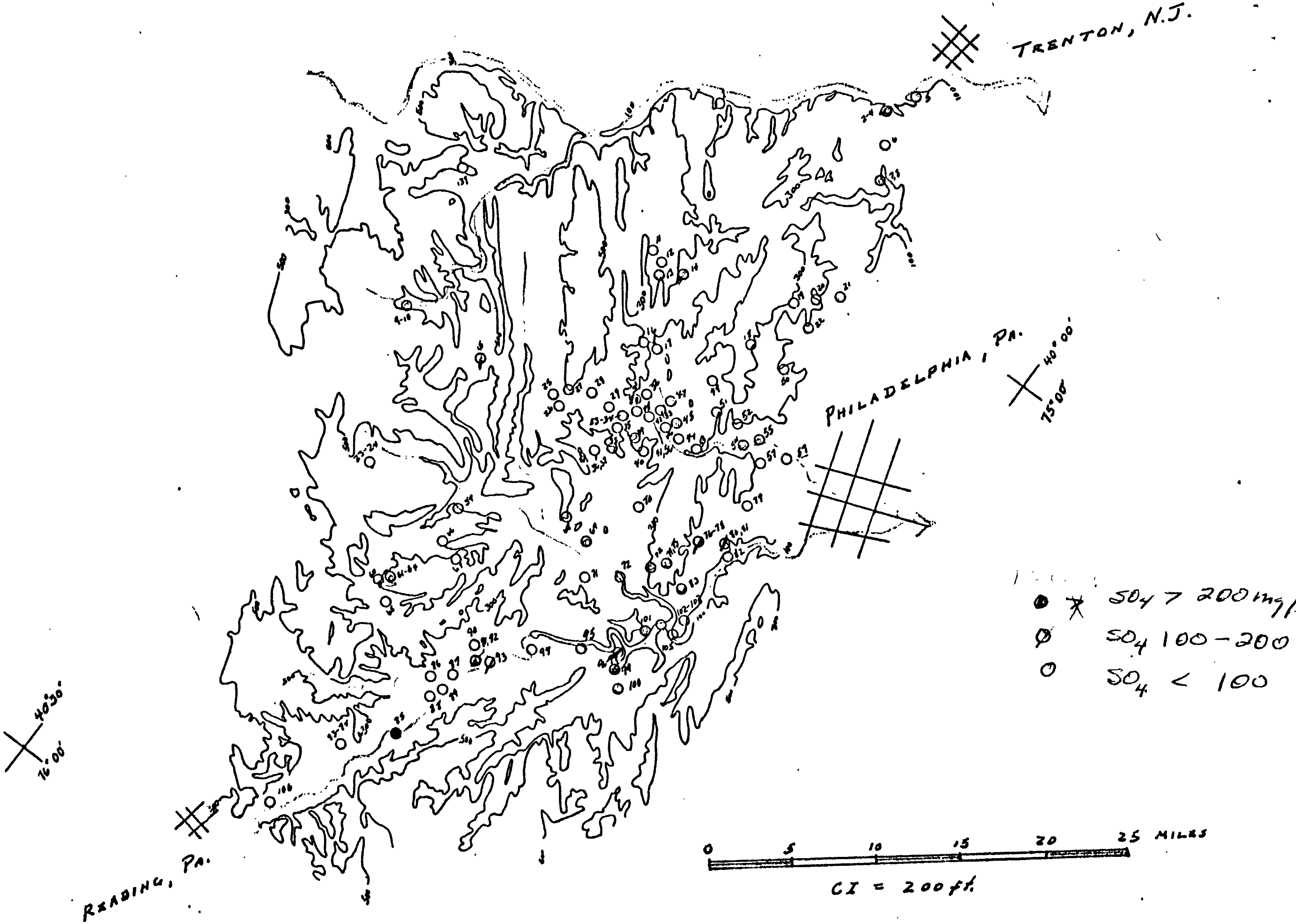


Figure 23.--Sulfate concentration in ground water from wells deeper than 400 feet in eastern Pennsylvania.

GEOPHYSICS

Electric and Radiometric Logs

The subsurface investigation of any geologic terrane is greatly facilitated by various kinds of geophysical logs which record inherent and induced physical and radiometric properties of rocks at depth.

Copies of almost all geophysical logs of deep wells in the Triassic have been assembled. However, there is great variation in geographic coverage, type of logs, and quality. Usually, only the commercial logs are calibrated and most holes have only the SP (Spontaneous-Potential) and resistivity logs. The most detailed log coverage of wells of the 400- to 1,000-foot range is in the Pennsylvania-Maryland area. The few good calibrated logs are limited almost entirely to the buried basins in the Coastal Plain, but even there, only SP and resistivity logs are generally available. The available borehole geophysical data are summerized in Table 5.

Bulk Density

A few gamma-gamma and neutron logs were available for deeper holes. Bulk density in the recently drilled 875-foot well at Dickerson, Md., ranged from 2.50 to 2.80 grams/cm^3, and averaged about 2.62 grams/cm^3 for the sandstones and 2.75 grams/cm^3 for the calcareous shales. All log-calculated sandstone porosities were well below 10 percent. Most were in the 1 to 5 percent range.

Bulk densities from a log of the Triassic rocks in the E. T. and Shirley Thompson 3,029-foot well in King George County, Va., ranged from 2.53 to 2.78 gm/cm^3, indicating porosities in the same general range as those in Maryland.

Gravity, Seismic, and Magnetic Intensity

Small-sclae Bouguer gravity anomaly (fig. 24) and magnetic-intensity maps and seismic profiles are available for the East Coast, Piedmont, and Coastal Plain. Seismic profiles made before 1966 can be found in Maher (1971). The maps and profiles reveal the complex fabric of the upper crust along the Atlantic Coast. A northeast grain sub-parallel to the Appalachian trend is quite pronounced, particularly on the aeromagnetic map (U. S. Naval Oceanographic Office, 1:1,000,000).

Fig. 24.--Map showing Bouguer gravity anomalies along the Atlantic Coast.

Both gravity and magnetic maps show a close, but not unique, correlation of Triassic basins with areas of low magnetic intensity and negative gravity. Both maps indicate a likelihood of Triassic grabens occurring on the submerged Piedmont between Long Island, N. Y. and the Delmarva Peninsula. The magnetic-intensity maps are not detailed enough to identify individual diabase intrusives which should show up as local "highs".

The gravity and magnetic maps clearly define the edge of the Continental Shelf and major transcurrent offsets in the crust. Three offsets of major importance are the Kelvin displacement approximately along the 40° parallel, the termination of Appalachian grain in northern Florida, and a north-south lineament in eastern North Carolina and Virginia at about 76°30' west longitude. Seismic and gravity studies have confirmed that the Piedmont surface beneath the Coastal Plain is not a simple monoclinal slope to the east. Instead, major northwest-southeast structural elements in the crust have fluctuated vertically in the geologic past to control the distribution of Coastal Plain sediment (Brown, Miller, and Swain, in press).

Although the above maps suggest the location and outline of buried Triassic basins, they are not sufficiently detailed to draw the conclusions about the existence of buried basins, much less their depth, geometry, or rock composition necessary for waste-storage evaluation.

Aeromagnetic surveys at flight-path spacings ranging from one half mile to one mile have been made for all of the eastern United States north of the Virginia-North Carolina border. Detailed aeromagnetic maps for most of the states in the northern Piedmont are being published at a scale of 1:20,000. The New England Office of Environmental Geology, U. S. Geological Survey, has found these maps useful in tracing and identifying Triassic faults in the Connecticut Valley.

Detailed gravity work is currently being done in several states by state geological surveys and universities. The Virginia Division of Mineral Resources, for example, has a current Bouguer gravity and vertical magnetic intensity mapping program, and maps are available that cover parts of the Triassic basins in that state (Johnson, 1971).

A statewide Bouguer gravity map is available for North Carolina (Mann, 1962), but detailed work is confined to specific small areas such as that done by Zablocki (1959) in the Deep River basin and by Thayer and others (1970) in the Danville basin. Residual gravity anomaly maps, such as prepared by Zablocki by subtracting regional gravity valued from measured valued, do a fair job of delineating major intra-basin structures and bracket the maximum and minimum depths to basement floor.

Seismic data in the Piedmont are few. Most of the available seismic profiles are restricted to the Coastal Plain. Seismic profiles have been made recently in the Brandywine basin of Maryland (Frank Jacobeen, personal communication) and in the Dunbarton basin of South Carolina-Georgia. There are also a few single-shot-point depths available. The Deep River basin of North Carolina is scheduled for detailed seismic study during the summer of 1972 by a major oil company.

The detailed seismic profile survey promises to be the most economical method of accurately determining Triassic-basin geometry in a short time.

Earthquake Frequency

The East Coast of the United States, although considered rather stable tectonically, experiences several-low intensity earthquakes each year. Some of these are felt over large areas. Bollinger and Hopper (1972) and Hopper and Bollinger (1971) have complied the earthquake history of the Central Atlantic States -- Maryland, Delaware, West Virginia, Virginia, and northern North Carolina -- for the period 1758-1970. The annual earthquake frequency for that period is quite variable, but is almost always 10 to 13 shocks per decade (Bollinger, 1969). The most severe earthquake in the above area occurred in Giles County, Va., in 1897. It was felt over a 280,000-square-mile area and had a modified Mercalli intensity of VIII.

Figure 25 is a map showing the location of earthquake epicenters in relation to the Triassic basins in the central Piedmont. Two things are immediately clear: (1) The epicenters are aligned along several east-west orientations or patterns transverse to the Appalachian (and Triassic) grain and possibly follow one north-south pattern between longitude 78° and 79° in addition to the possible northeast ones in western Virginia and North Carolina; and (2) only two epicenters are in or adjacent to known Triassic basins. Apparently, tectonic adjustments made in the crust in historical times have not been made along old border faults.

Fig. 25.--Map showing geographic relation of Triassic basins to historic earthquake epicenters in the central Piedmont.

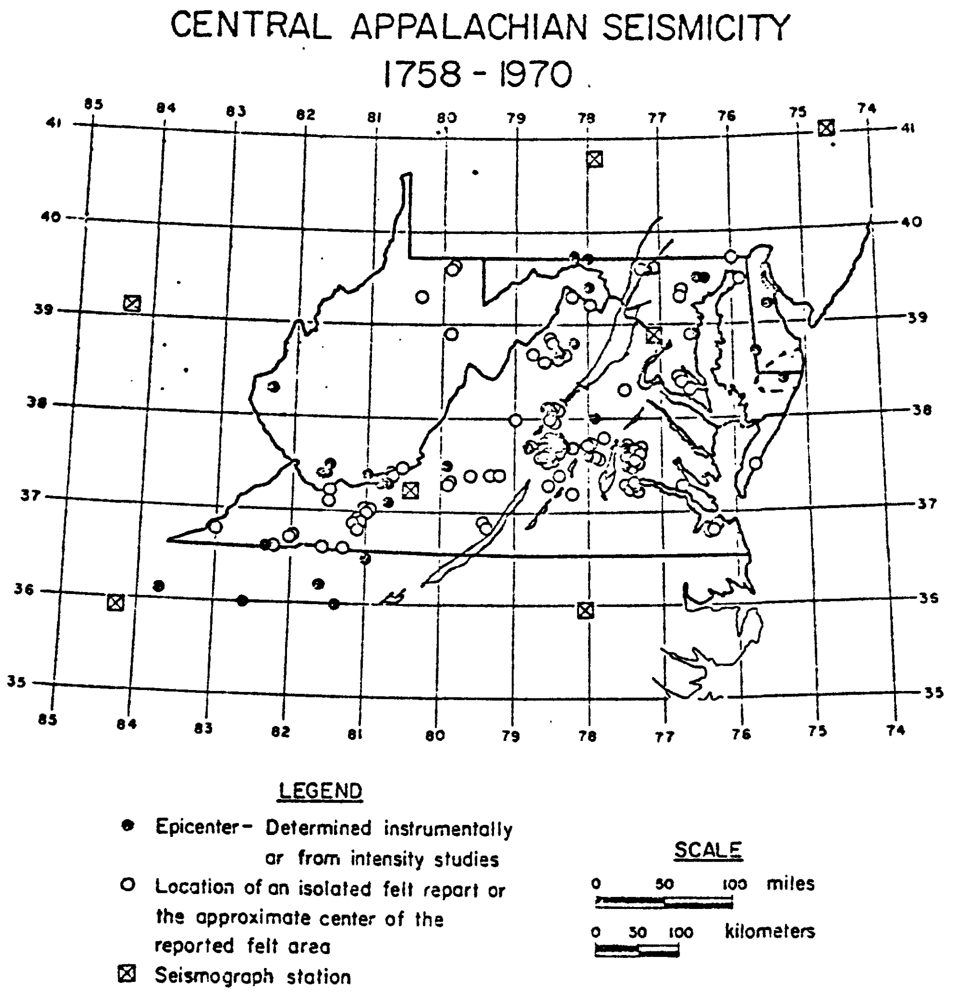


Figure 25.--Areal relation of Triassic basins to historic earthquake epicenters in the central Piedmont. After Bollinger and Hopper, 1972.

It is important to remember that the above area covers only about one third of the outcrop area of the East Coast Triassic, but it serves to illustrate that, in planning for surface or subsurface seismic sensitive structures, the active transverse fault zones may have been overlooked because of preoccupation with faults in the Triassic basins.

Epicenter and earthquake frequency data are available from the Coast and Geodetic Survey, NOAA. Jerry Hadley of the U. S. Geological Survey is currently compiling these data for the eastern United States in cooperation with NOAA and AEC.

Reservoir Competency

The point at which a rock ruptures under a given set of physical conditions is of prime importance in evaluating the potential of any geologic situation for the storage of liquids and gases. If the rupture point of rock containing injected toxic fluids is exceeded, the results can be disasterous. There are at least three additional types of data that should be considered in making a basin-storage evaluation -- pore pressure, rock strength, and regional tectonic stress or residual stress. The first can be evaluated during a drilling program and the second from rock core. The third is more difficult to obtain. Perhaps the necessary data can be obtained from observation of residual stress in the minerals of the rock core or from "stress" meters implanted in the core hole.

Very few data are available on pore pressure, residual stress, or rock strength of Triassic rocks in the deep subsurface. However, the tensile strength of core from the Deep River Coal Field, N. C., has been measured (Table 3) in anticipation of that need.

CONCLUSIONS

The data needed to determine whether the Triassic basins definitely do or do not contain suitable subsurface sites for the emplacement and storage of waste liquids are not available. Information considered absolutely essential for a preliminary evaluation and subsequently searched for in the literature and unpublished files included:

1. Some concrete evidence of the existence of reservoir rock having some useable primary or secondary pore space, below the zone of potable water.
2. The predictability of the lateral extent and fluid integrity of individual lithologies.

The amount and distribution of primary and secondary pore space in the rocks of the deep subsurface is unavailable simply because these rocks have not been tested. There are three wells below 1,500 feet on the Atlantic Coast from which rock samples have been tested for laboratory permeabilities.

There is no confident predictability to the few deep data available because geologists question the proper structural and sedimentary models to use in solving Triassic subsurface problems. In fact, the diversity of structural and sedimentological models in the literature proposed to explain surface observations about the Triassic, speaks eleoquently about the paucity of subsurface data.

There is nothing in the literature or elsewhere which suggests that the bulk lithologic character, texture, composition, etc. of the Triassic rocks in the subsurface differ materially from those lithologies, textures, and composition seen at the surface.

What is in doubt is the probable lithologic facies representation at a given depth at any site, due to uncertainty as to the correct stratigraphic interpretation. Here, too, the problem is primarily a sampling one. The rocks in question, at depth, -- far down dip -- have not been drilled and sampled. Geologists have had to rely upon projections of their own surface observations into the subsurface. In addition, each author has his own ideas as to what the sedimentary facies distribution might be.

The dearth of pertinent subsurface data has resulted in a report which deals mostly with what clues the surficial data might have to the geologic, hydrodynamic, and geochemical conditions at depth. The available data and literature suggest that:

1. The bulk of Triassic rocks are well cemented and due to their short and rapid transport, are poorly sorted, and feldspathic with low inherent primary porosity. However, sustained high energy depositional environments existed where a major stream discharged into a Triassic basin during Hammer Creek time in south central Pennsylvania. Sorting of the sandstones and conglomerates of the Hammer Creek were greatly improved, especially near the outer fringes of the deposit. Its superficial similarity to the rocks of the Colon cross Structure of the Deep River basin in North Carolina suggests that such sands may be more plentiful than formerly realized.
2. There is a marked decrease in secondary fracture porosity in the 300- to 500-foot-depth zone as indicated by fresh-water yields.

3. Substantial porosity and permeability of some kind exists in thin artesian aquifers below the shallow fracture-porosity zone to an unknown depth and to an unknown lateral extent in some of the Triassic basins as is evidenced by yields of the 2,000-foot Patterson, N. J., well and the Revere, Pa., well. Rima's (1955) work in eastern Pennsylvania also supports this proposition.
4. Ground water in Triassic basins discharges to the major trunk streams. The depth of effective circulation is unknown, but the depth of potable water (less than 1,000 mg/l TDS) appears to lie between 1,000 and 2,000 feet. Intra-basin circulation is modified (perhaps greatly so) by diabsase intrusives, extrusives, and faults.
5. Water yields (based on very few data) decrease southward from the Culpeper basin. Whether this reflects poor data, difference in recharge, difference in degree of regional fracturing, difference in sorting, difference in degree of cementation, or change in source rock is unknown.
6. Most Triassic basins are deep enough for waste disposal. The Connecticut and Deep River basins are at least 10,000 feet deep and the Newark-Gettysburg basin may be as much as 30,000 feet deep.
7. There is a possibility that blocks of Triassic sediment are encapsulated by Triassic diabase intrusives.

Plate 1.--Well location map.

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Table 3.--Physical properties of Triassic rocks.

Identification Number	Depth (ft)	Rock Unit	Specific Gravity (g/cm^3)	Density (g/cm^3)	Porosity (percent)	Permeability [$(\mu m)^2$] X 10^{-5} Vertical	Permeability [$(\mu m)^2$] X 10^{-5} Horizontal	Tensile Strength (psi)
DUNBARTON BASIN, SOUTH CAROLINA - GEORGIA								
Well No. P5R	1,309-1,309.8	Gray-brown fine sandstone	2.71	2.54	5.5	0.3	0.5	
Well No. DRB9	1,001.6-1006.1	Gray gritty plastic clay; Tuscaloosa Fm.	2.62	1.49	43.1	14.1		
	1,011-1,041	Top of Triassic rock						
	1,041-1,042.5	Red silty clay some schist particles	2.64	1.44	45.5			
	1,054.2-1,055.7	Red silty clay some schist particles	2.64	1.66	37.1	5.6		
	1,070.2-1,073.7	Red and gray hard gritty conglomerate	2.72	1.72	36.8	16.0		
	1,081.7-1,082.3	Red and gray hard gritty conglomerate	2.70	1.92	28.9	14.1		
	1,099.4-1,100	Red and gray hard gritty conglomerate	2.66	1.81	32.0			
	1,100.7-1,102.3	Red and gray hard gritty conglomerate	2.74	1.60	41.6	0.9		
DEEP RIVER COAL FIELD, NORTH CAROLINA								
Well No. DH-2, Specimen No. 1	952		2.64	2.58	2.04		4.9	1,765
2	1,062		Broken	--	--		--	--
3	1,423		2.62	2.53	3.35		3.9	

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		DUNBARTON BASIN, SOUTH CAROLINA - GEORGIA						
Well No. P5R	1,309-1,309.8	Gray-brown fine sandstone	2.71	2.54	5.5	0.3	0.5	
Well No. DRB9	1,001.6-1006.1	Gray gritty plastic clay; Tuscaloosa Fm.	2.62	1.49	43.1	14.1		
	1,011-1,041	Top of Triassic rock						
	1,041-1,042.5	Red silty clay some schist particles	2.64	1.44	45.5			
	1,054.2-1,055.7	Red silty clay some schist particles	2.64	1.66	37.1	5.6		
	1,070.2-1,073.7	Red and gray hard gritty conglomerate	2.72	1.72	36.8	16.0		
	1,081.7-1,082.3	Red and gray hard gritty conglomerate	2.70	1.92	28.9	14.1		
	1,099.4-1,100	Red and gray hard gritty conglomerate	2.66	1.81	32.0			
	1,100.7-1,102.3	Red and gray hard gritty conglomerate	2.74	1.60	41.6	0.9		
		DEEP RIVER COAL FIELD, NORTH CAROLINA						
Well No. DH-2, Specimen No. 1	952		2.64	2.58	2.04		4.9	1,765
2	1,062		Broken	--	--		--	--
3	1,423		2.62	2.53	3.35		3.9	

DEEP RIVER COAL FIELD, NORTH CAROLINA-CONT.

Well No. DH-2, Specimen No.4A	1,454		2.65	2.62	0.88	2.9		2,072
4B	--		--	--	--	--		2,552
5	1,341			--	--	--		--
6	175		2.65	2.37	10.72	43		753
Well No. BH-11,Specimen No. 7	222		2.66	2.53	4.82			636
8	246		2.68	2.49	7.11	43		1,446
Well No. BH-10,Specimen No. 9	63		2.71	2.00	26.38	207.2		725
10	104		2.71	2.49	8.00	9.8		1,088
Well No. BH-7, Specimen No.11	1,155		2.66	2.64	0.83	1.9		1,820
Well No. BH-9, Specimen No.12	475		2.68	2.37	11.8	59		789

BRANDYWINE BASIN, MARYLAND

Mudd No. 3, Lab. No. 8103	1,503	Triassic			9.4		0.08883	
8104	1,506	Triassic			--		0.06909	
8105	1,509	Triassic			--		0.08883	
8106	1,511	Triassic			--		0.07896	
8107	1,513.5	Triassic			--		0.06909	
8108	1,515.75	Triassic			--		0.06909	
8109	1,519	Triassic			--		0.06909	
8110	1,521	Triassic			--		0.07896	
8111	1,525	Triassic			--		0.05922	
8112	1,530.5	Triassic			--		0.08883	

BRANDYWINE BASIN,MARYLAND-CONT.

Mudd No. 3, Lab. No. 8113	1,533	Triassic	5.6			0.05922
8114	1,535.5	Triassic	--			1.974
8115	1,537.5	Triassic	--			0.987
8116	1,541	Triassic	--			0.05922
8117	1,546	Triassic	--			0.06909
8118	1,554	Triassic	5.1			0.06909
8119	1,556	Triassic	--			0.07896

STOCKTON FORMATION, NEWARK-GETTYSBURG BASIN, SOUTHEASTERN PENNSYLVANIA

Sample No. 57PA1	0	Conglomerate, very coarse-grained	17.3	38	49	
57PA2	0	Arkose, very coarse-grained	10.9	38	50	
57PA3	0	Arkose, very coarse-grained	19.4	49	50	
57PA4	0	Arkose, medium-grained	30.6	1,100	1,600	
57PA5	0	Arkose, fine-grained	14.4	16	160	
57PA6	0	Arkose, coarse-grained	19.2	210	160	
57PA7	0	Conglomerate, very coarse-grained, Arkosic	7.1	21	16	
57PA8	0	Sandstone, arkosic, very fine-grained, brick-red	10.5		2,100	
57PA9	0	Siltstone, sandy	9.7	16	12	

STOCKTON FORMATION, NEWARK-GETTYSBURG BASIN, SOUTHEASTERN PENNSYLVANIA-CONT.						
Sample No. 57PA10	0	Arkose, medium-grained, buff		25.6	50	110
57PA11	0	Arkose, medium-grained, tan		16.1	5	5
57PA12	0	Arkose, coarse-grained, tan		7.9	1.6	
NEWARK-GETTYSBURG BASIN, ROCKLAND COUNTY, NEW YORK						
Clarkstown	87	Gray sandstone	2.51	5.1		11
Clarkstown	83	Hard red shale and sandstone	2.52	4.7		1.9
Clarkstown	61	Red sandy shale	2.47	6.7		0.8
Orangeburg	0	Sandstone	2.50	10.8		--
Orangeburg	0	Sandstone, fine	1.50	9.8		--
Orangeburg	0	Sandstone, coarse	2.49	12.8		--
Orangeburg	0	Conglomerate	2.55	7.9		--
Rt. 59, east of Rose Rd.	50	Sandstone, fine to medium	--	15.5		0
Rt. 59, east of Rose Rd.	24	Sandstone, coarse	--	20.9		1,520
Rt. 59, east of Rose Rd.	46	Shale	--	10.0		0
Ramapo	0	Conglomeratic sandstone	--	1.1		0

CONNECTICUT BASIN

Specimen No. 38	0	New Haven arkose	<1
39	0	New Haven arkose	1
40	0	New Haven arkose	2
41	0	New Haven arkose	4
42	0	New Haven arkose	3
43	0	New Haven arkose	2
44	0	New Haven arkose	2
45	0	New Haven arkose	<1
46	0	New Haven arkose	1
47	0	New Haven arkose	4
48	0	New Haven arkose	3
49	0	New Haven arkose	2
50	0	New Haven arkose	2
51	0	New Haven arkose	6
52	0	New Haven arkose	4
53	0	New Haven arkose	10
54	0	New Haven arkose	3
55	0	New Haven arkose	<1
56	0	New Haven arkose	<1
57	0	New Haven arkose	<1
58	8	New Haven arkose	1

CONNECTICUT BASIN-CONT.

Specimen No. 59	0	New Haven arkose	6
60	0		<1
61	0	New Haven arkose	4
62	0	Hew Haven arkose	1
63	0	Sugarloaf Fm.	1
64	0	Longmeadow sandstone	<1
65	0	Mount Toby conglomerate	<1
66	0	Portland Fm.	<1
67	0	Portland Fm.	2
68	0	Portland Fm.	2
69	0	Portland Fm.	5
70	0	Mount Toby conglomerate	<1
71	0	Mount Toby conglomerate	<1

Table 5.--Borehole geophysical data from deep wells in eastern Pennsylvania.

Well No.	Total Depth (feet)	Water Character: Conductivity (µmhos/cm)	Resistivity (ohms-m²/m)	Chemical constituents in Mg/1: TDS	SO_4	HCO_3	Fluid Resistivity Log: General Character	Resistivity (Rw) (ohms-m²/m)	Resistance Log: Depth (feet)	Formation Resistivity (Ro)	Formation Factor (F): At specified depths	Ave. $F^{*}=\frac{Ro}{Rw}$
96	750	542	18.2	343	66	199	24-27ΩM most of hole	29	80	3500	120	
							to about 650 ft.	28	280	3200	114	106
							Min is 16M at 740 ft.	29	380	2500	86	
								29	530	3000	105	
96	750	549	18.0	354	70	198	about 28ΩM at top	27	75	2400	89	
								28	275	2100	75	78
								28	385	1800	64	
								28	523	2400	85	
97	752	489	20.0	346	123	127	ranges from 15ΩM to	27	185	6700	250	
							25ΩM. Most of hole	26	250	7500	290	235
							is 23-25ΩM.	25	435	7900	320	
								23	660	1800	78-50	
98	750							21	85	4000	190	
								20	245	4000	200	160
								19	350	2600	137	
								17	685	3800	220	
											57	
99	902	773	12.8	610	298	108						

* Calculated values may be misleading because most porosity is most likely fracture porosity.

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Table 2.--Physical character of selected wells.

Wells penetrate Triassic rocks unless otherwise noted.

Well No.	Location Lat.	Location Long.	Owner	Use of Water	QW Analysis	Log Data	Depth	Depth Cased	Diameter	Altitude	Water Level	Yield	Drawdown	Geology	Remarks
Massachusetts															
1			Montague Paper Company			G	875								High salt content
2	423311N	723711	Dana P. Randall	H			500	20	6	190	25	1			
3	423200N	723723	Consolidated Cigar Company				450	48?	6	160	16	5			
4	422628N	723422	Michael Rensick				475	270?	6	130	F	3			
5			Bedding Bros. Silk Company			G	3700	150?							Dry hole
6	421703N	723545	Charles E. Lyman	H	P		455	214	6	190	145	2			
7			Mt. Holyoke College			G	450								High salt content
8	421531N	723605	Earl Bagg	H			603	70?	6	170	76	4			
9	421306N	723545	Plastic Coating Corp.	N			462	50?	8	90	35	250			
10	421201N	723618	American Tissue Mills	H	P		350-400	350-400							Water unfit for drinking
11			American Writing Paper Co.				720	50?	8		14	450			Not used for boilers
12			Holyoke Cold Storage				500+		3½			25+			
13	421201N	723555	Worthington Corp.		P		404					250			
14	421202N	723252	Westover A.F.B.	H	P	D	755	180	6	245	25	104	147		DD after 54 hrs, hardness-1200, PT
15	421202N	723252	Westover A.F.B.	H	P	D	700	169	6		24	105			Hardness-400, PT
16	421202N	723252	Westover A.F.B.	H	P	D	690	155	6		24	104	203		DD after 54 hrs, hardness-360, PT
17	421202N	723252	Westover A.F.B.	H	P		600		6		24	97			Hardness-195, PT
18	421144N	723652	Farr Alpaca Co., Mill #2	H	P		500		6						Water unfit for drinking
19	421124N	723203	Westover A.F.B.	H		D	475	129	6	230	52	1			
20	421053N	724533	G. Danforth & H. Coomes	H			600		6	260		7			
21	420912N	723508	Fisk Rubber Company	N			808	70?	8	140	--	760			Temp.-57°
22	420919N	723515	Fisk Rubber Company	N	P		500		18-12-8	105		550			
23	420851N	723654	Moore Drop Forge Company	N	P		510	162?	6	70	19	120			Hard water, temp.-56°
24					C		490				270?	100			
25	420823N	723557	H. P. Hood & Sons	A			705	65	6	190	65	100			Temp.-49°
26	420736N	722946	Hillcrest Cemetery	I			400		6	228	12	50			
27	420751N	723654	Springfield Rendering Co.	N			705	65	6	190	65	100			Temp.-49°
28	420721N	723643	Moore Drop Forge Company	N	C		400		6	228	12	50			
29	420633N	723531	Liberty Brewing Company				454	60?	4	60	20	30			Hard water
30	420627N	723534	Springfield Brewery		P		525	87	8	60	22	97			Hard water, temp.-49°
31	420615N	723526	Springfield Cold Store	N			407	69?	8	90	19	125			
32			Highland Brewing Company				650					150	20		
33	420713N	724505	Woronoco Savings Bank	H			612	60	10-8	68	62	75			
34	420811N	724807	Westfield Town Farm				424	60?	10		30	80			Good quality
35	420634N	724427	Westfield Mfg. Company	U			500	108	6	155	18	3			
36			Daniel Bros. Paper Mill				980	66?		170		3/4			
37	420534N	724900	A. C. Smith				860		6	140	15	9½			Salty water
38	420555N	723527	Springfield Gas & Light	U		G	1100								Unsuccessful
39	420512N	723328	Stop and Shop	A			462	40?	6	240	F	25			Once yielded 125gpm, hard water
40	420517N	723318	F. B. Mallory	U			500	106	8	63	45	58			
41	420508N	723214	Diamond Match Company	N			500		6	190	35	30			
42	420512N	723217	Diamond Match Company		C		747	246	6	192	38	35			
							595	131?	8	200	25	125			
							620	130				78			

Footnotes

Use of Water

A - Air Conditioning
C - Commercial
H - Domestic
I - Irrigation
N - Industrial
P - Public Service
S - Stock

Log Data

E - Electric Log
G - Gamma-gamma Log
ML - Microlog
B - Baroid Log
D - Drillers Log
C - Caliper Log

Water Level

F - Well flows

Remarks

DD - Drawdown
gpm - Gallons per minute
ppm - Parts per million
mg/1 - Milligrams per liter
Sp. Cond. - Specific conductance
SC - Specific capacity in gallons per minute per foot of drawdown
PT - Pump test
TDS - Total dissolved solids, milligrams per liter
LSD - Land surface Datum
WL - Water level
Temperature - Degrees Farenheit

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Connecticut

1	420108N	723005	Conn. Dept. of Corrections	U			900	110				140		Hardness-900mg/1, S.C.=1.5
2	415957N	723041	Hazardville Water Co.	P			503	95	8	270	94	120	146	DD after 30 hrs, log
3	415823N	723959	Dr. A. Nath	H			210	38	6	145	--	30	--	Log
4	415858N	723254	Hazardville Water Co.	P			480	26	8	100	14	100	136	
5	415744N	722701	Cedar Knob Golf	I			400	60	6	260	18	50	252	DD after 4 hrs, log
6	415453N	725104	Robert Hannah	H		D	457	--	6	285	0		--	Quality rept. OK, high yield
7	415520N	724822	Lil Fredrikson	H		D	573	97	6		50	½		
8	415637N	724233	C. O. Cagne	H			120	48	6	150	12	15	18	DD after 1 hr
9	415502N	724127	Hank Snow	H			245	102	6	90	5	60	240	DD after 1 hr, log
10	415422N	723812	Shell Oil Company	C			240	32	6	80	25	4	175	DD after 4 hrs
11	415555N	723528	J. Mikalson	H			206	60	6	100	11	15	--	
12	415412N	723548	Alfred Jay	H			223	92	6	100	30	15	145	DD after 4 hrs
13	415308N	724702	Charles Lord	I	P		414	394	6	160	40-70	20	--	TDS=2282
14	415229N	724533	R. D. Shaw	H	C		210		6		26	20		
15	415214N	724316	Hartman Tobacco Company	H			590		8			35		
16	415125N	724530	A. C. Peterson FM	S			456	40	6	190	24	40	432	DD after 8 hrs, log
17	414906N	725338	Windsor Water Company				386	123+			40-60	30	5	590ppm $CaSO_4$(Pynchon,1904),H_2S odor
18	4151 N	7236	Biard Daniels Company				402	17+			10	120		
19	415159N	723433	I. R. Stitch Associates	P	P		500		10-8		23	350		
20	415235N	723359	Cons. Cigar Company	I			400	154	8	160	--	50	--	Log
21	415138N	722906	Vernon Gard Apt.	P			210	90	6	275	38	40	122	DD after 5 hrs, log
22	415005N	724905	American Sumatra Tobacco Corp.	U			460		8	170	12	10+		
23	414951N	724842	Hartford Special Machinery Company	N	P	D	632	166	8	182	34	235	86	DD after 48 hrs, Sp. Cond. 2.7
24	414854N	724429	Connecticut General Life Insurance Company	A	C		609		10-8		20	280		9 other similar wells
25	414853N	724156	J. M. Ney Company	N			400		10		F	200		
26	414747N	723108	Rogers Paper Company	N			575	24	10-8	200	8	448	96	DD after 24 hrs, log
27	414739N	723024	Manchester Water Company	P			650	43	10-8	280	37	300	298	DD after 100 hrs
28	414724N	723020	Manchester Water Company	P			700	32	10-8	295	22	149	188	DD after 10 hrs
29	414745N	723027	Lydall Foulds	N			602	25	10-8	250	35	457	59	DD after 24 hrs
30			Cheney Brothers	C	P		457		8-6		F	250	15	DD 27 at 600gpm, rept. hard
31	414752N	724629	C. F. Morway	H			400		8		14	50		
32	414715N	724638	F. B. Rentschler	H			437		6		11	100		
33	414642N	724152	Bryant & Chapman Dairy		P		398		8			40		Used for refrigeration
34	414715N	724010	Cushman Chuck Company	N			662		8			150		
35	414758N	723939	Fuller Brush Company	U	P		640		8			150		
36	414643N	723654	Burnside Theatre Company	A			600		6		30	140		
37	414633N	723634	Burnside Company	U			447		6		F	265		Very hard, 880ppm
38	414737N	723539	East Hartford Golf	I			400	50	8	120	--	45	--	
39	414600N	723407	Raymond Miller	H			400	125	6	130	--	50	--	
40	414532N	723312	Manchester Pack	N			550	50	6	170	40	18	310	DD after 4 hrs, log
41	414518N	723521	J. N. Della Ripa	H			386	138	6	95	--	½	--	
42	414447N	723350	A. Botticello	S			180	45	6	2-0	60	3	120	
43	414614N	724022	State Theater	A			566		8			97		2 other wells at this location
44	414619N	724051	General Ice Cream Company	U			445		8		--	60		
45	4146 N	7240	Hartford Light & Power Co.				620		12			125		Very hard due to $CaSO_4$
46	4146 N	7240	New England Brewing Company				462		10			350		Rept. hard
47	4146 N	7240	Armour & Company				420		6		F	150		
48	4146 N	7240	Hubert Fischer Brewing Co.	A			500		8		0	75		

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2-C

Connecticut-Cont.

49	4128 N	7314	Wildcat Oil Well			D?	1525							Drilled 1888, basement at 1235 ft.
50	4146 N	7240	East Hartford Manufacturing Co.		P		398				F			Very hard, unfit for boiler use (Pynchon 1904) very large yield
51	4146 N	7240	Mrs. Samuel Colt				1250							Drilled 1863, flowed until 1898
52	4146 N	7240	Armour & Company	A			430				1	100		Rept. hard
53	424558N	724044	Hartford Electric Light Co.	A			620		12-10		13	68		~~Used for refrigeration~~
54	414543N	724434	West Hartford Diner	A			500		6		—	60		
55	414523N	724335	A. C. Petersen Farms				391		6		10	20		Used for refrigeration
56	414523N	724226	Rivoli Theater	A			600		8		12	260		
57	414530N	724102	Billings & Spencer	N			733		6		19	110		
58	414506N	724232	Royal Typewriter Company	U	P		502		8		27	50		
59	414503N	724209	Kilian Steel Ball Corp.	N			480		8		55	160		
60	414438N	724102	Webster Theater	A			500		8		12	106		
61	414310N	724031	Hartford Electric Light Co.	A			700		10-8		—	325		2 other wells at this location
62	414303N	723852	Ballard Oil Company	U	P		404		8		5	--		
63	414321N	723558	Pequot Spring Water Co.	C			540		6		—	30		
64	414430N	724850	C. W. Deeds	H	P		745	100	6	290	40	40		No water below 300 ft.
65	411433N	724852	J. R. Swan	U	P		390		6	335	11	35		Used only for fire protection
66	414433N	724444	Rockledge Country Club	A			500		6					
67	414357N	724353	Elm Theatre	A			480		8		F	280		Flows at 10gpm
68	414347N	724335	Abbott Ball Company	N			702		8		16	200		
69	414427N	724327	Pratt & Whitney Co., Inc.	N			455		8		20	300		3 other wells at this location
70	414309N	724302	Tube Bends Inc.	N			325	205	6	70	36	25	143	Log
71	414323N	724358	HoloKrome Screw Corp.	N			500		8		4	160		
72	414329N	724350	Jacobs Manufacturing Co.	N			400		8		8	130		
73	414202N	724153	Camp Courant				394		6		F	54		Used for pool, flows at 5 gpm
74	414147N	724231	A. N. Jorgenson	H			330	20	6	290	150	10	--	Log
75	414125N	724225	Hi View Motel	H			440		6		70	20		
76	414121N	724426	Indian Hill CC	I			410	18	10-8	120	7	250	129	DD after 28 hrs, log
77	414213N	725142	Gros-Ite & Whitnon Mfg. Cos.	N	C		438	210	8	215		40		2 20-gal pumps set at 380 ft
78	414012N	724728	Fafnir Bearing Company	N			500		8		—	50		
79	414005N	724658	Rafael Department Store	A			540		6		—	93		
80	414004N	724655	LeWitt	A			404	38	6		30	125	90	
81	4136 N	7245	Connecticut Light & Power Co.	H	P		400		6		37	20		
82	413220N	724803	International Silver Co.				560	100+	6		5			Rept. very hard
83	413159N	724747	Charles Parker Company		C		1000			260	70	50?		Drilled 1905, too hard for boilers
84	4129 N	7254	Albert Eich				980?				F			Drilled pre-1909, rept. hard
85	411922N	725546	Winchester Repeating Arms				4000		8					Dry well (1893)
86	411906N	725338	New Haven Iron and Steel Co.				525	406+	6		10	1		
87	411807N	725532	Hoyt Beef Company	C			572	264+	6		10	7		

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2-D

Maryland

1	394050N	771715	Charles Copenhaver	H,S,I			55	6½	6	450	8	80		Pumping WL-40 ft
2	393940N	771020	Cambridge Rubber Company	C			530	23	8	510	8	30		Reported WL
3	393940N	771020	Cambridge Rubber Company				300	78	10-6	510	8			Yield-25gpm (4-3-48), 15gpm (2-?-52)
4	393928N	771010	Taneytown	P			394	33	10	500	36	180	245	SC=0.7-24 hr test
5	393920N	771035	Taneytown	P	C		600	131	12	495	39	300	361?	Sp. Cond.=396, TDS=236
6	393905N	770925	Taneytown	P			416	34	10	570	40	115	200	24 hr PT
7	393752N	770650	U. S. Geological Survey		C	E,C	692	60	6	505	16	40	25	Sp. Cond.=190
8	393657N	772438	City of Thurmont	P	P		105	29	8	470	5	480	42	HCO_3=130
9	393657N	772440	City of Thurmont	P	C	E,C	300	70	8-6	470	4	811	50	T=11,500ft^2/day, PT
10	393620N	771405	R. H. Sheppard-Donelson Co., #1 Roser, et al				6230			472				Oil or gas test well, plugged from 560 to 650 ft
11	392625N	772715	Fort Detrick	P			140	45	6	375	30	65		WL-30ft (9-12-52), 34.62ft (9-25-53)
12	392550N	772637	Fort Detrick	P						325		75		
13	392415N	772632	Joseph Himes	H,S,I			604-615		8-6	420		150		
14			U. S. Geological Survey			E,C,G	880	40	6	220	+6	80		
15	390822N	772418	Poolesville, #2		C	E,C,G	453	65	6	420	30	100	95	TDS=174½
16	390835N	772430	Poolesville, #1		C	C,G	597	65	7-6	405	22	50	137	TDS=158
17	390703N	772542	Levitt & Sons, Inc.		C	E,C,G	344	28	8	310	+3	20		Sp. Cond.=304, TDS=183
18	390410N	772022	National Park Service			E,G	135			190	18			
19	384549N	764810	Washington Gas Light Co., #2 Roberts				1752			211				Stratigraphic test for gas storage
20	384513N	764959	Washington Gas Light Co., #2 Butler				1720			165				Stratigraphic test for gas storage
21	384358N	765215	Washington Gas Light Co., #3 Mudd				1725			118				Stratigraphic test for gas storage
22	384313N	765114	Washington Gas Light Co., #2 Robinson				1818			230				Stratigraphic test for gas storage
23	384249N	765343	Washington Gas Light Co., #2 P. Moore				1523			172				Stratigraphic test for gas storage
24	384205N	765408	Washington Gas Light Co., #1 Hill				1611			219				Stratigraphic test for gas storage
25	384236N	770134	Fort Washington				1000			150				
26	382636N	750320	U. S. Geological Survey, Ocean City Test Well				1212			5	F			Stratigraphic test, open file, TDS= 203(363-373ft), 801(464-474ft), 5240(708-718ft) Not Triassic
27	382426N	750342	Standard Oil Co. of N. J., #1 Maryland Esso			E	7710			8				Oil and/or gas test, dry hole, Triassic (?)
28	381755N	751727	Soconoy-Vacuum Oil Co., #1 James D. Bethards			E	7178			30				Oil and/or gas test, dry hole, Triassic (?)
29	382048N	752913	Ohio Oil Co., #1 Larry G. Hammond			E	5568			70				Oil or gas test, dry hole, Triassic (?)
30	380424N	753422	City of Pocomoke				1540			-1	F			Water well, abandoned but still flows-well on land, overflow pipe is underwater, Cretaceous(?)

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2-E

New York

1	410352N	740002	Spring Valley Water Works & Supply Company	P	P	D	655	54	8	220	42	204		Pearl R. Field, well #22, SC 1.8
2	410810N	735630	Congers Realty, Inc.	H			450		8	140	80	21		
3	411050N	740220	J. Perine	H			317		6	500	35	10		
4	410852N	740253	Spring Valley Water Works & Supply Company	P	P		407	51	14	475	10	1515		New Hempstead Field, well #24, SC 25gpm/ft
5	410635N	740640	Spring Valley Water Works & Supply Company	P	C	D	413	45	8	425	F	240	114	Tallman test well, flows 5ft above LSD, DD after 11 hrs
6	410805N	735932	Spring Valley Water Works & Supply Company	P	P	D	430	53	8	210	11	220		New City Field, well #23, PT
7	410624N	735940	Spring Valley Water Works & Supply Company	P	P	D	477	50	14	286	7	267	195	Bardonia Field, well #19, DD at 270gpm
8	410624N	735940	Spring Valley Water Works & Supply Company				520		8	280	7	204		8ft from #7, connected to #7 by break in wall of rock hole
9	410703N	735945	Spring Valley Water Works & Supply Company	P	P	D	601	24	8	300	23	150		Germonds Field, well #21
10	410350N	740230	Spring Valley Water Works & Supply Company			D	402		6	285	--	67		Pearl R. test well #2
11	410030N	735420	D. Willard	U		D	528		12-8	100	--	--		
12	410339N	735915	Spring Valley Water Works & Supply Company				441		6	66	--	35	185	Naurashan test well
13	410715N	735715	H. Fulle	P	P		500		8	190	35	17		Well No. 2, supplies 35 houses
14	411110N	740315	I. Katz	H	C	D	371		6	540	20	33	69	Reported DD after 4 hrs
15	410653N	740855	Avon Allied Products	U			718	123	10-8	310	14	68		
16	411140N	735750	Haverstraw Laundry				452		8	30	F	90		
17	410405N	740220	Spring Valley Water Works & Supply Company			D	409		6	263	--	72	100	Pearl R. test well #3
18	411130N	740315	D. Walker	H			400		6	540	60	9	180	
19	410430N	740112	Lederle Laboratories, Inc.	C	P		718		8	312	50	44	190	Well D, DD at 100gpm, WL 48'-1947
20	410426N	740115	Lederle Laboratories, Inc.	C	P		400		8	323	28	85		Well E, WL 15'-Dec. 1946
21	410226N	735650	Orangeburg Mfg. Company	N			400		8	80	22	140	155	DD at 135gpm
22	410954N	740415	Pomona Heights Estates, Inc.	P	P		525		10	590	10	75		
23	410310N	735720	Sisters of St. Dominic	T	P		405		10	175	44	128		
24	410239N	735850	Rockland State Hospital	T	P		435		16	91½	38	65		Well No. 6
25	410222N	735651	Orangeburg Mfg. Company	N	P		513	45	8	90	26	150	125	
26	410232N	735647	Orangeburg Mfg. Company	N	P		400		8	80	12	175	52	Near #21
27	411155N	735905	Garnerville Ice Company	N			468		6	180	17	33	90	DD after 24 hrs
28	411205N	740030	The Birchwoods				400		6	390	--	60		Near #29
29	411205N	740030	The Birchwoods				460		6	360	--	65	200	Supplies hotel & swimming pool, DD after 10 hrs at 60gpm
30	411257N	735920	N. Y. State Rehabilitation Hospital	T			400		10	170	--	200		Reserve well
31	410139N	735730	Spring Valley Water Works & Supply Company	P	P	D	500	118	10	203½	83½	300		SC 3.6 in 1947

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2F

New Jersey

1	405537N	741925	Lincoln Park Water Company	P	C	109		5	250	F	30	0	Flows about 30gpm
2			Passaic Rolling Mill Co.		P	2100	1120	8-6 -4½		17& 30	100+	40	TDS-222 at 900ft, 5814 at 1700ft, 15,849 at 2100ft
3	405282N	735925	Tube Sales	C	P	450	89	10	5	3	82	187	SC=0.4
4	404715N	742708	Morristown Memorial Hospital	P	P	504	188	10	340	80	290	108	SC=2.7
5	404715N	742708	Morristown Memorial Hospital	P	P	507	148	10	340	73	325	88	SC=3.7
6	404737N	742630	F. Bott			767	337	6	400	180	115	70	SC=1.64
7	404733N	742570	Fairleigh Dickinson Univ.			602	192	8	221	23	85	27	SC=3.15
8	404342N	742242	Ciba Pharmaceuticals	N	C	600	41	10	210	65	160		
9	404341N	742248	Ciba Pharmaceuticals	N	C	600	36	8	220	80	300	170	SC=1.8
10	404324N	742245	Ciba Pharmaceuticals	N	C	719	199	10	230	109	401	141	SC=2.8-30 hr test
11	404218N	741646	Elas Stop Nut	N	C	503	70	8	105	55	172	85	SC=2.0-8 hr test
12	404215N	741432	Cooper Alloy Company	N	C	536	38	8	85	27	210	84	SC=2.5
13	404150N	741352	Bristol Myers	U	C	400	63+	10	60	28	540	82	SC=6.6-8 hr test
14	404131N	741332	Emeloid Company, Inc.	N	C	461	89	10	40	30	230	37	SC=6.2-8 hr test
15	404106N	741353	Elizabethtown Water	U	P	400	21	12	30	F	870	73	SC=11.9-8 hr test
16	404024N	741708	Elizabethtown Water	P	P	500	38	8	100	52	250	67	SC=3.7-8 hr test
17	404136N	741716	Pyro Plastics Company	N	C	344	326	10	95	14	250	173	SC=1.4-8 hr test
18	403933N	741622	Elizabethtown Water	P	P	508	37	12	70	28	457	111	SC=4.1-24 hr test
19	403900N	741450	Lambert Dairy		C	263			20	9	30		SC=0.2
20	403900N	741450	Lambert Dairy		C	803			30	26	12		SC=0.1
21	404006N	742314	Elizabethtown Water	P	P	540	38	12	225	76	135	119	SC=1.1-9 hr test
22	403940N	742247	Elizabethtown Water	U	P	650	132	8	221	98	300	50	SC=6.0-24 hr test
23	403938N	742250	Elizabethtown Water	P	P	665	125	12	215	112	351	78	SC=4.5-24 hr test
24	403938N	742238	Elizabethtown Water	P	P	708	142	12	230	128	150	84	SC=1.8-24 hr test
25	403928N	742249	Custom Molders	N		514	117	8	210	140	62	60	SC=1.0
26	403925N	742234	Scotch Plains Township	I	C	450	99	8	205	115	150	185	SC=0.8-8 hr test
27	403917N	742215	Elizabethtown	P	P	400	79	12	200	68	295	112	SC=2.6-48 hr test
28	403957N	742136	Elizabethtown Water	P	P	511	92	12	210	72	525	57	SC=9.2-24 hr test
29	403954N	742138	Elizabethtown Water	P	P	506	108	12	220	94	401	35	SC=11.5-24 hr test
30	403913N	742100	Elizabethtown Water	P	P	525	27	12	130	12	495	120	SC=4.1-24 hr test
31	403856N	742054	Elizabethtown Water	P	P	502	40	12	125	46	350	104	SC=3.4-26 hr test
32	403856N	742052	Elizabethtown Water	P	C	523	58	12	130	22	500	110	SC=4.5-26 hr test
33	403801N	741826	General Motors	N	C	504	33	12	65	41	660	46	SC=14.3-27 hr test
34	403746N	741819	U. S. Gypsum	N	P	505	49	12	70	25	536	51	SC=10.4-24 hr test
35	403714N	741341	Standard Oil Company			1556	15+		15	22			Drilled in 1920
36	403653N	741551	Merck Chemical Company	U	P	1108	34+	8	25	17	120		SC=0.5-8 hr test
37	403440N	741660	Security Steel		C	614			30	22	34		SC=0.1
38	403705N	742532	Tepper Brothers	N	P	427	42	12	90	16	560	84	SC=6.7-24 hr test
39	402031N	743813	Princeton Water Company	P	C	503	35	16-10	60	2	150	71	SC=2.1
40	401914N	743732	McLean Engineering Co.	A	C	393	89	8	60	9	150	71	SC=2.1
41	401935N	744740	Pennington Water Company	P	C	657	53	8	200	38	48	112	SC=4.2
42	401436N	744833	Wm. Stothoff Company	H	C	372		8	130	47	284	--	
43	404625N	740808	Pfaff Tool Company	N	P	590	54	8	8	67	185	113	SC=1.6
44	404625N	740808	Pfaff Tool Company	N	P	740	--	8	8	80	145	120	SC=1.2
45	404400N	740637	American Store	N	P	1041			8	28	60	322	SC=0.2
46	404355N	740860	P. Ballentine & Sons	N	C	875	95	16	12	227	375	153	SC=1.79
47	404359N	740925	J. Hensler Brewing Company	N	P	700	57	10-8	12	60	450	240	SC=1.79

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North Carolina

1	363055N	794125	Marshall-Field & Company			150		6	50			2 other wells each 300ft deep yielding 30gpm
2	363110N	794135	Hope Flinchum		P	105		6	20-30			Temp. 58°F
3	362940N	794535	Morehead Mills		P	205		6				Temp. 61.5°F
4	362730N	795435	Town of Stoneville		P	189		8		75		Temp. 61.5°F
5	362725N	795440	Stoneville Furniture			216		8		40		
6	362610N	795142	Roger Baughn			342		6	70	0		
7	362415N	795220	Mulberry Island Farm			290		6		15		
8	362350N	795805	Washington Mills Company	U		300		6		15-20		Hard water
9	362350N	795805	Washington Mills Company	U		700		8		15		Hard water
10	362310N	795800	Town of Madison			500		8		15		
11	362310N	795800	Town of Madison			700		8		15		
12	362235N	795815	Town of Madison			310		8		75		
13	362250N	795838	Town of Madison			300+		8		75		
14	362240N	795950	Y. L. Carter			340		2		3		Slightly hard
15	362225N	800030	H. R. Closson			334		2		5		Moderately hard
16	361810N	800840	Town of Walnut Cove	U		811		10				
17	361810N	800840	Town of Walnut Cove	U		400		8				
18	361725N	800850	N. C. Geological Survey			492						Core hole drilled 1891
19	361755N	800855	Town of Walnut Cove		P	1027		10	18	150	50	Temp. 62°F
20	361720N	800940	N. C. Geological Survey			1112						Core hole drilled 1892
21	361005N	783810	Hubert Gooch	H	C	152	15	6	52	2		Sp. Cond.=330, TDS=208
22	360850N	784350	J. T. Aikens	H	C	94	22	6	20	15		Sp. Cond.=292, TDS=200
23	360545N	784640	S. L. Coley	H		212	110	6	70	12		Well near mafic dike
24	360515N	784630	E. R. Coley	U		236	---	6		½		
25	360625N	785015	Fairntosh Farms		C	300		8	20	25		Sp. Cond.=470, TDS=267
26	360030N	785725	T. E. Scholl		C	300	15	6	---	3		
27						1640						Drilled before 1918?
28	355940N	784915	Kenneth Bailey		C	112		6	40	3		Sp. Cond.=725, TDS=410
29	355740N	784550	A. Lopez,Jr.		C	140		6	25	5		Sp. Cond.=860, TDS=492
30	355650N	785820	R. B. McFarland		C	270	10	6	90	2		Sp. Cond.=728, TDS=433
31	355315N	785020	Raleigh-Durham Airport			264		6		1		Observation well
32	355230N	784725	T. G. Johnson	U		285	---	6	---	2		Observation well?
33	355320N	785650	F. B. McKinney		C	109		6	30	9		Sp. Cond.=1440, TDS=806
34	355140N	785330	Triangle Brick Company			497	20	8	9	3		Observation well
35	354845N	784735	R. Daniel Rambeau	H	C	300	85	6	65	6		Sp. Cond.=2200, TDS=1180
36	354240N	785020	Phillips Gas Dist. Center	U		300	3	6	---	½		
37	353935N	785000	E. G. Brewer	H	C	163	96	6	18	7		Sp. Cond.=92, TDS=89
38	354240N	785725	E. E. Olive	H	C	125	55	6	30	25		Sp. Cond.=180, TDS=137
39	354025N	785620	J. H. Bright	H	C	130	60	6	65	8		Sp. Cond.=228, TDS=156
40	353830N	785635	W. C. Poe	H	C	150	18	6	10	4		Sp. Cond.=400, TDS=260
41	353710N	785435	C. P. Ragan	U		303	45	6	18	½		Hard water reported
42	353800N	790440	Chatham County Schools		C	120	---	4	22	8		Sp. Cond.=200, TDS=136
43	353800N	790315	J. T. Moore		C	140	---	6	13	½		Sp. Cond.=160, TDS=129, observation well
44	353425N	785835	W. O. Jefferies		C	118	28	6	2	0		Sp. Cond.=1150, TDS=696, observation well
45	352940N	791050	Roberts Company			300	20	8		10		
46	353150N	791100	Lyons Motor Court		C	151	---	6				Sp. Cond.=741
47	352440N	791400	Rip Van Winkle Motel		C	318		6				Sp. Cond.=101
48	353340N	791628	Gulf Creosote Company		C	220	---	6	25	15		Sp. Cond.=535, TDS=305

North Carolina-Cont.

49.	353337N	791307	Coal Products, Inc.	U		Ge	779			262			Drilled 1944
50.	353309N	791259	Eavenson, Alford, and Hecks	U		Ge	1254			234			Drilled 1930
51.	353300N	791337	Eavenson, Alford, and Hecks	U		Ge	1700			211			Drilled 1930
52.	353330N	791336	Norfolk & Southern RR					No record					
53.	353330N	791345	Eavenson, Alford, and Hecks	U		Ge	1015			232			Drilled 1930
54.	353351N	791334	Eavenson, Alford, and Hecks	U		Ge	511			229			Drilled 1930
55.	353358N	791417	Norfolk & Southern RR					No record					
56.	353407N	791446	U. S. Bureau of Mines	U		Ge	116			224			Drilled 1945
57.	353401N	791446	Walter Bledsoe & Co.	U		Ge	126			217			Drilled 1945
58.	353358N	791446	Walter Bledsoe & Co.	U		Ge	257			217			Drilled 1945
59.	353346N	791431	Norfolk & Southern RR	U		Ge	650			241			Drilled between 1915-19?
60.	353332N	791411	Norfolk & Southern RR					No record					
61.	353252N	791419	Eaveson, Alford, and Hecks	U		D	900			290			Drilled 1930
62.	353310N	791458	U. S. Bureau of Mines	U		Ge	1546			237			Drilled 1944
63.	353339N	791509	U. S. Bureau of Mines	U		Ge	922			227			Drilled 1944
64.	353334N	791546	U. S. Bureau of Mines	U		Ge	1020			234			Drilled 1944
65.	353317N	791541	U. S. Bureau of Mines	U		Ge	1468			247			Drilled 1945
66.	353257N	791530	U. S. Bureau of Mines	U		Ge	1936			260			Drilled 1944
67.	353238N	791524	U. S. Bureau of Mines	U		Ge	2328			246			Drilled 1947-1948
68.	353336N	791619	Walter Bledsoe & Co.	U		Ge	737			227			Drilled 1945
69.	353332N	791619	Walter Bledsoe & Co.	U		Ge	983			220			Drilled 1945
70.	353319N	791630	Walter Bledsoe & Co.	U		Ge	1300			249			Drilled 1945
71.	353302N	791652	Walter Bledsoe & Co.	U		Ge	1512			233			Drilled 1945
72.	353216N	791640	U. S. Bureau of Mines	U		Ge	2354			263			Drilled 1948
73.	353238N	791748	Walter Bledsoe & Co.	U		Ge	1425			250			Drilled 1945
74.	353231N	791849	Walter Bledsoe & Co.	U		Ge	578			220			Drilled 1945
75.	353211N	791848	Walter Bledsoe & Co.	U		Ge	1054			275			Drilled 1945
76.	353158N	791838	Walter Bledsoe & Co.	U		Ge	1247			270			Drilled 1945
77.	353132N	791849	Walter Bledsoe & Co.	U		Ge	1305			280			Drilled 1945
78.	353043N	792120	State of North Carolina					No record					
79.	353015N	792147	State of North Carolina					No record					
80.													
81.	352045N	792220	N. C. Highway Commission		C		779		6			4	TDS=32
82.	351540N	794200	Samarcand Manor		C		386	1	6			17	TDS=120
83.	351540N	794200	Samarcand Manor		C		265	200	8			50	TDS=118
84.	351350N	794140	P. C. Harman, Jr.				350	137	4			1	
85.	351240N	795155	B. E. Johnson		C		130	15	6			1	TDS=1510
86.	350110N	794930	J. P. Leak		C		260	34	5			1	TDS=155
87.	350408N	795830	Gus Little		C		210	90	6				
88.	345920N	800135	K. R. Pratt				300	270	6			4-5	
89.	345730N	800620	R. D. Atkinson		C		144	30	6		14	7	
90.	350030N	801240	Floyd Moore				175		6			50-100	
91.	345650N	801225	S. B. Bunderburks				304	45	6			½	
92.	345105N	801350	Clinton Edwards		C		150	30	6		30	30	
93.	345152N	801750	B. B. Austin				486	40	6		3		
94.	345020N	801620	John McCray				400-500	--	4				

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Pennsylvania

1	402150N	745714	Universal Paper Bag Company	N	C	511	--	8	100	20	32	
2	401422N	745025	Yardley Water & Power Co.	P	P	403		12-10	105	59	260	Sp. Cond.=596
3	401418N	745030	Yardley Water & Power Co.	P	P	485		14-10	110	63	440	Sp. Cond.=1220
4	401423N	745028	Yardley Water & Power Co.	P	C	500	--	--	105	--	--	Sp. Cond.=642, TDS=457, Sample log
5	401338N	744842	Yardley Water & Power Co.	P	C	554		12-10	40	17	135	Sp. Cond.=286, TDS=185
6	401306N	745219	Joseph Heacock Company	I		515	240	12	150	18	150	
7	401206N	745442	Langhorne Spring Water Co.	H	C	403	38	8	130	2	15	Sp. Cond.=121, TDS=120, Sample log
8	401206N	745442	Langhorne Spring Water Co.	P	C	487	50	8	130	1	165	Sp. Cond.=173, TDS=140, Sample log
9			Quakertown Water Co. Well #1		P	367		8		8	250	
10	402758N	752048	Quakertown Borough	U		300	248	8	490			
11	401927N	750728	Sylvania Electric Company			700						
12	401857N	750751	Sylvania Electric Company			700						
13	401834N	750848	Doylestown Borough Water Works	P	C	396	--	--	345	2	350	Sp. Cond.=310, TDS=195
14	401750N	750707	Doylestown Borough Water Works	P	C	600	105	8	315	15	90	Sp. Cond.=487
15	402308N	752020	Sellersville Born	P	C	765	--	10	550	--	45	Sp. Cond.=536, TDS=398, also wells of 1000 and 8750 ft
16	401700N	7512	Chalfont Water Works	U		720		8	280	30	20	
17	4012 N	7516	N. Wales Water Authority	P		500	--	8	--	--	750	
18	401230N	750835	U. S. Naval Air Station	P	C	396	--	--	310	48	100	Sp. Cond.=350, TDS=225, Sample log
19	401200N	750450	U. S. Naval Air Development Station	P	C	600	--	8	335	--	140	Sp. Cond.=315, TDS=209
20	401108N	750305	Southampton Municipal Authority	P	C	502	60	10	240	--	90	Sp. Cond.=277, TDS=251
21	401026N	750232	Southampton Water Authority	P	C	369		8	252	12	50	Sp. Cond.=202, TDS=160
22	4010 N	7505	Hatboro Authority	U	C	400	--	--	315			
23	4024 N	7530	Perkiomen School	U		1000		6	340	F	20	
24	4024 N	7530	E. Greenville Borough	N		550	--	8	400	--	40	
25			Sauderton Water Works			1100		6		F	2	
26	4018 N	7519	Sauderton Borough	U		600	--	--	450		12	Several unsuccessful wells here
27	4018 N	7518	R. T. French Company	N		400	40	8	390		100	
28	4017 N	7517	Hunter Spring Company	N	C	400	42	10	370	8	105	2 other wells here
29	4016 N	7517	Hatfield Borough	P		400-500	--	10	330		160	
30	4015 N	7516	Penndale, Inc.			600	30	8	367	85	30	
31	4016 N	7516	A. M. Kulp School	P		600	100	6	297	24	55	
32	4015 N	7515	Picolet Dye Works	N		820	--	6	430		4	
33	4015 N	7517	J. W. Rex, Inc.	U		504	85	8	315	105	9	
34	4015 N	7517	Landale Municipal Authority	P	C	400	83	10	310	25	135	
35	4015 N	7518	Lansdale Municipal Authority	P		560	--	12	340	77	90	
36	4015 N	7520	Nice Ball Bearing Company	N	C	500	60	10	285	55	200	
37	4015 N	7520	U. S. Geological Survey			500	32	6	270	62	125	Test well, observation well
38	4015 N	7520	Nice Ball Bearing Company	N	C	500	60	10	285	55	200	Sp. Cond.=378, TDS=239
39	4014 N	7518	Lansdale Borough	P		492	76	8	320	111	200	
40	4013 N	7518	Merck, Sharpe & Dohme			600		10	351	93	--	
41	4015 N	7516	American Encaustic Tile	N		400	116	10	360	94	100	
42	4014 N	7516	Lansdale Municipal Authority	U	C	388	22	8	366	76	8	TDS=201
43	4014 N	7516	Lansdale Municipal Authority	U		1108	18	8	366	83	8	
44			North Wales Water Co., well#7		P	400		8			90	
45	4013 N	7516	Lansdale Municipal Authority	P	C	388	37	12-10	341	23	240	Sp. Cond.=321

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Pennsylvania-Cont.

46	4013	N	7516	Lansdale Tube Company				500	78	8	365	100	195		
47	4014	N	7515	Picolet Dye Works Inc.	N			400		6	425	--	12		
48	4015	N	7517	Lansdale Municipal Authority	U		E	507	97	10	330	41	200		
49	4007	N	7511	Philadelphia Suburban Water Company	P	C		410	43	8	--	55	150		
50	4010	N	7508	Willow Ridge Farm	I			600	--	9	270	17	--		
51	401144N		751353	Ely	U			1014	500	6	320	--	30		
52	4013	N	7511	Novatang	H			404		6	295				
53	4012	N	7516	N. Wales Water Company	U			448	350	10	355				
54	4009	N	7514	American Paint & Chemical Co.	I	C		405				64	408		
55	400907N		751330	Keasby and Mattison	N	C		234	234	8	--	17	100		Sp. Cond.=1230, TDS=1040
56	4014	N	7516	Lansdale Municipal Authority	U			400	120	8	366	78	18		
57	400817N		751442	Ambler Borough Water Company	P	C		500	330+	10	290	--	62		Sample log
58	4007	N	7513	Harrington	H			660	--	8	180	23	6		
59	4019	N	7529	U. Perkiomen Valley Park	P			415	--	6	320	35	20		
60	4020	N	7536	Kawecki Company	N			405	19	6	320	20	150		
61	4020	N	7536	Kawecki Chemical Company	N	C		528	16	6	320	110	220		Sp. Cond.=976, TDS=710
62	4020	N	7536	Kawecki Chemical Company	U			500	35	6	320	26	20	27	DD after 4 hrs
63	4020	N	7536	Kawecki Chemical Company	U			400	46	6	310	4	86	35	DD after 4 hrs
64	4020	N	7536	Kawecki Chemical Company			E	125	14	6	315-	4	--		Well destroyed
65	4019	N	7537	Fashion Hosiery Mills, Inc.				600	10	8	340	7	60		Recharge well
66	4019	N	7537	Fashion Hosiery Mills, Inc.	N			400	50	6	340	8	150		
67	4018	N	7532	New Hanover Township School	P	C		500	--	--	365	--	--		Sp. Cond.=447, TDS=283
68	4014	N	7525	E. State Penitentiary	P			502	24	8	285	195	300		
69	4013	N	7526	E. State Penitentiary	P	C		600	--	10	270	180	90		Sp. Cond.=959, TDS=732
70	4012	N	7522	O. J. Hynes	N	C		450	--	8	265	63	--		Sp. Cond.=351, TDS=214
71	4012	N	7528	Collegeville-Trappe Joint Water Works	P	C		373	33	8	225	8	227	110	Sp. Cond.=313, TDS=200, DD after 24 hrs
72	4011	N	7526	Superior Tube Company	N	C		460	105	6	190		60		
73	4009	N	7524	Eagleville Sanatorium	U	C		511	--	6	425	--	9		
74	4009	N	7524	Eagleville Sanatorium	U			511		6	425	--	9		
75	400840N		7524	Eagleville Sanatorium		P		490		6			11		Dry in lower 300 ft
76	400822N		752117	Norristown State Hospital	P	C		474	--	8	248	160	120		Sp. Cond.=719, TDS=475
77	400820N		752126	Norristown State Hospital	P	C		484	--	8	248	150	136		Sp. Cond.=695, TDS=478
78				State Hospital for the Insane Well #1		P		410		10		136	178		Near reservoir, air line 319ft long
79	4007	N	7517	Philadelphia Suburban Water Company	P			600	40	8	--	49	135		
80	4007	N	7520	Adam Scheidt Brewery		C		600		10	80	10	40		
81	4007	N	7520	American News Company	U			1500	--						
82	4006	N	7520	Daring Paper Company	N			571	24	10		9	200		
83	4007	N	7524	Valley Forge Industrial Park	N			400	62	12	--	30	245		

South Carolina

1	341200N	794600	Town of Florence	P	G	1335	142	18	100	Lowest water at 1215-20ft, TDS=270
2	334700N	802300								Water well superintendent had piece of core from Layne Atlantic
3	325640N	801030	Oil Prospecting Well (company unknown)			2470	71			Cooke, 1936, reports Triassic from 1580 to 2470 ft
4	331600N	813540	Atomic Energy Commission		all	2055				
5	331320N	812820	Atomic Energy Commission		all	4212				
6	330820N	813705	Atomic Energy Commission			1310?				

Georgia

1	322400N	823200	Barnwell Drilling Co., James Gillis #1		3240	351	Drilled 1961
2	315300N	822400	Felsenthal & Weatherford, W. E. Bradley #1	E,G	4106	219	Drilled 1947
3	315800N	824000	Natural Resources Corp., C. M. Jordan Heirs #1	E,B,G, ML	3995	195	Drilled 1956
4	321800N	833000	R. O. Leighton, John Dana #1	E,ML	6035	328	Drilled 1957
5	321900N	832600	Ainsworth, Inc., E. H. Tripp, No. 1	E,G	2684	280	Drilled 1954
6	314200N	825600	Carpenter Oil Company, C. T. Thruman #1	E,G,B	4130	308	Drilled 1955
7	314100N	825500	Carpenter Oil Company, J. H. Knight #1	E,G	4151	--	Drilled 1956
8	313500N	844900	Sowega Min. Explor. Co., Inc., G. W. West #1	E,G	5265	345	Drilled 1950
9	310800N	840800	Stanolin Oil & Gas Company, J. H. Pullen, No. 1	E,G	7487	330	Drilled 1944
10	311200N	850500	Mont Warren, et al, A. C. Chandler #1	E,G	7320	182	Triassic rept. 5670-6600, drilled 1943

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Virginia

1	3907 N	773440	Town of Leesburg, Spring #1	P								200		
2	3907 N	773440	Town of Leesburg, Spring #2											
3	390650N	773410	Town of Leesburg #1		P		152		6		30	40	115	Drilled 1912
4	390650N	773410	Town of Leesburg #2		P		360		8		35	65	215	Drilled 1908, Yield=60 & DD=225(190?)
5	390650N	773410	Town of Leesburg #3		P		350		10		28	165		Drilled 1954
6	390622N	773504	U. S. Geological Survey	U			350	49	7	365	287	251	9	Yield and DD after 4 hrs
7	3905 N	7730	Leesburg Vic.		P		105	54	8	330		300-950	?	
8	390530N	773450	Frank B. Mason				181							Very hard water
9	390505N	773630	Piedmont Motel (Leonard Thompson)	C			96				36	17		Well may be in contact or fault zone
10	385900N	772230	Ange		C		1000							Drilled 1955 by Ange of Annandale
11	385730N	772440	Town of Herndon #1				200				165	50		Drilled 1931
12	385730N	772440	Town of Herndon #2				403	50	8		45-150	100		Drilled 1954
13	385700N	772410	Town of Herndon #3				420				40	25		Drilled 1958, used only in emergency
14	385540N	772800	Airport #3				1030	11	14			1000		Drilled 1960, yield estimated after 4 hrs pumping
15	385520N	772730	Airport #1		C		860	8	8		8	327	52	DD after 48 hrs, TDS=942
16	385505N	772800	Airport #2		C		955	7	8		4	600	155	DD after 52 hrs, TDS=856
17	384931N	774203	Va. Dept. of Highways			D,E	345	20	7	385	10	20		
18	384730N	773520	Atlantic Research Corp.	N			307		6			23		
19	384615N	772840	Jack Barrett Construction Co.				900±					300?		Drilled 1959
20	384620N	772840	Manassas Park #4				1000	62			56	327		Drilled 1956
21	384700N	772700	Manassas Park	P			875	51			60			Drilled 1954
22	384700N	772700	Manassas Park	P			807				60	120		
23	384650N	772605	"Theatre Well" Yorkshire				800 or 500		8			150	6	Yield and DD after 4 hrs
24	384700N	772630	Yorkshire Subdivision "Fort Well"	P			780		8			80		
25	384530N	772820	Liberia Subdivision #1	P			809	46	8		105	80		Log
26	384530N	772820	Liberia Subdivision	P			205	24	8		65	20		Log
27	384530N	772800	Manassas	U			406	60-70	10-8		85?	24		Drilled 1921, abandoned, yield-1922
28	384525N	772750	Town of Manassas #3		P		505		10		40	50	143	Drilled 1921±, yield-1924
29	384440N	772815	Town of Manassas #5		P		453	30	8		88	50		Drilled 1946
30	384515N	772805	Town of Manassas #6				485	50	12-8		75	30+		Drilled 1950
31	384440N	772815	Town of Manassas #7				350	50	8			172	330	Drilled 1953, yield and DD after 12hrs
32	3845 N	7728	Manassas Corp.	U			531	180	8-6		58	120		Never used, yield 42gpm in 1922
33	384430N	772940	Woodbridge Clay Products Co.	N			612	55	8		50	260	283	DD after 4 hrs
34	384430N	772940	Woodbridge Clay Products Co.				612½	55	8		50	260	283	Drilled 1956, DD after 51 hrs
35	3845 N	7740	Army #1	P	C		400	--	8		47-127	45	35	7½ hp Demming set at 250 ft
36	3845 N	7740	Army #2	P	C		450		8		58-104	36	35	7½ hp Demming set at 250 ft
37	3845 N	7740	Army #3	P	C		450		8		175	64	10	10 hp Varona set at 250 ft
38	3845 N	7740	Army #4	P	C		624		10		100	240	155	25 hp Cook set at 210 ft
39	384330N	774650	Town of Warrenton	P			400	60	10	480	60	60	127	Drilled 1945, yield and DD after 27hrs
40	384330N	774650	Town of Warrenton	P			416		8	504	12	400	41	Drilled 1954, yield and DD after 44 hrs, PT
41	384315N	774820	Town of Warrenton	P			300			580		40		Drilled 1920's, pumping WL
42	3815 N	7709	E. T. & Shirley Thompson #1				3029			153				

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Virginia-Cont.

43	3828	N	7800	Town of Culpepper #1	P	G	676	38	10 or 8		7	95	133+	Aquifer at 586-589 ft, SC about 1.3
44	3828	N	7800	Town of Culpepper #2	P		700	40	12		17	535	35	Yield and DD after 101-168 hrs
45	3828	N	7800	Town of Culpepper			980?		8		13	100		Aquifer at 568 ft
46	3803	N	7721	Town of Bowling Green		G	1550			215	75	25		
47	375240	N	753100	E. G. Taylor #1-G		G,E	6272							Deep test to basement, sample file (W-3180) Va. Div. of Min. Res.
48	3745	N	7729											
49	374130	N	771230	Townsend No. 1	U		3278	2610	7	37		7+		Salt water rept. at 900 ft
50	373230	N	764800	Chesapeake Corp.			1689							
51	3726	N	761930	Elkins Oil and Gas Co., Phillips #1		G	2325	134	12½	7				Drilled 1929, cored
52	3736	N	7742	Manakin										
53	3730	N	7739	Midlothian			2500							Basement not penetrated

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Table 4.—Chemical analyses of water from selected wells.

Analytical results are in milligrams per liter except specific conductance, pH (Calculated results given in parentheses. Water is from rocks of Triassic age unless otherwise noted.).

Well Number	Date Collected	Well Depth	Specific Conductance (micro-mhos at 25°C)	pH	Temperature	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Iron (Fe)	Manganese (Mn)	Dissolved Solids	Calcium, Magnesium Hardness	Non-carbonate Hardness	Geology	Remarks
Massachusetts																						
6	6- -67	455		8.5									[illegible]		0	0.16		318	92			
10	7- -37	350-400		7.5									8.2		0.12	2.8		557				
13	6- -58	404	1,080	7.0	58				98		127	390	39		0.5	0.08			354	250		CO_3=0
14	3- -68	755		7.3		4						1232	48		0	0.5			1200	1136		
15	3- -68	700		7.5		4.5						325	8		0	0.1	0		84	316		
16	3- -68	690		7.5		2.5						290	6		0	0.2	0		88	272		
17	3- -68	600		7.7	52								13		0.1	0.25	0		195			
18	4- -36	500		6.9									17.8			0.10		302				
22	3- -31	500			57								9.2			0.35			235			
23	9- 3-23	510			56								8.0		0	12.0		738	340			
24	3- -58	490	383	7.0	57	18	33	16	22	0.8	115	85	8.2	0.3	0	0.54	0.11	240	149	55		CO_3=0
28	2- -58	525	870	7.8	63	10	9.6	1.3	180	1.4	221	154	59	0.7	1.4	0.39	0.08	522	30	0		CO_3=0
30		650										854	84						1090			
42	3- -58	620	164	6.8	54	15	18	6.0	5.5	0.9	80	7.3	3.8	0.1	2.0	0.24	0.02	102	70	4		CO_3=0

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Connecticut

2	5- 8-69	503	263	7.3	12	17	32	7.3	7.3	0.7	74	29	14		16	0.07	0.00	166	110	50	
3	4- -69	210	1,460	7.7	13	15	208	40	57	1.0	104	720	27		0.0	0.06	0.27	1,260	?	199	
4	5- 8-69	480	227	7.4	12	16	32	1.6	9.3	0.6	64	20	13		18	0.05	0.00	145	86	34	
5	4-30-69	400	208	6.9	11	12	23	5.8	7.0	1.3	56	25	15		0.0	0.72	0.02	130	82	36	
8	4-23-69	120	1,840	7.6	11	20	360	37	34	1.5	102	1140	2.6		0.1	0.64	0.05	1,780	1050	967	
9	4- -69	245	1,190	8.1	13	14	7.4	1.5	244	1.3	108	445	8.5		0.0	0.10	0.03	784	?	?	
10	4- -69	240	763	8.2	11	15	90	23	43	1.0	129	264	18		0.0	0.02	0.04	516	319	214	
11	7-31-69	206	726	7.7	15	16	113	6.7	32	1.3	66	308	6.5		0.0	0.08	0.00	560	310	254	
12	5- 1-69	223	2,150	7.5	14	11	508	3.5	69	3.2	29	1350	13		0.0	0.03	0.02	2.060	1280	1260	
13	12- 8-57	414		7.3														2.035			Have outside analysis
14	5- -53	210	202	702	53		27	3.5	8.0		69	30	6.6		4.0	0.03		154	82	25	Al=0.13
16	4-23-69	456	431	7.6	13	17	51	17	8.6	1.0	134	30	34	--	38	0.03	0.02	261	197	87	
20	4-29-69	400	253	7.5	11	13	39	2.3	6.6	0.8	55	51	4.2		22	0.05	0.00	164	107	62	
21	4- -69	210	1,680	7.7	14	20	320	31	37	3.3	66	1000	1.3		0.0	0.03	0.25	1,650	?	?	
23	9- 8-54	632		7.7									4.0		2.7			(115)	77		Have outside analysis
24	3- -54	609	201	7.8	52	17	20	6.8	12	1.1	80	26	3.9		12	0.24	0.00	140	77	14	
26	4-21-69	575	353	7.5	14	17	50	10	7.6	0.6	86	94	7.5		14	0.00	0.02	239	166	96	
27	5- 7-69	650	135	6.8	14	8.2	8.8	2.6	11	1.0	14	15	22		2.6	0.30	0.03	80	32	21	
28	5- 7-69	700	169	7.0	14	9.1	11	5.4	10	0.9	30	17	22		4.3	0.18	0.00	104	50	25	
29	11- -54	602	233	7.8	55	14	27	10	2.3		80	31	5.6		18	0.08	0.10	148	109	43	
30		457				19	330	9.9	24			802	3.7		0.2	2.0		(1,296)			
33	3- -38	398					233	43	121		86	836	40		0.15				734		
35	6- -42	640	|	7.3	59										0.2	0.40		1,890	415		
38	4-21-69	400	258	7.8	12	13	38	1.9	10	0.9	91	13	14		21	0.10	0.01	158	103	28	
39	4-17-69	400	237	7.8	14	17	36	3.7	6.6	0.5	82	31	5.8		14	0.08	0.01	151	105	38	
40	4-21-69	550	551	7.8	16	13	76	0.9	44	1.2	108	162	18		4.6	0.00	0.02	386	193	104	
41	10- -51	386											3,000		0.0	4.0					
42	4-17-69	180	1,570	7.5	13	17	251	12	67	6.6	430	49	212		171	0.09	6.4	1,170	676	323	
58	3- -38	502					285	53	129		121	1029	28		0.0				930		
62	7- -36	404											17		0.5			300	160		
64	11- -48	745		7.9									16		0.53	0.10		(232)	118		
65	6- -35	390		7.3									7		0.18			(2,510)	1300		
70	4-24-69	325	732	8.1	14	13	92	23	24	0.9	108	273	7.2		0.0	0.14	0.16	559	324	236	
74	4-24-69	330	1,120	7.5	14	17	161	30	48	0.9	80	530	15		0.9	0.03	0.21	958	525	460	
76	8-14-69	410	771	8.0	12	22	105	22	18	0.4	118	242	10		12	0.09	0.05	512	353	256	
77	1- -56	438		7.7	51	16	17	1.3	20	0.8	78	20	5.2	0.0		0.20	0.01	(124)	48	0	CO_3=0
83	5- -15	1000				25	69	6.3	24		77	129	23		40			339	198		CO_3=0

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4-c

Maryland

5	11-10-71	600	396	8.0	14	19	44	10	20	0.6	167	24	17	0.2	17	0.02	0.0	236	151	14	CO_3=0
7	11-29-71	692	222	7.7	12½	23	29	6.2	7.2	0.3	121	4.1	3.4	0.1	6.6	0.07	0.00	140	93	0	CO_3=0
8	1969	105		7.3							130				22	0			180		Bicarbonate as $CaCO_3$
9	1-19-72	300	526	7.6	12	16	55	12	10	1.4	172	5.7	30	0	18	0.62	0.0	232	187	46	CO_3=0
15	9-26-69	453		7.6		7.0	56	2.4	12.4		183	3.9	16	0	0.6	0.02	0	175	150		CO_3=0
16	9- 8-69	597		8.1		6.5	51	2.1	9.4		165.9	3.3	12	0	0.5	0.02	0	158	136		CO_3=0
17	10-14-70	344	304	7.9	14	22	39	5.0	21	0.6	196	4.0	1.7	0.2	0.9	0.2	0	183	118	0	CO_3=0

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4-D

New Jersey

1	4- -59	109	230	7.3	52	25	34	4.9	4.0	0.5	96	27	8.2	0.0	2.1	0.06	0.00	150	105	27	
2		2050-2100					2320	470	2,750	50		1452	8,740					15,894			
3	5- -64	450	280	8.2					14		90	17	5.5		6.1				75	1	
4	7- -56	504		8.3		15	18	14	17		141	14	6.0			Trace	0.0		102	0	
5	12- -59	507		8.2		17	16	14	25		139	27	7.0			0.20	Trace		96	0	
8	8- 1-68	600	397	8.5		27	18	7.4	43	0.8	144	43	6.5	0.1	0.2	0	0.01	236	71	0	PO_4=0.18
9	8- 1-68	600	1,210	8.4		19	134	34	84	1.5	136	505	18	0.3	0	0.01	0.03	934	437	316	PO_4=0.11
10	8- 1-68	719	530	8.5		17	45	18	36	1.5	167	103	18	0.2	0.4	0	0.06	330	187	41	PO_4=0.29
11	7-18-68	503	482	8.3		17	58	14	9	2	137	55	20	0.1	22	0	0	271	202	85	PO_4=0.02
12	7-17-68	536	786	8.2		22	46	22	28	2.1	180	72	34	0.1	22	0.04	0.04	354	206	58	PO_4=0
13	1940	400		7.5		42	314	101	141		87	1312	50		0.4	1.0		2,280	1196	1127	
14	7-16-68	461	1,400	7.6		25	157	31	105	1.9	57	654	16	4.5	14	0.04	0.01	1,100	520	473	PO_4=0.24
15	9-18-64	400										25						--	--	--	
16	8- 8-68	500		8.1		18	45.6	13.12				48	27	0.15		Trace		--	168	--	
17	7-18-68	344	380	8.4		18	52	8	7.5	1.5	124	45	14	0	16	0.15	0.26	238	158	48	PO_4=0.18
18	8-12-68	508		8.0		20	68	16.52				89	38	0.1		0.10		366	238	--	
19	8- -60	?	759	8.0	55	15	28	11	124	1.4	189	209	13	0.2	12	0.13	0.00	512	0	115	This analysis assigned to well#19 but may be #20
21	8-23-68	540		7.3			53.6	13.1					28	0.1		0	0.02	--	188	--	
22	7-22-68	650		7.7		21	106.4	23.33				225	28	0.5		0.1		--	362	--	
23	7-22-68	665		7.8		22	141.6	23.33				260	28	0.5		0.1		--	450	--	
24	7-22-68	708		7.7		17	50.4	15.52				120	27	0.4		0.5		348	194	--	
26	9- 6-68	450	410	8.3		20	45	9.4	14	3.5	161	31	16	0	5.8	0.11	0.01	224	151	14	PO_4=0.04
27	7-22-68	400		7.7		17	50.4	15.52				110	28	0.4		0.1		--	194	--	
28	7-27-68	511		7.8		17	61.6	18.95				140	25	0.05		0.05		388	232	--	
29	7-27-68	506		8.0		20	66.4	18.47				139	24	0.15		0.05		378	242	--	
30	7-22-68	525		7.8		21	51.2	14.09				43	31	0.15		0		--	186	--	
31	7-22-68	502		7.7		20	50.4	18.95				37	38	0.20		0		318	204	--	
32	8-31-60	523	399	7.4		26	52	14	11	1.5	174	35	17	0.1	10	0.17	0.01	266	187	142	
33	8-31-60	504	1,060	6.9		31	167	25	43	1.4	144	454	11	0.3	8	0.05	0.05	856	520	118	
34	1946	505		7.3								434	10			0		--	638	--	
36	2-12-44	1108		7.3			280	42			120	1795	85			0.2		--	--	--	
	6-28-44	1108		7.3			260	42			126		83			0.4		--	--	--	
38	7-25-68	427		7.2		10	60.8	4.37				83	45	0.5		0.05		330	170	--	
39	11- -49	503	222	6.4		18	21	8.7	5.6	1.9	47	35	9.1	0.0	9.0			139	88		
40	4- -58	393	159	6.9		21	8.1	1.9	19	4.0	57	9.8	16	0.2	0.4	1.1	0.15	128	28	0	
41	9- -49	657	357	7.6		24	35	17	15	1.4	168	24	11	0.2	4.1	0.20		209	157		
42	4- -58	372	242	6.7		28	27	5.2	11	1.5	78	26	10	0.0	12	0.03	0.03	190	89	25	
43	5- -64	590	1,610	7.4					37		220	612	68		1.5				835	655	
44	5- -64	740	2,320	7.7					4.8		142	966	88		5.5				1240	1120	
45	5- -64	1041	3,480	7.3					274		80	566	755		0.0				1210	1150	
46	1- -48	875	6,960	7.3	59	31	865	173	447	7.0	210	911	1,900	0.0	6.2	0.15		4,780	2870		Total hardness
47	10- -37	700					152	31			162	240	12								

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New York

1	3-25-57	655		7.8	13	32	10			(117)		11	0.1	1.7		0	138	(122)	(26)	Analized by	Hackensack Water Co.
4	2-18-57	407		7.5	8.4	39	16			(159)	18	9	0.0	5.8		0	192	(162)	32	Analized by	Hackensack Water Co.
5	7-23-57	413	220	7.9	11	14	14	9	3.6	(129)	6.9	2.5	0.1	3	0.2	0	118	93	0	Analized by	U. S. Geological Survey
	4-22-57	413		8.3	9.6	13	15			(137)	15	8	0	0.6	0.18	0	108	(94)	0	Analized by	Hackensack Water Co.
6	3-18-57	440		6.1	6.4	11	1.7			(34)	9.3	7	0.0	2.2			52	(34)		Analized by	Hackensack Water Co.
7	3-25-57	477		6.6	11	26	4.8			(71)	21	11	0.1	2.1		0.02	112	(85)	27	Analized by	Hackensack Water Co.
9	3-22-57	601		6.5	11	20	2			(61)	14	6	0.1	0.5	0.2		76	(57)	7	Analized by	Hackensack Water Co.
13	4-24-50	500		8.3						(73)		2.4		0.6	0.1		--	60	0	Analized by	N.Y. State Dept. of Health
14	7-24-57	371	283	7.8	18	23	13	22	0.4	133	41	2.4	0.2	4.1	0.1		166	111	2	Analized by	U. S. Geological Survey
19	6-20-50	718		5.8						(63)		35		3.0	0.3		--	100	48	Analized by	N.Y. State Dept. of Health
20	6-20-50	400		6.1						(56)		27		4.0	0.4		--	108	62	Analized by	N.Y. State Dept. of Health
22	8-22-55	525		7.1						(164)				0.9	0.06		--	168	33	Analized by	N.Y. State Dept. of Health
23	6-17-49	405		8.4	10	48	10			116	55	10		0	0		--	135	44	Analized by	Travelers Indemnity Co.
24	6- 2-48	435		7.9						(82)		6	0.0	4.0	0.3		--	90	23	Analized by	N.Y. State Dept. of Health
25	1951	513		7.9		35	10			132	42	6					--	(128)	(20)	Analized by	Hall Laboratory
26	1951	400		7.9		35	10			132	42	6					--	(128)	(20)	Analized by	Hall Laboratory
31	4- 8-57	510		7.7	15	49	9.5			(159)	29	10	0	4.1		0	218	(162)	32	Analized by	Hackensack Water Co.

North Carolina

2	7-	-43	105								440	96	32			--			480		
3	7-	-43	205								214	48	16			0.36			202		
4	6-	-43	189								53	1	4			0.06			34		
19	8-	-43	1027								108	2	8			0.18			90		
21	2-	-62	152	330	7.4	28	9.8	3.0	59	1.2	160	5.4	16	0.1	6.0	0.00	0.00	(208)	37	0	Li=0.1, Al=0.0, PO_4=0.5
22	3-	-63	94	292	7.0	43	24	8.6	26	0.5	130	4.0	24	0.2	6.0	0.15	0.05	(200)	95	0	Li=0.0, Al=0.1, PO_4=0.0
25	1-	-63	300	470	7.3	24	51	10	30	0.7	203	12	39	0.0	0.2	0.01		(267)	170	3	Li=0.2, Al=0.1
28	1-	-63	112	725	8.0	9.9	18	4.3	135	0.2	222	9.6	122	1.5	0.0	0.04	0.01	(410)	62	0	Li=0.6, Al=0.0
29	1-	-63	140	860	7.2	40	86	37	35	1.3	339	13	111	1.1	0.4	0.07		(492)	370	92	Li=0.3, Al=0.2, PO_4=0.2
30	1-	-63	270	728	7.4	17	46	5.0	113	0.1	313	24	71	1.4	0.9	0.05	0.00	(433)	134	0	Li=0.6, Al=0.0
33	12-	-62	109	1,440	7.4	22	154	34	101	0.4	294	10	337	0.0	1.3	0.33	0.05	(806)	524	284	Li=0.9, Al=0.2
35	11-	-61	300	2,200	7.4	24	106	25	310	4.6	232	25	572	0.2	0.1	0.01	0.05	(1,180)	370	180	Li=1.4,Al=0.2,PO_4=0.0,Br=3.2
37	2-	-63	163	92	6.8	38	6.6	4.0	8.0	1.1	56	1.0	1.7	0.0	0.0	0.04	0.00	(89)	34	0	Li=0.0, Al=0.1, PO_4=0.3
38	2-	-63	125	180	6.8	40	14	5.0	16	0.7	84	1.8	11	0.2	6.8	0.19	0.00	(137)	56	0	Li=0.0, Al=0.1, PO_4=0.0
39	11-	-61	130	228	7.2	34	19	9.5	17	0.7	142	2.2	3.0	0.1	0.1	0.01	0.01	(156)	86	0	Li=0.2, Al=0.1, PO_4=0.1
40	2-	-63	150	400	7.4	30	17	5.3	70	1.1	217	2.0	27	0.2	0.0	0.06	0.05	(260)	64	0	Li=0.0, Al=0.1, PO_4=0.7
42	7-	-58	120	200	6.7	25	25	5.8	7.7	0.8	110	3.1	9.9	0.1	0.1			(136)	87	0	Li=0.0, Al=0.0
43	12-	-61	140	160	7.4	20	12	4.0	25	1.9	100	2.8	13	0.2	0.4	--		(129)	46	0	Li=0.3, Al=0.1
44	12-	-61	118	1,150	7.2	2.3	45	22	188	4.8	79	8.8	384	0.1	0.4	0.23	0.03	(696)	206	142	Li=1.3, Al=0.2
46	4-	-54	151		7.6	14	30	20	228		319	12	167	0.6	1.4	0.09		(741)	157		
47	1-	-59	318		7.2	41	8.0	1.9	11		73	0.1	4.0	0.2	0.2	3.8		(101)	43		
48	12-	-62	220	535	7.6	31	33	15	56	0.4	275	14	19	0.1	0.8	0.90	0.03	(305)	146	0	Li=0.2, Al=0.1
81	10-	-50	779		6.3	2.7	0.8	0.6	7.5		9	1.5	5.6	0.0	4.9	0.71		(32)	4		
82	11-54		386		7.0	16	16	5.1	17		97	8.3	5.5	0.1	0.1	0.99		(120)	60		
83	5-	-49	265		7.0	20	16	5.6	15		96	9.3	4.6	0.1	0.1	0.73		(118)	63		
85	4-	-54	130		7.3	16	58	42	472		668	3.0	560	0.9	0.3	0.14		(510)	317		
86	4-	-54	260		7.7	19	13	7.7	33		152	3.8	5.0	0.2	0.0	0.06		(155)	64		
87	3-	-62	210		6.6		13	7.5	14	0.3	86	5.0	12		6.7	0.08			64		
89	3-	-62	144		6.9		14	8.7	7.5	0.7	99	5.0	2.4		1.3	0.02			71		
92	3-	-62	150		6.9		287	108	156	4.6	391	18	744		89	1.0			1160		

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Pennsylvania

1	9- 8-53	511	487	7.7	56	17	49	14	26		0.6	156	53	22	0.1	21	0.06		311	180	52
2	8-23-50	403	596	7.5	57	--	--			31		102	224	6	--	3.8	--		--	260	176
	7-18-57	403	276	8.1	--	24	23	15	10		0.8	96	35	6.6	0.1	13	0.08		194	120	41
3	8-23-50	485	1,220	7.5	58	--		265		36		120	603	8	--	1.1	--		--	600	562
	7-18-57	485	589	7.6	57	18	63	26	16		1.5	112	118	6.6	0.2	8.2	0.24		399	267	174
4	7-18-57	--	642	7.3	56	22	68	31	19		1.4	113	213	7.4	0.1	10	0.12		457	297	205
5	8-23-50	554	281	7.5	57	--	20	2.4		35		88	36	17	--	2.5	--		-	60	--
	4- 9-53	554	286	6.9	54	10	19	4.9	35		2.3	96	37	16	0.1	7.8	0.08		185	68	0
	7-18-57	554	342	7.4	55	14	26	6.6	33		2.8	119	33	15	0.2	8.7	0.14		198	93	0
7	6-24-57	403	126	6.9	54	52	11	1.0	8.1		1.2	41	16	2.2	0.1	0	0.68		118	32	0
	6-27-57	403	121	6.2	54	49	13	1.1	8.1		1.3	46	16	2.5	0.1	0.4	1.3		120	38	0
8	7- 8-57	487	172	6.9	53	49	22	0.9		13		77	17	2.4	0.1	3.1	0.16		144	59	0
	7-12-57	487	173	7.3	54	48	23	0.8	8.8		1.4	80	16	2.4	0.1	1.4	0.12		140	62	0
9	9-30-25	367			52	33	152	29	28		4.0	155	401	10		1.4	0.30		786	499	
13	3-24-53	396	310	7.7	54	18	29	17	3.8		0.8	154	19	8.5	0.0	5.5	0.66		195	142	16
14	7-21-50	600	487	6.8	57	--	--	--		24		104	153	6	--	1.6	--		--	202	117
15	4- 8-53	765	536	7.5	55	25	94	9.1	4.4		1.0	126	169	2.2	0.1	0.3	0.01		398	272	169
19	12- 5-56	600	315	7.8	55	28	33	12		19		164	30	4.3	0.1	0.6	0.52		209	132	0
20	8-16-56	502	277	8.0	57	29	31	3.2		10		61	34	13	0.1	19	0.46		251	90	40
21	8-16-56	369	204	8.0	57	33	20	5.7		18		71	28	18	0.1	0.4	--		159	73	15
22	1950	400		7.5									25	6		1.0	0.1		184	134	
28	1960	400		7.9		12							16.8	8.0	0.0	0.08		0.0	298	232	70
34	1961	400												3.0		0.1		0.02	170	140	
38	2-28-61	500	378	8.0		16	30	8.2	45		0.5	173	48	3.5	0.0	3.7	0.38	0.03	239	109	0
42	9-28-25	388				32	36	15	11		1.8	173	15	8	--	2.5	0.05	--	201	152	10
44	9-25-25	400			54	18	47	17	9.4		2.1	194	23	13		7.5	0.06		232	187	
45	2-21-52	387	321	6.4		21	24	20	6		1.0	150	22	5	--	0.4	0.01	--	--	142	19
49	1964	410		7.7				27						12		1.5	0.17	0.05	252	221	
54	1954	405		7.4			620	50				431	4.3	6		0.3	0.30		980	670	
55	6-29-56	234	1,230	7.9		29	233	16		25		118	558	16	0.2	0.7	--		1,040	647	550
57	1963	500		7.4										9.0		0.5	2.0	2.0	260	145	
61	2- 5-62	528	976	7.8		15	141	31	35		1.0	228	229	35	0.3	3.6	0.23	0.02	710	480	293
67	3- 1-61	500	447	7.5		28	59	17	15		1.0	252	37	4.2	0.1	0.2	0.70	0.38	283	217	11
69	4- 9-62	600	959	7.3		20	116	51	22		0.8	163	370	11	0.1	11	0.44	0.02	732	500	366
70	3- 1-61	450	351	7.8		19	47	9.0	14		1.0	179	12	9.3	0.0	18	0.26	0.01	214	155	8
71	2- 7-62	373	313	7.5		17	45	5.4	12		1.0	134	26	10	0.1	13.0	0.07	0.00	200	135	25
72	1952	460		7.4									33	11		41	0.1			200	50
73	9-30-25	511	490		54	13	47	23	22		1.9	283	3.8	7.0		0.21	0.17		283	212	0
75	9-30-25	490			54	13	47	23	22		1.9	283	3.8	7.0		0.21	17		283	212	
76	7-24-56	474	719	7.7	55	26	69	27		34		145	116	80	0.1	6.7	0.08		475	283	164
77	11-21-57	484	695	8.1	--	23	82	28	22		1.4	142	193	34	0.1	10	0.41		478	320	203
78	9-30-25	410			55	30	72	49	20		3.5	156	279	7.2		0.69	0.06		570	381	
18	6- 8-56	396	350	7.5	58	23	31	20		8.1		144	40	8	0.1	7.4	0.07		283	212	0

Fe=17.0 in Pa. GW Bull. W-22

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4-H

Pennsylvania-Cont.

80	1947	600					109	10					158	72		7	0.1			314		
83	3- 2-61	375	941	7.8		15	59	20	135		3.5	214	298	7.5	0.3	2.7	0.76	0.03	645	229	54	
85	7-19-62	300	1,660	7.4		28	252	64	29		2.0	168	788	5.2	0.0	4.8	0.12	0.02	1,340	892	755	
90	1946	406		7.5			30	16					16	3.5								
91	3- 2-61	916	1,090	7.4	58	28	180	32	27		1.0	180	420	18	0.2	2.8	3.9	0.04	805	581	433	
93	1946	402		7.5			112	112					116	2.5								
94	4- 9-62	394	378	6.8		24	49	12	12		0.8	128	69	5.8	0.1	13	0.00	0.17	252	172	67	
96	9-18-57	750	542	7.3		22	59	23	21		1.1	199	66	24	0.1	12	0.10		343	242	79	
	10-24-57	750	549	7.3		23	59	23	21		1.1	198	70	26	0.1	14	0.11		354	242	79	
97	6- 7-56	752	489	8.1	57	26	45	24		17		127	123	9.5	0.1	2.7	0.14		346	211	107	
99	6- 7-56	902	773	7.9	58	26	110	19		27		108	298	8.0	0.2	2.1	0.52		610	353	264	
100	6- 7-56	485	280	8.3	54	26	29	11		11		114	26	7.0	0.1	8.6	0.10		199	118	21	
101	6- 7-56	375	425	8.4	56	12	42	19		12		166	45	10	0.1	5.3	0.05		260	183	40	
102	1955	425		6.9		20	100	46					52	13			0.0			146		
105	1929	500		7.8										8.0		6.0	0.2			80		
106	1-30-62	500	641	7.3		10	86	33	8.9		1.5	358	43	13	0.1	7.2	1.6	0.24	391	350	57	
110	5- 7-56	629	675	7.9		26	85	32		6.4		188	162	14	0.0	19	0.09		450	344	190	CO_3=0
111	5- 7-56	450	529	8.2		26	75	21		2.5		189	88	11	0.0	21	0.03		351	274	117	CO_3=0
112	5- 7-56	450	586	7.7		28	92	15		7.1		195	101	14	0.0	27	0.00		395	291	131	CO_3=0
113	5- 7-56	459	599	8.3		23	84	25		5.1		166	156	6.7	0.0	15	0.02		413	312	176	CO_3=2
122	10-31-60	6-1	411	7.1		18	52	12	12		1.0	198	27	13	0.0	1.8	0.03	0.03	239	179	17	
127	11- 3-60	500	394	7.5	56	21	45	12	20		1.1	174	23	22	0.2	18	0.03	0.01	248	161	30	
128	10-30-25	400			54	24	73	29		14		190	82	27		14	0.08		377	260		
130	5-10-56	776	1,170	8.0		28	176	45		1.4		164	434	16	0.1	22	0.03		820	624	490	CO_3=0
131	5-11-56	452	431	8.1		18	62	14		8.3		164	75	7.3	0.1	9.4	2.4		297	213	78	CO_3=0
132	6-20-51	450	370	6.9		28	54	8.5		7.8		163	24	11	0.1	15	--		237	170	36	CO_3=0
133	7-28-58	800	338	7.4		26	44	11	9.7		--	128	46	4.8	0.0	20	1.4		224	155	50	CO_3=0
134	5- 9-56	500	430	7.9		21	61	14		4.7		148	73	9.0	0.1	12	0.00		278	210	88	CO_3=0
135	6-12-56	451	652	7.1		22	98	22		15		210	172	7.5	0.1	7.7	0.15		462	335	163	CO_3=0
136	7-22-58	600	595	7.6		21	86	21	7.6		--	181	135	12	0.0	14	0.07		468	301	153	CO_3=0
137	7-23-58	600	463	7.7		16	66	13	10		--	126	111	12	0.0	5.7	0.06		317	218	115	CO_3=0
138	7-25-58	800	1,000	8.0		22	162	27	33		--	201	396	6.5	0.1	1.0	0.16		792	516	351	CO_3=0

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South Carolina

1	1890	1335			41	4.6	2.6	76	8.9		17	42.5								Analysis by Clemson Agricultural College, CO_3=82
4	7-14-69	2055	6,770	6.6	1.0	518	83	1,120	30	72	420	2,620	0.6		0.00		5,950	1636	1577	PO_4=0.03, SO_4=420
5	5-27-71	4212	18,000	6.4	3.5	1990	53	2,100	44	85	110	6,720	0.3	0.0	0.04	5.8	11,900	5220	5150	PO_4=0.01, SO_4=110, Li=0.28, Al=0.45

Virginia

3				7.1		12.7										0.1	0.1			228		
4	1931	360				17	68	19	19		4.7	239	19	29		50	0.18		331	248	—	
				7.1		14.5										0.2	0.2			233		
5				7.6		12.7										0.2	0.2			219		
7				7.3		11.9											0.1					
10	1955	1000	12,400	9.0		11	1860	42	777		2.7	1.8	177	4,500	0.0	3.6	3.4	0.00	7,390	4810	4800	CO_3=7.9, Al=0.2
15	7- -59	860	1,200	7.4	64	25	175	21	64		1.2	194	462	14	0.3	12	0.33	0.05	942	533	374	CO_3=0, Al=0.0
16	5- -59	955	1,010	7.8	62	67	131	42	54		1.3	275	327	13	0.2	0.4	0.15	0.06	856	500	274	CO_3=0, Al=0.2
28	1931	505				38	31	23	12		1.4	219	5.8	5.0		1.8	1.1		202	172	—	
29	2- -16	?		6.4		43	39	4.4		9.25		?	10.6	15	0.14	7.6	0.08	0		115		CO_3=34
	2-25-60			7.0			39	4.4		9.25			10.62	15.28	0.14	7.62	0.08			115		
35	3- 9-59		273	7.6	48	34	38	5.6		13		157	12	3.0	0.1	0.0	0.00		183	118	0	CO_3=0
36	3- 9-59		200	7.0	47	43	26	2.8		11		112	0.7	3.0	0.1	2.7	0.00		160	76	0	CO_3=0
37	3- 9-59		149	7.3	45	39	17	4.4		7.9		87	0.6	3.6	0.2	0.2	0.00		120	60	0	CO_3=0
38	3- 9-59		569	8.1	59	29	77	17		18		160	158	3.0	0.4	0.1	0.00		446	262	131	CO_3=0

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