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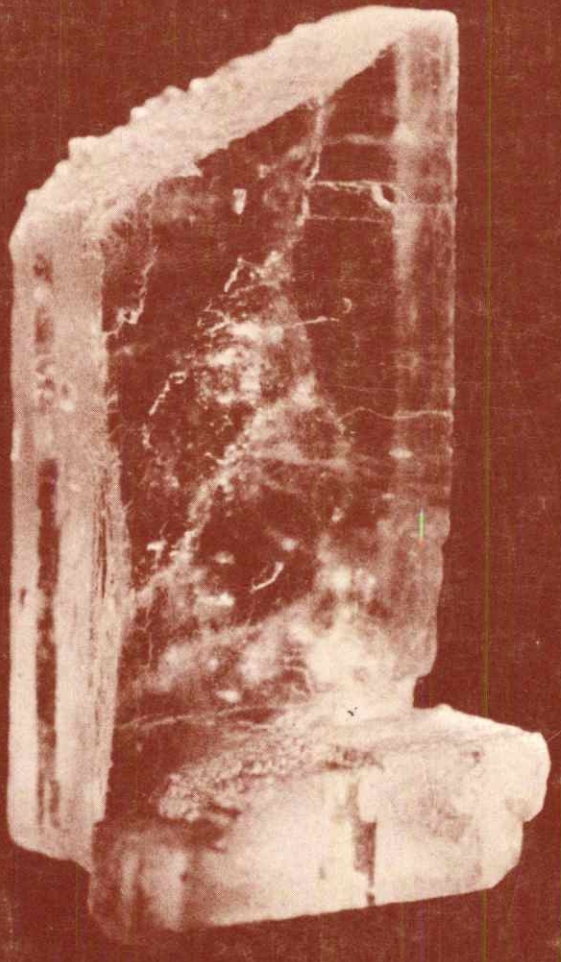

Compiled by Charles K. Bayne

SUPPLEMENTAL AREAS FOR STORAGE OF RADIOACTIVE WASTES IN KANSAS

The University of Kansas

March 1972

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Supplemental Areas for Storage of Radioactive Wastes in Kansas

Compiled by
Charles K. Bayne

Special Distribution Publication 60
State Geological Survey of Kansas
The University of Kansas
Lawrence, Kansas
March 1972

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Cover Photograph by Rod A. Hardy

Supplemental Areas for Storage of Radioactive Wastes in Kansas

INTRODUCTION

In December 1971 the State Geological Survey of Kansas prepared for the U.S. Atomic Energy Commission (A.E.C.) a report on areas potentially suitable for storage of high-level radioactive wastes in the salt beds in Kansas. These areas are supplemental to the federally proposed Lyons Repository site at Lyons, Kansas, on which the Survey also reported in detail.

The report on supplemental areas for the A.E.C. was published in limited numbers and the maps included in the report were larger than desirable for general use. The present report summarizes the data and results of the original report and is produced in a format more suitable for general distribution. In the preparation of the original report no field work was done; however, publications and unpublished data of the Kansas Geological Survey and other state agencies were searched for pertinent information. Selected references, on which much of the data in this report is based, are listed at the end of this report.

Factors considered important in determining the suitability of salt beds for waste disposal are: geology and hydrology, oil and gas developments, pipelines, thickness of salt beds, depth to salt beds, population centers, and potential mineral resource development of the area. Buffer zones having a radius of 6 miles around each population center are shown on the geologic maps for each area studied. The 6-mile radius is an arbitrary figure used in the original report for the A.E.C. It is based on no particular criteria other than the importance of safety to the population centers. No distinction is made as to size of the population centers.

Potential development is concerned principally with the future development of oil and gas. Also to be considered under this factor and related to population is recreational development around large reservoirs in and near potential repository sites. Although these recreational developments would have few permanent residents, large numbers of people could be present at times.

Eight areas (Fig. 1) in the state were selected for study. Selection of representative areas was based on a general knowledge of each area, the presence of at least 150 feet of salt at a depth of less than 2000 feet, and a minimum of oil and gas development. In Kansas thick beds of salt occur in Permian rocks at three horizons: the Hutchinson Salt Member of the Wellington Formation (Fig. 2), the Cimarron salt which occurs in the Ninnescah Shale just below the Stone Corral Formation (Fig. 3), and the Blaine salt which occurs in the Flower-pot Shale just below the Blaine Formation (Fig. 4). "Cimarron salt" and "Blaine salt" are informal names used in this report. The relation of these salt beds to other rocks in Kansas is shown on Figure 5. Salt has been mined in Kansas only from the Hutchinson Salt. The location and status of mining operations is shown in Figure 1. In seven of the areas (Areas 1-7) the suitability of the Hutchinson Salt was studied and in Area 8 the Blaine salt was studied.

The quality and thickness of the Hutchinson Salt is known through the mining operations and the study of cores and many gamma-ray-neutron logs.

The salt beds which occur in the Ninnescah Shale (Cimarron salt) in association with the Stone Corral Formation are known through study of sample logs and geophysical logs. These salt beds were not investigated during this study.

The salt beds which are associated with the Blaine Formation are known from sample logs, geophysical logs, and core descriptions.

Salt in the Permian rocks of Kansas does not occur as a single massive bed of pure salt, but as a succession of layers of relatively pure salt interbedded with shale or anhydrite. Shale is more common near the margins of the salt basins. The occurrence of anhydrite is more common toward the centers of the basins. Key beds within the salt section can be correlated over only relatively short distances, indicating a continual shifting of the locus of deposition within the basin and consequently a change in the thickness

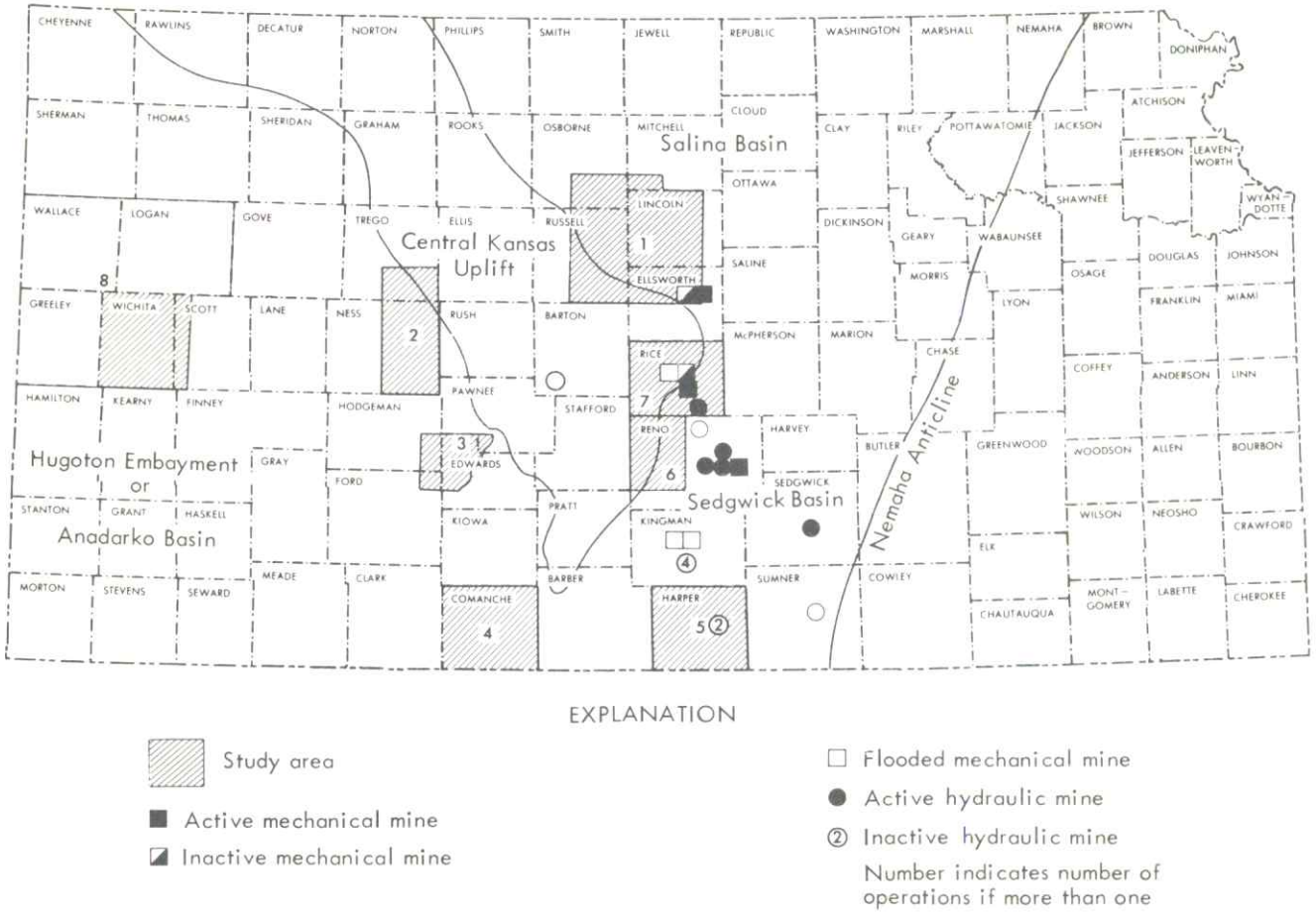


FIGURE 1.—Map showing supplemental study areas, structural features, and salt mines.

of the different lithologies occurring within the salt section.

Quality of a salt section is judged on the basis of the unique signature of each lithology (kind of rock) on radioactive logs. Absolute percentages cannot be determined but the interbedding of shale and anhydrite with salt is clearly displayed and, in addition, dispersed impurities within the salt may be indicated by the displacement of the radioactive curve in its entirety. Each lithology within the salt section may have special properties in reference to the engineering problems which may occur in the salt section of a repository site. The engineering problems associated with quality of the salt section are not considered in this report. Instead, the relative quality of the salt section, as expressed in this report, takes into consideration primarily the overall purity of the section and the definition of a thick mineable salt unit.

The areas selected for study are discussed in separate sections of this report in the numerical order in which they were selected by the study group; this arrangement does not indicate degree of suitability.

ACKNOWLEDGMENTS

Many people contributed to the compilation of the report, *Preliminary Geological Investigations of Supplemental Radioactive Waste Repository Areas in the State of Kansas* (Angino, *et al.*, 1972), which was prepared for the U.S. Atomic Energy Commission. The section on quality of salt, salt thickness, and thickness of overburden was the responsibility of E. D. Goebel, now Department of Geology and Geography, the University of Missouri at Kansas City; L. F. Dellwig, Department of Geology, The University of Kansas; and D. W. Brinkley and Shirley Paul, State Geological Survey of Kansas. The section on oil and gas and transportation was the responsibility of Margaret O. Oros, State Geological Survey of Kansas. The section on geology, water resources, and population was the responsibility of Charles K. Bayne and E. E. Angino. Thomas McClain, State Geological Survey, assisted Bayne in preparation of the section on geology and hydrology in Area 8. Data presented in the report to the A.E.C. are used in the present report. To the authors of the various chapters and the special consultants who contributed to *Preliminary Geological Investigations* . . . , we express our thanks.

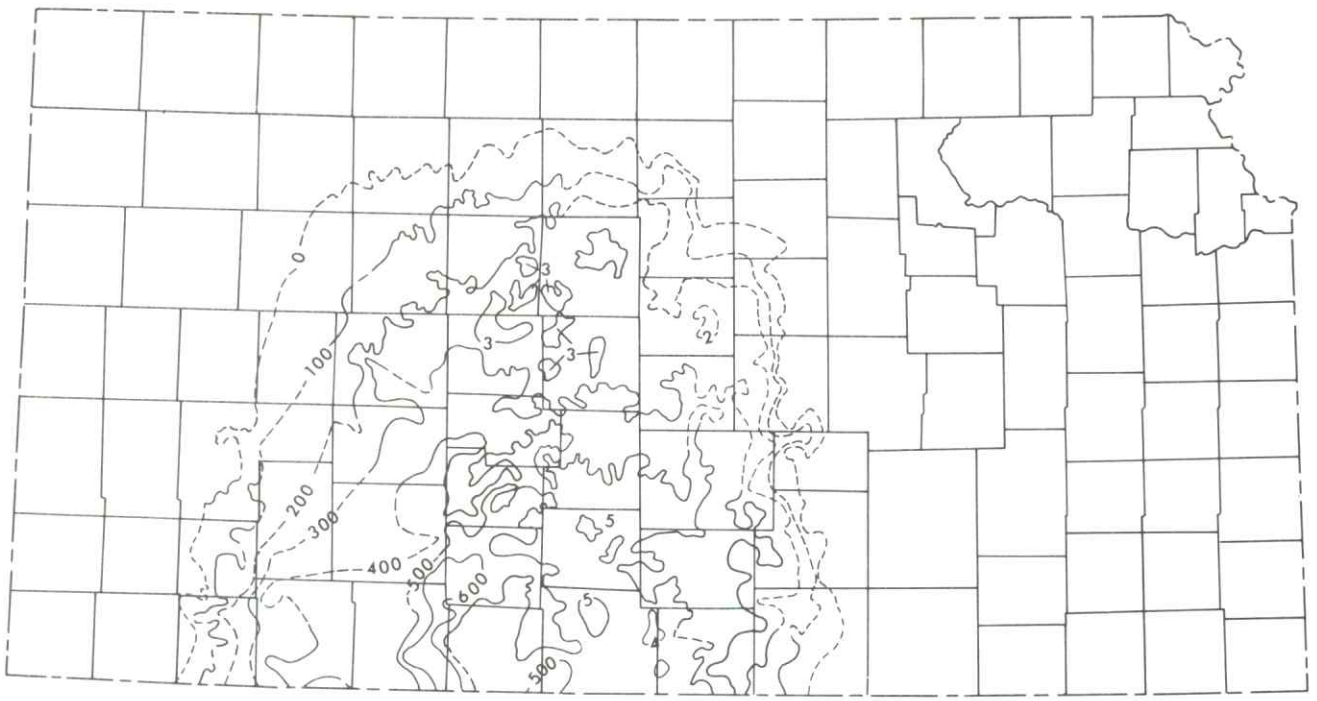


FIGURE 2.—Thickness and limits of the Hutchinson Salt (contoured by Robert O. Kulstad).

AREA 1

Location

Area 1 includes parts of Ellsworth, Lincoln, Mitchell, Osborne, and Russell counties in central Kansas in an area drained by the Smoky Hill River and the Saline River. Structurally the area lies in the Salina Basin just east of the Central Kansas Uplift (Fig. 1).

Geology and Hydrology

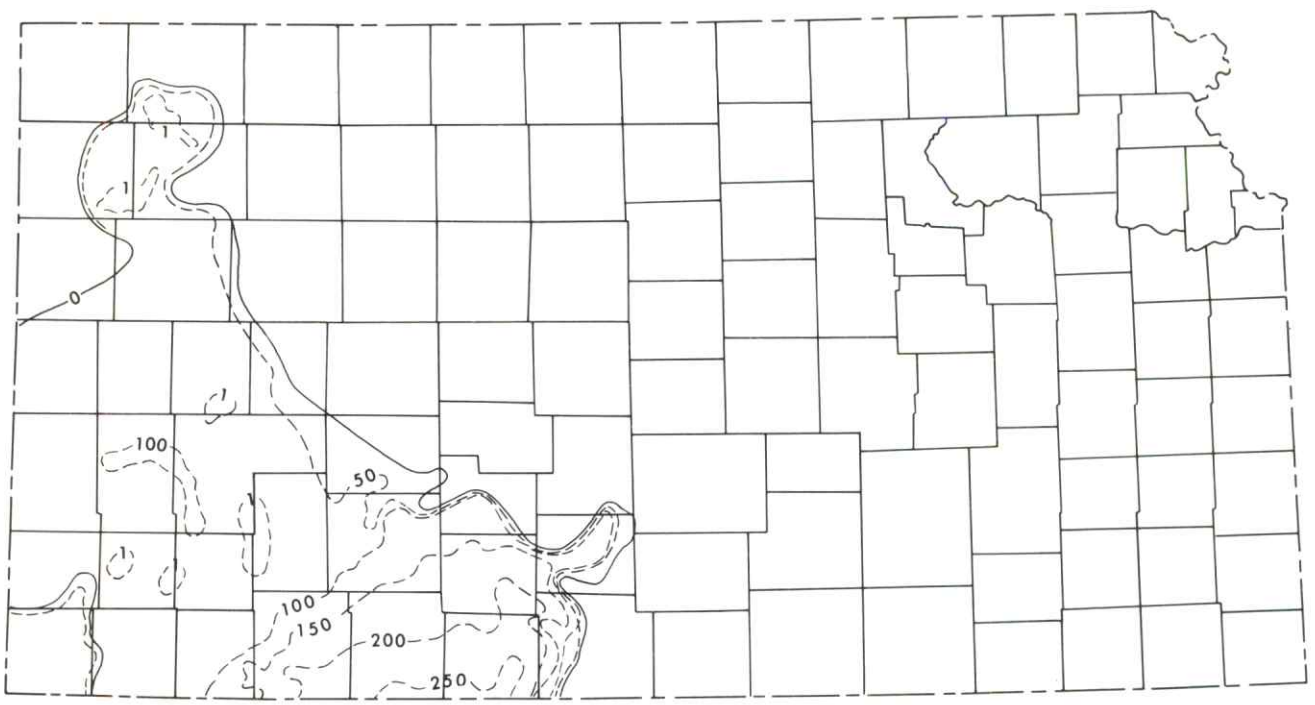
About 500 feet of rock consisting principally of shale but containing some dolomite, anhydrite, and gypsum is present above the Hutchinson Salt Member of the Wellington Formation and below the Stone Corral Formation. The lower 250 feet belongs to the Wellington Formation. This 250-foot unit is primarily gray and blue-gray shale but contains some red shale in the upper part. The upper 250 feet comprises the Ninnescah Shale which is primarily red shale but contains some gray shale. Neither the Wellington nor the Ninnescah contain water in this area.

The Stone Corral Formation overlies the Ninnescah Shale and consists of about 20 to 25 feet of dolomite, anhydrite, and gypsum. Anhydrite and gypsum are the dominant components. Little if any water can be obtained from this unit.

The Harper Sandstone overlies the Stone Corral Formation in this area. The Harper is principally red silty shale and contains little sandstone. It will yield little or no water to wells. The upper surface of the Harper is an erosional surface and marks the boundary between Permian and Cretaceous rocks in the area.

The Cheyenne Sandstone is the lowermost Cretaceous unit present in Kansas. In Area 1 the Cheyenne does not crop out and is present in the subsurface only in the westernmost part of the area. In much of the area the Cheyenne consists of a very fine silty sand and is not an important aquifer; however, west of Area 1 and probably locally in Area 1 the Cheyenne contains much sand, and moderate quantities of highly mineralized water should be available.

The oldest rock unit which crops out in this area is the Kiowa Formation (Fig. 6). This unit conformably overlies the Cheyenne Sandstone where the Cheyenne is present and unconformably overlies Permian rocks where it overlaps the Cheyenne. The Kiowa consists primarily of dark-gray and brownish shale, but con-



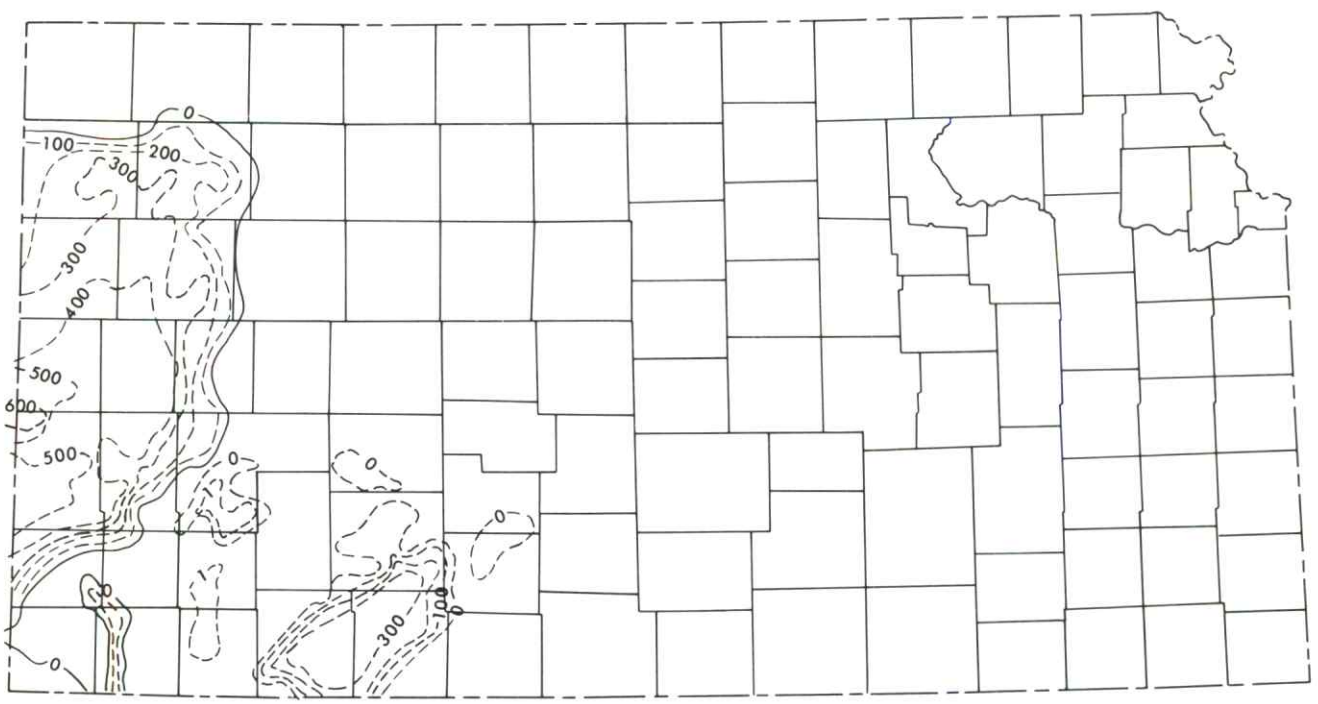
EXPLANATION

50 Contours indicate thickness of Cimarron salt

0 50 100

Scale in miles

FIGURE 3.—Thickness and limits of the Cimarron salt (contoured by Robert O. Kulstad).



EXPLANATION

100 Contours indicate thickness of Blaine salt

0 50 100

Scale in miles

FIGURE 4.—Thickness and limits of the Blaine salt (contoured by Robert O. Kulstad).

tains thin to massive sandstone beds, thin shell beds, and lignite. In the southern part of the area, a full section of the Kiowa, if present, is about 150 feet in thickness. The unit thins toward the north and may be less than 100 feet thick in Mitchell and Osborne counties. Sandstone beds in the Kiowa are more commonly found in the southern part of the area. Here water yields as large as 100 gallons per minute (gpm) may locally be available to wells. Toward the north and west where the Kiowa thins and sandstone beds are less common or absent, little or no water is available.

The Dakota Formation overlies the Kiowa Formation. The Dakota is composed of clay, shale, sandstone, and locally some lignite. Light-gray, dark-gray, and red shale comprises about two-thirds of the total thickness of the unit which is about 250 feet. Sandstone beds occur throughout the unit. The Dakota is the principal aquifer in this area. Yields of wells may locally be as much as 250 gpm but more commonly are less than 50 gpm. In Ellsworth County and southern Lincoln County the water from the Dakota is of good quality; however, in Osborne, Mitchell, and Russell counties, water from the Dakota may be too highly mineralized for use.

Cretaceous rocks which overlie the Dakota Formation in Area 1 are, in ascending order, the Graneros Shale, the Greenhorn Limestone, and the Carlile Shale. The Graneros is a dark-gray, clayey to platy shale which weathers to a brownish color. The unit ranges in thickness in Area 1 from about 25 to 35 feet. The Greenhorn Limestone is composed of about 70 to 90 feet of thin chalky limestone beds interbedded with thicker chalky shale. The limestone beds range in thickness from a fraction of an inch to about 10 inches. The thickest and most prominent bed is the "Fencepost limestone" which occurs at the top of the Greenhorn. The Carlile Shale is composed primarily of chalky shale but contains thin beds of nodular chalky limestone in the lower part. Thin beds or seams of bentonite occur throughout the Graneros, Greenhorn, and Carlile in this area. None of these units is a good aquifer. Only small quantities of water are available from the upper weathered parts of the units.

Alluvial deposits which occur in the valleys of the Smoky Hill River and the Saline River and in the abandoned Wilson valley, which extends from the Saline River near northwest Ellsworth County southeastward to the Smoky Hill River a few miles west of the city of Ellsworth, are arkosic-type materials that indicate a western source. These alluvial deposits are generally little more than 50 feet in thickness. Maximum water yields are near 250 gpm; however, they are more commonly less than 100 gpm. In the abandoned Wilson valley the alluvial deposits are somewhat thicker; however, these deposits occur in a channel cut in an upland area which has been beheaded at both ends by more recent erosion or downcutting of the streams. The channel is largely drained of water and yields only small quantities.

Population and Transportation

Cities within Area 1 are mostly located in or near the principal stream valleys. Railroads built in the area were located in the valley areas to avoid steep grades and cities grew along the railroads. The main line of the Union Pacific Railroad crosses Ellsworth and Russell counties in the southern part of the area and a branch line of the Union Pacific Railroad serves the northern part of the area in the valleys of the Saline River and Wolf Creek. Interstate Highway 70 and State Highways 40 and 18 traverse the area from east to west. State Highways 14, 181, and 232 are north-south highways through the area.

The 1970 populations of the cities in Area 1 are shown on Figure 6. The circles with radiuses representing 6 miles denote buffer zones around population centers.

Oil and Gas

A few wells producing small amounts of oil and gas have been drilled in the southern part of Area 1 (Fig. 6). The most recent discovery is the Wilson gas field located north of Wilson in northwestern Ellsworth County. On Figure 6, in areas where there is a heavy concentration of wells, only the outlines of the fields are shown. In areas where exploration wells are scattered, the individual wells are shown. Several areas of township size in the northern part of the area have had no holes drilled.

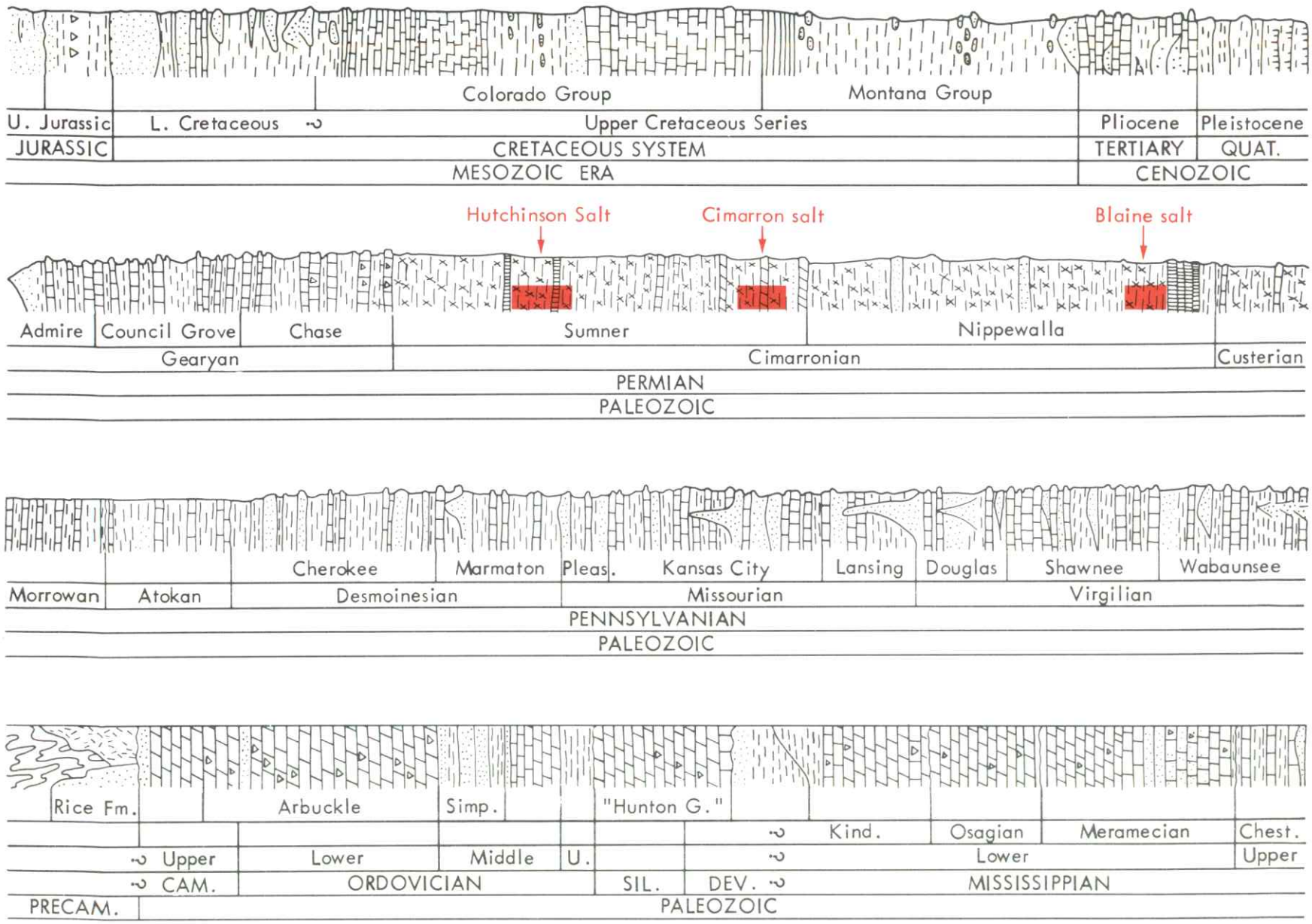
Much of Area 1 lies in the western part of the Salina Basin, an area not considered to be promising for future development of oil and gas.

Salt

The Hutchinson Salt occurs in Area 1 at depths ranging from about 600 feet in the southeastern part to about 1200 feet in the northwestern part of the area (Fig. 7).

Nearly 300 feet of salt is present in the west-central part of the area (Fig. 7). The salt thins toward the east and north. Salt in about one-third of the total area is near or less than the minimum required thickness of 150 feet.

The quality of the salt in this area is judged to be comparable to that of the salt at the Lyons Repository site. In T. 11, 12 S., R. 10-12 W. are areas where the thickness of the salt is more than 150 feet and the


Colorado Group
Montana Group
U. Jurassic
L. Cretaceous
Upper Cretaceous Series
Pliocene
Pleistocene
JURASSIC
CRETACEOUS SYSTEM
TERTIARY
QUAT.
MESOZOIC ERA
CENOZOIC
Hutchinson Salt
Cimarron salt
Blaine salt
Admire
Council Grove
Chase
Sumner
Nippewalla
Gearyan
Cimarronian
Custerian
PERMIAN
PALEOZOIC
Cherokee
Marmaton
Pleas.
Kansas City
Lansing
Douglas
Shawnee
Wabaunsee
Morrowan
Atokan
Desmoinesian
Missourian
Virgilian
PENNSYLVANIAN
PALEOZOIC
Rice Fm.
Arbuckle
Simp.
"Hunton G."
Kind.
Osagian
Meramecian
Chest.
Upper
Lower
Middle
U.
Lower
Upper
CAM.
ORDOVICIAN
SIL.
DEV.
MISSISSIPPIAN
PRECAM.
PALEOZOIC

depth is about 1000 feet. Few holes have penetrated the salt in this area. The range in thickness of the potential vault section is 50 to 90 feet.

AREA 2

Location

Area 2 includes part of southeastern Trego County and eastern Ness County. The northern part of the area is drained by the Smoky Hill River and the southern part is drained by Walnut Creek. Structurally the area lies on the west flank of the Central Kansas Uplift (Fig. 1).

Geology and Hydrology

Rocks between the top of the Hutchinson Salt and the Stone Corral Formation comprise the upper part of the Wellington Formation and the Ninnescah Shale. The upper Wellington is composed of about 200 feet of gray and blue-gray shale. Some thin anhydrite and dolomite beds are present. The Ninnescah Shale is composed of about 200 feet of predominantly red shale; however, some gray shale is present. The Wellington and Ninnescah contain no permeable rocks and contain little if any water in this area.

The Stone Corral Formation overlies the Ninnescah Shale and is composed of about 25 feet of anhydrite and probably some gypsum. Permeability has not been developed in these rocks and little if any water is present in the formation.

The Harper Sandstone overlying the Stone Corral is composed principally of red siltstone and shale in this area. The unit is about 150 feet in thickness and contains little sandstone. It is not an important aquifer.

Lower Permian rocks between the Harper Sandstone and the Blaine Formation consisting of the Salt Plain Formation, the Cedar Hills Sandstone, and the Flower-pot Shale have an aggregate thickness of about 500 feet in Area 2. Sandstone is commonly quite prominent in the Salt Plain and the Cedar Hills and locally in the Flower-pot. Moderate to large quantities of highly mineralized water are available from these rocks.

The Blaine Formation is present in the southern part of Area 2 where it is about 15 to 20 feet in thickness. The unit is not identified in the northern part of the area.

Lower Permian rocks consisting of the Dog Creek Formation and the Upper Permian Whitehorse Formation are present in the southern part of the area but are absent in the northern part where they were probably removed by pre-Cretaceous erosion. Small to moderate quantities of water are probably available in local areas from sandstone in the Whitehorse.

Lower Cretaceous rocks consisting of the Cheyenne Sandstone, Kiowa Formation, and the Dakota Formation are present in the area and unconformably overlie Permian rocks. They have an aggregate thickness of about 500 feet in the area. The Kiowa is quite thin and contains little if any sandstone. Sandstone is the main constituent of the Cheyenne and is an important constituent of the Dakota. Moderate to large quantities of highly mineralized water are available from the Cheyenne and yields up to 300 gpm of good-quality water have been obtained from wells in the Dakota.

Upper Cretaceous rocks consisting of the Graneros Shale, Greenhorn Limestone, Carlile Shale, and the Niobrara Chalk, with an aggregate thickness of about 450 feet, crop out in Area 2 (Fig. 8). The Graneros Shale and the Blue Hill Member of the Carlile Shale are blocky to fissile clay shales. The other Cretaceous units which crop out in the area are composed of chalky shale or chalky limestone. Little if any water is available from the Upper Cretaceous rocks in this area.

Thin deposits of silt, clay, sand, and gravel comprising part of the Ogallala Formation of Pliocene age are present in the highest uplands in Area 2. Small quantities of water are locally available from these deposits.

Alluvial deposits of Pleistocene and Recent age are present in the valleys of the Smoky Hill River and Walnut Creek. Yields of wells in these deposits in the Smoky Hill valley may be as much as 500 gpm in local areas. In the Walnut Creek valley yields of wells generally do not exceed 50 gpm; however, locally as much as 200 gpm may be obtained.

Population and Transportation

Population centers in the southern part of Area 2 are located along a branch line of the Atchison, Topeka, and Santa Fe Railroad in the Walnut Creek valley and in the northern part of Ness County along a branch line of the Missouri Pacific Railroad (Fig. 8).

State Highways 4 and 96 cross the area in an east-west direction and U.S. Highway 283 runs north-south along the west side of the area.

Oil and Gas

In the eastern part of Area 2 there is a highly developed area of oil and gas production (Fig. 8). The western part of Area 2 has had less development al-

FIGURE 5.—Position of salt beds in Kansas Stratigraphic Column.

though there are scattered fields with one or two wells each. Area 2 is currently (1971) quite active and will probably be quite active in the future. It is located on the western flank of the Central Kansas Uplift and oil and gas is produced from small structural and stratigraphic traps on the truncated Mississippian surface.

Salt

In Area 2 the Hutchinson Salt occurs at depths ranging from about 1800 feet in the southeastern part of the area to about 2200 feet in the northeastern part (Fig. 9). In about one-half of the area the depth to the top of the salt is greater than the 2000-foot maximum depth.

Thickness of the salt ranges from about 150 feet in the northeast to about 300 feet in the southern part of the area. The thickness in almost all the area is greater than the 150-foot minimum (Fig. 9).

The quality of the salt is judged to be not as good as that of the Lyons Repository site or of Area 1. The thickness of the potential vault section is about 85 feet. The area that lies at a depth less than 2000 feet is in the area of greatest oil and gas production and is an active exploration area.

AREA 3

Location

Area 3 includes parts of Pawnee, Edwards, Hodgeman, and Ford counties. The northwestern part of the area is drained by tributaries of the Pawnee River and the remainder of the area is drained by the Arkansas River. Structurally the area lies on the western flank of the Central Kansas Uplift (Fig. 1).

Geology and Hydrology

The upper part of the Wellington Formation and the Ninnescah Shale are present between the Hutchinson Salt and the Stone Corral Formation. The Wellington is predominantly gray and blue-gray shale and the Ninnescah is predominantly red shale. In the northern part of Area 3 the combined thickness of these rock units is about 400 feet, and in the southern part, about 500 feet. Thickening is due to the presence of the Cimarron salt which occurs near the top of the Ninnescah Shale. This salt is present only in the southern part of the area, with a maximum thickness of about 100 feet.

The Stone Corral Formation overlies the Ninnescah Shale. This unit is about 25 to 30 feet in thickness and is composed principally of anhydrite in this area.

The Harper Sandstone, the Salt Plain Formation, the Cedar Hills Sandstone, and the Flower-pot Shale, with an aggregate thickness of about 630 feet, are present between the Stone Corral and the Blaine formations. Only the Cedar Hills Sandstone contains appreciable quantities of sandstone in the area. Moderate to large quantities of highly mineralized water are available from this section of rocks in Area 3.

The Blaine Formation, composed principally of gypsum and about 20 feet thick, is overlain by about 250 feet of silty shale and dolomite. This 250-foot section of rocks comprises the Dog Creek Formation and the Upper Permian Whitehorse Formation. Little sandstone is present in these rocks in this area and only small quantities of water are available.

Unconformably overlying the Upper Permian rocks in Area 3 are about 400 to 450 feet of Lower Cretaceous rocks comprised of the Cheyenne Sandstone, Kiowa Formation, and the Dakota Formation. The Cheyenne contains much sandstone, and moderate to large quantities of highly mineralized water are available from the unit in this area. The Kiowa Formation is thin and composed principally of dark-gray clay shale and is not an important aquifer. The Dakota Formation crops out in a small area in the northwestern part of Area 3 (Fig. 10). This unit is composed principally of clay, shale, and sandstone. A few miles west of the western border of Area 3 the sandstone in the Dakota thickens and is very permeable. In this area as much as 1000 gpm of good-quality water can be obtained from wells. Eastward the sandstone thins and is less permeable and yields of wells are considerably smaller; however, yields of 200 to 300 gpm can be obtained locally.

The Upper Cretaceous Graneros Shale and Greenhorn Limestone crop out in the northwestern part of Area 3. These units are composed of shale, chalky shale, and chalky limestone and yield little or no water to wells.

In the northern part of this area thin deposits of sand, gravel, silt, and clay which are a part of the Ogallala Formation of Pliocene age are present. These deposits yield small to moderate quantities of water to wells in local areas.

Pleistocene deposits underlie most of the land surface of Area 3 (Fig. 10). Only in the northern and northwestern parts of the area do older rocks occur at the surface. In the uplands west of the Arkansas River valley the surface is immediately underlain by loess. The loess overlies older Pleistocene silt, clay, and locally, sand and gravel. Small to moderate quantities of water are available locally in this area. Alluvial deposits in the Arkansas River valley commonly yield as much as 1000 gpm to wells.

Population and Transportation

Population centers in this area are located along the railroads. Kinsley, the largest city, with a 1970 population of 2283, is located in the Arkansas River valley at the junction of the mainline of the Atchison, Topeka, and Santa Fe Railroad and the Great Bend Branch of the Santa Fe (Fig. 10).

U.S. Highway 50 crosses the southern part of the area from east to west. U.S. 56 crosses the area from northeast to southwest and U.S. 183 crosses the area from north to south.

Oil and Gas

Relatively small fields from which oil or gas has been produced are found in all parts of Area 3 (Fig. 10). In T. 24 S., R. 19, 20 W., no oil or gas has been produced. Several dry holes have been drilled in this part of the area.

At the present time there is little drilling activity in Area 3; however, the area is located on the west flank of the Central Kansas Uplift, and the possibility of finding oil in stratigraphic or structural traps on the truncated Mississippian surface will probably cause more interest in the future.

Salt

The Hutchinson Salt occurs in Area 3 at depths of about 1650 feet in the northeastern part of the area and about 1950 feet in the western part. The thickness of the salt in Area 3 ranges from about 350 feet to 400 feet (Fig. 11).

The quality of the salt is comparable to that in Area 2 which is not as good as that of the Lyons Repository site or Area 1. The thickness of the potential vault section is about 85 feet in T. 23 S., R. 20 W., which is the area with the least number of drill holes penetrating the salt.

AREA 4

Location

Area 4 includes all of Comanche County, which is adjacent to Oklahoma in south-central Kansas. The western part of the area is drained by the Cimarron River and its tributaries. The eastern part of the area is drained by Salt Fork Creek.

Structurally the area lies on the northern flank of the Anadarko Basin in a part of the basin which has been called the Dodge City Embayment. The area is west of the Pratt Anticline and southwest of the Central Kansas Uplift (Fig. 1).

Geology and Hydrology

In Area 4 the upper part of the Wellington Formation and the Ninnescah Shale between the Hutchinson Salt and the Stone Corral Formation have an aggregate thickness of about 800 feet. The Wellington portion of this section of rocks is composed principally of gray and blue-gray shale and is about 260 feet in thickness. The Ninnescah Shale in this area is principally red shale but contains beds of gray shale. In this area about 200 feet of Cimarron salt is present in the upper part of the Ninnescah. The section of rock between the top of the Ninnescah Shale and the top of the Blaine Formation (Fig. 12), comprised of the Stone Corral Formation, Harper Sandstone, Salt Plain Formation, Cedar Hills Sandstone, Flower-pot Shale, and the Blaine Formation, is about 600 feet in thickness. The Stone Corral is composed principally of anhydrite in the area and the Blaine Formation is predominantly gypsum. The other rock units in the area are chiefly silty shale or siltstone; however, in local areas much sandstone occurs in the Cedar Hills Sandstone. Sandstone is less prominent in the Salt Plain Formation. Moderate quantities of highly mineralized water are probably available from the sandstone beds.

The Flower-pot Shale is the oldest rock unit which crops out in Area 4 (Fig. 12). The Flower-pot is overlain by the Blaine Formation which is in turn overlain by the Dog Creek Formation of Lower Permian age, and the Whitehorse Formation of Upper Permian age. Salt which occurs just below the Blaine in counties north and west of Area 4 is not present in this area. The Whitehorse has the greatest areal distribution of the bedrock units in the area. Small exposures of the Big Basin Formation occur in the southern part of the area.

The Lower Cretaceous Cheyenne Sandstone and Kiowa Formation unconformably overlie the Whitehorse Formation in the northeastern and central part of Area 4, and locally overlie the Big Basin Formation in the southern part of the area. The Cretaceous rocks are overlain by sheet-like deposits of sand and gravel of probable early Pleistocene age. Only small quantities of water are available from the Cretaceous rocks near the outcrop.

Alluvial deposits of Pleistocene age which occur in the western and southwestern part of Area 4 are generally thin. The sheet-like deposits in the northern part of the area may be as much as 100 feet in thickness. In this area wells may yield several hundred gpm locally. Near the outcrop margins the deposits are largely drained and yield only small quantities of water.

Alluvium and low terrace deposits in and adjacent to the principal streams are generally thin and yield only small quantities of water to wells; however, locally these deposits thicken and may yield several hundred gpm.

Dune sands which occur adjacent to streams in the western part of the area and in an upland position in the central part of the area are thin and unimportant as a source of water.

Population and Transportation

Population centers are located along the Englewood Branch of the Atchison, Topeka, and Santa Fe Railroad (Fig. 12). Clearwater, with a 1970 population of 1208, is the largest city. U.S. Highway 160 crosses the area in an east-west direction and U.S. Highway 183, a north-south highway, serves the northern part of the area.

Oil and Gas

Area 4 has scattered oil and gas fields in much of the area. Numerous dry holes have been drilled throughout the area; however, there are several areas in which little or no drilling has been done (Fig. 12). In Area 4 exploration has been quite active. Production is from the Pennsylvanian, Mississippian, and Ordovician rocks and is related to structural and stratigraphic traps.

Salt

Salt occurs at two horizons in the Permian rocks in Area 4. The Cimarron salt (Stone Corral) which occurs in the upper part of the Ninnescah Shale is about 200 feet thick and occurs at a depth of about 900 to 1000 feet, about 600 to 800 feet above the Hutchinson Salt. The Cimarron salt was not investigated in this study.

The Hutchinson Salt occurs in Comanche County at a depth ranging from about 1650 to 1800 feet. The thickness of the Hutchinson Salt in this area ranges from about 450 to 500 feet (Fig. 13).

The quality of the Hutchinson Salt in this area is judged to be not as good as that of the Lyons Repository site or of Area 1. The quality is similar to that of Areas 2 and 3. The potential vault section is about 75 feet thick in T. 34, 35 S., R. 16-19 W., where the least amount of drilling activity has occurred.

Area 4 is not far distant from areas where solution has occurred in the salt beds. In Meade County, to the west, collapse features occur which are believed to be associated with solution of salt along faults. In Clark County, Big and Little basins are collapse features which probably are associated with salt solution in a local area (Campbell, 1963). Drilling records of western Comanche County give inconclusive evidence of salt solution in this area. Solution features in Meade and Clark counties are probably associated with solution of the Blaine salt which occurs about 600 feet above the Cimarron salt in the counties west of Comanche County (Malone, 1962). The Blaine salt does not occur in Comanche County. Valleys, oversized for their present streams in much of this part of Kansas and northern Oklahoma, may be an indication of solution of this salt and a general lowering of the surface rocks. There is no known evidence of solution in the Hutchinson and Cimarron salts.

AREA 5

Location

Area 5 includes all of Harper County, which borders Oklahoma in south-central Kansas. The area is drained in the west by Spring Creek and in the east by Bluff Creek and the Chikaskia River, all of which are tributaries of the Salt Fork River in Oklahoma.

Structurally the area lies within the Sedgwick Basin on the east flank of the Pratt Anticline.

Geology and Hydrology

About 250 to 300 feet of the upper part of the Wellington Formation is present between the Hutchinson Salt and the base of the Ninnescah Shale in this area. The Wellington in Area 5 is composed principally of gray and blue-gray shale but also contains some red shale and anhydrite. The Wellington contains little if any water in this area.

The Ninnescah Shale is about 400 feet thick in the southern part of the area but thins toward the north. The upper part of the Ninnescah crops out in eastern Harper County (Fig. 14). This rock unit is a blocky dolomitic or calcareous silty shale. The unit is predominantly red or brownish red; however, light-gray and dark-gray shale occurs in the upper part. The Ninnescah yields little or no water to wells in the area except from the upper weathered zone in the outcrop area where small quantities of water are available locally.

The Harper Sandstone and the Salt Plain Formation overlie the Ninnescah in Area 5. The Stone Corral Formation, which occurs between the Ninnescah Formation and the Harper Sandstone in other areas of the state, is absent in Harper County. The Harper Sandstone and the Salt Plain Formation are composed principally of red silty shale but locally contain thin beds of fine sandstone. The two units are generally not separable in the field. Their combined thickness in this area is about 500 feet. Water is generally not available from the Harper Sandstone or the Salt Plain Formation in this area except for small supplies, locally, from the sandstone beds.

Deposits believed to be a part of the Ogallala Formation of Pliocene age crop out in the southeastern part of Area 5 is a high upland position. These out-

crops are thin and are largely composed of sand and gravel derived from Cretaceous and Permian rocks, although some arkosic gravel is present. These deposits yield no water to wells in the area.

Pleistocene sand and gravel deposits of the Nebraskan and Kansan stages are present in the uplands in northern and northwestern Harper County. These deposits are as much as 100 feet in thickness and locally may yield as much as 300 gpm to wells.

Kansan age deposits occur in a high terrace position along Bluff Creek in the southern part of Area 5 (Fig. 14). In this area much silt is present in the deposits and yields to wells are generally small.

Sand and gravel in channels beneath thick silt deposits occupying the slope between the upland Nebraskan and Kansan deposits and Sand Creek valley in the area near and east of the city of Harper are probably Illinoisan in age. These deposits may locally yield as much as 500 gpm.

Alluvium and low terrace deposits in and adjacent to the stream valleys yield only small quantities of water to wells.

Population and Transportation

Popuation centers in Area 5 are located along railroads (Fig. 14). Much of the county area is included within the 6-mile radius of the cities.

The Kiowa Branch of the Atchison, Topeka, and Santa Fe Railroad and several other branch lines of the Santa Fe serve the area. A branch line of the Missouri Pacific Railroad serves the southern part of the area.

U.S. Highway 160 crosses the area in an east-west direction and several state highways cross the area in both east-west and north-south directions connecting all of the cities to the highway system.

Oil and Gas

Part of the Spivey-Grabs-Basil oil and gas field, one of the larger fields in Kansas, covers much of the northwestern part of Area 5 (Fig. 14). Many smaller fields are located in the area, principally in the northern and eastern parts of Area 5. Many exploration holes have been drilled throughout Harper County. Most producing wells have not had large initial production but they have continued to produce for many years. The area is considered to have good potential for future exploration.

Salt

In Area 5 the Hutchinson Salt occurs at a depth of about 550 feet in the northeastern part and about 1000 feet in the northwestern and southwestern parts of the area (Fig. 15). The thickness of the salt ranges from about 200 feet in the east-central part of the area to about 400 feet in the western part. In the area of least drilling activity the salt is about 350 feet thick.

The quality of the salt in this area is the poorest of any of the eight areas studied. Many shale and anhydrite beds occur within the salt beds and clay inclusions within the salt are common. The potential vault section which includes the section with the fewest shale or anhydrite beds is about 75 feet thick. Although the quality of the salt is poorest in this area, the absence of water above the salt beds makes it an area for consideration.

AREA 6

Location

Area 6 includes 12 townships in western Reno County north of the North Fork Ninnescah River. The southern part of the area is drained by the Ninnescah River and the northern part by the Arkansas River.

Structurally the area is located in part in the northwestern part of the Sedgwick Basin and in part on the eastern flank of the Central Kansas Uplift (Fig. 1).

Geology and Hydrology

Lower Permian rocks consisting of part of the Wellington Formation, the Ninnescah Shale, and the Stone Corral Formation occur above the Hutchinson Salt but do not crop out in Area 6. The upper part of the Wellington Formation consists of about 200 feet of principally gray shale but contains some red shale near the top and a few thin beds of anhydrite and dolomite. The Ninnescah Shale is composed of about 300 feet of red shale and minor amounts of siltstone. The Stone Corral Formation is composed of about 20 feet of anhydrite and dolomite. Little or no water is available from these rock units in this area.

The Harper Sandstone which overlies the Stone Corral Formation is the oldest rock unit which crops out in Area 6 (Fig. 16). The unit is composed of silty shale and siltstone. It is about 150 feet in thickness and red is the dominant color. The Harper Sandstone yields small quantities of water to a few wells from the upper weathered part of the formation.

Sand and gravel deposits containing much silt believed to be part of the Ogallala Formation of Pliocene age are present in an upland position in the southern part of Area 6. These deposits are red or dark reddish-brown and are composed of materials largely derived from Permian and Cretaceous rocks. They occur in relatively thin, sheet-like deposits. Other sand and gravel deposits similar in lithology and color occur in channels in this same general area but at a somewhat

lower elevation. These deposits may be earliest Pleistocene in age (Nebraskan) and derived from the older Ogallala deposits. Small to moderate quantities of water are available to wells from these deposits.

A deep channel cut into the Permian bedrock extends southeastward from the northwest corner of the area to a point about 7 miles south of the northeast corner of the area. This channel is filled with Pleistocene stream deposits. The lower part, locally as much as 100 feet in thickness, contains red and reddish-brown sand and gravel similar to the channel deposits in the southern part of the area. These deposits are thought to be Nebraskan in age and they contain highly mineralized water. The Nebraskan deposits in the channel area are overlain by younger Pleistocene deposits of probable Kansan and Illinoisan age. These younger sheet-like deposits underlie the surface and rest on Permian rocks in all of Area 6 except in and near the valley of the Ninnescah River. The Pleistocene deposits may be as much as 100 feet in thickness and yield large quantities of water to wells in local areas.

Dune sand principally of Wisconsinan age overlies the earlier Pleistocene deposits in much of the area (Fig. 16). In most of the area the dunes are well stabilized; however, in the northwest part of the area some dunes are active and drainage is poorly developed.

Thin loess deposits overlie the Kansan and Illinoisan deposits in the southeastern part of Area 6.

Recent alluvium and low terrace deposits are present in the valleys of the Arkansas and Ninnescah rivers. In the Ninnescah valley these deposits are thin and only moderate quantities of water are available. In the Arkansas River valley yields of wells in excess of 1000 gpm are obtained.

Population and Transportation

Population centers are located along the main lines of the Rock Island and Pacific Railroad in the southern part of Area 6, along the main line of the Atchison, Topeka, and Santa Fe Railroad in the central part of the area, and along the Great Bend Branch of the Santa Fe in the northern part (Fig. 16). The largest city within the area is Arlington, which had a 1970 population of 503. Hutchinson, located about 12 miles east of the area, had a 1970 population of 36,885.

U.S. Highway 50 crosses the area in an east-west direction and State Highway 14 crosses the eastern part of the area in a north-south direction. State Highway 61 crosses the area in a northeast-southwest direction in the southern part of the area.

Oil and Gas

The Zenith-Peace Creek Field in northwestern Reno County dominates the oil and gas production in Area 6. Other smaller fields occur in the northern two-thirds of the area (Fig. 16). Production is from rocks ranging in age from Ordovician to Permian. Large areas are present in the southern part of Area 6 where no production has been obtained although the area has been extensively drilled.

Area 6, located in the northwestern part of the Sedgwick Basin and on the eastern flank of the Central Kansas Uplift, has possibilities for additional production from stratigraphic traps.

Salt

The Hutchinson Salt occurs in Area 6 at depths of about 700 feet in the eastern part of the area and about 1000 feet in the western part. Thickness of the salt in the area ranges from 350 feet to about 435 feet (Fig. 17). The thickest salt occurs near the center of the area where it overlies a structural high. Lee (1956) interpreted the thickening of salt beds over structural highs as the result of evaporites yielding or "flowing" toward the structural high. In the present study, no evidence of a correlation between thick salt sections and structural highs has been found that could not be satisfactorily explained by facies changes, pinchout, overlap, and other original depositional features. The quality of the salt in Area 6 is intermediate between that of Lyons and that of Area 5. It is probably of somewhat better quality than the salt of Areas 2 and 3. The thickness of the salt interval at a potential vault section is 90 feet.

AREA 7

Location

Area 7 includes all of Rice County, which is located near the center of the state. The area is drained on the south and west by the Arkansas River and on the east by the Little Arkansas River. A small area in the northeastern part of Rice County is drained by tributaries of the Smoky Hill River. The eastern part of the area lies within the Sedgwick and Salina basins. The western one-half of the county is located on the flank of the Central Kansas Uplift (Fig. 1).

Geology and Hydrology

The upper part of the Wellington Formation between the top of the Hutchinson Salt and the base of the Ninnescah Shale ranges in thickness from about 250 feet to about 300 feet. The Wellington is composed principally of gray and blue-gray shale but con-

tains thin beds of red shale and anhydrite. The unit contains little or no water in this area.

The upper part of the Ninnescah Shale crops out in eastern Rice County (Fig. 18). This unit, composed chiefly of red and reddish-brown shale, is about 300 feet thick in the area. Only about the upper 50 feet of the unit is exposed. The Ninnescah contains little or no water except in the upper weathered part which yields small quantities of water to wells in the outcrop area.

The Stone Corral Formation overlies the Ninnescah Shale and crops out in eastern Rice County. On the outcrop the Stone Corral is about 6 feet thick and is composed principally of dolomite. West of the outcrop in the subsurface the Stone Corral is about 18 feet thick and is composed of anhydrite, dolomite, gypsum, and shale. The Stone Corral yields small quantities of water to wells in the area of outcrop and contains only small quantities of water near the center of the county. In the northern and western parts of the county the Stone Corral contains little if any water.

The Harper Sandstone overlying the Stone Corral is the youngest Permian rock unit in Area 7. The Harper is about 150 feet in thickness where a full section is present. The unit is composed principally of red silty shale and red siltstone and yields little or no water to wells in the area.

Lower Cretaceous rocks overlie the Harper Sandstone in this area. The contact between these rocks and the Permian rocks marks a major unconformity in this area. The oldest Lower Cretaceous rock unit in Kansas is the Cheyenne Sandstone which overlies the Permian Harper Sandstone in the western part of Area 7. The Cheyenne is composed of very fine silty sandstone and siltstone and is not an important aquifer. The Cheyenne does not crop out in the area.

The Kiowa Formation overlies the Cheyenne Sandstone in the western part of Rice County. Eastward the Kiowa overlaps the Cheyenne and rests on the Harper Sandstone. The Kiowa Formation, when a full section is present, is about 150 feet thick. It thins to zero thickness toward the south and east. The Kiowa is composed predominantly of dark-gray to black thinly laminated shale in the lower part and yellow-brown and light-gray mottled shale in the upper part. Sandstone beds may be present throughout the unit but are more common in the upper part. Lignite and thin calcareous shell beds are present throughout the unit. The availability of water in the Kiowa is dependent upon the presence and thickness of the sandstone beds. These beds range in thickness from a few inches to several tens of feet. Yields of wells range from only a few gallons per hour to as much as 50 gpm.

The Dakota Formation overlies the Kiowa Formation in the northern part of Rice County, and may reach a thickness of 200 feet. The unit thins to zero thickness toward the south. It crops out principally in the headwater area of the Little Arkansas River (Fig. 18). In the north-central and northwestern part of the area the Dakota is overlain by silts of Pleistocene age and crops out only in small isolated areas. The Dakota is principally composed of clay, shale, and sandstone but contains some lignite and beds of iron-cemented sandstone. Colors range from red, brown, and gray to white. Sandstone beds occur throughout the formation and may comprise about one-third of the total thickness. The quantity of water which may be obtained by wells from the Dakota is dependent on the amount of sandstone present. Maximum yields are probably about 200 gpm; however, smaller yields will generally be obtained.

The Ogallala Formation of Pliocene age is represented in this area by a soil caliche formed during the long period of weathering which occurred prior to the deposition of Pleistocene deposits in the area. The soil caliche is thin and not everywhere present.

Pleistocene rocks unconformably overlie the bedrock units in much of Area 7. Alluvial deposits are present in the valleys of the Arkansas River, Cow Creek, and the Little Arkansas River. Early Pleistocene channel deposits underlie alluvial deposits in the west-central part of the area roughly parallel to Cow Creek and in the south-central part of the area underlying the valleys of the Arkansas River and Cow Creek. Large quantities of water are available to wells from these deposits.

Dune sand overlies the alluvial deposits in the valleys of the Arkansas River and Cow Creek. It overlies channel deposits or Cretaceous rocks in west-central Rice County and Permian rocks in southeastern Rice County. The dune sand deposits are not important aquifers in Area 7.

Loess underlies the surface in much of the upland areas of the county (Fig. 18). Very small quantities of water are available to wells locally from these deposits, however, most wells penetrate the deeper rocks to obtain more dependable supplies.

Population and Transportation

Population centers in Rice County are located along railroads which serve the area. Lyons, the largest city, is located near the center of the county and is served by branch lines of the Atchison, Topeka, and Santa Fe Railroad, the Missouri Pacific Railroad, and the St. Louis and San Francisco Railroad. The main line of the Missouri Pacific Railroad serves population centers in the extreme northern part of the county.

The city of Sterling, in the southern part of the area, is served by the Great Bend Branch of the Santa Fe Railroad.

U.S. Highway 56 passes east-west through the center of the county. State Highway 4 passes east-west through the extreme northern part of the area, and State Highway 14 crosses north-south through the center of the area (Fig. 18).

Oil and Gas

Rice County is one of the most heavily drilled areas in Kansas. Oil and gas fields occur throughout Area 7 and many exploratory holes have been drilled outside the fields (Fig. 18). Production has been obtained from rocks ranging in age from Precambrian to Permian. The western part of the area is located on the eastern flank of the Central Kansas Uplift and the eastern part of the area is in the westernmost parts of the Salina and Sedgwick basins. Although the area is highly developed, exploration is expected to continue at a high level of intensity.

A natural gas storage area is located near Alden in the southwestern part of Rice County.

Salt

In Area 7 the Hutchinson Salt occurs at depths ranging from about 450 feet in the east to about 1000 feet in the west. Salt thickness in the area ranges from 230 feet to about 390 feet (Fig. 19). On Figure 19, the thickness of the salt in the area studied in detail in the Lyons site report (Angino and Hambleton, 1971) is shown in somewhat more detail than in the remainder of the county.

The quality of the salt in Area 7 is similar to that of Area 1 and is somewhat better than that of Areas 5 and 6. Thickness of the potential vault section is about 90 feet.

AREA 8

Location

In the original report on supplementary sites which was prepared for the A.E.C., Area 8 included Wallace, Logan, Greeley, Wichita, and western Scott counties. Parts of Wallace, Logan, and Greeley counties failed to meet one or more of the criteria considered essential for storage of radioactive waste in salt beds. In Wichita and western Scott counties the limits were generally acceptable and for this reason maps showing only the area including Wichita and western Scott counties are used in this report, although the entire original area is discussed in the text.

Wallace and Logan counties and a small part of northern Greeley, Wichita, and Scott counties are drained by the Smoky Hill River. The remainder of Greeley, Wichita, and Scott counties is drained by Whitewoman Creek which empties into the Scott-Finney depression and has no connection with major trunk streams. The area lies in the northern part of the Hugoton Embayment (Fig. 1).

Geology and Hydrology

Permian rocks between the Blaine Formation (Lower Permian) and the Morrison Formation of Jurassic age thin toward the north and east in this area. In Greeley County the Permian section of rocks is about 320 feet thick. In Wichita County it is about 280 feet thick and in Wallace and Logan counties, about 170 and 150 feet respectively. Thinning is probably due to post-Permian—pre-Jurassic erosion. Generally the rocks are composed principally of silty to sandy shale; however, the Whitehorse Formation in Area 8 contains sandstone and should yield some highly mineralized water to wells.

The Morrison Formation in this area is about 100 feet thick and is composed principally of shale and sandy shale but may locally contain thin beds of limestone.

The Lower Cretaceous Cheyenne Sandstone, Kiowa Formation, and Dakota Formation have a nearly constant aggregate thickness of about 400 feet in Wichita, Greeley, Wallace, and Logan counties. The Cheyenne and Dakota both contain appreciable amounts of sandstone and should yield moderate to large quantities of water to wells. Water from the Dakota is locally of usable quality but Cheyenne water is probably everywhere too highly mineralized for use.

Upper Cretaceous rocks between the top of the Dakota and the base of the Niobrara Chalk are composed of shale, chalky shale, limestone, and chalk. These rocks comprise the Graneros Shale, Greenhorn Limestone, and Carlile Shale and are about 400 feet thick. Little if any water is available from these rocks.

The oldest bedrock unit which crops out in this area is the Smoky Hill Chalk Member of the Niobrara Chalk. This unit is extensively exposed in the valley of the Smoky Hill River in Logan County but crops out only in small exposures in the valley of Chalk Creek in Scott County (Fig. 20). It is not exposed in Wichita County. In parts of Wallace and Logan counties the Niobrara Chalk is about 650 feet thick where it has not been eroded. In northwestern Wichita County the Niobrara is about 500 feet thick but thins toward the south and east.

The Pierre Shale overlies the Niobrara Chalk in parts of Wallace and Logan counties. The Pierre may

be as much as 600 feet thick locally in Wallace County. The unit thins toward the east where it has been eroded. The Pierre may be present below the Ogallala Formation in northern Greeley County but is apparently absent in Wichita and Scott counties.

Earliest Ogallala deposition occurred in relatively shallow, broad channels cut in the eroded and beveled Cretaceous surface. Continued deposition of these clastic (composed of fragments) deposits soon filled the channels and by middle Ogallala time had topped the divide areas between the channels. At the end of Ogallala time, this area, most of western Kansas, and large areas in adjoining states formed a broad alluvial plain with a gentle eastward slope. Since the end of Ogallala deposition several hundred feet of Ogallala and Upper Cretaceous rocks have been eroded in the valley of the Smoky Hill River. In Logan County the thickest Ogallala deposits are presently in the northern part of the county. These deposits thin to zero thickness toward the Smoky Hill River valley. Thin deposits of Ogallala occur in the uplands in western and southwestern Logan County.

In Wallace County more than 300 feet of Ogallala is present in local areas; however, the normal thickness is considerably less. In north-central and northeastern Greeley County the Ogallala is quite thick although somewhat thinner than in Wallace County. In western and southern Greeley County the Ogallala ranges in thickness from 150 feet to about 200 feet. In the southern part of Wichita and Greeley counties the formation thins to less than 50 feet in local areas.

In northern Logan County moderate to large supplies of water are obtained from the Ogallala. In Wallace County where the thickest deposits occur, wells yielding as much as 1500 gpm are obtained; however, more commonly in this county and in northern Greeley County yields of wells are about 1000 gpm. In western and southern Greeley County where the Ogallala is thin, much less water is available to wells. In northern Wichita and Scott counties, yields of wells are commonly about 1000 gpm. Southward in these counties yields of wells diminish and in the extreme southern part of the area little water is available to wells.

During the Pleistocene several hundred feet of older deposits were eroded in Logan and eastern Wallace counties.

Pleistocene fluvial deposits occur as low terrace deposits or alluvium in the Smoky Hill valley and in the valleys of the larger tributaries. In Greeley, Wichita, and western Scott counties erosion during this period was much less severe. In eastern Wichita County Whitewoman Creek flows about 100 feet below the highest uplands on either side of the stream. The degree of erosion was probably controlled by the fact that Whitewoman Creek flows into a closed basin and does not have surface access to a through-flowing stream. Thin alluvial deposits of Pleistocene age occur in the valleys of Whitewoman and Ladder creeks in these counties (Fig. 20). Large water supplies are generally not available from Pleistocene deposits in Wallace, Logan, Greeley, Wichita, and western Scott counties except locally in the Smoky Hill River valley.

Loess principally of late Pleistocene age and ranging up to 50 feet in thickness overlies older deposits in much of Area 8. In the upland areas the loess overlies Ogallala deposits (Fig. 20). In the valley of the Smoky Hill River thin loess overlies Cretaceous rocks in local areas.

Faulting and Solution Features

Numerous small faults can be observed in the Cretaceous rocks in Wallace and Logan counties. Generally, displacement along faults is small; however, a displacement of as much as 35 feet has been observed in Wallace County (Moore, 1926; Hodson, 1963). In Logan and Gove counties (east of this area) displacements greater than 100 feet have been observed. From our present knowledge of the area, it is not known whether faulting affects deeply buried rocks in the area or is confined only to the Cretaceous rocks. Faulting is seen only in the Cretaceous rocks and does not appear to have affected the Ogallala or younger deposits. If the faulting is deep seated, it no doubt extends beyond the area where it can be observed. However, if the faulting is related to adjustments which may have occurred due to unloading of the Cretaceous rocks when great quantities of overlying rocks were eroded, the faulting may be relatively shallow and confined to the valley area where erosion occurred.

Two instances of development of sinks or collapse of surface rocks have occurred in Wallace County since this area has been inhabited. The earliest collapse of historic record occurred in 1900 and is located in section 1, T. 12 S., R. 39 W. The second occurred in 1926 in section 33, T. 13 S., R. 39 W. The initial collapse at the latter location affected an area about 350 feet by 250 feet and was reported to be between 300 and 500 feet in depth before filling with water from the Smoky Hill River. Other areas of sinking in which Cretaceous rocks are affected have been observed in Wallace County. These may represent collapse features which occurred before the area was inhabited. The abnormal saturated thickness of the Ogallala in local areas in Wallace County may be an indication of

old collapse features. No similar collapse features have been observed in Logan County.

The cause of the collapse of surface rocks may be attributed to solution of the chalk or, if the faulting in the area is deep seated and affects the deeply buried rocks, solution of salt may have occurred permitting the overlying beds to collapse. Chalk is soluble in water to some extent and especially if the water is slightly acidic; however, in Area 8, large quantities of water are not known to occur in the chalk nor is the chalk cavernous on the outcrop.

Much water is available in the Lower Cretaceous rocks several hundred feet above the Blaine salt. If this water has migrated downward through the salt through fractures or faults, solution could have occurred in this way.

West of Area 8 in Cheyenne County, Colorado, and a few miles west of the Kansas state line, a problem of loss of circulation during drilling begins in many wells at a depth of about 600 feet and continues to a point below the evaporites or near the top of the Chase Group rocks. Circulation problems are not experienced in all bore holes; however, such problems are quite common in this area.

The cause of circulation problems in this area is not definitely known; however, several oil operators have expressed the belief that salt solution or flowage may have caused the overlying rocks to be fractured, thus causing loss of circulation, but there is no agreement as to the cause. Drilling operations in Area 8 have not been as concentrated as in eastern Colorado; however, at least one operator has experienced circulation problems in Wallace County. A few wells have been drilled in southern and southeastern Wichita County where some production of oil is obtained. In Wichita County circulation problems have not been reported.

Population and Transportation

Population centers in Wallace and Logan counties, with the exception of Russell Springs, Logan County, are located along the Union Pacific Railroad which enters the area at the northeast corner of Logan County and enters Colorado near the center of the west line of Wallace County.

The only incorporated cities in Wichita and Greeley counties are located near the centers of the counties on the Missouri Pacific Railroad (Fig. 20).

Wallace and Logan counties are served by U.S. Highway 40 which passes east-west through the area. State Highway 25 crosses Logan and Wichita counties in a north-south direction. State Highway 27 crosses Wallace and Greeley counties from north to south. State Highway 96 is an east-west highway serving Wichita and Greeley counties.

Oil and Gas

Wallace, Logan, Greeley, Wichita, and western Scott counties have had little oil and gas drilling. Production from a few wells has been small. This area is in the northern part of the Hugoton Embayment, north of the large Hugoton Gas Area. At the present time that part of eastern Colorado adjoining Area 8 is receiving considerable attention by oil operators. There is considerable potential for finding production from structural and stratigraphic traps in Wallace and Greeley counties. Few wells have been drilled in Wichita County and only minor oil and gas production has been found in this area (Fig. 20).

Salt

Area 8 was included in this study when it was recognized that salt deposits just below gypsum beds of the Blaine Formation met the assigned study parameters of thickness and depth. This salt deposit is referred to as the Blaine salt. In northwestern Wallace County the Blaine salt occurs at a depth of about 2800 feet and is only about 100 feet thick. In central Logan county the Blaine salt occurs at a depth of about 1750 feet and is near 300 feet in thickness but it thins rapidly toward the north and east. In eastern Greeley County the Blaine salt occurs at a depth of about 2000 feet and is about 200 feet thick; however, the depth to salt increases and the thickness decreases toward the west. In northwestern Wichita County the salt occurs at a depth of about 2000 feet. In southeastern Wichita and western Scott counties the salt occurs at a depth of about 1450 feet. Thickness ranges from about 350 feet in the north to about 440 feet in the south (Fig. 21). Study of core descriptions and radioactive logs indicates that the salt in this area is of better quality than that of any of the other areas examined. The thickness of the potential vault section is about 200 feet in southern Wichita County.

DISCUSSION AND CONCLUSIONS

By John C. Halepaska and Ernest E. Angino

In the matter of suitability for radioactive waste storage, the Kansas Geological Survey has not evaluated the importance of those criteria enumerated in the introduction. However it is the opinion of the Survey staff that these criteria can be ordered generally. The first consideration is the safety of people. Adequate safety buffers are absolutely necessary. Second in importance are engineering and geologic considerations which include depth of salt, salt thickness,

salt quality, subsurface geologic structure, old oil and gas holes, and probably most importantly, ground water. Obviously, a most vigorous attempt to minimize breaching the integrity of the salt vault associated with storage is in order. Third would include transportation (assuming inherent danger remains fixed regardless of site), pipelines, and potential recreational and oil and gas development.

Owing to the nature of this study, unfavorable aspects of an area may be more explicitly described and defined than favorable aspects. In areas where information is sparse a broader regional interpretation is required. Obviously, focus must be on regionally good areas where a maximum amount of reliable information exists.

On a regional basis, Area 1 deserves close scrutiny. It is distant from regional oil and gas development and appears to have adequate buffer space. The area fits reasonably well the structural engineering criteria (e.g., thickness, depth, and quality of salt). The likelihood of unknown hydraulic connection between the salt and an aquifer above or below the salt in Area 1 caused by an old drill hole or fracture pattern is less. The potential for oil and gas development is considerably less than in any of the other seven areas considered. All factors being equal, Area 1 is the best prospect for future study.

Area 2 lies on the western side of an area of regional oil and gas development. It is now undergoing active exploration, and in addition, has good potential for future oil and gas development. The area is marginal in terms of structural engineering criteria in that the salt is near the 2000-foot depth limit. The potential for water problems above and below the salt, in addition to old holes and depth to salt, makes this area a poor candidate for further study.

Area 3 can be categorized much the same as Area 2 and is a poor prospect for future study.

Area 4 lies to the west of regional oil and gas development. It lies east of a large area that appears to have undergone some salt solutioning and faulting. The study area has been, and is now, actively explored for oil and gas. This area, like Areas 2 and 3, is marginal in meeting the structural engineering criteria. The salt is about 1700 feet deep. Water problems above and below the salt, existence of old holes, depth to salt, and salt solutioning immediately to the west make Area 4 a poor prospect for future study.

Area 5, slightly south of the regional oil and gas development, is marginal in terms of structural engineering criteria. Oil and gas exploration has been active; however, sparsely drilled areas do exist. The salt is of poor quality although it is within the limits for thickness and depth. This area does, however, have considerably less ground water above the salt than any other area. A trade-off between thin, poor-quality salt and salt with little or no water above it may make Area 5 worth consideration.

Area 6 lies to the south of the Lyons site on the southeast flank of the regional oil and gas development trend. The area has been, is being, and will continue to be actively explored. The salt fits the structural engineering criteria. Water problems above and below the salt beds will be as great as in any area studied. Because of old oil and gas holes and copious quantities of ground water in the area, Area 6 ranks below Areas 1 and 5, but above Areas 2, 3, and 4.

Area 7 lies on the east flank of the regional oil and gas development. This area has the most producing wells, the greatest history of exploration, and the highest potential for future development of any area considered. The salt fits the structural engineering criteria well. Medium to low quantities of ground water exist above the salt. Large numbers of old oil and gas holes, water above and below the salt, possible deep-seated structural problems, high potential for development in the future, and an inadequate buffer zone make Area 7 the poorest candidate for future study.

Area 8 lies in extreme western Kansas, far to the west of the major Kansas regional oil and gas producing areas, but on the eastern fringe of an active area of oil and gas development in eastern Colorado. The western part of Area 8, though largely undrilled, will probably undergo vigorous exploration. The salt in this area is more than 2000 feet deep. The salt in the eastern part of Area 8 is of high quality, is quite thick, and is 1700 feet deep. Lost-circulation problems and occasional absence of the salt in the western half of this area (Wallace and Greeley counties, Kansas, and eastern Colorado) raise a caution light. A regional hydrodynamic analysis indicating high head differentials across the salt, together with the problem of a regional fault system, may account for the missing salt section. In addition, locally high saturated thickness in the Ogallala Formation indicates possible anomalous structural conditions. Sandstone both above and below the salt may contain large quantities of water. While this area has high-quality salt, its suitability ranks below that of Area 1 and possibly Area 5.

In summary, Areas 2, 3, 4, 6, and 7 rank far below Areas 1, 5, and 8. Area 7 is least suitable. A trade-off between poor quality of salt and little or no ground water in Area 5 may be worth considering. The western part of Area 8 has unanswered questions, but the eastern part of Area 8, with high-quality salt, is worthy

of consideration. It is, however, definitely rated below Area 1 and above Area 5. In conclusion Area 1 appears to be the best candidate for future study.

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Figure 7

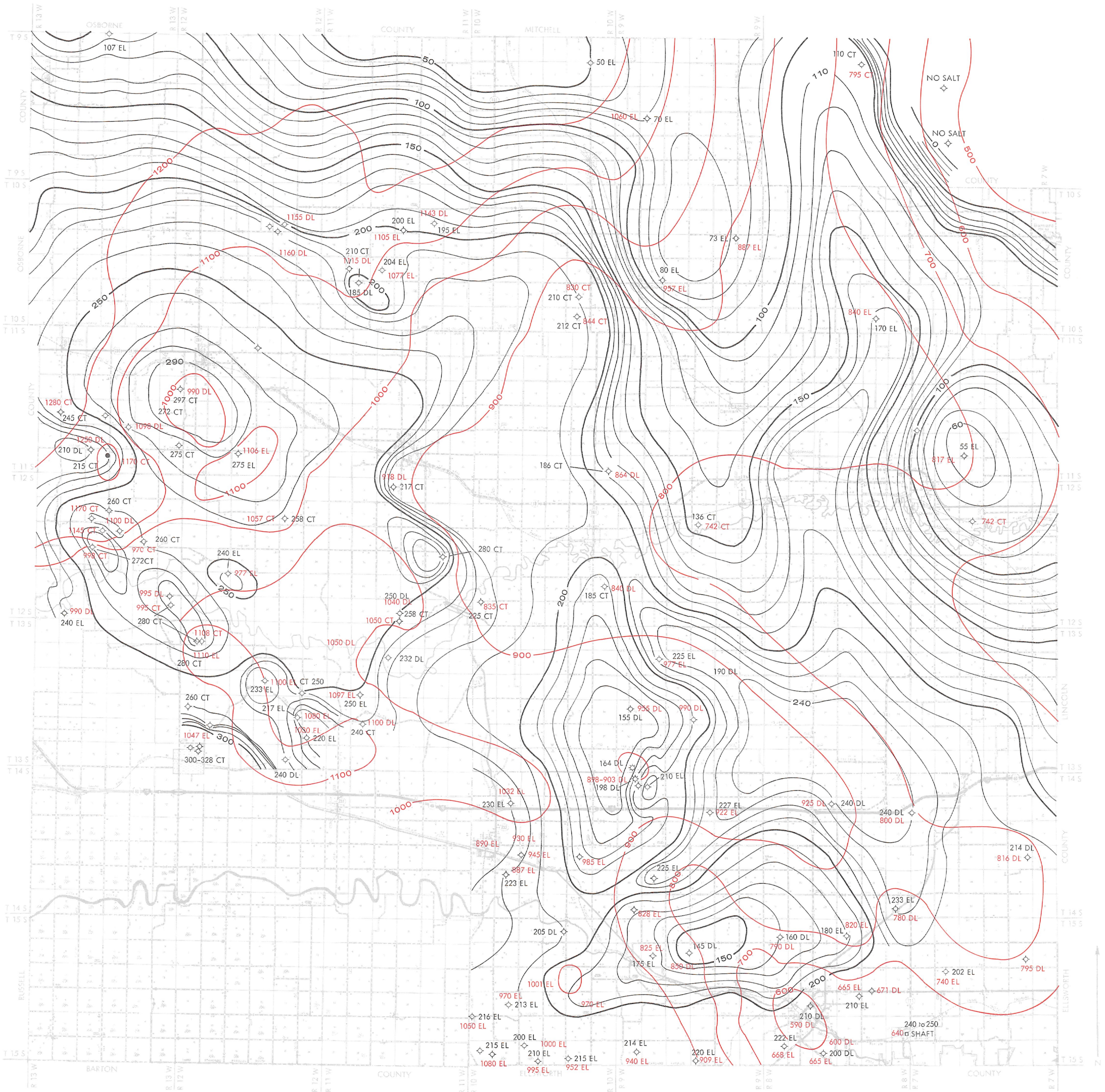
Area 1

Thickness and Depth to Hutchinson Salt

Parts of Ellsworth, Lincoln, Mitchell, Osborne and Russell Counties

Contour Interval 10 feet

Contour Interval- 100 feet



EXPLANATION

Source of Information

EL- Electric Log, CT- Cable Tool, DL- Drillers Log

✧ Drilled and abandoned well • Oil well ☼ Gas well

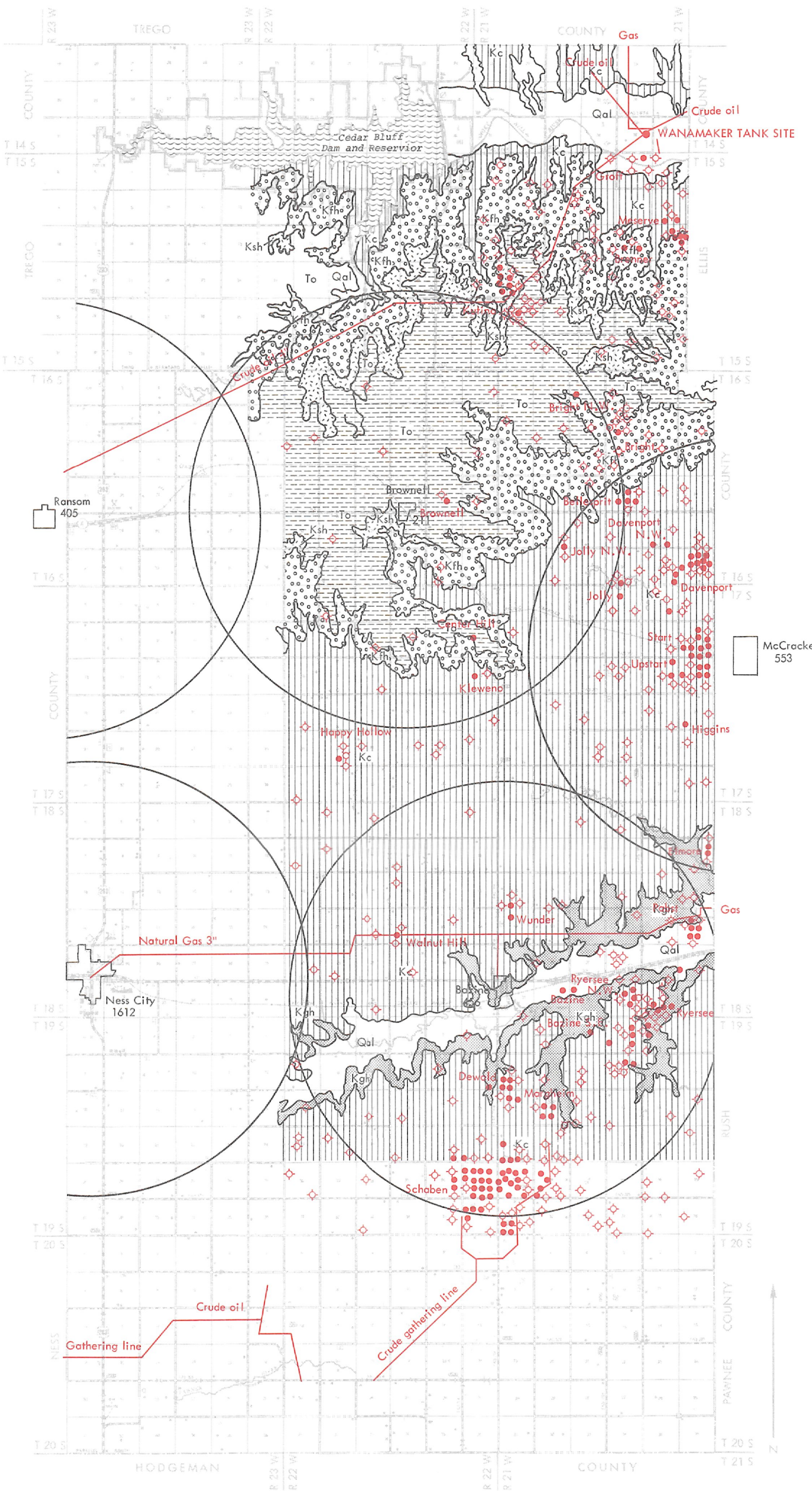
0 — 6

Scale in miles

Figure 8 Area 2

Areal Geology, Population Centers and Oil and Gas Developments

Parts of Ness and Trego Counties, Kansas



EXPLANATION

- Qal — Alluvium and low terrace deposits
- To — Ogallala Formation
- Ksh — Smoky Hill Chalk Member of Niobrara Chalk
- Kfh — Fort Hays Member of Niobrara Chalk
- Kc — Carlile Shale
- Kgh — Greenhorn Formation Graneros Formation
- Incorporated cities Numbers refer to 1970 census
- D & A well
- Service well
- Pipelines
- Oil well

0 6

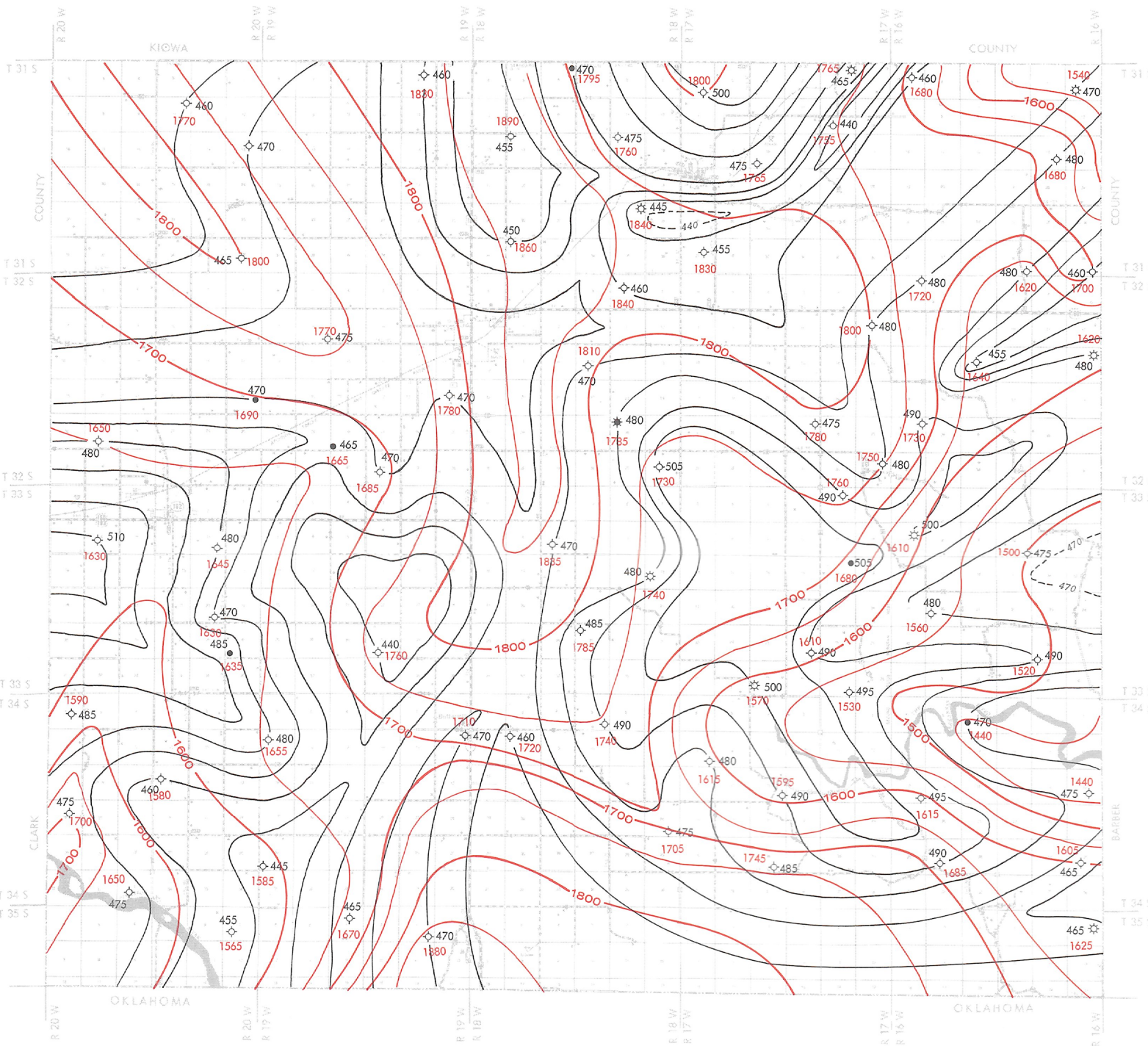
Scale in miles

Figure 13

Area 4
Thickness and Depth to Hutchinson Salt
Comanche County, Kansas

Contour Interval 10 feet

Contour Interval 50 feet



EXPLANATION

Data Point (data taken from wire line logs)

1680 Depth to the top of the salt in feet

480 thickness of the salt

✧ Drilled and abandoned well

☼ Natural gas well

✷ Oil and gas well

● Oil well

0 — 6

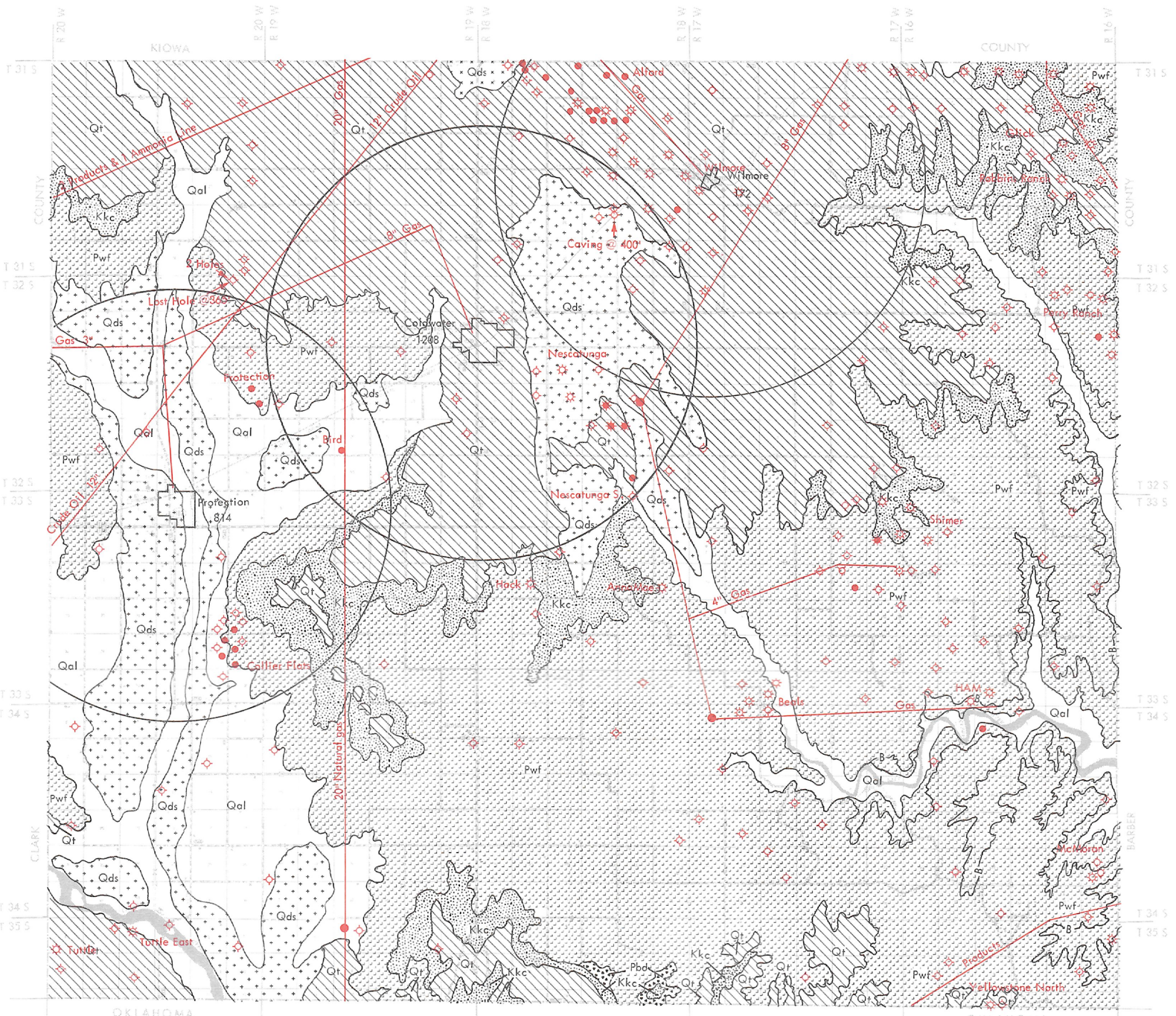
Scale in miles

Figure 12

Area 4

Areal Geology, Population Centers and Oil and Gas Developments

Comanche County, Kansas



EXPLANATION

- Qal — Alluvium and low terrace deposits
- Qds — Dune sand
- Qt — High terrace deposits
- Kkc — Kiowa Formation and Cheyenne Sandstone
- Pbd — Big Basin Formation
- Pwf — Whitehorse Sandstone, Blaine Gypsum (Base - B) and Flowerpot Shale
- Incorporated cities
  Numbers refer to 1970 census

0 — 6
Scale in miles

- Compressor station
- Gas well
- D & A well
- Service well
- Oil well
- Pipelines

Figure 14

Area 5

Areal Geology, Population Centers and Oil and Gas Developments

Harper County, Kansas

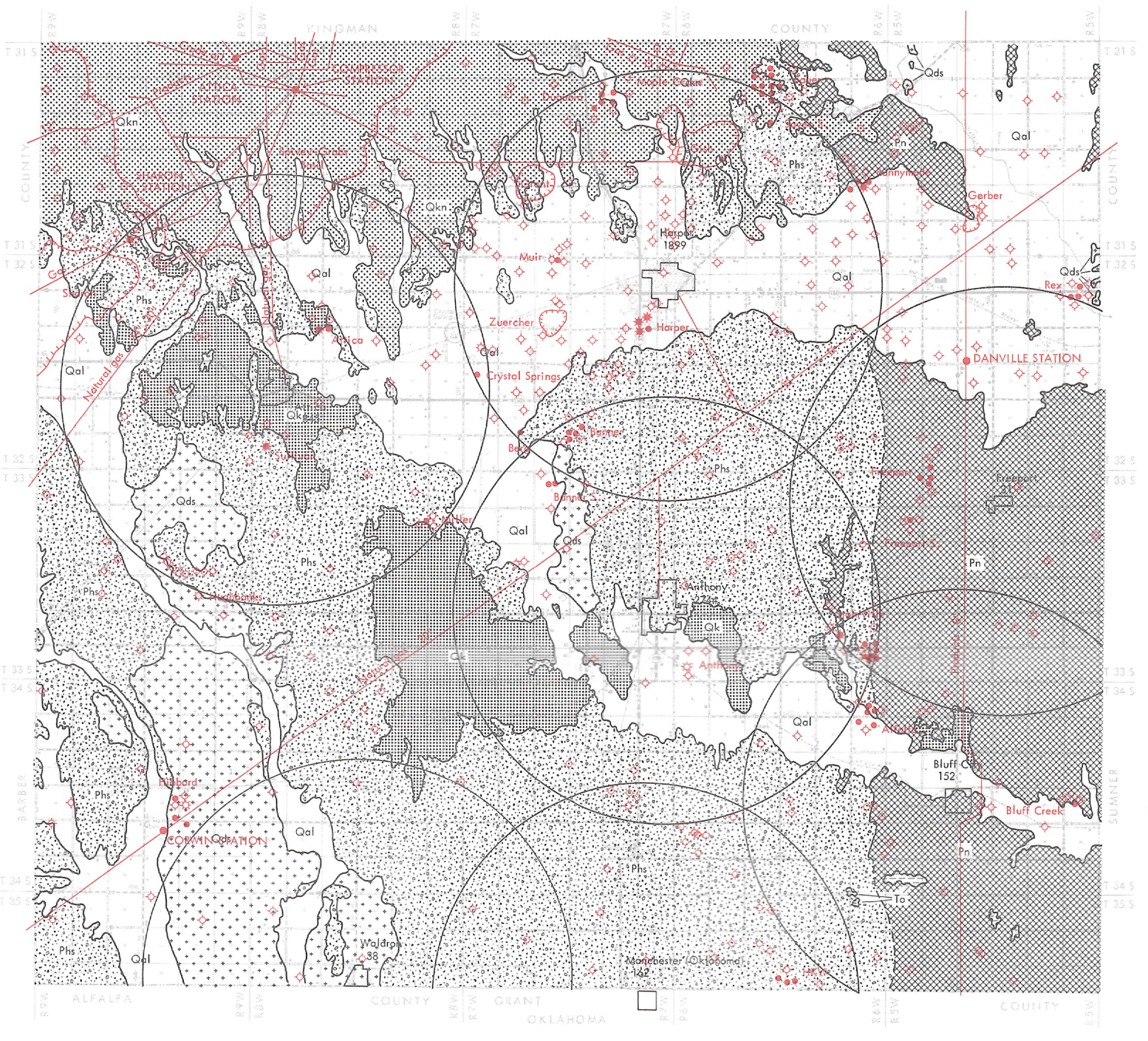


Figure 15

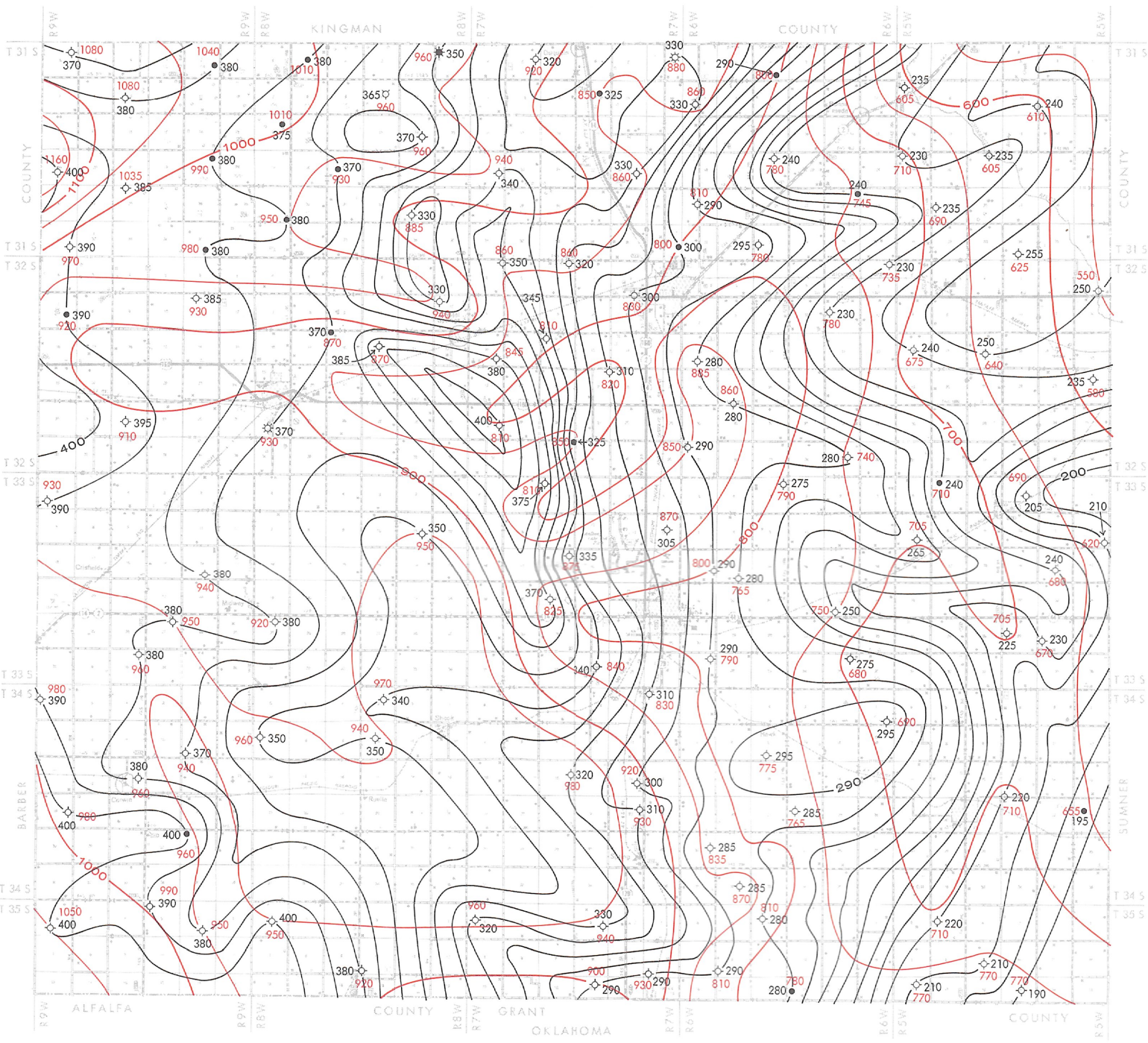
Area 5

Thickness and Depth to Hutchinson Salt

Harper County, Kansas

Contour Interval 10 feet

Contour Interval 50 feet



EXPLANATION

Data Point (data taken from wire line logs)

640 Depth to the top of the salt in feet

230 thickness of the salt

- Drilled and abandoned well
- Oil and gas well
- Gas well
- Service well
- Oil well

0 6

Scale in miles

Figure 16 AREA 6

Areal Geology, Population Centers and Oil and Gas Developments

Part of Reno County, Kansas

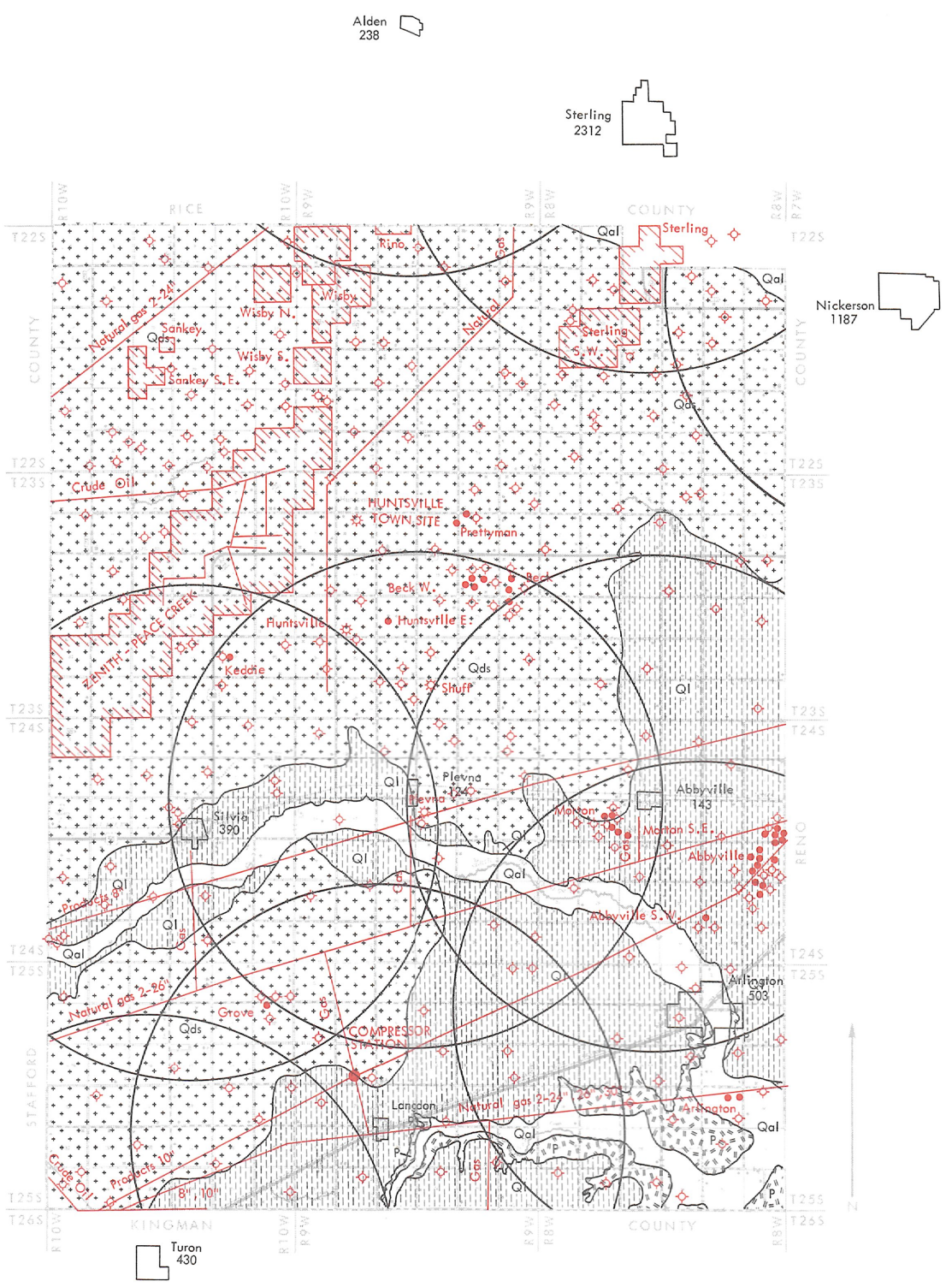
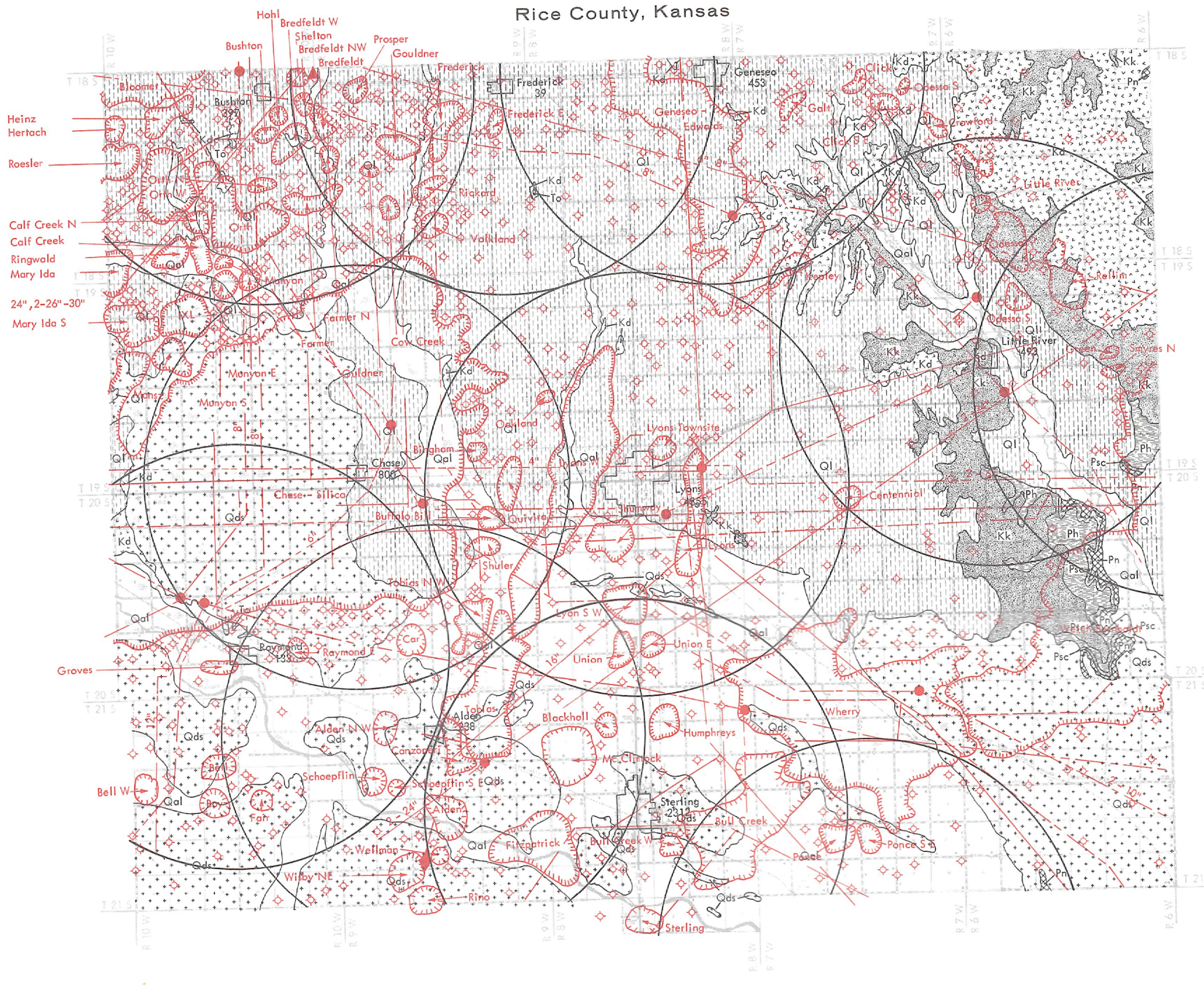


Figure 18

Area 7

Areal Geology, Population Centers and Oil and Gas Developments

Rice County, Kansas



EXPLANATION

- Qal — Alluvium and low terrace deposits
- Qds — Dune sand
- Ql — Loess
- Incorporated cities (Numbers refer to 1970 census)
- Products
- Compressor station
- To — Ogallala Formation
- Kd — Dakota Formation
- Kk — Kiowa Formation
- Oil fields
- Natural gas
- Dry holes
- Ph — Harper Sandstone
- Psc — Stone Corral Formation
- Pn — Ninnescah Shale
- Natural gas storage area
- Crude oil
- Natural gasoline plant

0 6

Scale in miles

Figure 20

Area 8

Areal Geology, Population Centers and Oil and Gas Developments

Wichita and Western Scott Counties, Kansas

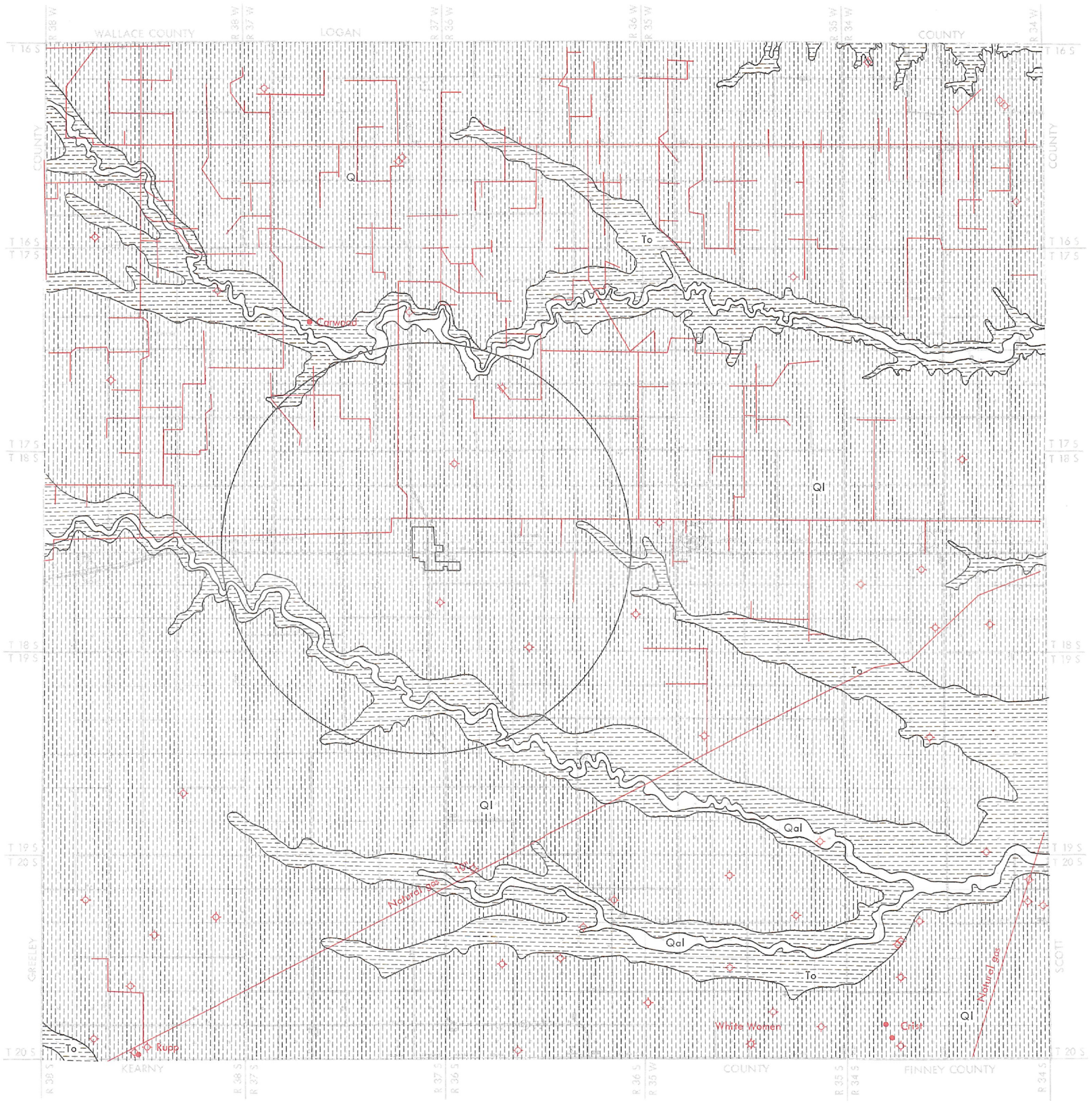


Figure 17

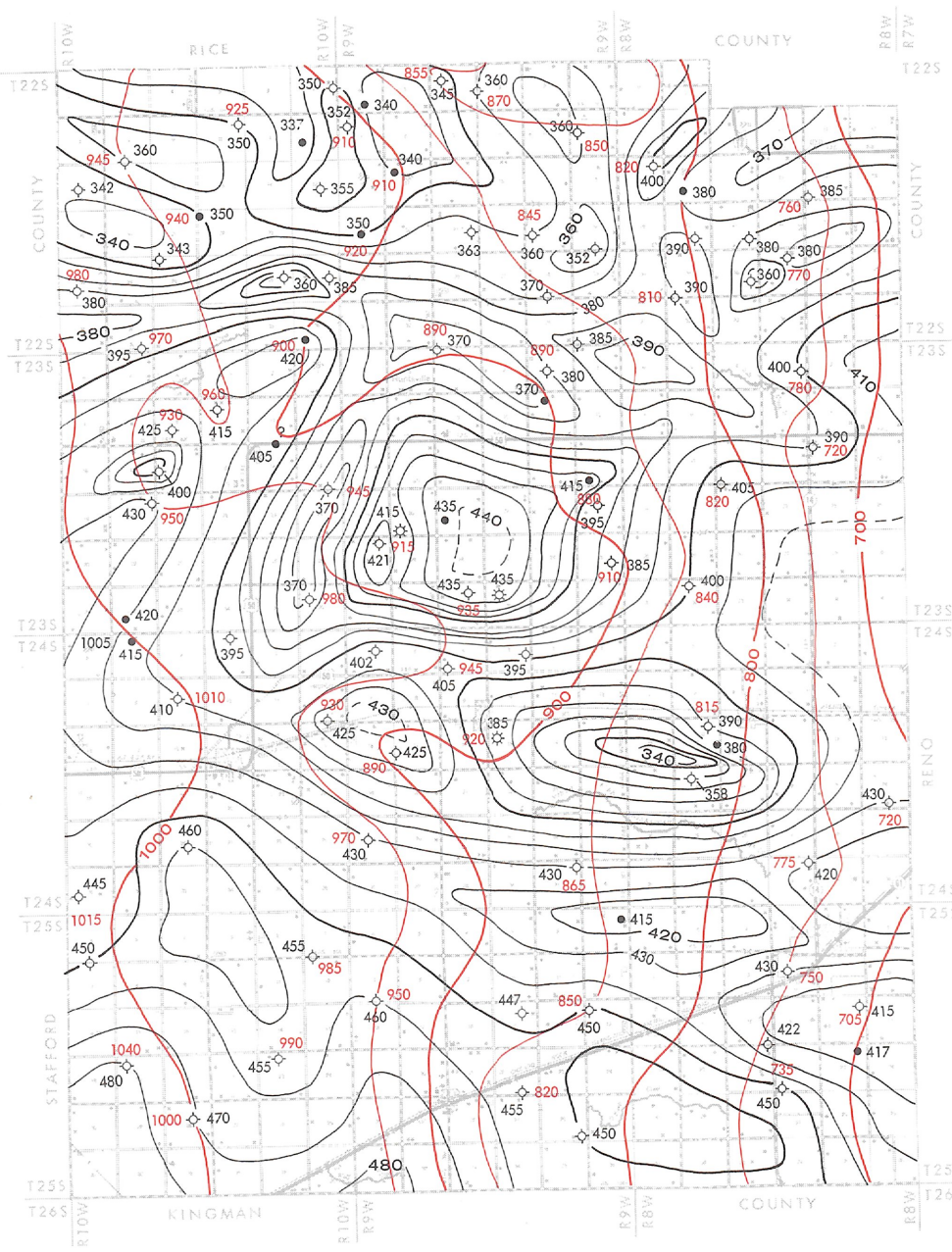
AREA 6

Thickness and Depth to Hutchinson Salt

Part of Reno County, Kansas

Contour Interval - 50 feet

Contour Interval - 10 feet



EXPLANATION

Data Point (data taken from wire line logs)

370 thickness of the salt

760 Depth to the top of the salt in feet

● Oil well ☼ Gas well ☼ Drilled and abandoned well

0 6

Scale in miles

Figure 19

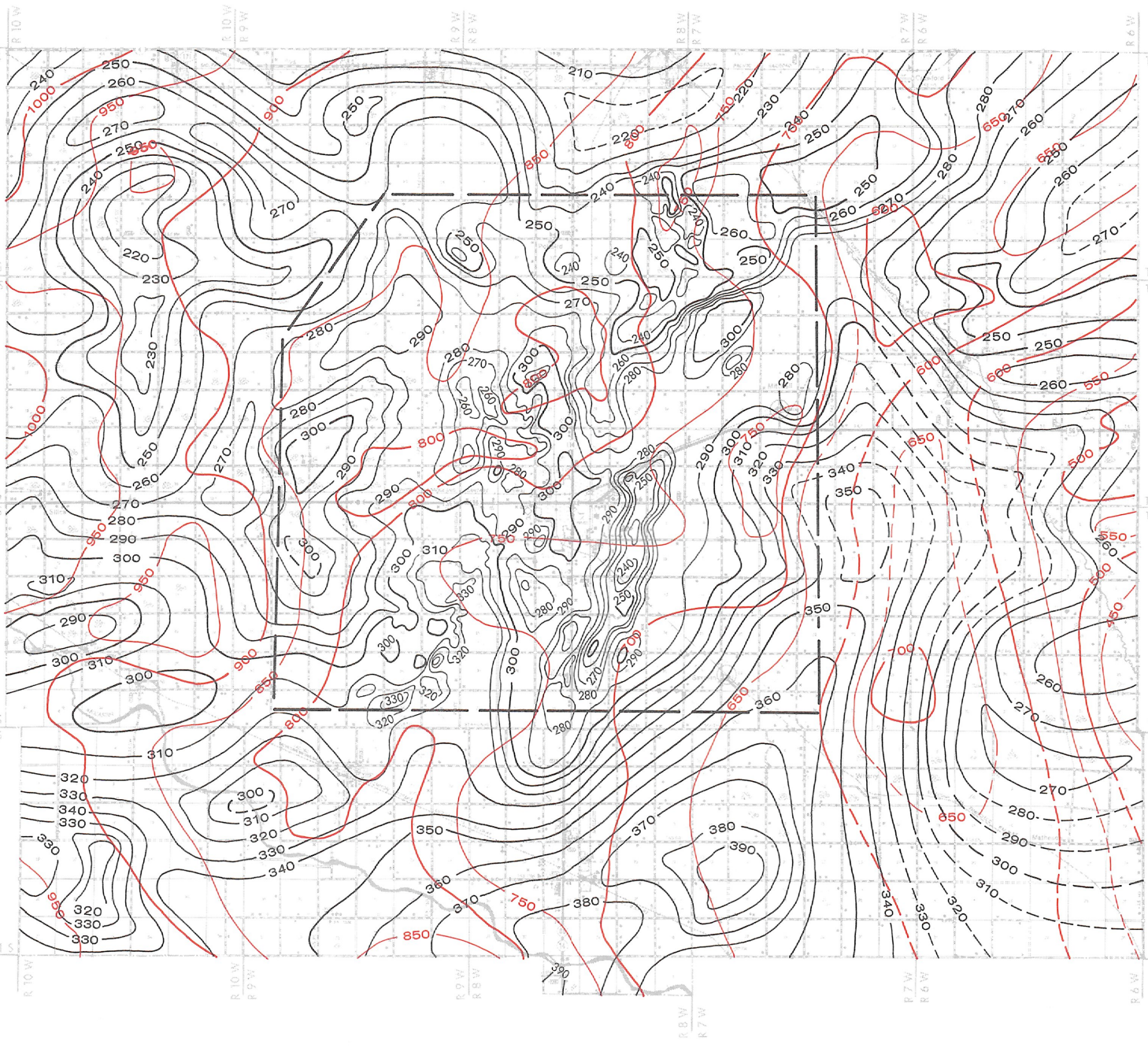
AREA 7

Thickness and Depth to Hutchinson Salt

Rice County, Kansas

Contour Interval - 10 feet

Contour Interval - 50 feet



EXPLANATION

Data Point (data taken from wire line logs)

260 thickness of the salt

Dashed area taken from the Final Report. Geology and Hydrology of the Proposed Lyons, Kansas Radioactive Waste Repository Site, March 1971. Figure 39. Isopachous Map of Salt Section of the Wellington Formation prepared by Shirley Paul and E.D. Goebel.

0 6

Scale in miles

Figure 9

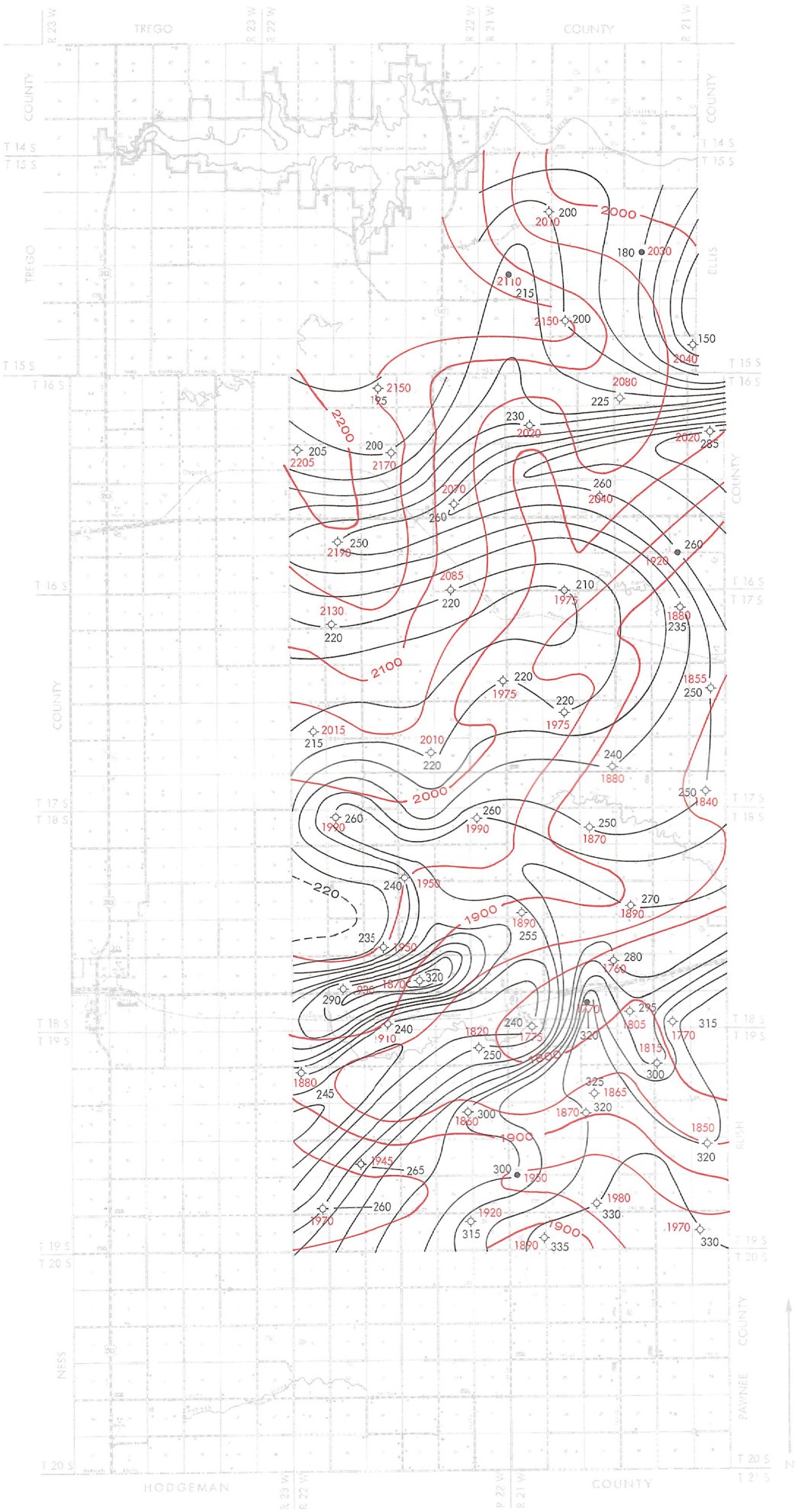
Area 2

Thickness and Depth to Hutchinson Salt

Parts of Ness and Trego Counties, Kansas

Contour Interval 10 feet

Contour Interval 50 feet



EXPLANATION

Data Point (data taken from wire line logs)

2030 Depth to the top of the salt in feet

260 thickness of the salt

Drilled and abandoned well

Oil well

0 6

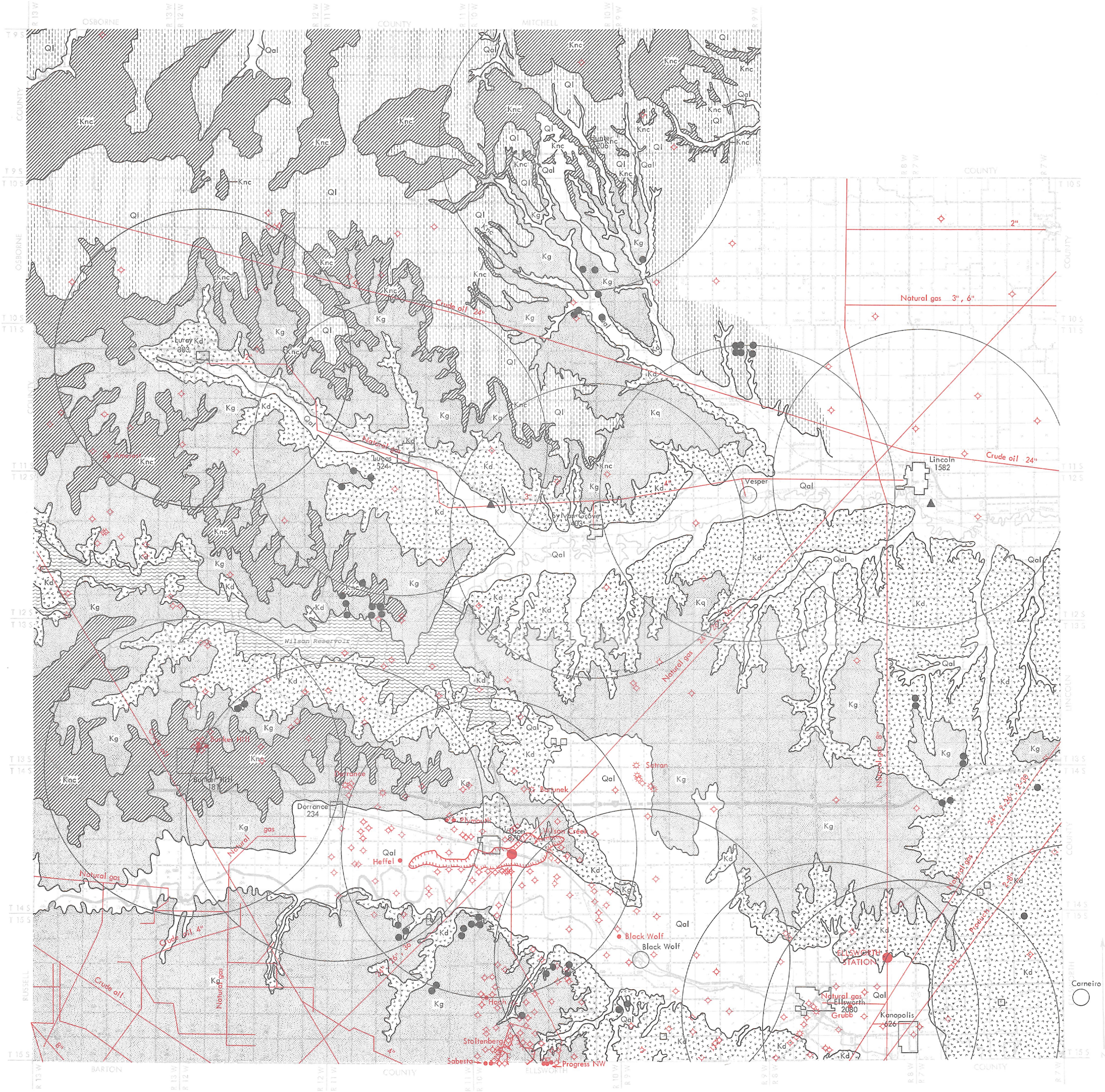
Scale in miles

Figure 6

Area 1

Areal Geology, Population Centers and Oil and Gas Developments

Parts of Ellsworth, Lincoln, Mitchell, Osborne and Russell Counties, Kansas



EXPLANATION

- Qal — Alluvium and terrace deposits
- Ql — Loess and colluvium
- Knc — Fort Hays Member of Niobrara Chalk and Carlile Shale
- Kg — Greenhorn Limestone and Graneros Shale
- Kd — Dakota Formation and Kiowa Formation
- Incorporated cities (Numbers refer to 1970 census)
- Unincorporated communities
- Compressor station
- Lignite mines
- Oil
- Volcanic ash
- Lincoln "quartzite"
- Gas
- D & A & salt shafts
- Service
- Pipelines

0 — 6
Scale in miles

Figure 11

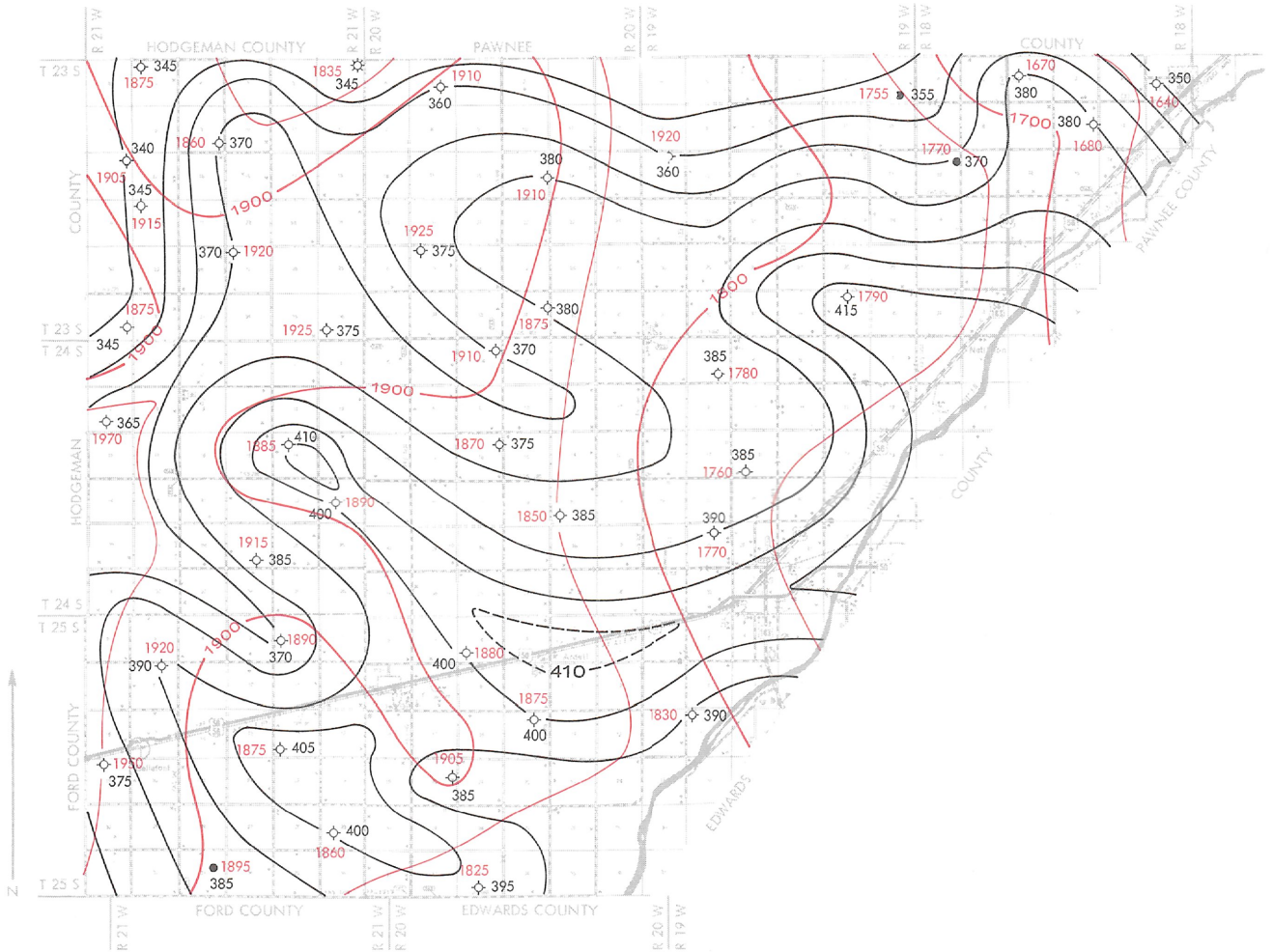
AREA 3

Thickness and Depth to Hutchinson Salt

Parts of Pawnee, Edwards, Ford and Hodgeman Counties, Kansas

Contour Interval - 10 feet

Contour Interval - 50 feet



EXPLANATION

Data Point (data taken from wire line logs)

1770 Depth to the top of the salt in feet

380 thickness of the salt

● Oil well ✧ Drilled and abandoned well ☼ Gas well

0 6

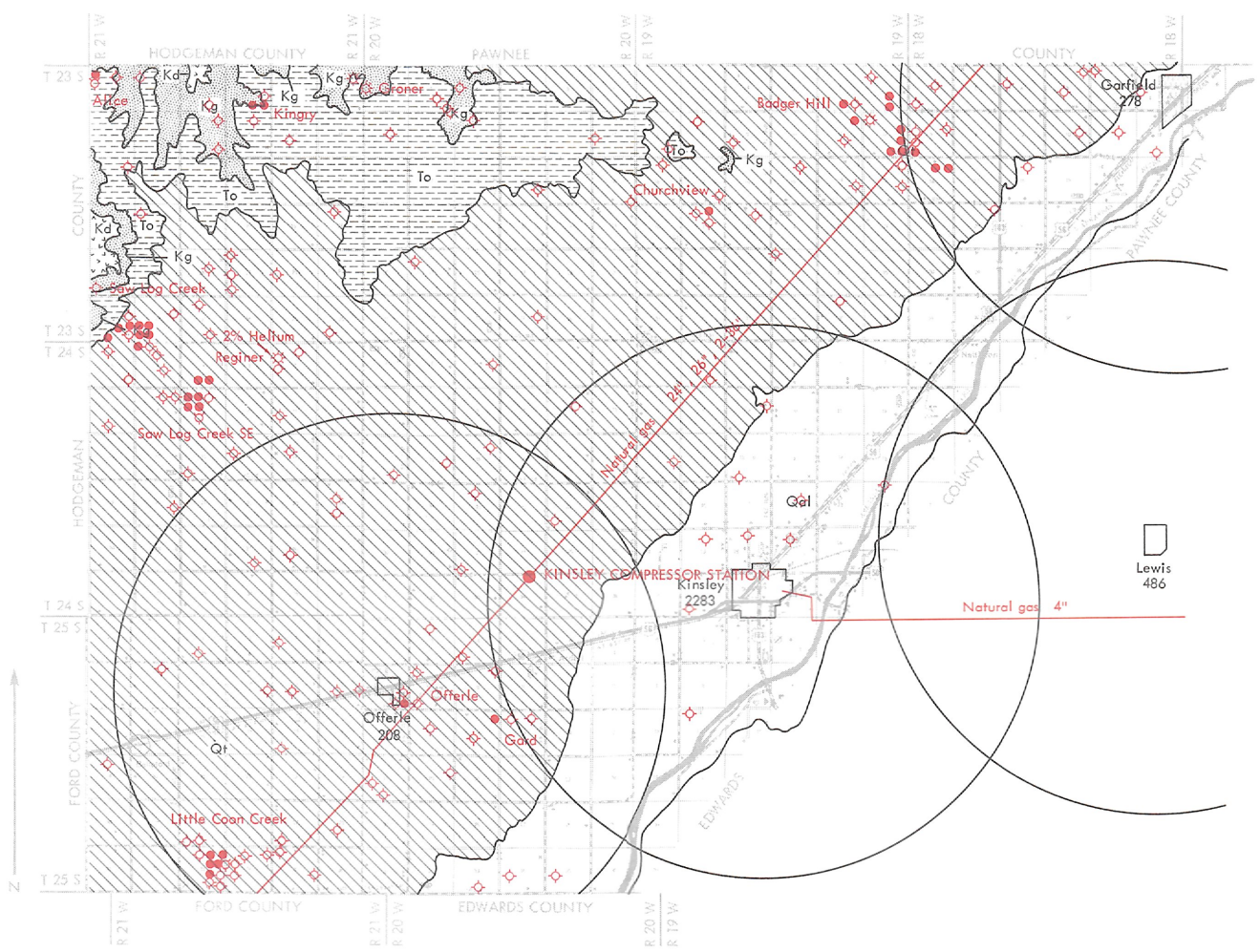
Scale in miles

Figure 10

Area 3

Areal Geology, Population Centers and Oil and Gas Developments

Parts of Pawnee, Edwards, Ford and Hodgeman Counties, Kansas



EXPLANATION

- Qal — Alluvium
- Qt — Terrace deposits
- To — Ogallala Formation
- Kg — Dakota Formation and Kiowa Formation
- Kd — Greenhorn Limestone and Graneros Shale

- Incorporated cities
  Numbers refer to 1970 census
- D & A well
- Gas well
- Service well
- Oil well
- Pipelines

0 — 6

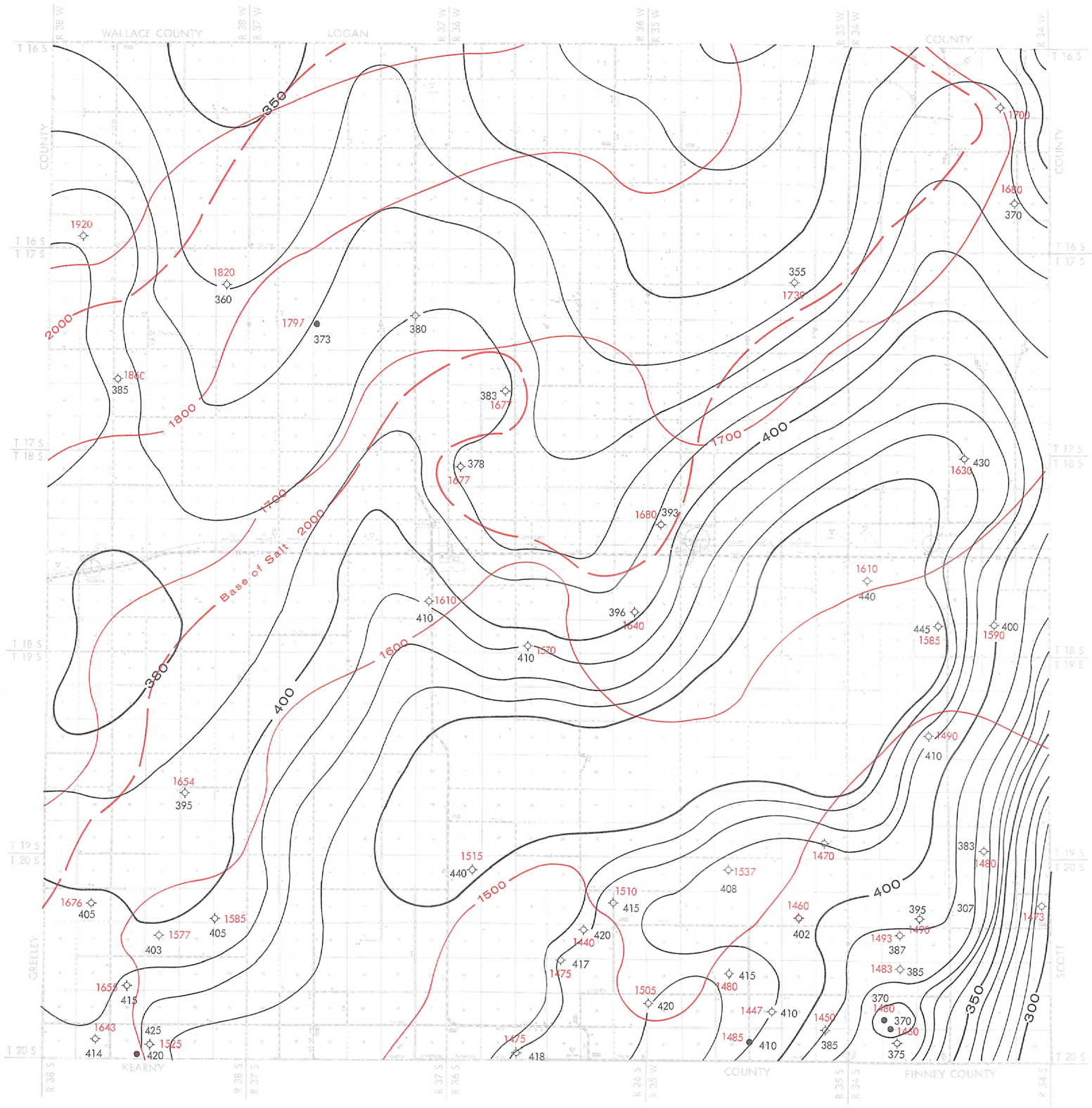
Scale in miles

Figure 21

Area 8
Thickness and Depth to Blaine Salt
Wichita and Western Scott Counties, Kansas

Contour Interval- 10 feet

Contour Interval- 100 feet



EXPLANATION

Data Point (data taken from geophysical logs)

1800 Depth to the top of the salt in feet

300 thickness of the salt

☼ Gas well

✧ Drilled and abandoned well

● Oil well

— — Base of the salt

0 6

Scale in miles