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BASINS IN SOUTHEAST UNITED STATES

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BASINS IN SOUTHEAST UNITED STATES

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Abstract

Triassic basins are elongated deep basins, filled with thousands of feet of sediments. They are usually asymmetrical grabens in metamorphosed and crystalline Paleozoic and PreCambrian rocks. A major normal fault and coarse clastics can occur on either or both flanks. Border faulting and sediment deposition were contemporaneous. Basin faulting (longitudinal and transverse) and igneous intrusion (diabase dikes and sills) occurred during the late stage of deposition.

The sediments, commonly some shade of red, range from shales to boulder beds. All have poor sorting and a high clay content. Porosity and permeability is low.

Triassic basins extend from Nova Scotia to Florida. From North Carolina south all known basins are aligned northeast-southwest. The Deep River Basin and the Wadesboro Basin outcrops in the Piedmont Province of North Carolina. They are typical Triassic basins, bounded on the southeast by a major fault and on the northwest by a series of smaller faults. In the former the coarsest sediments occur along the southeast border and in the latter along the northwest border. Maximum thickness is 10,000 feet. The Deep River basin contains a few thin coal beds. Montmorillonite and illite are the most abundant clay minerals. Longitudinal and cross faults are present as are diabase dikes and sills. A large portion of these basins have been destroyed by erosion.

In South Carolina one well and geophysical data suggests the presence of a Triassic basin (Florence) under approximately 600 feet of Coastal Plain sediments. The only well established basin (Dunbarton), six miles wide, occurs near the Savannah River plant. A major normal fault forms the northwest border.

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Less is known of the southeast borders. The sediments are typical. Fanglomerates occur in the northwestern border and shales and siltstones on the southeast. Coastal Plain "overburden" ranges from 800 to 1200 feet.

In the Georgia Coastal Plain probable Triassic sediments occur in an area 80 to 100 miles wide which extends from approximately 60 miles southwest of the South Carolina border across the Florida panhandle out into the Gulf of Mexico. Maximum thickness is more than 4,000 feet. This appears to be one large basin but data is meager. Arkosic sands are encountered along the northwest flank and shales and siltstones along the southeast flank. Overburden ranges from 2500 to 8000 feet. In north Florida the overburden ranges from 4000 to 10,000 feet.

Geophysical methods can be used to help locate buried Triassic basins but because of the presence of igneous intrusions the data is not definitive.

Water wells in the shallow, outcropping Triassic sediments in the North Carolina yield 0.5 to 0.01 gallons per minute per foot of well. Permeability decreases with depth. Cores from the more deeply buried Triassic rock in the Dunbarton basin, S. C. have extremely low hydraulic conductivity values and permeabilities; however, in two of the five wells drilled the water is geopressured and has heads 222 and 365 feet above the head of the overlying Coastal Plain aquifer.

The geopressures are thought to be caused either by tectonic compression, climatic changes or osmotic membrane phenomena. The abundant fractures in the crystalline-metamorphic rocks bordering the basin allows them to have larger water flow rates than the Triassic sediments.

Most of the Triassic sediments of Georgia and north Florida are buried too deep to be of interest for cavern waste storage. The area with less than 1000 of cover is restricted to a belt approximately 15 miles wide. A relatively large portion of the Coastal Plain of South Carolina and North Carolina contains less than 1000 - 1500 feet of post-Triassic sediments. This would appear to be the best area to consider for the subsurface storage of waste. Porosities, permeabilities, organic and pyrite content are all low. Basin faults appear to have low permeabilities. Montmorillonite is relatively abundant and could cause a problem. The regional extent of geopressured

water needs to be determined. The excess pressures may be caused by tectonic compression and not easily controlled.

Field investigations should be conducted on the shallow Florence basin in the northwestern portion of the Coastal Plain of South Carolina. Additional research must be done to determine the extent and cause of geopressures in Triassic basins.

Introduction

The eastern Triassic basins extend from Nova Scotia to Florida (Fig. 1). They have many features in common but differ in detail (McKee, et al. - 1959 and Eardley - 1962). The northern basins have been fairly well studied and most general statements about Triassic basins are based on these studies.

The basins are long, narrow and are filled with from several thousand feet to more than 20,000 feet of clastic sediments. On the basis of shape they could be considered ideal for the storage of waste products. From the North Carolina - South Carolina boundary north most of the basins are in the Piedmont Provinces and are subaerially exposed. In South Carolina, Georgia and northern Florida the Triassic basins occur in the Coastal Plain and are overlain by varying thicknesses of Cenezoic sediments.

Scattered occurrences of Triassic sediments are reported from the Coastal Plain north of South Carolina but little is known about their lateral extent (Milton and Hurst - 1965).

All the Triassic basins which have been explored in detail are bordered on one or both sides by major normal faults. In turn, sediments have been derived from one or both sides of the basin and rest unconformably on Paleozoic and Precambrian deformed rocks similar to those on the flanks of the basin. Precambrian gneiss, schist and granite are more abundant from Virginia south and Paleozoic metamorphosed rocks from Virginia north. Strike faults occur within the basin sediments and are approximately parallel to the border faults. Transverse faults are common and in places the two sets produce a thombic pattern. Some of the transverse faults extend into the surrounding folded and thrust-faulted Paleozoic rocks.

Border faulting is believed to have been a fairly continuous process during which sediments accumulated as the basins progressively deepened. In conjunction with the development of the border faults,

which are believed to be late Triassic, large amounts of basic magma entered the basins. Most entered along the borders and spread into the sediments as sills and dikes. Magma intrude some of the strike and transverse faults in the basins. Most of the basin sills are cut by faults, though it is generally believed that most of the faulting, other than the border faults, occurred after most of the sediments were deposited.

Both the faulting and the dike intrusions spread into the rocks adjacent to the basins. The Triassic sediments were much more extensive than now. In places sediments bury the border faults and spread over the upthrown blocks.

It is believed that the faulting and magma activity is associated with the initial rifting of North America and Africa (Dewey et al. - 1973 and Sanders - 1971).

It has been suggested (Russell - 1880) that some of the present isolated basins were originally connected and that post depositional faulting, folding and erosion has caused their apparent isolation. Klein (1969) presented stratigraphic data, K-Ar data and paleocurrent analyses on basin from North Carolina to Nova Scotia (Fig. 2) that indicated the sedimentary rocks were locally derived from the margins of the basins and concluded that each was a separate basin. There is little doubt that the rocks are locally derived but this does not prove the basins were separated.

Klein (1969) points out that in a graben a symmetrical facies distribution is to be expected - coarse sediments on both flanks of the graben and finer sediments in the center. He suggested on the basis of studies of some Recent grabens, that structural basin margins do not have to coincide with physiographic boundaries. Thus, one flank can contain coarse alluvial fan deposits and the other flank can contain deeper water fine grained sediments. This is called a half-graben (Fig. 3). The half-graben concept implies it is not always necessary, when coarse alluvial deposits are present on only one flank of the basin, to assume that the other half of the basin has been eroded. The half-graben concept can be useful when prospecting for the fine grained facies in a Triassic Basin.

The sediments filling the Triassic basins are largely clastic and dominantly red in color. Fanglomerates, conglomerates, arkosic sandstones, siltstones, shales and argillites are the most common sediments. Minor limestone and coal are present in some basins. The depositional environment was entirely continental.

Local topographic relief is believed to have been low in the south and moderate to high in the north (McKee, et al., 1959). This is presumably based on the relative abundance of coarse sediments and sediment thickness.

North Carolina

The southern most Triassic basin outcrops are in North Carolina. These will be reviewed briefly in order to obtain some idea of what should be expected in the less thoroughly studied basins lying beneath the Coastal Plain sediments of South Carolina and Florida.

The Deep River Triassic Basin, 36 miles long and 5 to 14 miles wide, lies in the north central part of the state in the Piedmont Province (Reinemund - 1955). The northeast trending basin is a tilted and down faulted trough-shaped block, in which the sediments dip generally south-eastward (Fig. 4). The southeast edge is formed by the Jonesboro fault, a northwest-dipping normal fault having a maximum vertical displacement equal to the maximum thickness of Triassic sediments in the basin (7,000 to 10,000 feet). The northwest edge is irregular and reflects an erosional contact between the Triassic and Pre-Triassic rocks. Within the basin, longitudinal faults roughly parallel the Jonesboro fault. They are displaced several hundreds or thousands of feet. Cross faults, commonly followed by dikes, have displacements ranging from a few feet to a few hundred feet. Tilting and differential subsidence within the rectangular fault framework has caused many variations from the regional strike and dip.

The basin is bordered by pre-Triassic metamorphic and igneous rocks. The rocks to the northwest are part of the "Carolina Slate Belt" (metamorphosed volcanics and sediments). The rocks on the southeast flank contain some similar rocks but also contain gneiss, schist and granite.

There is a basal conglomerate derived largely from rocks a short distance northwest of the basin; however, most of the sediments were derived from the southeast flank of the basin (Fig. 4). Boulder-bearing aluvial fan sediments were deposited along the southeast edge of the basin by streams flowing northwest. Finer grained sediments were deposited towards the center of the basin. In the center and northwest portion of the basin fine grained sediments were deposited in lake and swamp environments. Thin coal beds were deposited along with these sediments.

Although gross lithologies are similar from outcrop to outcrop, individual beds change rapidly in thickness laterally, and in lithology both laterally and vertically (Bain - 1966).

Most basin sediments contain less than 15% feldspar but some contain more than 25%. Metamorphic rock fragments are abundant. The medium and coarse grain sands are held together by quartz cement, clay paste and by inter-locking of rock particles.

Structural development of the Deep River basin begin by tilting and spasmodic subsidence along the Jonesboro fault (Fig.). It was accompanied by uplift and erosion of the source area to the southeast. After the sediments were deposited the tensional cross faults developed. Renewed longitudinal faulting then occurred, followed by the emplacement of basic magmic material. Both the Triassic and pre-Triassic rocks were peneplaned and a large part of the original Triassic basin was eroded and, in part, overlain by Coastal Plain sediments. The Coastal Plain cover was later eroded.

The Triassic sedimentary rocks are more easily eroded than the metamorphic and igneous rocks of the Piedmont. Therefore, the Triassic belt is a trough-like topographic lowland for most of its length.

X-ray analysis of 50 samples from the northern part of this basin (Hooks and Ingram - 1955) gave the following results:

Frequency of Abundance of Clay Minerals

	Percentage of Samples in which the Mineral is			
	the Most Abundant	Common or Abundant	Rare	Absent
Montmorillonoids	37	70	15	15
Illite	53	68	15	17
Kaolin	7	17	44	39
Vermiculite	2	4	7	89

Of interest is the relative abundance of montmorillonite in 70% of the samples.

Bain (personal communication) is presently conducting a detailed study of the Deep River basin using a wide variety of geophysical techniques. He plans to drill a well in the near future. He will use this basin as a model for a later regional study of the Triassic basins of the east coast.

The Triassic Wadesboro basin lies in-line and to the southwest of the Deep River basin. It is bounded on the southeast by a major fault and on the northwest by a number of smaller faults and lies unconformably above rocks of the Carolina Slate Belt (Randazzo et al. - 1970).

A major fault defines the eastern border. It is thought to be an extension of the Jonesborous fault which forms the southeast flank of the Deep River Basin or the continuation of the Governors Creek fault which lies within the Deep River basin. Portions of the fault are covered by Coastal Plain sands.

The fault system on the western edge of the basin are of smaller magnitude and consist of many narrow, elongated horsts and graben filled with fanglomerates. Both longitudinal and cross faults are present in the main basin. The latter cut the western border faults in many places. Dikes accompany many of the cross faults. The basin sediments strike $N41^{\circ}E$ and dip $20^{\circ}SE$. Sediments are predominantly alluvial.

Fanglomerates are limited to the western edge of the basin. This in contrast to the Deep River basin where the coarse facies occurs on the east flank of the basin. Argillite pebbles and cobbles, derived from the Carolinate Slate, are abundant. Arkosic sands, containing 35-65% moderately fresh angular feldspar, occur in the interior and eastern portion of the basin. The character of both sediments indicate they were derived from source areas close to the basin. Red siltstones and claystones are abundant throughout the basin and occur alone or interbedded with sandstone.

Clastic sediments were derived from both margins but only fine to medium-grained sediments were deposited along the eastern border. Because a major fault lies along this border, they suggest a coarse facies was deposited and has been eroded. It is also possible that the upthrown block was tilted to the southeast and drainage was away from the basin rather than into it.

Of importance in evaluating the distribution of lithologic facies in Triassic basin is the fact that throughout the Deep River and Wadesboro basins have similar structural configurations the coarse facies occur on different sides in the two basins.

The Crowburg basin southwest of the Wadesboro basin includes the southernmost outcropping Triassic sedimentary rocks in eastern North America. The wedge-shaped basins is 4 mi long and as much as 1 mi wide. Fanglomerates are the only sediments observed in the outcrops (Bell, et al. - 1974).

South Carolina

Triassic sediments have been found in three different localities beneath the Coastal Plain cover in South Carolina. The Florence basin was inferred from magnetic anomalies (MacCarty - 1936) and seismic data (Bonini and Woollard - 1960) and confirmed from cores (Siple - 1959). McKee et al (1956) show this basin extending northeast into North Carolina. Top of the Triassic is at 588 feet (Woollard, et al., 1957).

Little data is available on this basin but as it is the shallowest known basin in the Coastal Plain it should be seriously considered for further investigation.

Cook (1936) describes a well near Summerville, 20 miles northwest of Charleston which penetrated 980 feet of probably Triassic coarse red sandstone and shales with a few pebbles and diabase dike. It is overlain by 1,580 feet of Coastal Plain sediments. Mansfield (1936) believed this material was Cretaceous. Woollard et al. (1957) found no seismic evidence for a basin in this area.

The northeast trending Dunbarton basin is aligned perpendicular to the South Carolina and extends a short distance into Georgia. It has been described in some detail by Marine and Siple (1974).

The basin has been outlined on the basis of an aeromagnetic survey, seismic - refraction and seismic - reflection surveys and confirmed by drilling. It is approximately 30 mi long and 6 mi wide (Fig. 5). The upthrown western flank of the basin consist predominantly of schist, gneiss and some quartzite. There is a 80 feet weathered zone between the base of the Coastal Plain sediments and the top of the crystalline rocks. Seismic and well data indicate a major normal fault forms the northwest border of the basin though it is not certain whether this is a border fault or a longitudinal fault just outside the basin (it occurs in gneiss). The contact between the basin sediments and the basement gneiss dips 35° SE. The nature of the southeastern boundary is not known but as the sediments dip to the southeast it is assumed to be a normal fault of greater magnitude than the one forming the northwest border (Fig. 6).

Well samples indicates the western portion of the basin contains maroon arkosic siltstone with abundant gneissic pebbles and boulders (fanglomerate). Near the center of the basin the sediments consist of red to maroon mudstone, gray-brown fine-to-medium-grained sandstone and pink to

buff medium - to coarse - grained arkosic sandstone. Clay is abundant in the two types of sandstone. Calcareous cement is common.

The calcareous cement is thought to have been formed from water which moved downward through the fanglomerate along the western margin and upward in the basin center where evaporation caused carbonate and other salts to concentrate.

The sediments on the southeastern flank consists half of maroon clay stone and siltstone containing gray calcareous nodules and half grayish-brown very fine-to fine-grained arkosic sandstone with calcareous nodules. Thus, there is a systematic decrease in grain size from nothwest to southeast. This resembles a half-graben distribution.

A thin (3 to 8 feet) weathered zone occurs between the base of the basin sediments and the top of the underlying crystalline metamorphic rocks. The Triassic sediments are overlain by 824 feet to 986 feet of Coastal Plain sediments. There is a 10 feet to 46 feet mildly weathered zone between the top of the Triassic and base of the Coastal Plain sediments. This zone is overlain by 40 feet to 132 feet (thickening from northwest to southeast) of gray sandy clay which should form an effective caprock.

Georgia

No unequivocal Triassic basins have been identified in the Georgia Coastal Plain; however, numerous wells have penetrated diabase dikes and sills and red arkosic sediments beneath the Cretaceous and it is reasonable that some of these are Triassic in age. K-Ar dates on some of the dikes indicate a Triassic age. In some wells these rocks are underlain by Paleozoic sediments.

Milton and Hurst (1965) have summarized the well data up to 1965 (Fig. 7). I have attempted to bring the data up to date and also included the interpretations of other authors on Milton and Hurst's map (Fig 7).

Milton and Hurst (1965) have indicated the counties in which true crystalline metamorphic rocks have encountered immediately under Coastal Plain sediments. These occur along the northwestern updip portion of the Coastal Plain, bordering the Fall Line. They have also outlined the counties in which probably Triassic rocks (basalt, diabase, volcanic ash, arkose?, sandstone in siltstone) were found. Relatively little section has been penetrated in most wells, as once diabase, basalt or granite (arkose) is encountered drilling usually stops.

In Echols County (south central Georgia) Upper Cretaceous (Herrick-1961) sediments rest on Paleozoic shales and sandstones. Basement rock to the east and northeast of Echols County are largely altered volcanic ash and are similar to and considered to be equivalent to the slate belt rocks of the Piedmont. Two recently drilled wells in Camden County and one in Charlton County are reported to have penetrated Paleozoic black shales, siltstone and quartzite at depths of 4400 to 4600 feet (Barnett-1975). Marine and Siple (1974) show Triassic rocks in this area. I do not know what this is based on. Identification is questionable in this area.

Northwest of this area sandstones and shales along with diabase dikes are the most common rocks. Five wells drilled in 1973-74 in Lowndes County (immediately west of Echols County) penetrated red shales, siltstones, sandstones and diabase dikes (Georgia Geol. Survey files). These sediments are believed to be Triassic and have been called the Eagle Mills formation. The top of the Triassic occurs between 4000 and 4400 feet. The deepest

penetrated 3750 feet of possible Triassic and bottomed in Paleozoic.

Our own x-ray analyses of shales from the thick Triassic section in Lowndes County indicated they have a clay suite similar to those reported for the North Carolina Triassic. The clay suite is complex containing varying amounts of illite, montmorillonite, chlorite and kaolinite. The first two clays are predominant. Montmorillonite is the major clay in many of the samples.

The relatively high montmorillonite content of the Triassic sediments is a factor to be reckoned with when considering them for waste repositories.

To the north and northwest of Lowndes County most of the Triassic sediments described by Milton and Hurst (1965) are arkoses or granite wash. A well in Mitchell County encountered Triassic at 6230 feet and penetrated 1070 feet of sand and shale. A well in Thomas County bottomed in Triassic at approximately 6000 feet. A recent well in Dodge County (personal communication) drilled through 1200 feet of "granite wash" or weathered granite. Top of Triassic in this area is 2500 to 3000 feet.

The limited well data suggest there are major deposits of Triassic sediments in the central and southwestern Coastal Plain of Georgia. The sediments in the northwestern part of the area are arkosic sands, whereas, shales and silts are apparently more abundant to the southeast (Lowndes County). This may be one large basin.

Recently published cross-sections (AAPG - 1975) also indicates a Triassic basin in this area. The interpretation is presumably based on more complete data obtained by the oil companies. A north-south cross-section (Fig. 8) shows a thin (1000 to 2000 feet) deposit of Triassic extending from Crisp County to Lowndes County. Drilling suggest there is nearly 4000 feet in Lowndes County so the thickness may be underestimated.

An east by south-east cross-section shows steep normal faults in Pulaski and Dodge Counties with a maximum of 4200 feet of Triassic. The Triassic is in the shape of a wedge which thins out near the coast in Wayne County (Fig. 8).

Earlier McKee et al. (1959) indicated a Triassic basin existed in the southwestern half of the Coastal Plain. They indicate the axis of the basin swung west into Alabama and southwest into Florida and thickened in both Alabama and Florida. The shape and location is similar to that of the Appalachicola Embayment which persisted in this general area from the Paleozoic to the Miocene.

In Georgia the Triassic sediments are overlain from 2000 to 8000 of Coastal Plain sediments. They would seem to be too deep to be of value for shallow waste disposal. Most of the area with less than 2000 feet of Coastal Plain sediments, is underlain by crystalline metamorphic rocks, though, small isolated basins could well occur in this area.

North Florida

Barnett (1975) has completed a comprehensive evaluation of the basement rocks in Florida and southern Georgia. He shows the presence of a deep Triassic graben underlying the region of the Apalachicola or Southwest Georgia Embayment (Fig. 9). It is nearly 60 miles wide and filled with coarse red feldspathic and arkosic clastics containing numerous diabase sills. Maximum thickness is unknown but should exceed 4,000 feet. The upthrown blocks consist of Paleozoic sediments which have suffered low-grade metamorphism.

The Triassic rocks are overlain by from 4,000 feet to over 10,000 feet of sediments which thin towards the northeast into Georgia.

Arden (1974) explored the smaller Triassic basin to the west of the Apalachicola Embayment. A north by northeast trending seismic cross-section through the central portion of the Florida Panhandle showed the presence of a faulted Triassic basin approximately 15 miles wide with a maximum thickness of 6,000 feet. It is overlain by 6,000 feet of Gulf Coastal Plain sediments. Gravity and magnetic data confirm the interpretation.

Geophysics

Wollard et al (1957) established that the seismic velocities of gneiss, schist, slate and granitic rocks range from 15,900 to 19,200 feet per second; diabase velocities averaged 22,500 feet per second; Triassic sediments ranged from 10,400 to 14,500 feet per second; Cretaceous Coastal Plain sediments averaged 9,600 feet per second. Theoretically it should be possible to identify Triassic basins.

Unfortunately, many of the basins contain diabase intrusion which increases the average velocity to the point where it is similar to that in the surrounding metamorphic rocks.

Gravity data also causes a problem in some areas because it is not possible to distinguish between arkose, granite wash and basement granite.

Magnetic data is also of limited value because of the presence of diabase dikes.

Where dikes are absent or scarce, as in the Dunbarton basin, magnetic and seismic techniques can probably be used to locate Triassic basins.

Figure 10 is a map showing the depth to Pre-Cretaceous Basement and the location of areas containing Triassic clastic sediments. Pre-Cretaceous basement is mostly either Triassic or older crystalline metamorphics. The map is in good agreement with one constructed by Herrick and Vorhis (1963).

Hydrology

Hydrologic data on the Triassic sediments are relatively scarce. Marine and Siple (1974) and Marine (1974) published data on two groups of wells drilled in the Dunbarton basin.

The first three wells provided the following results (Marine and Siple 1974). Laboratory analysis of core samples show that all rocks have low hydraulic conductivity (10^{-5} to 10^{-8} m per day). This is caused by the poor sorting and high clay content of all samples. Effective porosity of the sandstone cores was $\sim 8\%$ and mudstone cores $\sim 0.5\%$.

Eight year field tests of the well in the fine-grained sediments on the southeast flank of the basin indicated the hydraulic conductivity was 2.4×10^{-7} m per day; the transmissivity of the region surrounding the well was 4.6×10^{-6} m per day; the average permeability was 2.4×10^{-7} m per day. The permeability values of the fanglomerates on the northwest flank were comparable to those in the fine-grained sediments. This indicates the ever-present clay matrix is the factor limiting and controlling permeability and transmissivity and grain size is of little consequence.

This materially increases the volume of sediments that could be considered suitable for the storage of radioactive material.

Basin faults were not detected in this initial study.

Additional geophysical data and analysis suggested the presence of several longitudinal faults in the basin. The faults do not extend into the Cretaceous indicating they are more than 100 m.y. old. Two wells were drilled on either side of one of the faults.

Cores from the weathered zone in the upper 100 to 150 feet of Triassic rocks swelled and cracked when exposed to wetting and drying. Cores of the Triassic from both holes were predominantly maroon, fine-grained, dense mudstone. One well was slanted to intercept the geophysical fault but none was encountered.

Of the five wells; two have heads above land surface and 222 feet and 365 feet above the head in the overlying Coastal Plain aquifer. These two wells are located in the northwestern portion of the basin. Because of the very low permeability no well has yet achieved a water level that is in equilibrium with that of the formation, though in two months time one well was near equilibrium.

Marine list ten possible methods by which geopressured reservoirs can form and concluded three were feasible. Tectonic compression, if happening in the last one million years, could cause the head in the Triassic basin. Earthquakes are common in this area but could be caused either by compression or tensional forces.

Long-term climate changes can influence temperatures to great depths. During the Pleistocene Epoch the Triassic rocks were probably cooler and have since been warming. This increase in temperature could account for an excess head of between 200 and 400 feet of water.

Osmotic membrane phenomena are another possibility. The dissolved solids in the Triassic waters range from 6000 to 18,000 mg/liter; in the overlying Coastal Plain aquifer the value is 30 mg/liter. Calculations indicate the equilibrium osmotic pressure differential should be about 245 and 390 feet of fresh water at the two wells.

Regardless of the reason, the geopressures are real and pose a serious problem both from the standpoint of contamination of shallow aquifers and stability of storage facilities.

In order to obtain some additional data on the hydrologic characteristics of the Triassic, several North Carolina Ground-Water reports were examined.

In the Deep River basin near Durham, N. C. the rocks dip 10° to 20° southeast. Though the porosity and permeability is generally low, water percolating downdip through the more permeable sandstones develops sufficient head to produce flowing wells in some localities (Bain - 1966). Wells in the Triassic sediments yield from 0.5 to 0.1 gallons per minute per foot of well. Wells commonly have from 50 to 100 feet of uncased depth and produce 7 to 11 gallons per minute. The yield per foot of well decreased with depth. In part this is related to the development of secondary openings formed by weathering near the surface.

Bain (personal communication) says there is some porosity at depth but virtually no permeability.

Where diabase dikes are present downgradient from the direction of groundwater movement, impounding can occur. This makes the best location for water wells. Same such mechanism might explain the geopressures in the Dunbarton basin.

To the east in the Raleigh area (Maynard and Thomas - 1968) Triassic sediments yield from 0.01 to 0.11 gallons per minute per foot of well or from 3 to 9 gallons per minute per well. Yield decreases with depth. Rocks are largely arkosic sandstones, argillaceous sandstones, shales and fanglomerates. Rocks are largely impermeable and water is stored in and moves along joints and fracture planes.

The ground water studies indicate that minor water movement does occur in the Triassic sediments but generally is related to fractures. Water production decreases with depth (maximum depth usually less than 300 feet) suggesting that at depths of several hundred feet there should be little ground water movement.

Studies have been made (Marine - 1966, Marine - 1967a, Marine - 1967b, and Webster et al., - 1970) of the hydrologic characteristics of the basement crystalline-metamorphic rocks near the Savannah River Plant. These rocks are presumably typical of the rocks that flank and underlie the Triassic basins.

The upper thousand feet of rock is pervaded by small fractures and hydraulically connected. Transmissivity is low. Response to withdrawal is slow. Also present are fractures open wide enough to permit transmission of waters at a faster rate. These fractures occur in vertically restricted but laterally extensive zones.

Field test indicated there was numerous intervals that produced from 1 to 18 gallons per minute of water. One third of the core samples with the highest values, had permeabilities that average 0.0005 gpd/sq ft.

Injection tests into most sections were so low as to be unmeasurable. Swabbing test indicated the average permeability is 0.0003 gpd/sq ft.; however, some fracture zones have a coefficient of transmissibility of 160 gpd/ft. The apparent permeability of hydraulically transmissive zones is 1 gpd/sq ft.; some zones exceed this value.

Tracer tests were conducted and calculations indicated the coefficient of permeability was 0.35 gpd/sq ft; porosity, due to fractures, was 0.10%; flow velocity was 4.0 feet per day. The measured velocity was 5.5 times higher than the calculated velocities based on gradient, permeability and porosity.

The crystalline rocks are apparently more permeable and transmit water more rapidly than the Triassic sediments.

Conclusions

The seismic risk map for the United States indicates that South Carolina is a major to moderate risk area. The southwest Coastal Plain of Georgia is classed as a minor risk area. In this respect the latter area is a more desirable site for subsurface waste disposal.

Only one reasonably well identified Triassic basin occurs in South Carolina (Dunbarton). This is a typical Triassic basin, though no diabase has yet been found. Two possible basins may be present (Florence and unnamed).

Scattered well data and some seismic data indicate a large volume of Triassic sediments occur in the southwest Georgia Coastal Plain and northern Florida. It is not known whether there is one large or a number of small basins in this area. Our seismic and gravity data indicate it is quite probable that a major Triassic basin exists in this area. It is fairly certain that a basin over 60 miles wide extends across the Georgia - Florida border (in contrast to the 6 mile wide Dunbarton basin). However, Florida Geological Survey geologists believe some of the rocks identified as Triassic are Paleozoic.

Most of the Triassic is at least 1000 feet thick and the maximum thickness is apparently on the order of 6000 feet.

In South Carolina two basin areas are overlain by less than 1200 feet of Coastal Plain sediments. The probable Triassic in Georgia and North Florida is overlain by 2500 to 10,000 feet of younger rocks. In Georgia there is a belt approximately 40 miles wide adjacent to the Fall Line which could contain Triassic basins with less than 2000 feet of overburden; the less than 1000 feet belt would be only about 15 miles wide. The Coastal Plain sediments are considerably thinner in South Carolina than in Georgia - North Florida. North Carolina has the thinnest section of Coastal Plain sediments along the east coast.

In general the basin sediments are well suited for the storage of liquid waste. They are poorly sorted, have a high clay content and contain little

organic matter or pyrite. Porosity and permeability values are low in all lithologies. Arkose and granite wash apparently comprise a major portion of the Georgia - North Florida sediments. These rocks may be more permeable than those to the north. Montmorillonite and probably vermiculite are abundant in the clay fraction. These water bearing clays are temperature sensitive and are a potential source of trouble. Marine (1974) reported there was little montmorillonite in the Dunbarton basin but it is abundant in the other basins that have been studied.

Both longitudinal and cross fractures are present in these basins. Little is known about the fault density. Even in the outcropping basins faults are difficult to detect. Faults are the major conduit for water in the metamorphic - crystalline rocks and in the shallow Triassic rocks. The role of faults in the transport of water in the deep Triassic sediments is not known. Many of the cross faults extend into the bordering metamorphics and if the faults have any permeability this could be a source of trouble. Measurements indicate the faults in the crystalline rocks have significant permeabilities as do the shallow faults in the Triassic sediments. Due to the high clay content of the Triassic rocks it is likely that, at depth, the faults are relatively impermeable.

One of the major concerns would seem to be the geopressures measured in the Dunbarton basin. If the geopressures are due to temperature increases or osmotic membrane phenomena they could possibly be controlled. If they are due to tectonic compression it is likely that little could be done to control them.

It is of interest to note that Sbar and Sykes (1975) showed that the eastern United States is a region of high horizontal compressive stress. The pattern of stress appears to be post-Mesozoic in origin and they suggest the stress is generated by the same mechanism that drives the large lithospheric plates. The compressive stresses cause earthquakes along unhealed faults of late Paleozoic or younger age. They cite the Charleston earthquake as an example of a compression generated earthquake.

It will be necessary to determine if geopressures exist in the other Triassic basins in the southeast. If they do, it will be necessary to establish the cause and see if it can be controlled.

If field studies are to be conducted, I recommend that the shallow Triassic Florence basin in northeast South Carolina be the primary target.

Bibliography

- American Association of Petroleum Geologists (1975) Southeastern Region, Geological Highway Map.
- Arden, D. D. (1974) A geophysical profile in the Suwannee Basin, North-western Florida, in Symposium on the Petroleum Geology of the Georgia Coastal Plain, Ga. Geol. Survey Bull. 87, 111-122.
- Bain, G. L. (1966) Geology and ground-water in the Durham area, North Carolina. North Carolina Ground-Water Bull. 7, p. 147.
- Barnett, R. S. (1974) Basement structure of Florida and its tectonic implication, Original manuscript. Paper to be published in the Transaction Gulf Coast Assoc. Geol. Societies.
- Bell, H. A., J. R. Butler, D. E. Howell, and W. H. Wheeler (1974) Geology of the Piedmont and Coastal Plain near Pageland, South Carolina and Wadesboro, North Carolina. Carolina Geol. Soc. Guide Book p. 23.
- Bonini, W. E. and G. P. Woollard (1960) Subsurface Geology of the North Carolina-South Carolina Coastal Plain from seismic data. Amer. Assoc. Petroleum Geol. Bull. 44, 298-315.
- Cooke, C. W. (1936) Geology of the Coastal Plain of South Carolina, U. S. Geol. Survey Bull. 867, 196p.
- Dewey, J. F., W. C. Pittman III, W. B. F. Ryan and J. Bonnin (1974) Plate tectonics and the revolution of the Alpine System, Geol. Soc. Am. Bull. 84, 3137-3180.
- Eardley, A. J. (1962) Structural geology of North America, Harper and Row, New York, 743 p.
- Herrick, S. M. (1961) Well logs of Coastal Plain of Georgia, Georgia Geol. Survey Bull. 70, 462 p.
- Herrick, S. M. and R. C. Vorhis (1963) Subsurface geology of the Georgia Coastal Plain, Ga. Geol. Survey, Infor. Cir. 25, 78 p.
- Hooks, W. G. and R. L. Ingram (1955) The clay minerals and the iron oxide minerals of the Triassic "red beds" of the Durham Basin, North Carolina, Am. Jour. of Sci., 253, 19-25.

- Klein, G. de V. (1969) Deposition of Triassic sedimentary rocks in separate basins, eastern North America, Geol. Soc. Am. Bull., 50, 1825-1832.
- MacCarthy, G. R. (1936) Magnetic anomalies and geologic structures of the Carolina Coastal Plain, J. Geol., 44, 396-406.
- Maher, J. C. and E. R. Applin (1971) Geologic framework and petroleum of the Atlantic Coastal Plain and Continental Shelf, U.S.G.S. Prof. Paper, 656, 98 p.
- Mansfield, W. C. (1936) Some deep wells near the Atlantic Coast in Virginia and the Carolinas, U. S. Geol. Survey, Professional Paper 186, 159-161.
- Marine, I. W. (1966) Hydraulic correlation of fracture zones in buried crystalline rock at the Savannah River Plant near Aiken, South Carolina. U.S.G.S. Professional Paper 575-D, 223-227.
- Marine, I. W. (1967a) The permeability of fractured crystalline rock at the Savannah River Plant near Aiken, South Carolina, U.S.G.S. Professional Paper 575-B, 203-211.
- Marine, I. W. (1967b) The use of a tracer test to verify an estimate of the ground water velocity in fractured crystalline rock at the Savannah River Plant near Aiken, South Carolina in Isotope Techniques in the Hydrologic Cycle, Am. Geo. Union, Geophy. Mineral, 171-179.
- Marine, I. W. (1974) Geohydrology of the buried Triassic basin at the Savannah River Plant, Ground Water, 12, 84-96 and Am. Assoc. Petrol. Geol. Bull. 58, 1825-1837.
- May, V. J. and J. D. Thomas (1968) Geology and ground water resources in the Raleigh area North Carolina. North Carolina Ground Water Bull. 15, 135p.
- McKee, E. D. and others (1959) Paleotectonic map of the Triassis System, U. S. Geol. Survey, Misc. Geol. Inv. Map I-300, 33 p.
- Milton, C. and V. J. Hurst (1965) Subsurface "basement" rock of Georgia, Ga. Geol. Survey Bull. 76, 56 p.
- Randazzo, A. F. , W. Swe, and W. H. Wheeler (1970) A study of tectonic influence on Triassic sedimentation, The Wadesboro Basin, central Piedmont, J. Sed. Petrol., 40, 998-1006.

- Reinemund, J. A. (1955) Geology of Deep River coal field North Carolina, U.S.G.S. Professional Paper 246, 159 p.
- Russell, I. C. (1880) On the former extent of the Triassic formation of the Atlantic States. *Am. Naturalist*, 14, 703-712.
- Sander, J. E. (1971) Triassic rocks, northeastern North America: Regional tectonic significance in light of plate tectonics. *Geol. Soc. Am. Abs. with Programs (Ann. Meg.)* 3, 781-783.
- Sbar, A. I. and A. R. Sykes (1974) Contemporary compressive stress and seismicity in eastern North America: an example of intra-plate tectonics, *Geol. Soc. Am. Bull.*, 84, 1861-1862.
- Siple, G. E. (1959) Guidebook for the South Carolina Coastal Plain field trip of the Carolina Geological Society, Nov. 16-17, 1957: South Carolina State Devel. Board Div. Geol., Bull, no. 24, 27 p.
- Webster, D. S., J. F. Procter and I. W. Marine (1970) Two-well tracer test in fractured crystalline rock, U.S.G.S. Water-Supply Paper 1544-I 22 p.
- Woollard, G. P., W. E. Bonini and R. P. Mayer (1957) A seismic refraction study of the sub-surface geology of the Atlantic Coastal Plain and Continental Shelf between Virginia and Florida, U. of Wisconsin, Tech. Report, 128 p.

Fig. 1 Exposed and buried Triassic sediments. Modified from Marine and Siple(1974), particularly Georgia-Florida area. If the Georgia-Florida basin is not a complex of basins it is the largest Triassic basin on the east coast. Coastal Plain basins have not been eroded as much as Piedmont basins, so it is possible that a basin of this size exists.

Fig. 2 Triassic regional dispersal patterns. From Klein (1969).

Fig. 3 Fault trough facies models. (A) Physiographic coincidence model. (B) Half-graben model based on present-day facies distribution in Deep Sea. From Klein (1969).

Fig. 4 Theoretical sections shown in development of Deep River Triassic Basin, North Carolina. From Reinemund (1955).

Fig. 5 Aeromagnetic map showing the outline of the Dunbarton Triassic Basin and the location of wells and seismic investigations. From Marine and Siple (1974).

Fig. 6 Postulated sequence of geologic events for the Dunbarton Triassic Basin. From Marine and Siple (1974).

DEEP TEST IN GEORGIA

EXPLANATION

- Triassic diabase or or near fault line
- Diabase or basalt
- △ Granophyre or rhyolite
- Ash
- Shale, sandstone, quartzite, or arkose
- ◻ Shale, sandstone, quartzite, or arkose with intruded diabase or basalt
- ◻ Altered granite (?) or cemented arkose(?), in Pierce County only
- True basement (crystalline metamorphic rocks)

Names of counties in which drilling reached true basement are underlined, counties in which drilling did not reach true basement are outlined

4955 Depth in feet

1965

Fig. 7

Fig. 8 Cross sections showing location of Triassic Basins in Georgia Coastal Plain. From AAPG (1975).

Fig. 10 Depth to pre-Cretaceous basement based on seismic data and wells. From Wollard et al (1957). Areas containing known or probable Triassic clastic sediments are outlined.

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