POTENTIAL HAZARDS TO WATER RESOURCES ALONG A TEST-FLIGHT PATH, 1952; POSSIBLE DISPOSAL OF LIQUID WASTE IN A DEEP SALINE AQUIFER, 1954; AND HYDROLOGIC ASPECTS OF A PROPOSED BURIAL GROUND, 1965

By C. V. Theis

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FOREWORD

During his long and productive life, C.V. Theis, regarded by his scientific peers as the father of quantitative ground-water hydrology, authored about 150 reports. About one third of these reports were prepared for various U.S. Federal and Military agencies during and following World War II and never released to the public. These agencies (or their present day equivalents) have agreed that it is desirable to make these reports available for study by historians, scholars, and others interested in the development of the science of ground-water hydrology.

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GEOLOGY AND HYDROLOGY OF AREA INVOLVED IN PROPOSED FLIGHT TEST BY CONVAIR

By C. V. Theis

December 1952

General Nature of Proposed Project

Convair proposes to convey a nuclear reactor in the bomb bay of a B-36 bomber with take-off at Carswell Air Base at Fort Worth, flight along an east-west corridor a little north of Fort Worth, and test in a rectangular area, the boundaries of which are approximately, on the west, the Pecos River; on the north; the latitude of the north boundary of Lea County, New Mexico; on the east, the east boundary of Conchran and Yockum Counties, Texas; on the south, about the 33d parallel.

The corridor and test areas have been chosen to avoid large towns. The test procedure that will be followed, according to Convair officials, will be to fly the reactor inoperative out of Fort Worth, use it in the test area, and return to Fort Worth with the reactor shut down but still quite radioactive.

The reactor will eventually reach a power of about 1,000 kilowatts and will be water-cooled and moderated. This water system will be about 200 gallons in volume. At the conclusion of the test the water will be drained from the reactor into a special tank. The reactor itself with sheet-type fuel elements will be contained in a shell of 3/4-inch stainless steel. The normal dissolved solids of the water will become radioactive perhaps to a level of 1 or 2 curies, barring any contamination from imperfect fuel elements.

The hazards to be considered are (1) a crash at take-off or landing at Fort Worth, (2) a possible crash during an emergency landing at Roswell, which will probably be the best alternate landing field, and (3) crash elsewhere in the corridor and test area.

Resume of Geology of Flight Corridor and Test Area

The area involved consists of a great downwarp or trough of the older rocks covered on both its east and west sides by younger sediments laid down over the truncated edges of these older rocks. (See figure 1.) The older rocks are Pennsylvanian and Permian in age, the former outcropping from about 40 to about 110 miles west of Fort Worth or from about the western edge of Parker County to the vicinity of Albany and Throckmorton, and the latter from there to about 20 miles east of Post. These rocks consist of shales, impure sandstones, and some limestone and gypsum. As a consequence, ground water is of little consequence, and all the larger public water supplies in the outcrop of these rocks are taken from surface waters. A few small supplies, indicated on Figure 1, are drawn from shallow alluvial deposits.

East of the western border of Parker County, Cretaceous rocks lie across the leveled edges of the older rocks and dipping eastward in a short distance attain a great thickness.

These Cretaceous rocks contain the Travis Peak ("Trinity') and Paluxy sands and some other less important aquifers. The Travis Peak formation, the chief aquifer of this part of Texas, outcrops in western Parker County and the Paluxy sands, in the strip west of Fort Worth. In this part of the flight strip, the public water supplies, with the exception of that of Fort Worth, are derived from wells.

From Post, in Garza County, westward for 120 miles, the flight strip and maneuver area are over the Staked Plain, or Llano Estacado, which is underlain by unconsolidated, silt, sand, and gravel of the Ogallala formation of Tertiary age. This area is, in effect, a great mesa consisting of these sediments from 0 to 300 feet thick lying on a platform essentially of Triassic red beds with a few patches of Cretaceous sand and shale intervening in places between the Ogallala and Triassic, which, in turn, overlie the Permian rocks at considerable depth. The lower part of the Ogallala formation is saturated with water. All the public supplies of this area are derived from wells, and in addition, the southern part of the maneuver area in Lea County, New Mexico, and, to a lesser extent, the area in Texas support considerable pump irrigation.

From the western edge of the High Plains almost to the Pecos River, a distance of about 25 miles, the maneuver area as mapped lies over Quaternary unconsolidated sandy deposits, the Mescalero sands. Water supplies are scanty in this area, and the country is used for ranching.

A few miles east of the Pecos River, the Permian rocks again come to the surface. In the proposed maneuver area as outlined, these rocks are gypsiferous red shale. At the western edge of the maneuver area and from there for about 10 miles west, the irrigated area of the Roswell Basin extends, which is a comparatively thickly populated rural area. In the area, about half the wells draw water from the alluvium of the Pecos Valley, and about half, from the underlying San Andres limestone of Permian age.

Conditions at Fort Worth

The geological and hydrological situation at Fort Worth has been described in a previous report (Richardson, 1952). The landing strip at Carswell Air Base lies in a north-south direction and abuts against Lake Worth. The flight course must pass over the southeastern part of Lake Worth and, in general, near the other parts of the lake. The capacity of Lake Worth is 28,660 acre-feet (Lohr and others, 1952). If a crash should occur in the lake at take-off or landing, the moderator and shield water might become mixed in this water. If this water has an upper limit of total radioactivity of 2 curies, as has been stated, of radioactive components of normal Fort Worth water, dilution in 1 acre-foot of water would reduce the activity to 1.62×10^{-3} microcuries per cubic centimeter ($2 \times 10^6/3.25851 \times 10^5 \times 3.785 \times 10^3$). This is below drinking water tolerance for all components of the water excepting calcium-45, as given by the Subcommittee on Internal Dose, National Committee on Radiation Protection. Considering the nature of a crash, it seems improbable that the dilution could be any less than to a depth of 1 foot over an area 200 by 200 feet. Inasmuch as the daily consumption of water in Fort Worth is about 60 acre-feet, it would seem impossible for anyone to get water above tolerance for internal use even for a short time because of the loss of the moderator or shield water.

The possible effect of loss of fission products by exposure to the fuel elements to leaching cannot be evaluated. The reactor is in a shock-resistant compartment, and the uranium is plated. Presumably, if water had access to crushed elements, solution could take place only at sharp flexures and cracks of fuel elements and would proceed comparatively slowly. A crashed plane in Lake Worth could probably be removed comparatively rapidly because of the availability of heavy wrecking equipment. Nevertheless, some hazard exists. In case of such a disaster, there seem to be two possibilities of remedial action other than the prompt removal of the reactor from the lake. One would be the waste of water of Lake Worth. This lake has a capacity of 28,660 acre-feet, and Eagle Mountain Lake and Bridgeport Lake upstream have a combined capacity of 503,000 acre-feet (Lohr and others, 1952). Water would be available to replace the waste under almost any hydrologic conditions. Contaminated water passing through the system would pass down the West Fork of Trinity River through Fort Worth and through Dallas but would not be used for water supply at any place.

A crash into Lake Worth would almost certainly stir up considerable sediment. The turbidity of the raw water at the treatment plant varied from 10 to 37 parts per million in 1951 and averaged 24 parts per million. Adsorption on the stirred up silt would probably be large, and much probably would be reprecipitated on the lake bottom. The shores of the lake are inhabited, and small craft frequent the lake. In an emergency as a second remedial measure, it might be advisable to promote adsorption by dosing the vicinity of the crash with bentonite or perhaps ion-exchange resins in order to remove as much activity as possible. However, such a procedure would probably result in the temporary fixation of the activity on the bed of the lake.

The total capacity of the Fort Worth water-treatment plant is 79,000,000 gallons a day (Lohr and others, 1952) as against an average daily use for the maximum month in 1945 (Sundstrom and others,1949) of 27,900,000 gallons. This treatment involves sedimentation and rapid sand filtration. Apparently, therefore, excess treatment capacity would be available to filter excess clay or other solids that might be put into the raw water.

It would appear that, despite the improbability of contamination of the lake, the eventuality should be foreseen and that provision be made to reduce the hazard as much as possible. In case of any possibility of contamination, it would be necessary to monitor the water carefully. If water had to be wasted from the lake, there would be water that could be withdrawn before the contamination moved to the inlet of the water works. Careful control would be necessary. Provisions should be made to monitor the Fort Worth water supply as a matter of routine. Inasmuch as the nuclear operations of Convair cannot be kept entirely secret, it would seem advisable to have radiation detection equipment installed in connection with the Fort Worth water-treatment plant to give a background for later use in case of emergency, to allay public apprehension as to normal operations, and to give experience to the city water officials in variations of radioactivity not related to the local Convair operations.

Conditions in Flight Corridor and Test Area

In case of any crash in the corridor or any release of radioactivity on the ground by any other method, the hazards to water supply would vary with location. The local variations in degree of hazard cannot be enumerated in the present report, but it is recommended that, if the present reactor project is approved, a more thorough report be prepared in order to give necessary local information in case of an accident. The present report will present only the general features characteristic of the major subdivisions of the rocks.

In the western part of the outcrop of Cretaceous rocks in western Parker County, recharge to the Travis Peak ("Trinity") sands occurs. Ground water moves slowly through these silty sands. As a consequence, most of the fission products would be adsorbed before much travel and nonadsorbed isotopes, such as ruthenium, would lose their activity before traveling far. In case of an accident, any wells within a few miles of the vicinity should be monitored immediately and for several years thereafter as a precautionary measure, but it would be expected that results would be negative.

The Pennsylvanian rocks, cropping out from the edge of the Cretaceous westward about to Throckmorton and Albany, consist largely of shale and sandstone but also include some limestone beds that locally are thick. There are no prominent aquifers in this section and the public water supplies all utilize surface water. In places, however, the limestones yield good supplies of water to farm and ranch wells. Localities probably exist where limestone is cavernous enough to conduct water fairly rapidly underground and which would represent hazards of contamination in case of accident in them.

The Permian rocks lying to the west of the Pennsylvanian outcrop and extending about to the west edge of Kent County are red shales, sandstone, limestone, and gypsum. There are no good freshwater aquifers in the Permian rocks, and all the larger public water supplies of the area involved in this report are derived from surface water. Through Throckmorton and Haskell Counties, the Permian rocks (Wichita and Clear Fork Groups) contain several limestone and dolomite beds. Westward, the Permian rocks (Whitehorse, Cloud Chief, and Quartermaster formations) contain little limestone but extensive gypsum beds. It is possible that there may be fairly rapid movement of water underground in some of the areas underlain by limestone and gypsum. In the areas underlain by the red beds, the chief hazard would be from surface drainage into public supply reservoirs or into the more numerous small stock tanks.

The Triassic formations, extending about to Post in Garza County, are also red beds and contain no good aquifers. It is anticipated that no difficulty would arise from underground movement in this section and that the chief hazard would be surface drainage.

The western section of the corridor and most of the maneuver area lie over the Ogallala formation, of Tertiary age, of the Staked Plain. The Ogallala consists of unconsolidated silt, sand, and gravel. There is very little surface drainage within or from the Staked Plain. Light rains simply wet the soil, and heavy rains accumulate in the multitude of depressions or sinks that dot the surface of the plain from which the water percolates slowly to the water table from 20 to 200 feet below. Any radioactive material on the surface would, in ordinary times, be largely adsorbed by ion-exchange, and nonadsorbable ions would probably be largely brought back to the surface by evaporation or would seep very slowly downward. In case of a disaster, presumably, the ground should be fenced, and cattle excluded for some years.

A considerable part of the High Plains is irrigated by water pumped from wells. In those areas, irrigation causes a more rapid movement of water downward and might result in more leaching of adsorbable ions. In case of a crash in irrigated areas, irrigations should be prohibited in the endangered area until all radioactivity has been removed.

After heavy rains, the sinks of the area are filled with water, and recharge takes place comparatively rapidly. If a crash should occur in a water-filled sink, it would probably be advisable to pump the water from the lake onto the land in the vicinity in order to dissipate it largely by evaporation rather than to let the contamination sink to the water table.

High winds are prevalent in the area especially in the spring and these move the dust on the surface. In case of contamination, therefore, adsorbed isotopes would be moved by wind and could be inhaled by animals and men. In case of a crash, it would probably be advisable to fix the contaminated soil with oil or other means.

The western part of the maneuver area lying between the western escarpment of the Staked Plain and the Pecos River would probably present the minimum hazard. This area is a plain sloping from the edge of the Staked Plain to the Pecos River and is underlain, in most part, by loose wind-blown sand, called the Mescalero sands. There is no through drainage, and rainfall is almost entirely adsorbed in the sands. There are no good aquifers, and the country is used only for ranching. Contamination in this area would seep into the sand and probably would be largely adsorbed near the surface. There are some ranch wells which would have to be considered in case of a crash near them.

Conditions at Roswell

Engine trouble in the course of testing over the maneuver area would probably result in landing at Walker Air Force Base, Roswell, which would probably be the preferred alternate field, inasmuch as B-36 planes are already based there. The Roswell city supply and the supply of the airbase are derived from artesian wells. The artesian wells draw water from the San Andres limestone of Permian age, which is overlain by gypsiferous shales of the Chalk Bluff formation, and this, in turn, by the alluvium of the Pecos Valley. The San Andres dips eastward and consequently goes farther underground to the east and rises to the surface a few miles west of the airbase. Any release of radioactive materials on the ground at the air base would not affect the artesian water supply.

Some irrigation with water pumped from the alluvium is done in the vicinity. Small quantities of radioactivity, such as are involved in the cooling system, would doubtless be adsorbed in the sandy and somewhat silty materials of the alluvium before they could travel off the airbase as the water moves slowly in the alluvium, and large masses of the aquifer would be involved. Major releases of radioactivity might be adsorbed or largely decay before the activity could travel to any wells in the vicinity, but further research is needed on the ion-exchange characteristics of the alluvium before this can be established.

A few miles west of the airbase, the recharge area of the artesian aquifer begins. This is an area of sinkholes and rapid percolation of surface water underground. Release of radioactivity on the ground in the recharge area if followed by rain might result in the entry of radioactive contamination into the aquifer. No dilution could be counted on after its entry into the aquifer, and its course of movement, although in general eastward, could not be predicted in detail. It might appear in one of the public supplies and it might be brought to the surface in any of several hundred irrigation wells. The Roswell artesian aquifer is a cavernous limestone and hence the opportunities for adsorption during passage underground are much less than in sandy aquifers. In case of a crash in this area with release of radioactive materials any bare rock surfaces down slope from the plane should be covered with soil and every effort made to prevent drainage away from the contaminated area in case of rain.

Recommendations

1. The water treatment plant at Fort Worth should be equipped with a recording continuous radiation detector in order to be in readiness should an accident occur either by the air-borne or land-based reactor; to give a record available to the city of fluctuations of radioactivity in their water supply, particularly after atomic-bomb bursts; and as a public relations act in order to give the city assurance that no untoward situations are arising.

2. In case of a crash on land with subsequent danger of radioactive contamination, the drainage around the crash should be controlled to prevent overland movement of contaminated water. This will be of particular necessity in the area west of Roswell and in the area of Permian gypsiferous sediments between Throckmorton and Post. In case of a crash, geologist familiar with hydrology should be brought to the scene to help in assessing the danger of overland and underground movement of radioactivity at the particular spot.

3. A more thorough investigation of the geology and hydrology of the maneuver area and particularly the corridor should be made if the reactor project is approved. Such an investigation would involve (a) bringing the information on public supplies up to date (b) mapping the zones of gypsum and limestone and other soluble rocks in the Pennsylvanian and Permian areas of the flight corridor (c) locating faults and other structural features that might control the direction of underground drainage in these zones (d) collecting typical samples of soil-materials to make a study of their ion-exchange characteristics (e) acquiring a familiarity with the terrain by one or more geologists so that in case of an accident he or they would be able to appraise the hazards in the immediate vicinity of the endangered locality

This investigation would be conducted by field reconnaissance, study of aerial photographs, a study of the literature, and study of materials in the files of oil companies. As the studies are closely related to studies of ground-water hydrology that have been performed in Texas and elsewhere for years by the U.S. Geological Survey they could be carried on without arousing public curiosity or apprehension.

The Geological Survey is now in process of obtaining Q-clearance on two of its men assigned to the Austin office of the Survey. If the air-borne reactor project is approved, this office has much of the necessary experience and knowledge already available to undertake such an investigation.

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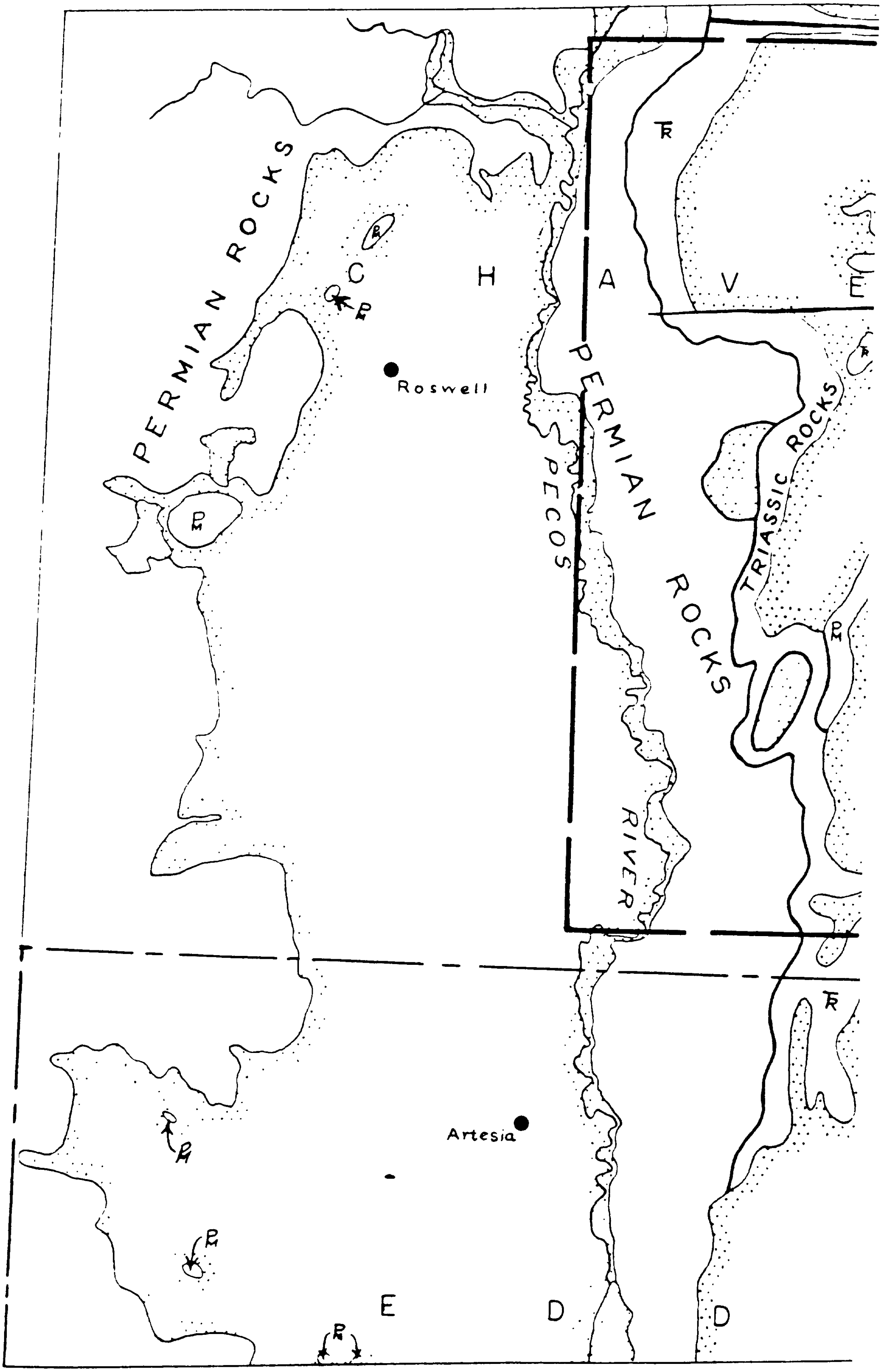
Figure 1.-- MAP SHOWING PROPOSED FLIGHT PATH FROM NEAR ROSWELL, NEW MEXICO TO NEAR FORT WORTH, TEXAS

MAP ASSEMBLY

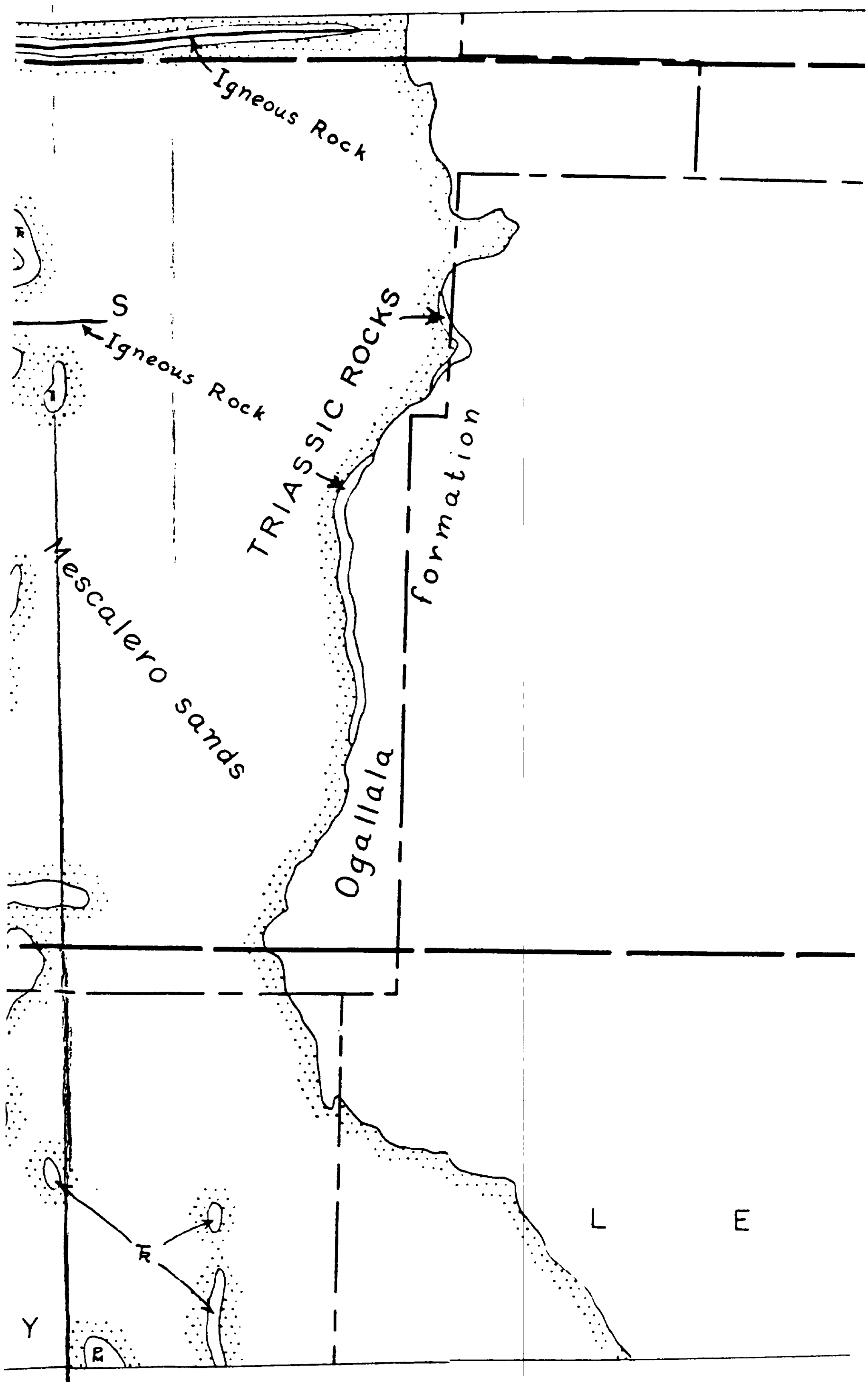
Map A	Map B	Map C	Map D	Map E	Map F	Map G	Map H	Map I	Map J	Explanation

MAP A



Joins Map B

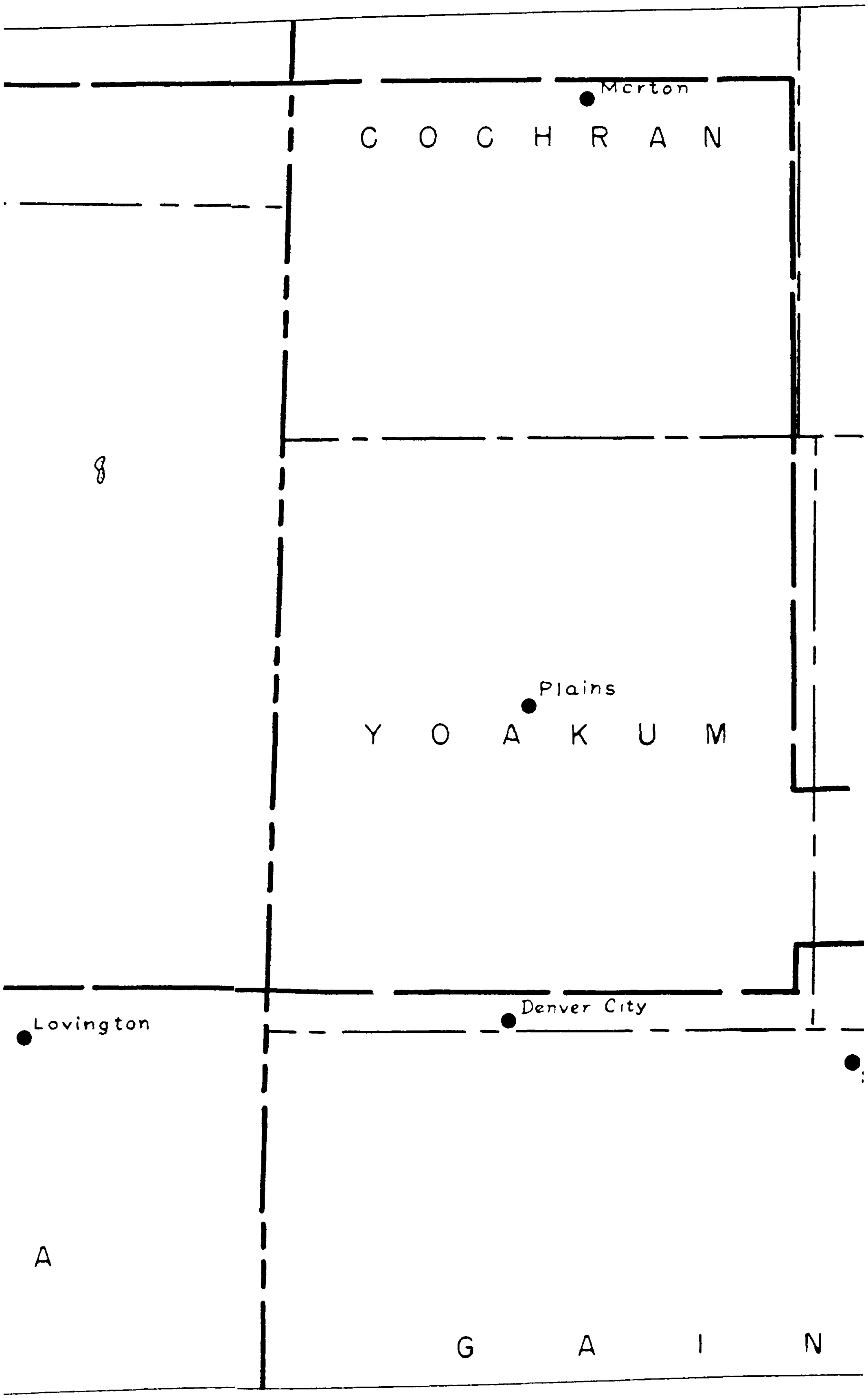
MAP B



Igneous Rock
S
Igneous Rock
TRIASSIC ROCKS
Mescalero sands
Ogallala formation
L
E
Y
Joins Map A
Joins Map C

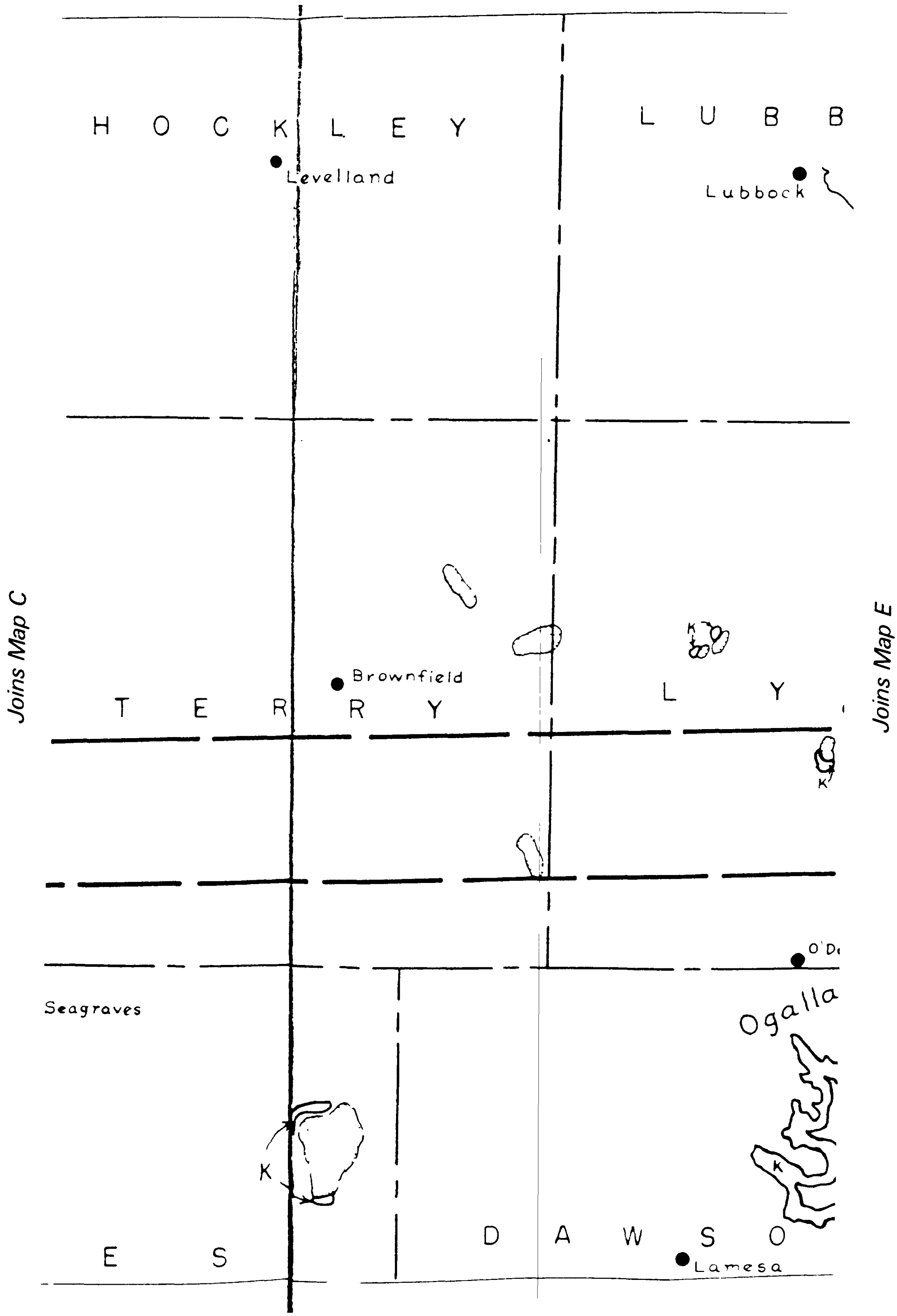
MAP C

Joins Map B

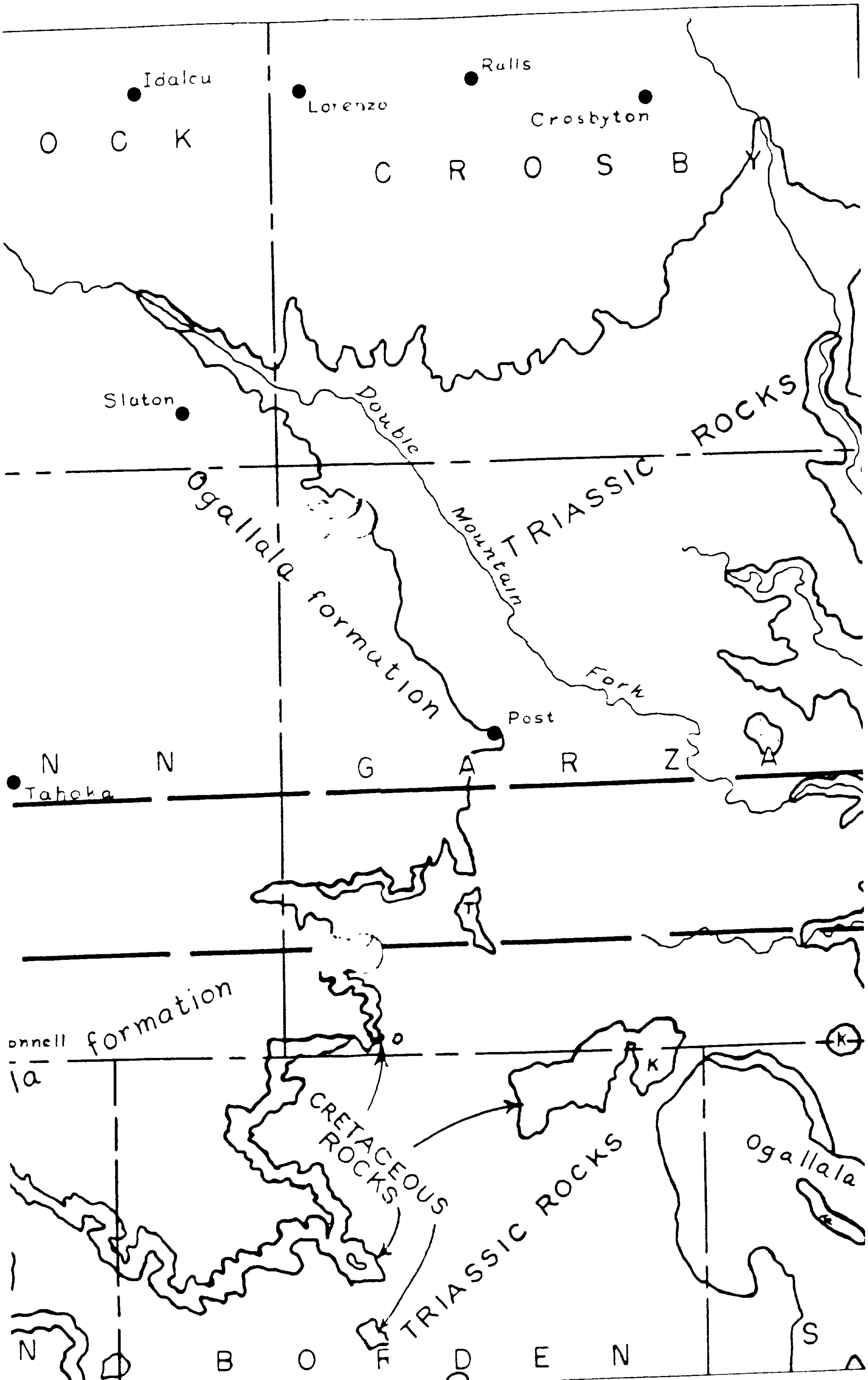


Joins Map D

MAP D


HOCKLEY
LUBB
Levelland
Lubbock
Joins Map C
Joins Map E
Brownfield
TERRY
LY
K
K
Seagraves
O'D
Ogalla
K
K
ES
DAWSO
Lamesa

MAP E



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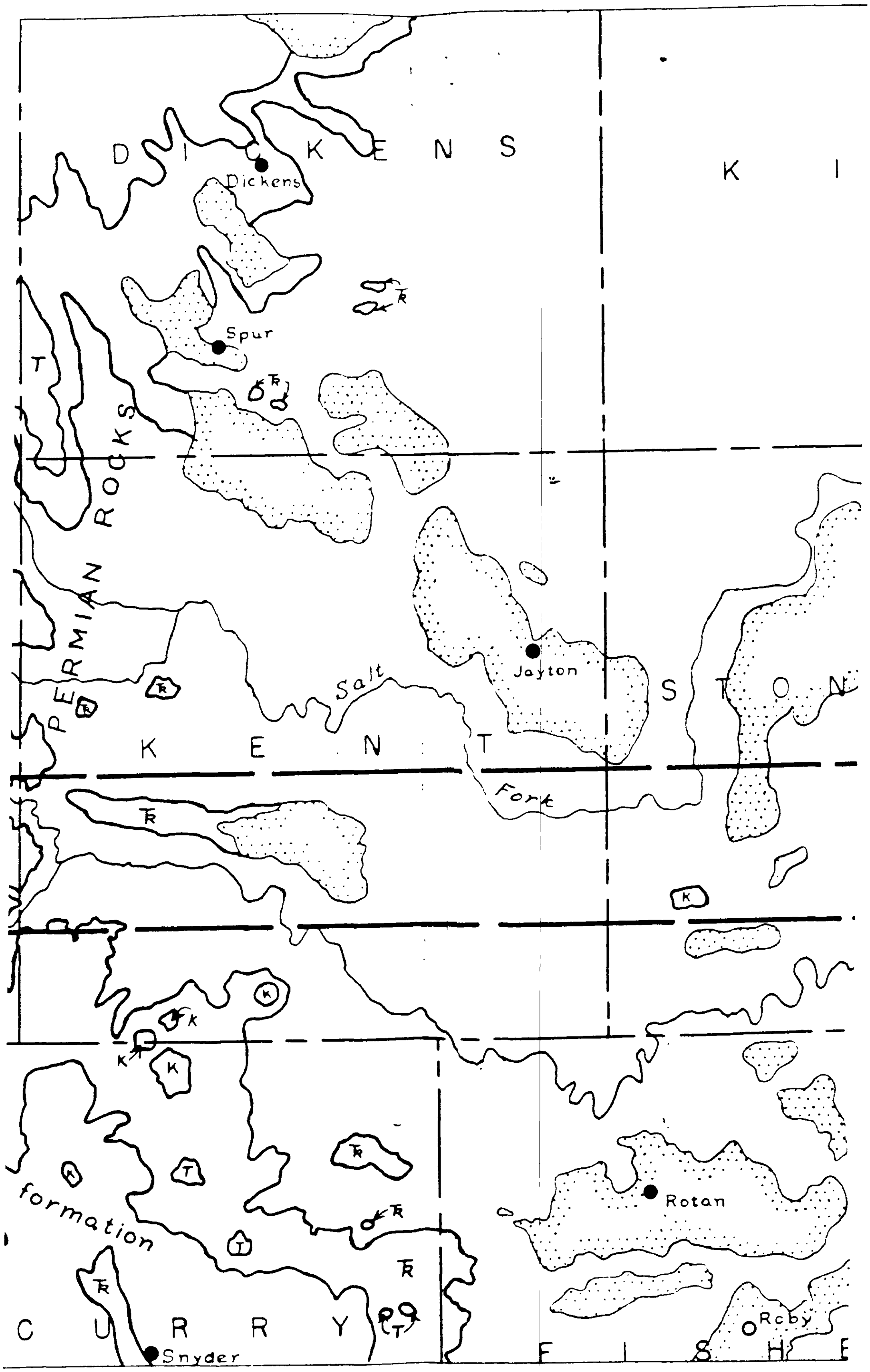
Joins Map F

MAP F

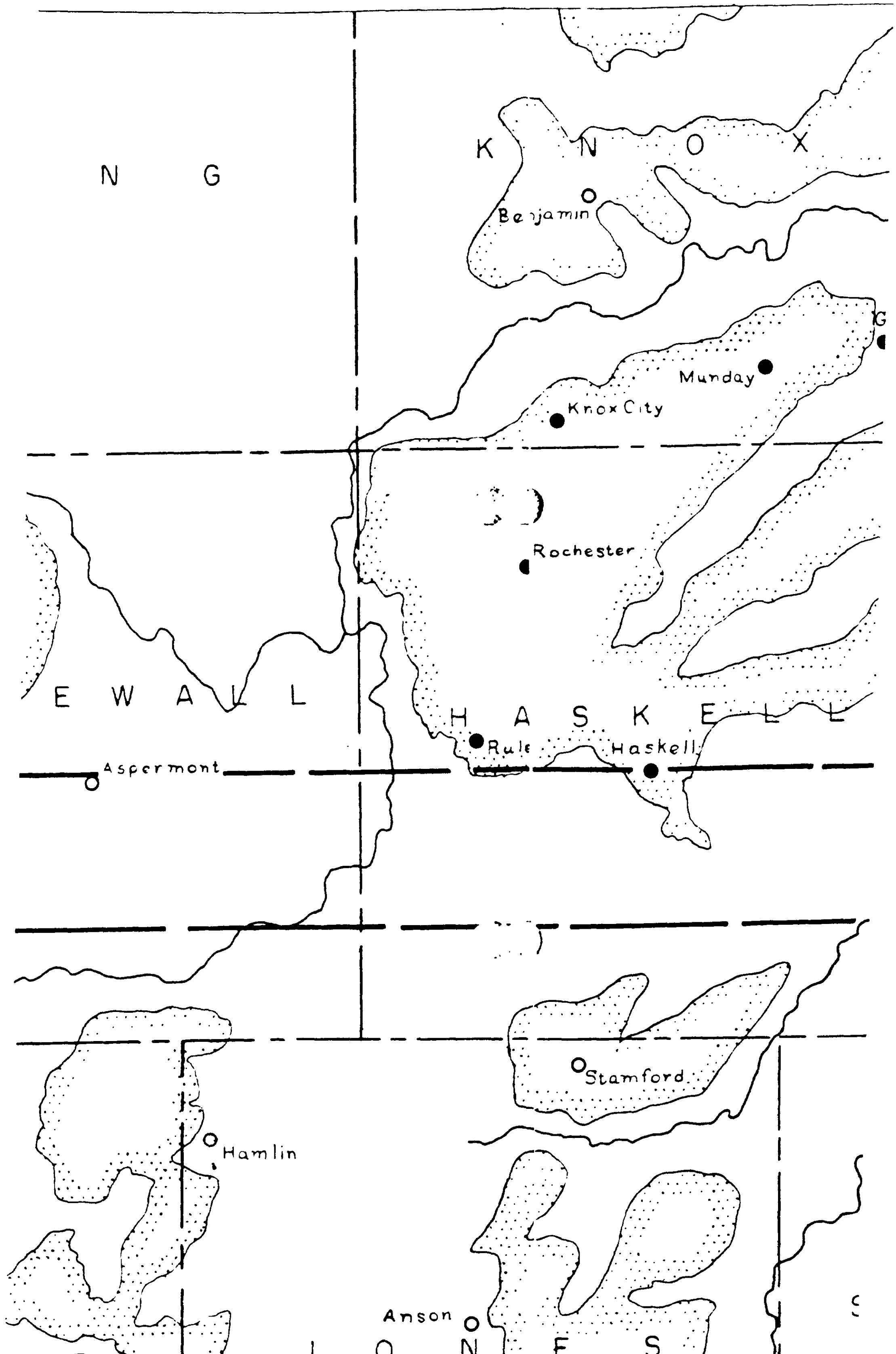
Joins Map E



Joins Map G

MAP G

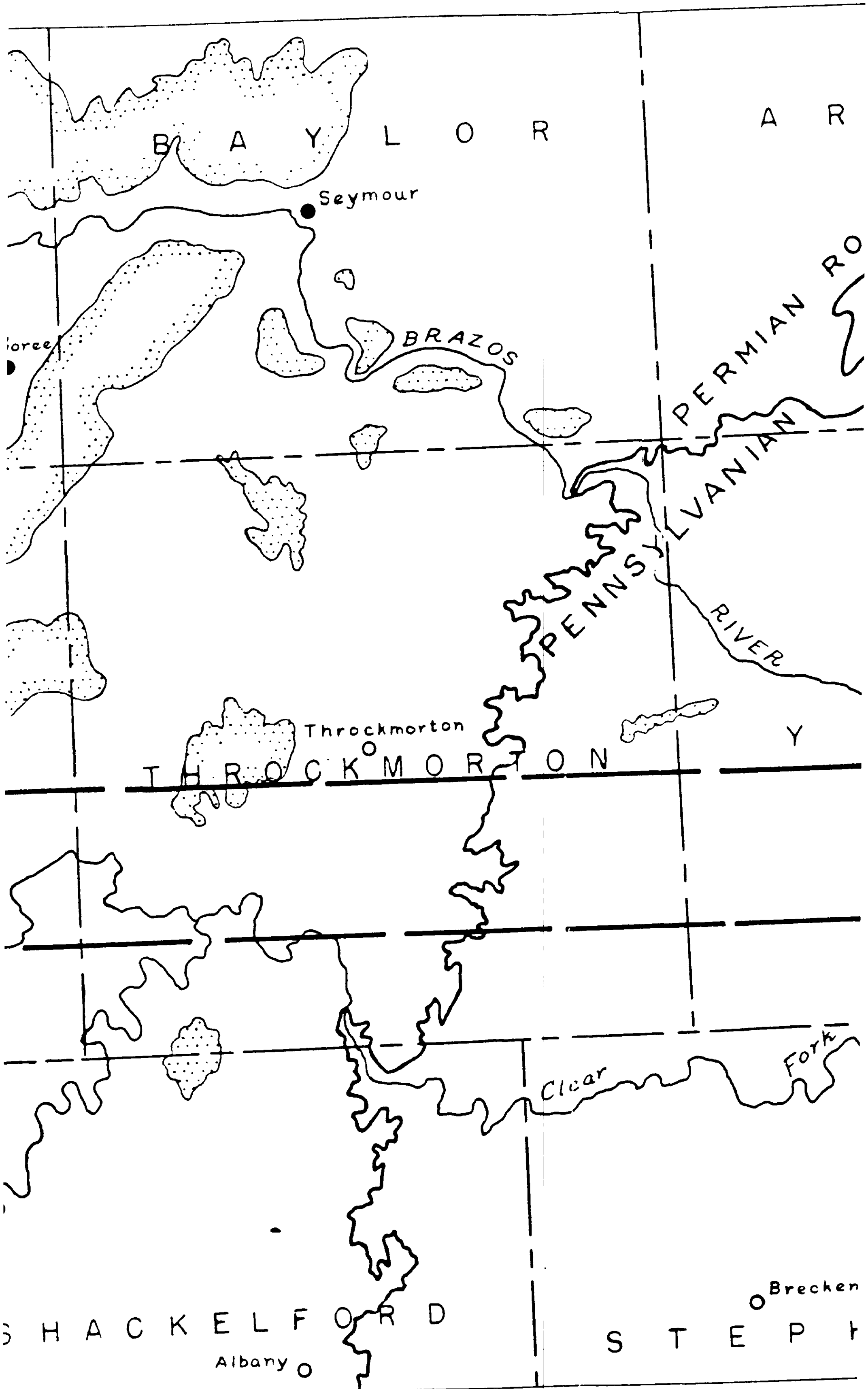
Joins Map F



Joins Map H

MAP H

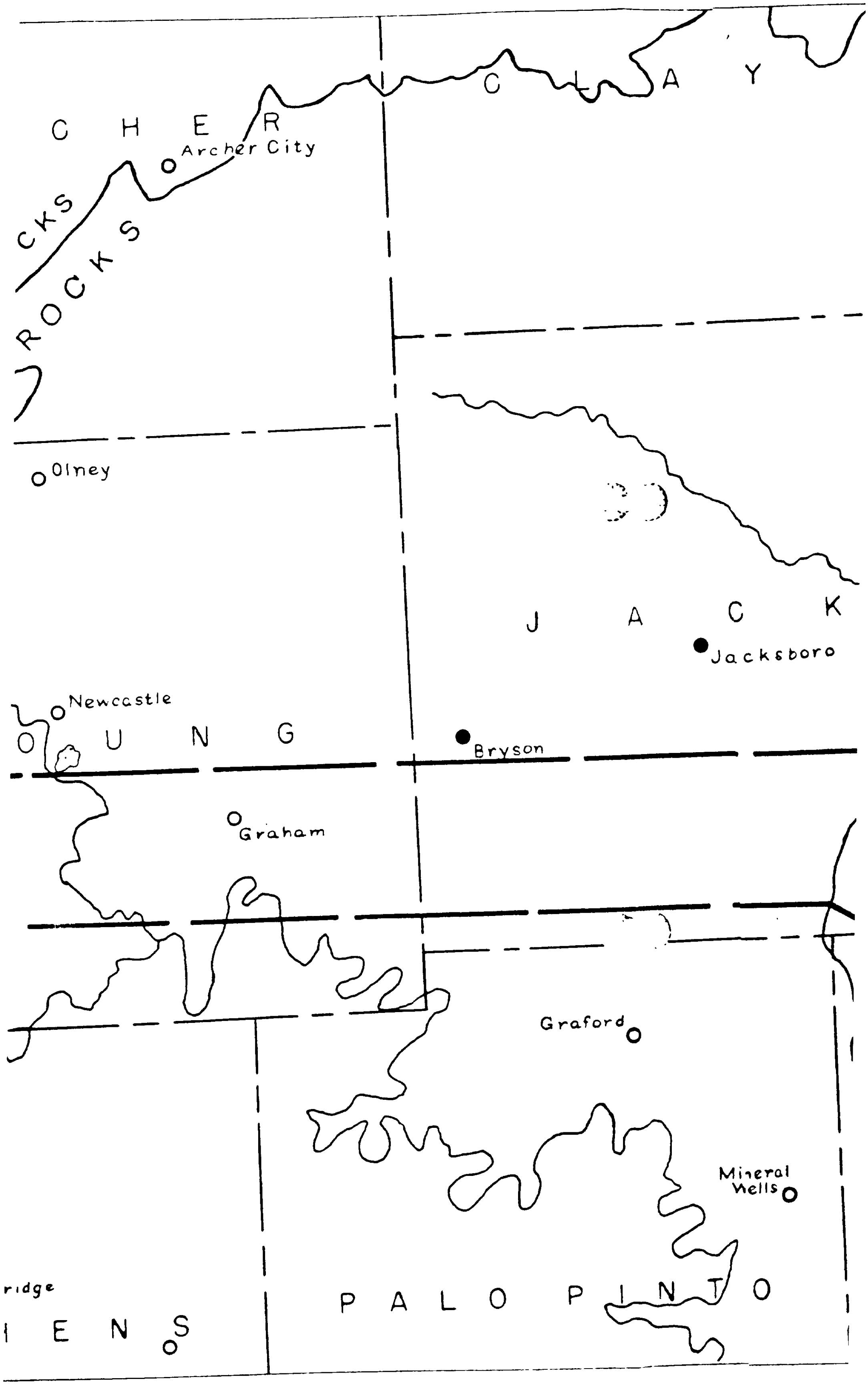
Joins Map G



Joins Map I

MAP I

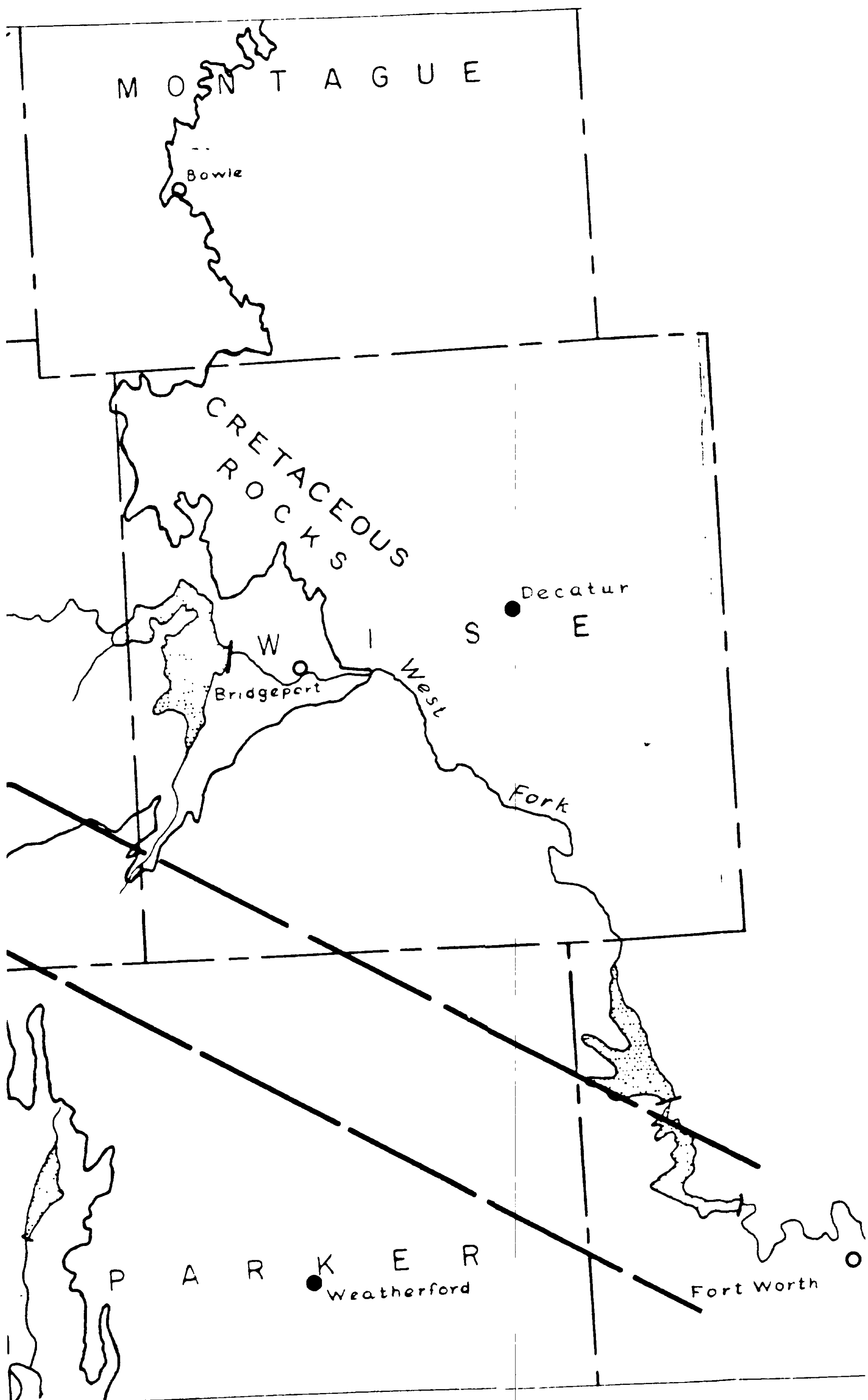
Joins Map H



Joins Map J

MAP J

Joins Map I



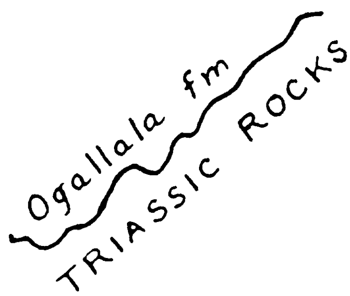
EXPLANATION

Scale 1:500,000; approximately 1 inch equals 8 miles

● Municipality with water supply derived from ground-water sources

o Municipality with water supply derived from surface-water sources

Lake or reservoir



Boundary between major divisions of outcropping rocks

Unconsolidated sand, silt and gravel of Quaternary age

Small outcrops of one division of rocks within general area of another shown thus:

(T) Ogallala formation

(K) CRETACEOUS ROCKS

(₸) TRIASSIC ROCKS

(P) PERMIAN ROCKS

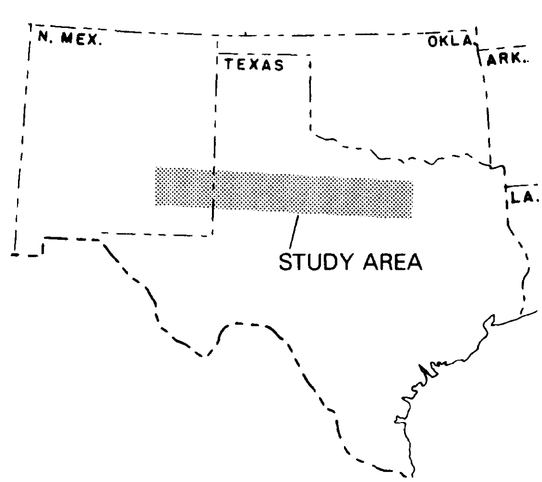


Figure 1.--Map showing proposed flight path from near Roswell, New Mexico to near Fort Worth, Texas.

MEMORANDUM ON VISIT TO CARBORUNDUM METAL PRODUCTS COMPANY

By C. V. Theis

February 1954

Problem

At the request of A. E. Gorman, Sanitary Engineer, U.S. Atomic Energy Commission, Mr. Asselstine and I visited the Carborundum Metal Products Company, at Akron, New York, on January 22, 1954. We spent the day with Mr. A. T. McCord, Chief Chemist of the company, and consulted also with Mr. N. C. Bartholomew, General Manager. Mr. Bob Steele, of one of the gas companies of the area, lately affiliated with the Iroquois Gas Company, spent part of the afternoon with the group.

The company at present produces about 10,000 gallons of industrial waste per day, of which ammonium thiocyanate (NH_4CNS) is an essential part. Thiocyanate compounds are not poisonous, but, under certain conditions, the thiocyanate can be oxidized to cyanide, for which the tolerance in water is one-tenth of a part per million. Among other means of disposal, a waste well is being considered. The present wastes consist of ammonium salts. If waste to the ground is used, the salts will consist essentially of calcium chloride and calcium thiocyanate, and, according to Mr. McCord, the waste solution would have a density of only 1.01 or 1.02. The figures given in the addendum suggest that the density of the present waste is 1.04

Geology of the Area

The location of the plant, as shown on the Niagara quadrangle, is about 1/2 mile west of the town of Akron, New York, which is about 30 miles east of Buffalo. This area is at the southeast corner of the quadrangle covered by the Niagara folio (Kindle, E. W., and Taylor, F. B.). The plant is located near the top of the Salina formation and on the broad southward-dipping moncline of Silurian and Devonian rocks south of Lake Ontario. Proceeding northward from Akron toward Lake Ontario, one would go up the dip of the rocks, passing from the Salina formation into the Lockport dolomite about 6 miles north of Akron then, about 5 miles farther, over the Niagara escarpment, in which in a distance of 1 1/2 miles the Clinton formation and the Albion sandstone are exposed, and hence over the Queenstown shale about 10 miles to Lake Ontario. The nature of these formations, according to the folio (Kindle and Taylor, p. 6), is given in the table below.

<u>Silurian system:</u>

Cayuga group:

Salina formation; 400 feet thick; gray magnesian shale with thin layers of dolomite and gypsum; including at top Bertie limestone, 35 feet, magnesian limestone.

Niagara group:

Lockport dolomite, 150 feet thick; gray- to chocolate-colored dolomite.

Medina group:

Albion sandstone, 135 feet thick; alternating red and gray shale and sandstone with 5 feet of hard gray sandstone at top (Thorold sandstone) and 20 feet of coarse, white sandstone (whirlpool sandstone) at base.

Silurian or Ordovician

Medina group:

Queenstown shale, 1,200 feet thick; red, argillaceous and sandy shale.

These formations thicken to the southeast below the surface. In the vicinity of Akron, the Albion sandstone is approximately 900 feet below the surface, indicating a thicker stratigraphic section than that given above.

These Silurian beds dip, as indicated above, to the south and pass under overlying beds and under topographically higher land. They do not come to the surface again except in central Ohio and in the folded Appalachian Mountains at higher altitudes than they have at their outcrops near Lake Ontario. In the neighborhood of Akron, the dip of the rocks is about 50 feet to the mile.

Natural gas in the Akron area

Natural gas has been produced in the Buffalo-Akron area since 1859. Several formations have produced some gas, but the Albion (or "Medina') sandstone has been the most productive. The gas occurs only in comparatively small pockets, no great production has been found, and no petroleum is present. Gas has been produced in the immediate vicinity of Akron and the Carborundum Metal Products Plant, but there are no producing wells at present.

Although sufficient data for definitive conclusions are not available, it appears that the initial gas pressures were equivalent to a hydrostatic head equal to the difference in attitude between the outcrop of the albion sandstone and the altitude of the sandstone where the gas was struck; that is, about 150 to 250 pounds per square inch.

Hydrology

The liquid in the Albion sandstone appears to be a nearly saturated brine. Mr. Steele reported that when a gas well is "washed,' in which process from 5 to 20 barrels of water are placed in the well and left standing for a few days, the water bailed out is a strong brine. Mr. Steele also reports that the well casings and tubings corrode rapidly.

The only analysis of this water at present available to me is given in the Niagara folio (p. 24). This follows:

Analysis of mineral water from well at Akron

(in parts per million)

Hydrogen sulfide (H_2S)	Trace
Ferrous sulfide (FeS)	25
Calcium sulfate ($CaSO_4$)	622
Calcium chloride ($CaCl_2$)	14,000
Magnesium chloride ($MgCl_2$)	13,800
Sodium chloride (NaCl)	131,500

This analysis represents a brine of a density of about 1.15. The density of the brine is of considerable interest from the standpoint of waste disposal. In the event that a disposal well is used, further search probably will yield other analyses of the brine.

The hydraulic gradient of the liquid in the aquifer is not definitely known. Inasmuch as about the only wells tapping the formation are gas wells and static pressures on these are seldom obtained and inasmuch as these wells are plugged as soon as abandoned, the prospects of obtaining a good piezometric map of the area are poor.

Some generalizations about the circulation can be drawn. Inasmuch as the region around Lake Ontario is the lowest point of outcrop of the Silurian rocks in the region east of the Cincinnati arch--which extends from Nashville, Tennessee, to the western end of Lake Erie--the natural movement of the liquid of the Albion formation must have been to this area and, therefore, northward and up the dip of the rocks in the vicinity of Akron. Recharge was probably in the Appalachian region, and discharge, at the foot of the Niagara escarpment just south of Lake Ontario. The presence of apparently nearly saturated bine in the formation gives almost conclusive indication that the rate of movement was very slow, although a source of salt is present in the Salina formation through which the water may have passed. As mentioned above, although the presently known values of the rock pressure of the gas wells are not extensive enough to make certain the conclusion, these pressures seem to have been about equivalent of the hydrostatic pressure required to move the water to the outcrop of the Albion sandstone.

It is probable that the extraction of gas from the vicinity has greatly modified the direction of movement of the brine. The extraction of gas seems to be attended by a rapid drop in gas pressure, as reported by Mr. Steele. Apparently the brine follows the extraction of gas very slowly, and it appears that readjustments to the local relief of pressure in the sandstone and the increase in volume available to the liquid caused by the extraction of gas probably take place for a considerable time, perhaps years or decades, after a gas field has been exhausted. Inasmuch as the larger accumulations of gas have been found south of the Akron area, the present direction of movement may be south or downdip or at least have a southerly component. In short, because of the extraction of gas, the movement of the brine may be in almost any direction.

The permeability of the formation has not been determined to my knowledge. The Albion sandstone is, according to description, somewhat shaly and compact enough to be used for building stone. As noted above, the brine appears to follow behind the gas slowly. It seems probable, from consideration of its lithology, that its permeability probably is less than 1 gallon per day per square foot under a unit hydraulic gradient, or less than 50 millidarcies in the units used by petroleum geologists.

A limestone which, according to the section in the Niagara folio, is separated from the Albion sandstone by 5 feet of shale (Sodus shale) may be, in places, in contact with the sandstone. It is probable that liquids could move through solution passages in this much more rapidly than they could through the sand. However, the fact that commonly the gas wells die off in pressure seems to indicate that there is no rapid movement of liquids within the gas-bearing beds.

In case a disposal well is used at the Carborundum plant, more intensive investigation, which may yield more accurate concepts for the flow of water, should be made.

Movement of Waste Underground

The waste that may be put in the ground at the Carborundum Plant presumably will be a clear effluent of a density only slightly greater than unity. The brine in the formation probably has a density of about 1.15. However, as the data about the brine are few and incomplete and as the density of the waste may be varied to some extent, it may be well to consider first the movement of a waste that is of the same density as the natural liquid and second of one that is heavier or lighter than the natural liquid.

Certain considerations about an injection well apply, regardless of the density. The waste must be free of particulate matter and must contain nothing that would precipitate by interaction with the substances in the aquifer or its contained natural liquid. Much trouble is experienced with injection wells because of clogging of the formation. The static water level in the well used for injection may be very low, or it may rise to an altitude of about 300 feet. Except for the effect of extraction of gas, the water level in the well would be expected to stand about at the level of the outcrops of the rocks into which the well was drilled. However, because of the withdrawal of gas and the presumed slow motion of the bine into the void from which the gas was extracted, the pressure in the aquifer and, consequently, the water level in any well in this area are likely to be considerably lower than would be indicated by the altitude of outcrops.

Pumping waste into a well will raise the water level. The amount of rise will depend on the permeability and thickness of the formation. Adequate data on the permeability are not available, but, if a value of permeability in the range of consolidated sandstones is assumed, a rise in water level of something in the order of 10 feet for each gallon per minute introduced may be assumed in order to estimate the effect produced. If 10,000 gallons per day are introduced at a uniform rate, this would indicate a rise in water level of about 70 feet. The effective permeability might very well be less than this, and the rise in water level might be greater.

Considerations of possible rise in water level upon the introduction of waste make the use of an abandoned well inadvisable. The casing of an abandoned well is likely to be corroded and leaky, and, as a consequence, the increase in head in waste well may force waste into an overlying water-bearing formation. Even if the casing is intact, the waste may rise between the casing and the well-bore and contaminate upper strata.

Movement of waste of same density

If waste is introduced at a uniform rate through a well penetrating the entire thickness of the formation, it will spread out from the well more or less as a cylinder and then drift with the motion of the natural liquid, occupying a volume equal to that occupied by an equal volume of the natural liquid. The waste will remain essentially intact and will not be diluted. In an ordinary aquifer, the width of the mass of introduced material at equilibrium can be computed, but, for the condition of introduction of a rather small quantity of waste into a formation of low permeability, the condition of equilibrium would not be reached for generations and so has no significance to the present problem. The waste would move out from the well in a cylinder and only slowly would drift with the natural movement, unless it was under high hydraulic gradients induced by the withdrawal of gas in the vicinity.

Oil-field sandstones range in porosity from a few to about 30 percent. If the reasonable assumption is made that the Albion sandstone is 100 feet thick and has a porosity of 10 percent, each day's production of 10,000 gallons would occupy a volume of 13,400 cubic feet of sandstone and cover an area of 134 square feet. A year's production at this rate would occupy a cylinder 125 feet in radius, and the production of 100 years would occupy a cylinder 1,250 feet in radius. The cylinder even in the latter case probably would be only slightly distorted down gradient, except perhaps in localities near which natural gas had been withdrawn.

Density effects

The density of the proposed waste will be only slightly greater than 1, according to Mr. McCord, whereas the density of the natural brine in the Albion sandstone apparently is about 1.15. There will be, therefore, a tendency for the liquids to separate and for the waste to move to the top of the formation. The driving force to separate the liquids in a formation 100 feet thick will be equivalent to a head of water equal to the thickness times the difference in density, or about 15 feet in the present case, operating over the entire mass of waste and, therefore, will produce only a small pressure gradient except in the early stages of discharge. The mass of waste probably would be shaped like a cylinder, occupying the entire thickness of the formation near the well but with lensing sides near the periphery of the mass so that it would be somewhat broader at the top.

The difference in density also will have two other effects. A lighter liquid will tend to migrate up the dip of the rocks and hence, in this Akron area, to the north. Apparently, however, the migration under any natural influence will be of small amount compared with the rate of introduction of even the small quantity of waste and, at least temporarily, can be disregarded. The other effect will be a tendency toward entrapment of the lighter waste in pockets in the roof of the formation. The occurrence of gas in the formation shows that some traps are present. However, as the efficacy of a trap depends on the difference in density between the two fluids involved, many structures that could trap gas could not trap a fluid of the density of water. It is improbable that this feature of circulation of a two-fluid system would have any significance in the Akron vicinity, inasmuch as it appears that the slow rate of natural movement will cause the waste to remain largely in a mass saturating the formation.

In the event that the wastes were heavier than the natural liquid in the aquifer, the same principles would apply: a tendency would exist for the waste to move down the dip of the formation (south) and to accumulate in pockets in the floor of the formation; however, under the probable conditions existing at Akron, neither of these phenomena would be significant.

Conclusions

By way of synopsis of the preceding the following points should be noted:

1. The data available are not complete enough to predict with certainty the movement of the waste. General information, however, can bracket quantitatively the rate of movement and suggest its direction of movement.

2. The formation into which the waste would be put would be the Albion sandstone at a depth of about 900 feet at Akron. Overlying formations are limestones which furnish water to domestic wells and in which movement of the waste might be erratic and rapid. Casing of the well should be intact and should be cemented below the Lockport dolomite.

3. The liquid in the formation probably is a nearly saturated sodium chloride brine. It probably contains considerable methane in solution. Its direction of movement under undisturbed natural conditions doubtless was north. Its rate of movement was very slow, probably on the order of a foot per year.

4. The withdrawal of natural gas from the surrounding area undoubtedly has reduced locally the pressure in the brine and caused its movement toward the areas of withdrawal.

5. For purposes of bracketing the movement of the waste, the Albion sandstone may be considered to have a porosity of 10 percent and to be approximately 100 feet thick. Under these assumptions, waste put in at the rate of 10,000 gallons per day would occupy a cylinder of 125-foot radius in 1 year and of 1,250-foot radius in 100 years, the radius increasing as the square root of the time. The cylinder might be distorted in the direction of large withdrawals of natural gas.

6. Because of the probable low permeability and the consequent low rate of flow of the natural liquid in the formation, the effects of differences of density of the waste and natural fluid will be small and, at least for preliminary consideration, may be disregarded.

Recommendations

1. The waste of the Carborundum Metal Products Plant may be put into a waste well without any known danger under the following conditions:

    a. It should be discharged into the Albion sandstone through a well with casing known to be intact, cemented above the Albion sandstone and below all aquifers that have potable water.

    b. The natural liquid in the Albion in the vicinity should be proved to be impotable.

    c. There should be no use of the natural liquid within a few miles for "medicinal" purposes.

    d. The waste should contain no suspended matter.

2. In case further consideration is given to a disposal well, further investigation should be made, including:

    a. A study of the permeability and porosity of the Albion, first examining the possibility of obtaining data from the gas companies, but probably involving sampling of the outcrop and possibly from cores the gas companies may have, with laboratory tests of the samples.

    b. A field test wherein a considerable quantity of water is placed in some well into the Albion, and the rate of loss of head measured. This would indicate the "transmissibility" of the formation; that is, the rate at which the fluid moves through the formation.

    c. Collection of data from the gas companies concerning the amounts of gas withdrawn from the Albion in the vicinity of Akron and the time of withdrawal, how much water invasion there has been as the gas pressure of a field lowered, and other factors that would suggest the permeability and porosity of the rock and the direction in which movement of the natural liquid has been induced.

3. In case disposal is made into a well, a program of study should be worked up, involving the collaboration of the company, the A.E.C., and the Geological Survey, to follow the progress of the waste and to develop and check principles of underground hydraulics involved in waste disposal.

MEMORANDUM ON THE HYDROLOGIC ASPECTS OF THE PROJECTED BURIAL GROUND AT THE PANTEX PLANT, TEXAS

By C. V. Theis

1965

Outline of Project

This memorandum is written at the request of Mr. Claude Davis, Chief of the Health Protection Branch, Operational Safety Division, Albuquerque Operations Branch, A.E.C.

The Pantex Plant of the Atomic Energy Commission operated by Mason and Hanger--Silas Mason Co., Inc., is in the process of constructing a solid-waste burial facility. The plant is located a few miles east of Amarillo, Texas, on the High Plains.

The waste to be buried will consist largely of clothing, swatches, etc., which have come into contact with metallic plutonium and uranium or the oxides of these metals. Because it will also include some waste of a classified nature involving these metals, the facility will be located in a secure area.

According to the description of the project submitted to A.E.C. by the contractors, the packaged wastes will be inserted into buried hollow concrete cylinders 6 feet I.D. by 15 feet high. These cylinders are to be constructed of interlocking rings grouted together, each ring 2 feet 6 inches high with 3-1/4-inch side walls. The lower ring is to have a reinforced bottom 8 inches thick. A reinforced concrete cap is to be place on top of the cylinder after it is filled. Each concrete cylinder is to be placed in a drilled cylindrical excavation, will rest on about 6 inches of sand fill, and will be surrounded with a sand fill about 18 inches thick. The exteriors of the concrete cylinders are to be waterproofed with a coat of mastic surrounded by a double wrap of 6-mil polyethelene film. A mound of earth at least 3 feet deep is to be placed over each cylinder after filling and capping.

The waste is to be packaged in plastic bags, which will be taped shut and placed in sealed metal containers before placement in the cylinders. The containers are to be numbered and a catalog kept of the contents.

Six such cylinders to be constructed immediately are estimated to take care of the burial requirements for 3 years. The total area in the burial ground is approximately 400 feet square and will provide for the placement of 180 cylinders.

Hydrologic Setting

The area lies upon the Staked Plain, or Llano Estacado, which is a broad plain extending westward into New Mexico. It has a remarkably even surface, sloping for altitudes of 4,500 feet at its western edge to about 3,550 feet at the Pantex site, marked by hundreds of ephemeral "sinks" or lakes, a few of which are on the Pantex site. The site is near the eastern breaks of the plains and is on the divide between drainage north to the Canadian River and southeastward to the Prairie Dog Fork of Red River.

The plain is underlain by the Ogallala formation, consisting of unconsolidated sand and silt, apparently about 250 feet thick at the site. Beneath this are red shaly sediments of Triassic and Permian age.

The usable ground water under the High Plains is contained almost entirely within the Ogallala formation. It is recharged by precipitation upon the Staked Plain, and, under natural conditions, the ground water moved very slowly east-southeast to discharge at the eastern scarp of the Staked Plain. Although the natural rate of movement was probably less than a foot per day, it may be locally more because of heavy pumping for irrigation. Recharge occurs at a yearly rate equivalent to a depth of water over the Staked Plain of a small fraction of an inch and apparently largely or entirely through the sinks that accumulate water after a heavy rain. Irrigation since World War II has lowered the water level at a rate that, if continued, would practically exhaust the ground water in a generation.

Ground Water Conditions at the Pantex Site

Several wells furnish water to the Pantex Plant, shown on the layout for the plant site (not found in archives). Water levels in these wells are not known to the writer, but may be available at the site. The following table gives water levels in observation wells surrounding the site that were measured by the U.S. Geological Survey and the Texas Board of Water Engineers in February 1960. (Bulletin 6061, Texas Board of Water Engineers, 1960.) The well numbers are designations used in this bulletin.

Well No.	E 14	E 22	E 30	J 6	K9	J 12	J17
Water level (feet below land surface)	406	412	364	366	342	225	200
Change since early 1959 (feet)	-5.11	-2.81	-2.00	-2.84	-1.71	-0.13	-2.98
Location with reference to site	North	North	NE	E	E	S	S
Miles north of S.W. corner of Carson Co.	14-1/2	12-1/2	11-1/4	8-3/4	6-3/4	5	2
Miles East	2-1/2	1-3/4	5-1/2	7	7-3/4	5	4-1/2

The great variation in water levels in the various wells is, in part, the result of irrigation by these or neighboring wells. The lowering of water level represents the rapid depletion of the ground water that is occurring in most places throughout the Staked Plain.

The water table at the site is, therefore, 200 feet or perhaps more beneath the land surface

Conclusions

1. It is believed that contamination of ground water by the burial of solid wastes at this site in the manner described cannot occur for the following reasons:
   a. The use of concrete-containing vessels gives much better containment than is practiced at any of the major burial grounds at A.E.C. installations.
   b. The radioactive contamination on the buried materials, according to Mr. Davis, is metallic uranium and plutonium and oxides of these metals, which are nearly insoluble.
   c. The water table lies at least 200 feet below the burial ground, and, hence, any contamination in water that might, in some manner, leave the burial area would pass through this sand and silt and almost certainly be sorbed before entering the ground-water circulation system.

Recommendations

1. Additional security against the possibility of contamination of the ground water can be obtained by insuring that no water can enter the sand annulus surrounding the concrete cylinders. If the sand surrounding the cylinder is coarse, any water that may enter the soil elsewhere and seep downward into it will remain by capillary forces in the finer natural materials and will not enter the sand. It has been pointed out by Mr. Davis that water entering this sand might float the concrete cylinders or, in case of faulty construction through human error or otherwise, might enter the waste material. Mr. Davis states that it is planned now to seal the surficial sand with asphalt and slope the surface outward to prevent direct access of storm rainfall or runoff into the sand.

   It is recommended that (a) the sealing procedure be certainly followed, (b) the sand used for fill around the concrete cylinders be of a coarse grade, (c) the excavated material be placed up the surface slope from the burial ground to form a berm to divert storm rainfall around the burial ground or at least around the part being used, and (d) no surface depressions that might pond water during heavy storm be permitted to remain or form on the burial ground.

   Careful treatment of the area could isolate the radioactive material from the hydrologic environment even into the unpredictable future.

2. If any questions as to ground water at the site arise, the best source of information will be the office of the Texas Board of Water Engineers at Austin or the local office of the U.S. Geological Survey located in the Federal Building, 300 East 8th Avenue, Austin.

Notes Beyond the Scope of this Memorandum

This memorandum is concerned only with the hydrologic features of the burial ground. In the coarse of the study, two features not pertinent to this subject have been observed that may be of interest to the operators of the Pantex Plant.

The first concerns the disposal pond in the eastern part of the plant area. It has been pointed out above that the natural recharge to the entire Staked Plain takes place largely through the "sinks" or lakes. Very probably some of the water in the disposal pond, which is in one of these "sinks," is seeping to the ground water and may move either to the production wells at the site or possibly off site to one of the heavily pumped irrigation wells in the vicinity. Attention should, therefore, be given to the possibility of any deleterious waste, either of a radioactive or purely chemical nature, seeping from this pond to the ground water.

The second point concerns the water supply of the plant, which is apparently from wells into the Ogallala formation at the site. The operations should be aware (and may have already considered) that the water table throughout the Staked Plain is falling rapidly owing to wide-spread irrigation. Unless information is currently available on water levels in the plant wells, it is possible that the wells may rather rapidly lose their water.