

**KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 71-14**

**GEOLOGY AND HYDROLOGY OF THE PROPOSED LYONS,
KANSAS RADIOACTIVE WASTE DISPOSITORY SITE
FINAL REPORT**

compiled by

Staff of the Kansas Geological Survey
under direction of

Ernest E. Angino and William W. Hambleton

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FINAL REPORT
Geology and Hydrology
of the
Proposed Lyons, Kansas
Radioactive Waste Repository
Site

Compiled by:
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Ernest E. Angino and William W. Hambleton

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INTRODUCTION

The sequence of events leading up to the selection of the Lyons, Kansas area as a potential storage site for high level radioactive wastes had its beginnings in 1955 when a committee of the National Academy of Sciences proposed storage of high-level radioactive waste in salt, and recommended substantiating studies. Natural salt formations attracted the attention of the Committee because salt is abundant and can heal its own fractures by plastic flow at high temperatures and pressures. Furthermore, salt transmits heat readily and exhibits compressive strength and radiation-shielding properties similar to those of concrete. In 1963, the Atomic Energy Commission chose an abandoned salt mine of the Carey Salt Company at Hutchinson, Kansas, for study of the representative salt properties of Kansas salt. Simulated radioactive wastes and heaters were brought into the mine in order to create an environment that would simulate the expected environment of a real repository. The mine was instrumented with devices for recording heat, radiation and mechanical properties.

Subsequent selection of the Lyons, Kansas, site in 1970 (Fig. 1) as a potential storage location was based partly on research information obtained from study of the nearby Hutchinson mine, and the existence of an abandoned Carey Salt Company mine at Lyons. Other selection factors included the seismic stability of central Kansas, availability of a 300-foot section of salt overlain by 800 feet of rock containing impermeable shales, and a salt deposit of great horizontal extent.

In August of 1970 the State Geological Survey of Kansas in cooperation with the U.S. Geological Survey, the U.S. Army Corps of Engineers and the State Department of Health initiated a detailed study of the surface geology, the subsurface geology and ground water hydrology in a nine-square mile area centered on Lyons, Kansas. Funding for this program was provided by the Atomic Energy Commission through the Union Carbide Corporation operator of the Oak Ridge National Laboratory, Oak Ridge, Tennessee. Additional funding for the studies included in this report was provided by the different agencies involved.

In addition to those topics enumerated above included with this report is an evaluation of the possible effects of high intensity radiation (radiation damage effects) on salt and a discussion of the heat transfer problem related to storage of the waste material in salt. It should be emphasized here that all the conclusions drawn herein are predicated on preliminary information regarding the site development and the proposed waste to be stored at the site. These data include: (1) burial depth of approximately 1,000 feet, (2) total accumulated doses of wastes of approximately 10^{10} rads, (3) vertical storage of canisters, (4) canister size of

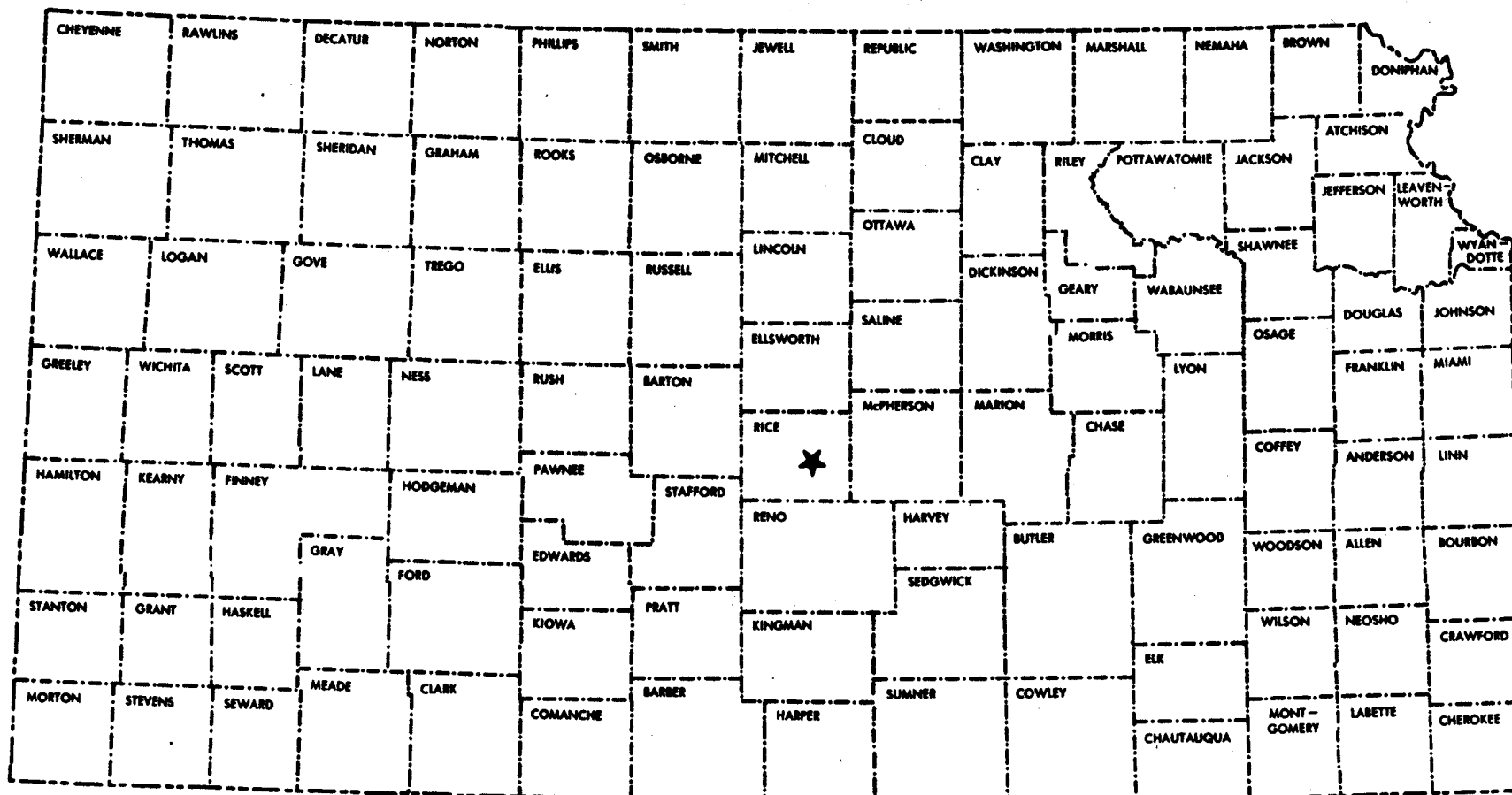


Fig. 1--Index map of Kansas counties.

★ The location of the Proposed National Radioactive Waste Repository site.

2 inches to 2 feet X 10 feet. No firmed-up plan or mining technology is presently available for retrieval of the wastes. If the base line information or storage plan changes, then conclusions drawn herein will of necessity require reevaluation. These findings are subject to revision as additional information becomes available. For the purposes of simplicity, this report is subdivided into five chapters. Each chapter devotes itself to a particular subject related to the charge of developing information for a study of the safety of the Lyons, Kansas area as pertains to the storage of radioactive waste. Inasmuch as the radiation damage effects and heat transfer mechanisms are related in a very integral and intimate way to the nature of the materials present on the site (i.e., the geology of the immediate storage area) an evaluation of the present status of these problems is included herein.

The State Geological Survey of Kansas is charged with the responsibility for continuing studies on the geologic effects of storing high-level radioactive materials in subterranean areas. At the present time the State Geological Survey of Kansas neither endorses nor opposes the storing of radioactive material at the Lyons site. Our position is a neutral one as our primary charge is to the State of Kansas and the people of Kansas. It is our prime concern that before we give endorsement to the concept of storing high level radioactive wastes it must be completely demonstrated that it is indeed safe to store the radioactive materials in salt deposits. It is in this light that the report is prepared and upon which any future report will be based. The Geological Survey is determined that the safety and integrity of the site must be assured before final decision is reached.

Ernest E. Angino

Chapter 1

SURFACE GEOLOGY AND GROUND-WATER HYDROLOGY

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INTRODUCTION

This chapter is concerned with the geology and hydrology of the near surface rocks which lie above the Ninnescah Shale of Permian age in the area within about a 20-mile radius of the repository site. This area includes all of Rice County, Kansas, and parts of Barton, Ellsworth, McPherson, Reno and Stafford Counties, Kansas (Fig. 2, Pocket).

The area will be discussed in three main sections. The first section is concerned with the environment of deposition, lithology, areal extent and hydrology of the geologic units in the area within a 20-mile radius and is based on reports by Bayne and others (1971), Bayne and Fent (1956), Fent (1950), Latta (1950), and Williams and Lohman (1949). The second section is based on information collected on the repository site by the State Geological Survey of Kansas and the U.S. Geological Survey and is concerned with geologic and hydrologic conditions existing in the site area. The collection of data and the determination of hydraulic characteristics of the shallow bedrock aquifers within the site was in part supported by the following offices of the Water Resources Division of the U.S. Geological Survey: Office of Radiohydrology, Washington, D.C.; Kansas District Office, Lawrence, Kansas; A.E.C. Project Office, Denver, Colorado. The third section is concerned with the geology and hydrology of an area extending several miles in all directions from the site area and is based on information collected during the fall of 1970 and January and February 1971.

The area shown in Figure 2 is underlain by bedrock units ranging in age from Early Permian to Late Cretaceous (Fig. 3). Some of the rock units described in Zeller (1968) are not present in the area. These missing units were either never deposited in the area or were removed during periods when the area was exposed and subject to erosion. Tertiary rocks in the area are represented only by remnants of a soil caliche developed during late Pliocene time. Quaternary rocks are present in much of the area where they mantle older rocks.

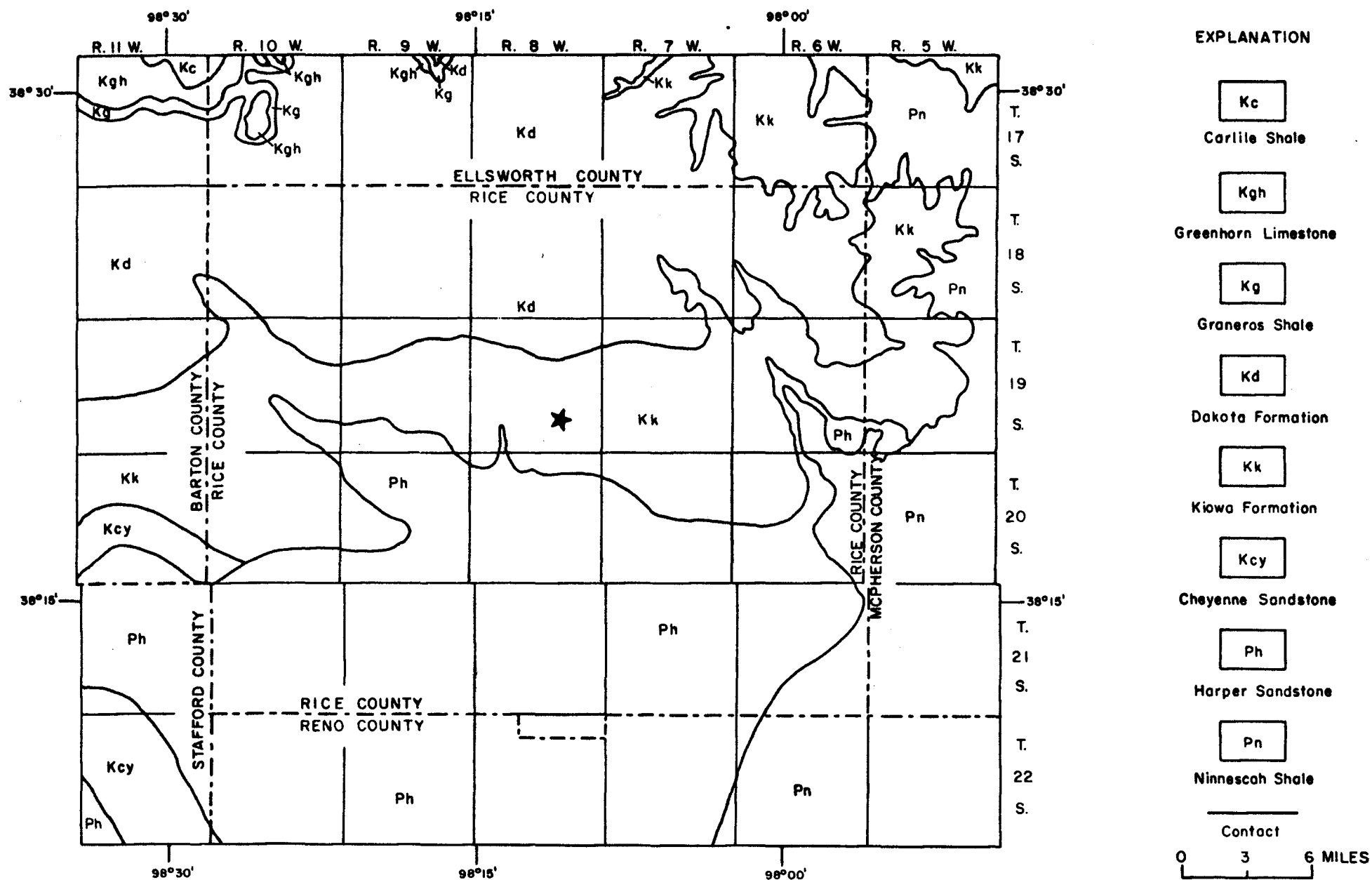


Fig. 3--Approximate distribution of bedrock units in the report area. ★ The location of the Proposed National Radioactive Waste Repository site.

PERMIAN SYSTEM

The Ninnescah Shale of Early Permian age is the oldest rock unit, and is described briefly in this chapter. This unit will be described in a later chapter. The Ninnescah either crops out or is present in the subsurface over the entire area and consists predominately of red and grayish-green silty shale. Thin limestone and dolomite beds are present locally. Gypsum occurring as fillings in fractures is common throughout the formation. This rock unit averages 300 feet in thickness. It thins northward in the State and thickens considerably southwestward where salt occurs in the Formation. The Ninnescah probably was deposited in a shallow brackish sea. Deposits in the area of this study were probably deposited not far from the margin of the sea.

South of this area, in northeastern Harper County, the Runnymede Sandstone occurs at the top of the Ninnescah; however, in the study area the Runnymede is not present or cannot be identified separately from the Ninnescah.

In much of the area shown on Figure 2, the Stone Corral Formation overlies the Ninnescah Shale. The Stone Corral crops out in eastern Rice County where the unit is about 6 to 8 feet in thickness. In the subsurface near the repository area, the Stone Corral is composed of an upper thin dolomite bed underlain by a thin shale which in turn is underlain by several feet of anhydrite and gypsum. The lowermost few feet of the unit is generally composed of dolomite. The aggregate thickness of the Stone Corral is commonly about 18 feet in the subsurface. On the outcrop the gypsum and anhydrite are removed by solution which accounts for the reduced thickness. Southward from the outcrop the dolomite bed is not well developed. Westward, anhydrite becomes the principal component. In northeast Rice County, the Stone Corral is absent. In this area the Stone Corral was probably removed during post Permian-pre-Cretaceous time when this area was a land area and subject to erosion. The present distribution of the Stone Corral is about the same as that of the Harper Sandstone shown in Figure 4D. Only very small quantities of poor quality water are available from the Stone Corral except in the outcrop area where the unit has been made more permeable by removal of gypsum and anhydrite. The hydrology and quality of water from the Stone Corral in the repository area will be discussed more fully later in this report.

The Harper Sandstone conformably overlies the Stone Corral Formation. Southward from the report area the Harper consists of two members, the Chicaskia Sandstone Member at the base and the Kingman Sandstone Member in the upper part. Where a full section of the Harper is present the unit is about 220 feet in thickness. Siltstone

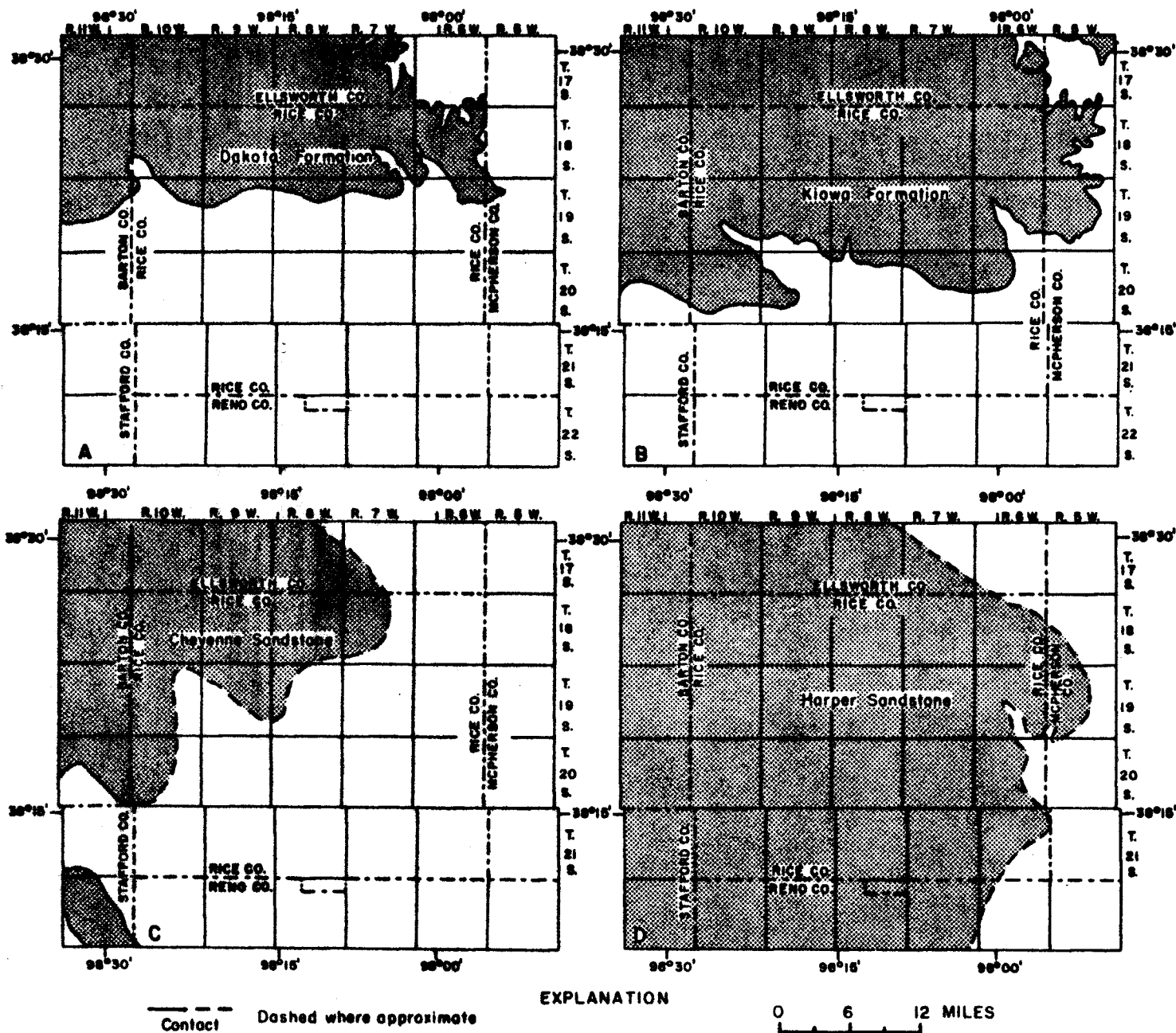


Fig. 4--Distribution of: A-Dakota Formation, B-Kiowa Formation, C-Cheyenne Sandstone and D-Harper Sandstone.

and silty shale are the principal components of the Harper in this area although silty sandstone and sandy siltstone are commonly present in the Kingman Sandstone Member. In the area of this report, the members of the Harper cannot be distinguished. The unit consists principally of red and greenish-gray siltstone or silty shale and seemingly contains only very minor amounts of sandstone. Red is the dominant color although the upper few feet in the study area are consistently a light greenish-gray. The upper surface of the Harper marks an unconformity representing post-Permian-pre-Cretaceous time in this area and the light greenish-gray color may be a characteristic color developed due to weathering. In this area the Harper is about 130 feet thick. The present distribution of the Harper Sandstone in the outcrop area and in the subsurface is shown in Figure 4D. The Harper Sandstone was deposited in a shallow, brackish sea that supported little if any aquatic life. The dominant reddish color of the Harper is probably due to the reddish detrital material deposited in the sea rather than weathering after deposition.

Generally, the Harper Sandstone yields little water to wells except in those areas where sandstone is present. In the area of this report, little if any sandstone is present and little water can be obtained from the unit. High-angle fractures were observed in the Harper in cores taken from A.E.C. core hole no. 1. Many of these fractures were cemented with gypsum. If these fractures were reopened due to subsidence or by some other means, water could migrate downward through these fractures.

CRETACEOUS SYSTEM

Following deposition of the Harper Sandstone, many feet of younger Permian rocks were deposited over this area but were removed along with part of the Harper during post-Permian-pre-Cretaceous time when the area was a land area and extensively eroded. The rock unit next above the Harper Sandstone in the report area is the Cheyenne Sandstone of Lower Cretaceous age. This unit was deposited near the margin of a comparatively shallow Cretaceous sea. The Cheyenne is present in the subsurface in the western and northwestern part of the report area but probably was never present as far east as the repository site. The present distribution of the Cheyenne Sandstone in this area is shown in Figure 4C. The Cheyenne is composed principally of light gray, fine- to medium-grained sandstone but locally contains sandy siltstone or claystone. In the report area the thickness probably does not exceed 50 feet. Data on the quality of water from the Cheyenne in the area of this report is not available but in Stafford County a few miles west of this area analysis of water from the Cheyenne indicated a chloride concentration in excess of 30,000 parts per million.

Conformably overlying the Cheyenne Sandstone in the western part of the report area and unconformably overlying the Harper Sandstone in the northeastern part of the area is the Kiowa Formation of Early Cretaceous age. Figure 4B indicates the approximate present distribution of the Kiowa Formation in this area. Outcrops of the Kiowa Formation are present in Kansas as much as about 50 miles east of this report area and probably were present originally many more miles to the east.

The Kiowa Formation is composed predominately 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 occurs throughout the Formation but is more abundant in the upper part. The sandstone beds range in thickness from only a few inches to several tens of feet. Pyrite, lignite and thin shell beds occur throughout the Kiowa but are more abundant in the lower part.

Owing to the unconformable contact with Permian rocks below and the erosional contact with Pleistocene deposits above, the thickness of the Kiowa is quite variable over much of the eastern part of this area. In this area the thickness ranges from a feather edge to about 130 feet. In the northwestern part of this report area where the Kiowa is underlain by Cheyenne Sandstone and overlain by Dakota Formation, the thickness is about 150 feet. In much of the southern part of the study area, the Kiowa has been removed entirely by Tertiary and Quaternary erosion.

Individual sandstone beds may pinch and swell within short distances in the Kiowa Formation. These beds may not have great lateral continuity and cannot be traced with confidence over any great distance. Where sandstone beds with appreciable thickness occur, they are a potential source of much water. In the repository area as much as 50 gallons per minute (gpm) may be available from wells in local areas, but in other parts of the area only a few gallons a minute are available from wells.

High angle fractures similar to those described in the Harper Sandstone occur in the Kiowa Formation. Some of these fractures appear to be open where others have been cemented with gypsum or calcite. Should these fractures be reopened or enlarged by subsidence or some other means they would be a means of downward migration of the shallow fresh water to deeper zones.

The Dakota Formation overlies the Kiowa Formation in much of the northern part of the report area. Figure 4A shows the approximate present distribution of the Dakota. As the Kiowa seas regressed or receded toward the west in this area, the marine deposits of the Kiowa were covered with terrestrial deposits of the Dakota Formation. It is

probable that some of the early terrestrial deposits assigned to the Dakota Formation may be equivalent or even older in absolute age than some of the deposits classed as Kiowa in the western part of the State. The Dakota Formation is comprised of white, red, brown and tan kaolinitic claystone, mudstone, shale, siltstone and much interbedded and lenticular sandstone. Generally as much as one third of the Dakota may be sandstone but in any area the ratio of sandstone to other components may be appreciably more or less.

Only in the northwestern part of the report area is a complete section of the Dakota Formation present. In this area the Dakota is about 200 feet in thickness. Post-Cretaceous erosion has removed much of the Dakota and south about 7 miles from the north line of Rice County, the formation has been entirely removed. The Dakota is the principal source of ground water in the northern and northwestern part of the area. Water from the Dakota in this area is generally of good quality but locally may have objectionable amounts of iron. Yields from wells up to 200 gpm are obtained from the Dakota in the northern part of the area.

Late Cretaceous rocks of Graneros Shale, Greenhorn Limestone and Carlile Shale having an aggregate thickness of about 150 feet overlie the Dakota Formation in the northwestern part of the report area.

The Graneros Shale is composed of dark gray and yellowish brown thinly laminated clay shale, thin fossiliferous limestone and very minor amounts of sandstone having a thickness of about 30 feet.

The Greenhorn Limestone is composed of minor amounts of limestone and calcareous shale. This unit is about 90 feet thick in the report area.

The Carlile Shale is composed of thin chalky limestone bed and chalky shale. Only the lower 20 or 30 feet of the Carlile is present in the area.

No water is available from any of these three rock units in the area.

TERTIARY SYSTEM

Pliocene Series

Overlying the Cretaceous deposits in much of the report area are thin deposits consisting of clay and some gravel composed of reworked resistant Cretaceous rocks and a zone of caliche. These deposits probably represent residual materials formed during the long period of weathering before the deposition of Pleistocene deposits in the area. The caliche has a distinctive banding commonly observed in the "Algal Limestone"

at the top of Ogallala Formation of Late Pliocene age. The caliche is probably a soil caliche formed during late Pliocene time. The lowermost caliche present in some drill holes in this study area at the base of Pleistocene deposits and resting on Kiowa shale is probably of equivalent age and represents a soil caliche developed prior to deposition of the Pleistocene deposits in the area.

QUATERNARY SYSTEM

Pleistocene Series

Unconsolidated sand, gravel, silt and clay deposits of Pleistocene age underlie the surface of much of this report area. The lower part of the Pleistocene beds in the area consist of silt, sand and gravel and locally volcanic ash deposited in narrow valleys incised 150 to 200 feet below the present surface. The fillings in these valleys represent a nearly complete record of Pleistocene deposition in the area. In all of the report area except the northeastern part, drainage is associated with an ancestral Arkansas River drainage or the present Arkansas River drainage. In the northeastern part of the area, drainage is associated with the Smoky Hill River. In early Pleistocene time Smoky Hill River drained through McPherson Channel from a point west of Lindsborg in McPherson County to the ancestral Arkansas River near Wichita in Sedgwick County.

In the part of the area associated with Arkansas River drainage the oldest Pleistocene deposits are found in the lower part of the old channels with progressively younger deposits superimposed on older deposits. In the Smoky Hill drainage oldest deposits are found at the highest elevations with younger deposits found at progressively lower levels.

Figure 2 shows the distribution of Pleistocene deposits in the study area. These deposits are of fluvial and aeolian origin. On Figure 2 the areas identified by the symbol Qal are underlain by alluvial deposits consisting of silt, sand and gravel ranging in thickness from only a few feet in smaller tributary valleys to as much as 200 feet in the deeper early Pleistocene buried valleys. In local areas yields greater than 1,000 gpm of water from wells can be obtained. The areas identified by the symbol Qds are underlain by dune sand which ranges in thickness from a few feet to several tens of feet in thickness. Generally only small quantities of water are available to wells from the dune sand, however, in much of the area of Arkansas River drainage and Cow Creek drainage the dune sand overlies alluvial deposits and large supplies of water are available. The large dune sand tract in the southeastern part of the report area rests on Permian bedrock and generally only small to moderate supplies of water are available. In the northeastern part of the report area the areas identified by the symbol Qt are underlain by

high terrace deposits composed of silt, sand and gravel. These deposits are topographically high and are largely drained of water. The areas identified on Figure 2 by the symbol Q1 are underlain principally by aeolian deposits. Locally some water laid material is present in these deposits but they are principally composed of silt and some caliche and yield only small quantities of water. In the area identified by the symbol Q1 in Ts. 19 and 20S., R. 9W., the aeolian silts are underlain by early Pleistocene deposits. In this area large quantities of water are available but locally these deposits contain highly mineralized water in the lower part.

GEOLOGY AND HYDROLOGY OF REPOSITORY SITE

Four shallow test holes were drilled northeast of the town of Lyons, Kansas near the corners of the proposed repository. The four holes range in depth from 255 feet to 317 feet. The purpose of drilling the test holes was to study the lithologic and hydrologic characteristics of two geologic formations, the Kiowa Formation of Early Cretaceous age and the Stone Corral Formation of Early Permian age. In the Kiowa, lenticular beds of sandstone were considered the most likely to yield any significant quantities of water; therefore, hydrologic tests in the Kiowa were made only in the sandstone.

Prior to drilling the four test holes for hydrologic testing, two test holes for detailed lithologic and geologic information were drilled 6 feet from the proposed test holes 3S and 4S. For test holes 1S and 2S, the logs of core holes 1 and 2 drilled by the Corps of Engineers were used. The test holes 1S, 2S, 3S and 4S were each drilled to a point a few feet above the uppermost sandstone in the Kiowa. Casing was set and cemented at this point then the hole was drilled through the interval to be tested. After testing the upper zone, the hole was drilled through the Stone Corral Formation and tested at this level.

Methods of Testing and Analysis of Test Data

Inflatable packers were used to isolate specific intervals of the holes. The intervals were tested by instantaneously injecting or removing water through tubing and observing the rate of recovery of the water level.

Specific capacity of a well is yield per unit of drawdown during pumping such as gallons per minute per foot of drawdown. Relative specific capacity is similar to specific capacity in that the units and implications are similar. However, relative specific capacity is different in that it is derived from a short test of a defined interval rather than from a long test of an entire well. Relative specific capacity is determined by the volume change of water in

tubing for a 1-minute interval of time as related to the departure from the static conditions of the water level during this time interval. Because of measuring and testing techniques the same time interval is not used for every test.

A type-curve method for determining the transmissivity of an aquifer that is applicable to testing of selected intervals in deep wells was introduced by Cooper and others (1967). This analysis involves an instantaneous charge of water to a well. The type curves are derived by plotting H/H_0 versus $\beta = Tt/r_c^2$ (a dimensionless time parameter) for values of $\alpha = r_s^2 S/r_c^2$ where

H_0 = water level in tubing above initial head in aquifer immediately after injection, in meters (m)

H = water level in tubing above initial head in aquifer, in meters, at time, t

T = transmissivity, in cubic meters per day per meter (m^3 pd per m)

r_c = radius of injection tubing, in meters

r_s = radius of open hole, in meters

S = storage coefficient.

Once a value of T is obtained, hydraulic conductivity, K , can be calculated by the equation

$$K = T/b$$

where K is in cubic meters per day per square meter (m^3 pd per m^2) and b = thickness of the water-bearing interval, in meters.

Figures 5 through 8 present the measured data and analyses for hydraulic tests in the four test holes. Each test is represented by two graphs. One graph, depth to water versus time, shows the measured water levels during the test. The other graph, H/H_0 versus time, shows the same data plotted in type-curve form.

Results of Hydraulic Tests

A summary of results from the hydraulic tests is presented in Table 1. These results indicate that hydraulic conductivity of the beds of sandstone in the Kiowa Formation ranges from 0.76 to 8.8 gpd per ft^2 (gallons per day per square foot) in the test holes. The low value represents the hydraulic conductivity of sandstone that is thinly interbedded with clay and shale. The high value represents the hydraulic conductivity of massive sandstone. The results of

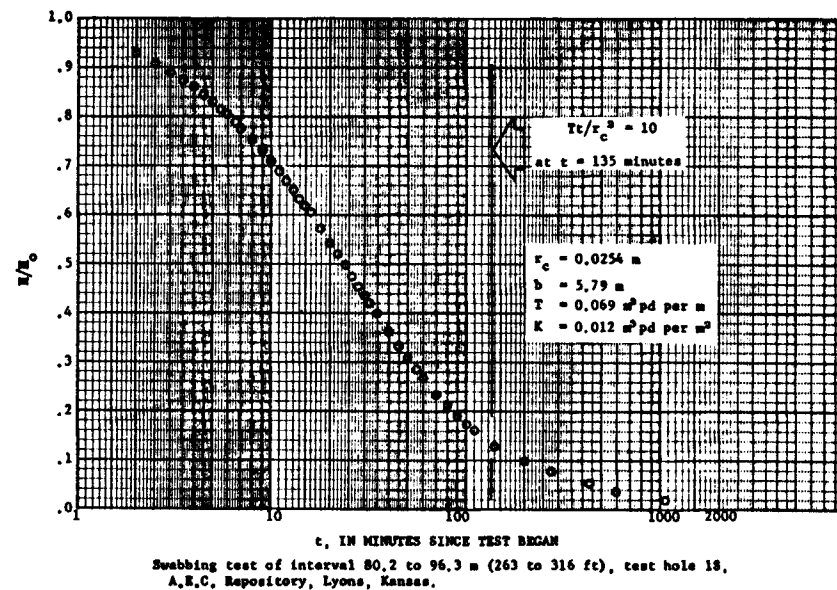
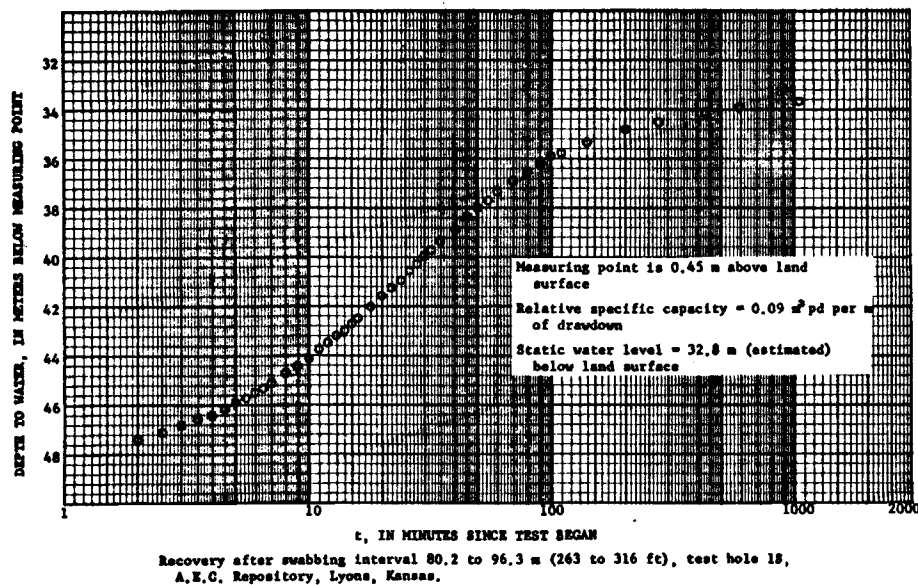
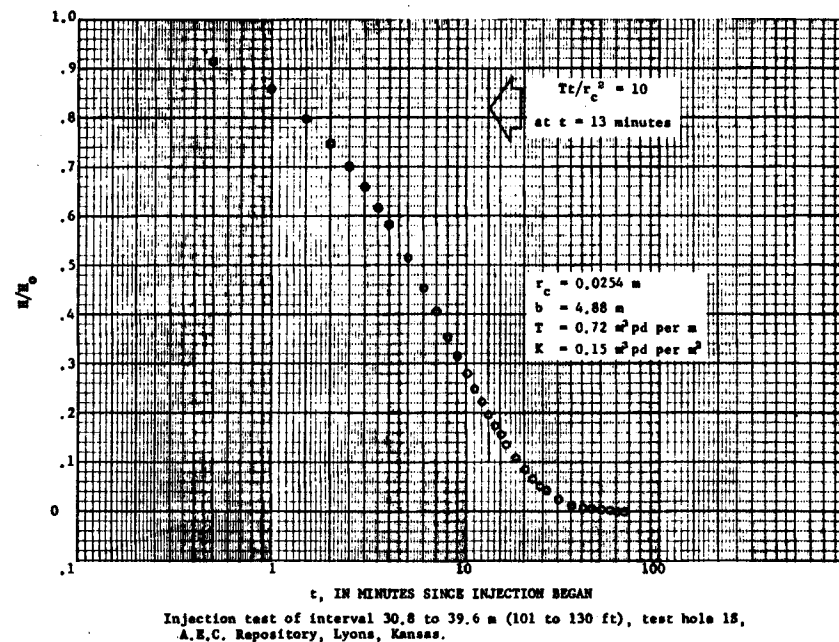
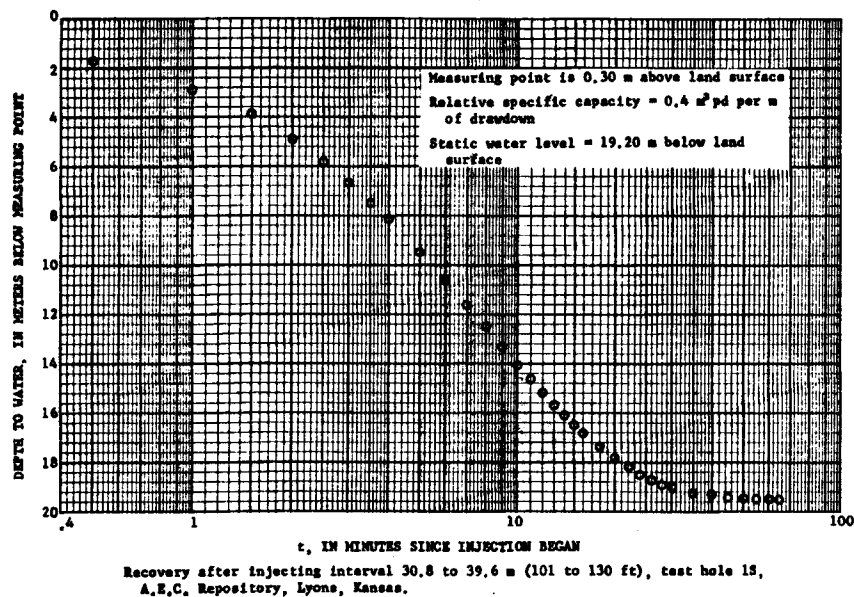


Fig. 5--Hydrologic tests on test hole 18.

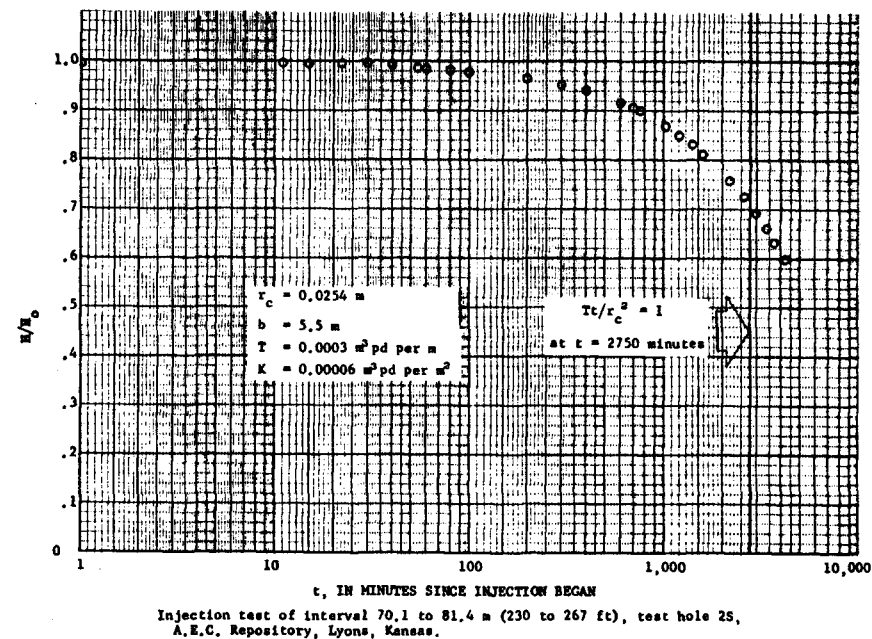
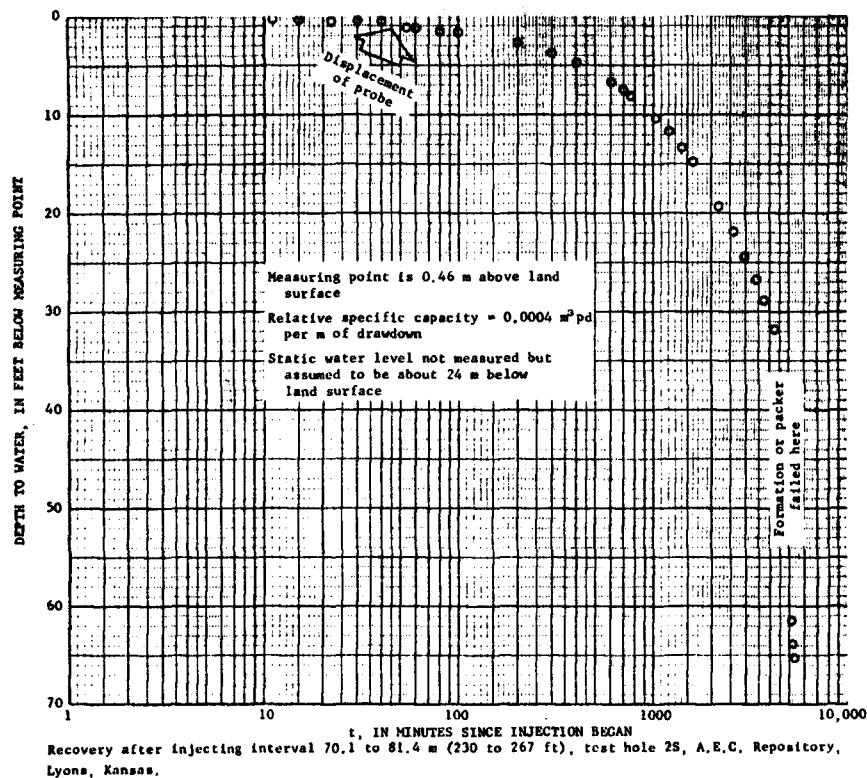
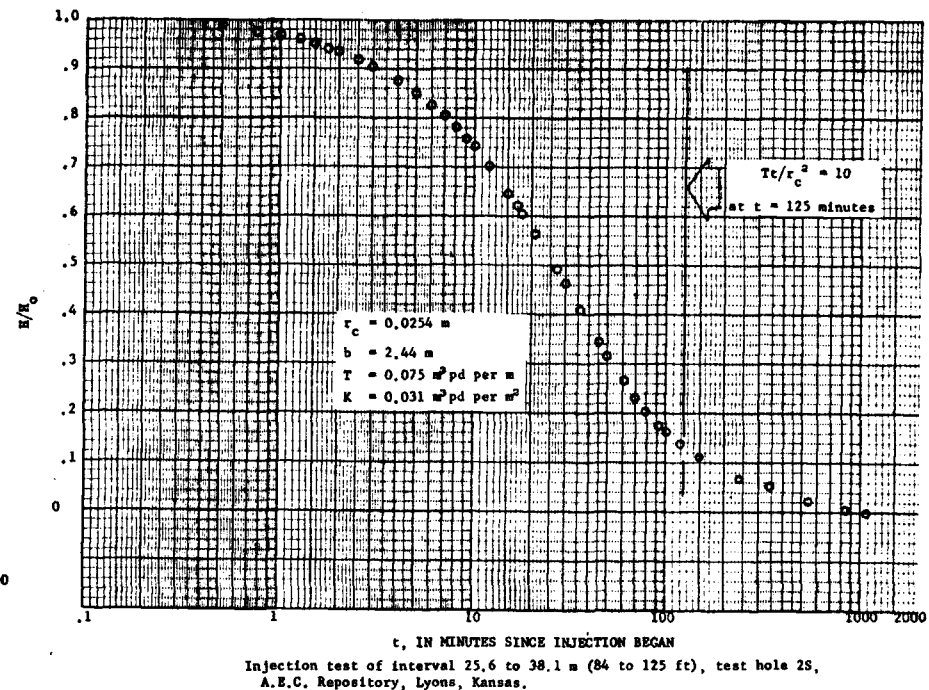
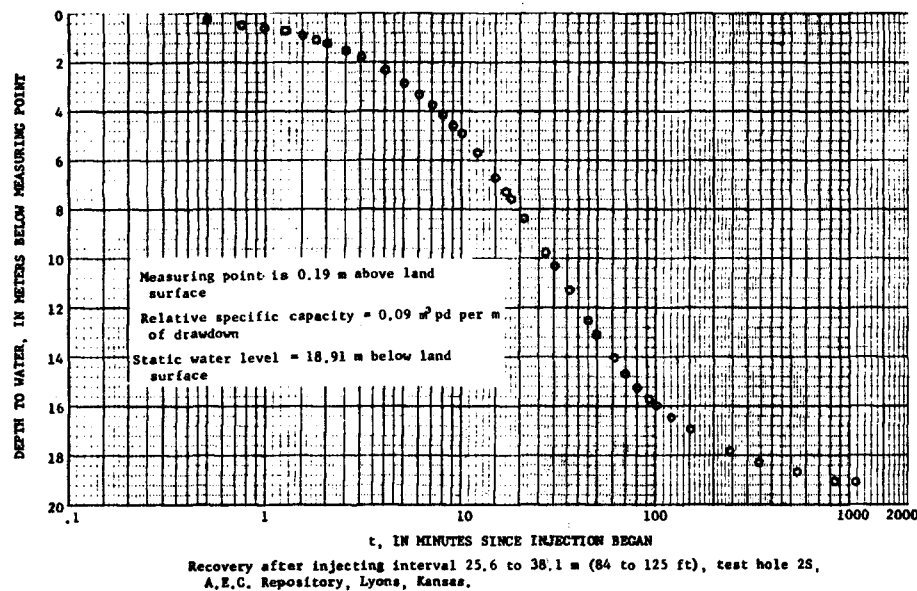
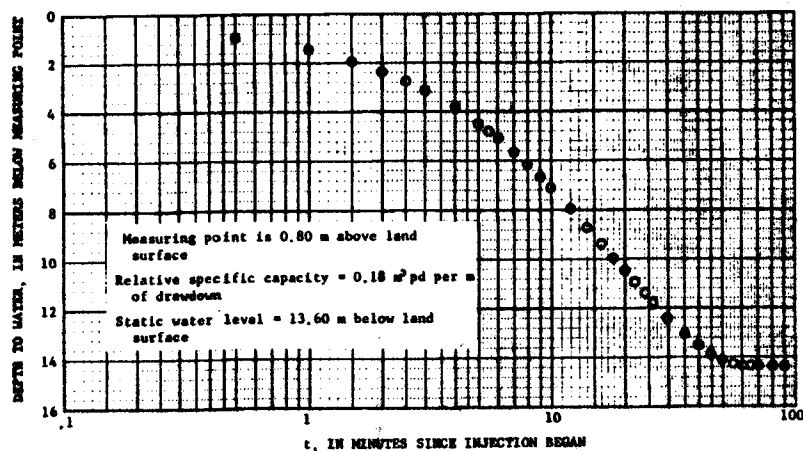
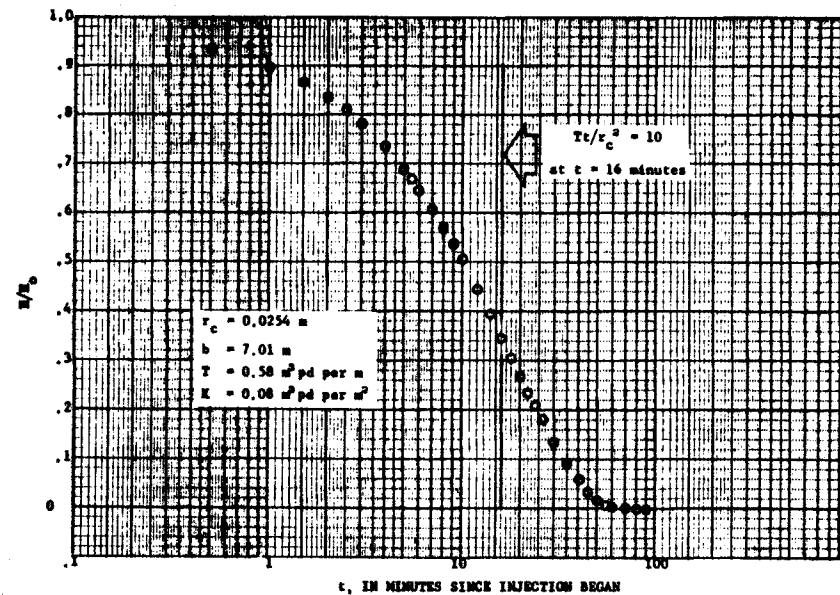


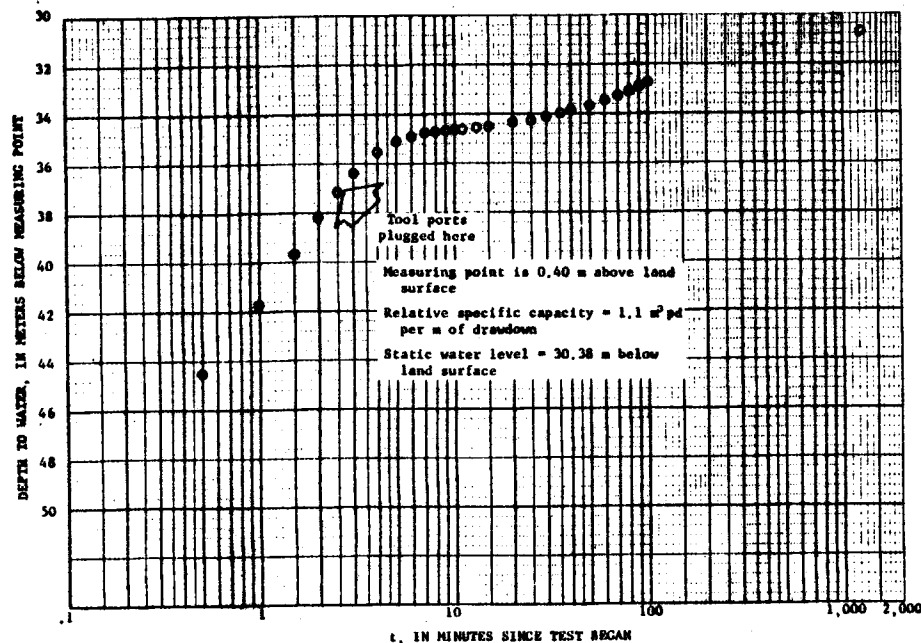
Fig. 6--Hydrologic tests on test hole 2S.



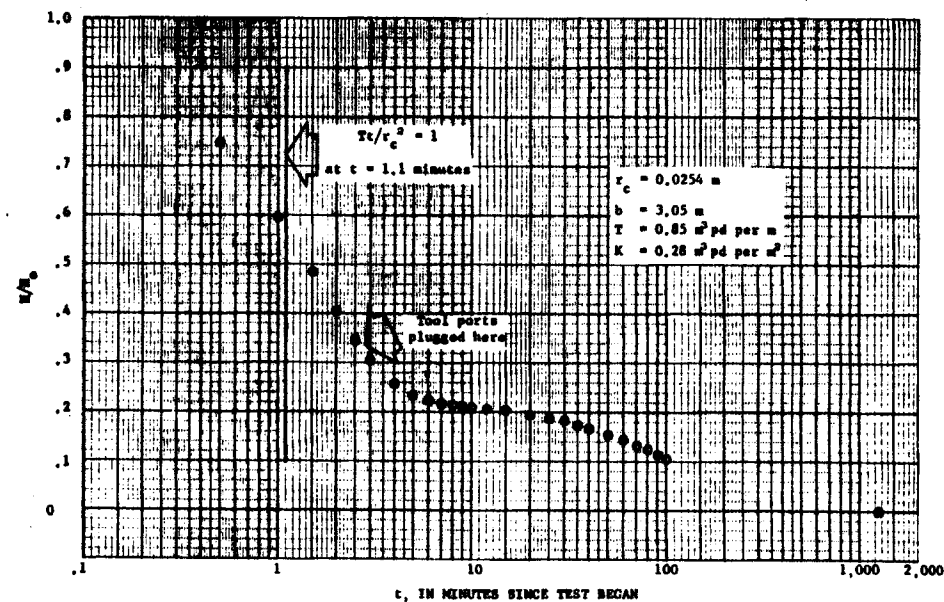
Recovery after injecting interval 24.4 to 45.7 m (80 to 150 ft), test hole 3S, A.E.C. Repository, Lyons, Kansas.



Injection test of interval 24.4 to 45.7 m (80 to 150 ft), test hole 3S, A.E.C. Repository, Lyons, Kansas.

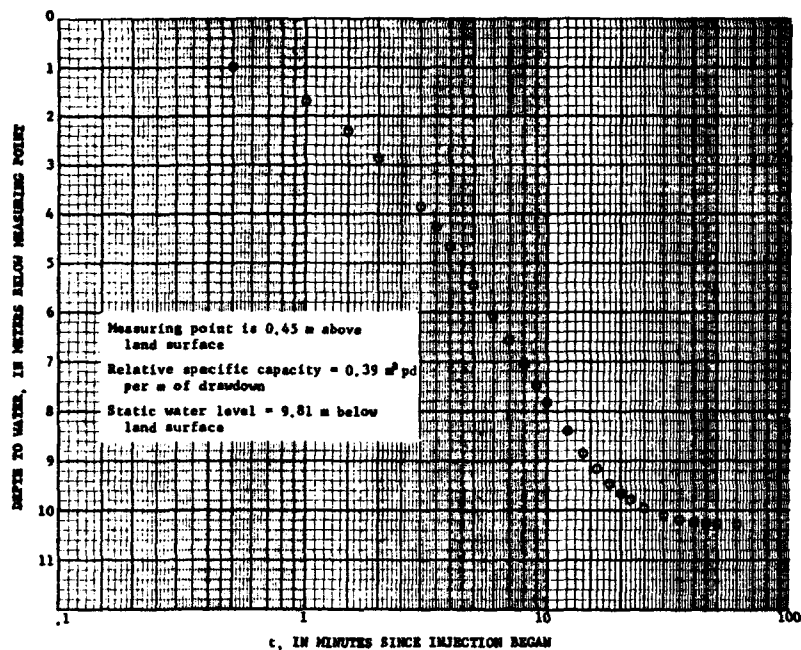


Recovery after swabbing interval 66.1 to 96.0 m (217 to 315 ft), test hole 3S, A.E.C. Repository, Lyons, Kansas.

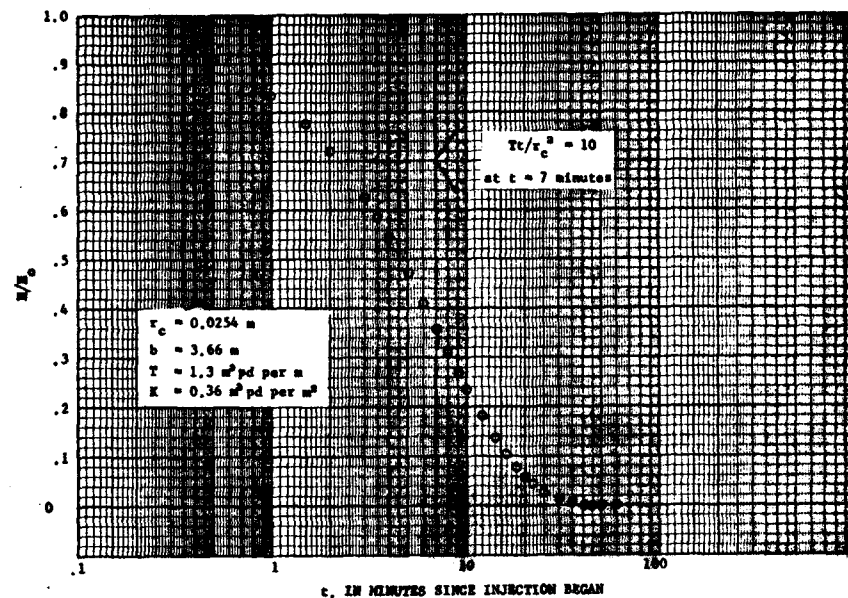


Swabbing test of interval 66.1 to 96.0 m (217 to 315 ft), test hole 3S, A.E.C. Repository, Lyons, Kansas.

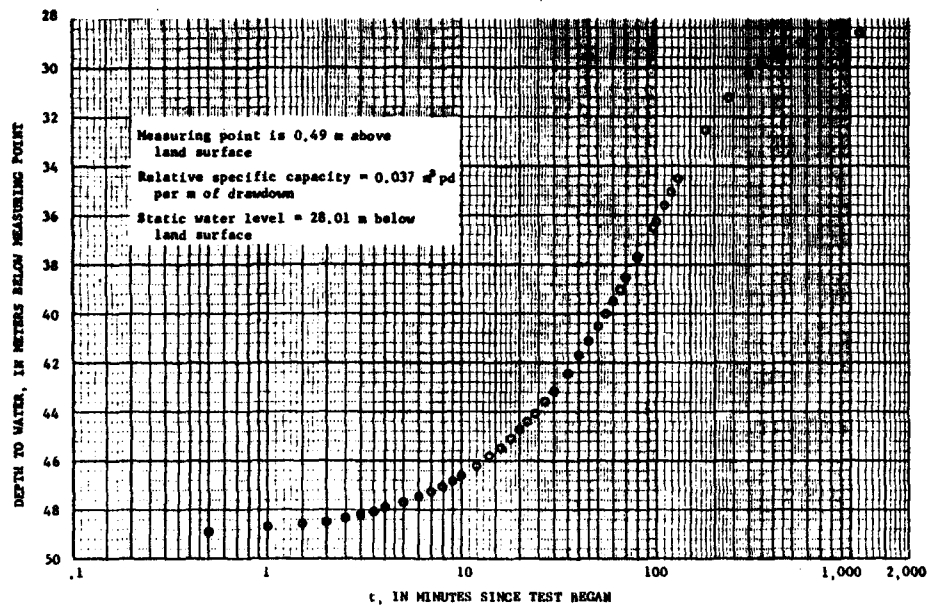
Fig. 7--Hydrologic tests on test hole 3S.



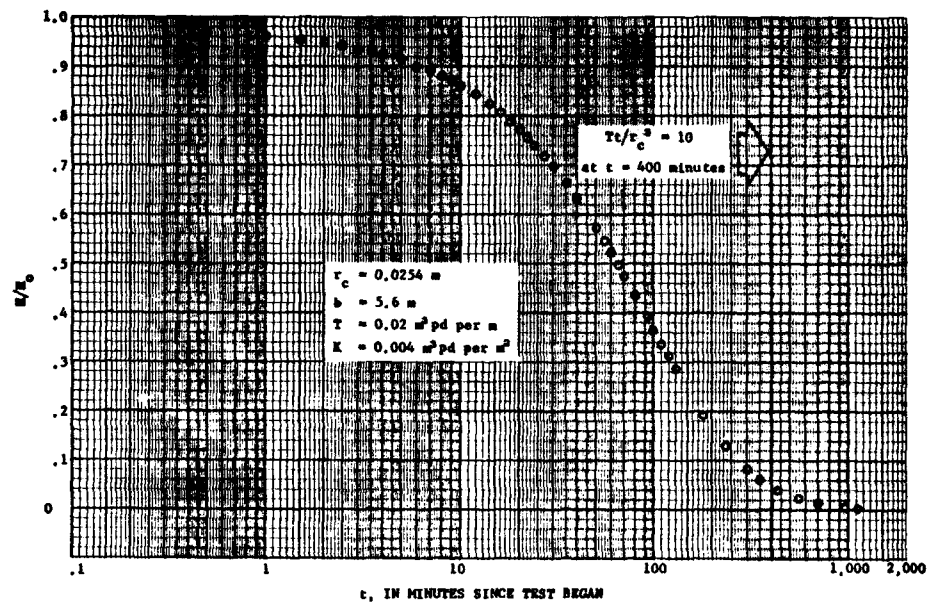
Recovery after injecting interval 18.3 to 38.4 m (60 to 126 ft), test hole 4S, A.E.C. Repository, Lyons, Kansas.



Injection test of interval 18.3 to 38.4 m (60 to 126 ft), test hole 4S, A.E.C. Repository, Lyons, Kansas.



Recovery after swabbing interval 79.2 to 91.4 m (260 to 300 ft), test hole 4S, A.E.C. Repository, Lyons, Kansas.



Swabbing test of interval 79.2 to 91.4 m (260 to 300 ft), test hole 4S, A.E.C. Repository, Lyons, Kansas.

Fig. 8--Hydrologic tests on test hole 4S.

Table 1 .--Summary of hydraulic testing in test holes, A.E.C. Repository, Lyons, Kansas

Hole 1S												
Interval tested		Static water level		Relative specific capacity		Transmissivity		Hydraulic conductivity		Water-bearing interval		Rock type
ft below lsd	m below lsd	ft below lsd	m below lsd	gpm per ft of dd	m ³ pd per m of dd	gpd per ft	m ³ pd per m	gpd per ft ²	m ³ pd per m ²	ft below lsd	m below lsd	
101-130	30.8-39.6	63.00	19.20	0.02	0.4	58	0.72	3.7	0.15	110-126	33.5-38.4	Sandstone
263-316	80.2-96.3	107.6	32.80	.005	.09	5.6	.069	.29	.012	296-315	90.2-96.0	Dolomite

Hole 2S												
84-125	25.6-38.1	62.04	18.91	.005	.09	6.0	.075	.76	.031	87- 95	26.5-29.0	Sandstone
230-267	70.1-81.4	--	--	e .00002	e .0004	e .02	e .0003	e .001	e .00006	235-253	71.6-77.1	Dolomite

Hole 3S												
80-150	24.4-45.7	44.62	13.60	.01	.18	47	.58	2	.08	90-127	27.4-38.7	Sandstone
217-315	66.1-96.0	99.68	30.38	.06	1.1	68	.85	6.9	.28	286-298	87.2-90.8	Dolomite

Hole 4S												
60-126	18.3-38.4	32.19	9.81	.02	.39	105	1.3	8.8	.36	63- 75	19.2-22.9	Sandstone
260-300	79.2-91.4	91.90	28.01	.002	.037	1.6	.02	.1	.004	266-284	81.1-86.6	Dolomite

Explanation:

ft - feet	gpd - gallons per day
lsd - land-surface datum	ft ² - square feet
m - meters	m ² - square meters
gpm - gallons per minute	ft pd - feet per day
m ³ pd - cubic meters per day	mpd - meters per day
dd - drawdown	e - estimated

testing also indicate that hydraulic conductivity of the Stone Corral Formation ranges from 0.001 to 6.9 gpd per ft². The Stone Corral is composed partly of massive dolomite and partly of anhydrite. Most water yielded by the Stone Corral probably comes from fractures in the massive dolomite; therefore, the low values for hydraulic conductivity are for tested intervals where the massive dolomite is either missing or is not fractured.

Hydraulic - Potential Distribution

Figure 9 shows contours on the potentiometric surface as determined by hydraulic potentials measured in beds of sandstone in the Kiowa Formation. The contours indicate a groundwater gradient southwestward, and they display a pattern similar to that of the potentiometric surface in the overlying deposits of Pleistocene age although somewhat lower at coincident locations. This indicates that there is potential for the Kiowa Formation to be recharged from above. The groundwater gradient in the Kiowa is toward an area to the southwest where the Kiowa has been eroded out, and it is very likely that ground water discharges from the Kiowa to the shallow aquifer in this area.

The hydraulic potential in the Kiowa Formation in test hole 2S in section 35 was not used as control for the contours in Figure 9. This hydraulic potential appears to be anomalously low without logical reason. A test hole was drilled to a depth of 82 feet, 4 feet north of test hole 2S, to determine whether a sandstone bed had been cased off in test hole 2S. The bottom of this test hole was 2 feet above the bottom of the cemented casing in test hole 2S. Only 2-three-inch-sandstone beds directly below the Pleistocene silts were found in the test hole. The hole was pumped for several hours and the water level lowered. During the period the test hole was pumped no change in water level was observed in test hole 2S. This indicates that the casing is properly set, that there was no hydrologic connection between the sandstone aquifer in test hole 2S and the interval pumped in the test hole, and that measurements taken in test hole 2S during the hydrologic test are valid.

A possible explanation is that this zone in the Kiowa is an isolated zone or one that has poor hydrologic connection with other sandstone lenses in the Kiowa. With the present knowledge of the area it cannot be said with confidence which condition exists. If the aquifer tested at test hole 2S is completely isolated from other sand bodies in the Kiowa, then the anomalous hydraulic potential in this test hole can only occur if water is being or has been withdrawn either through a well pumping from the aquifer or being discharged downward through an old drill hole or fracture. There is no record present or past of water being pumped from this zone. If there has been no discharge either through surface wells or

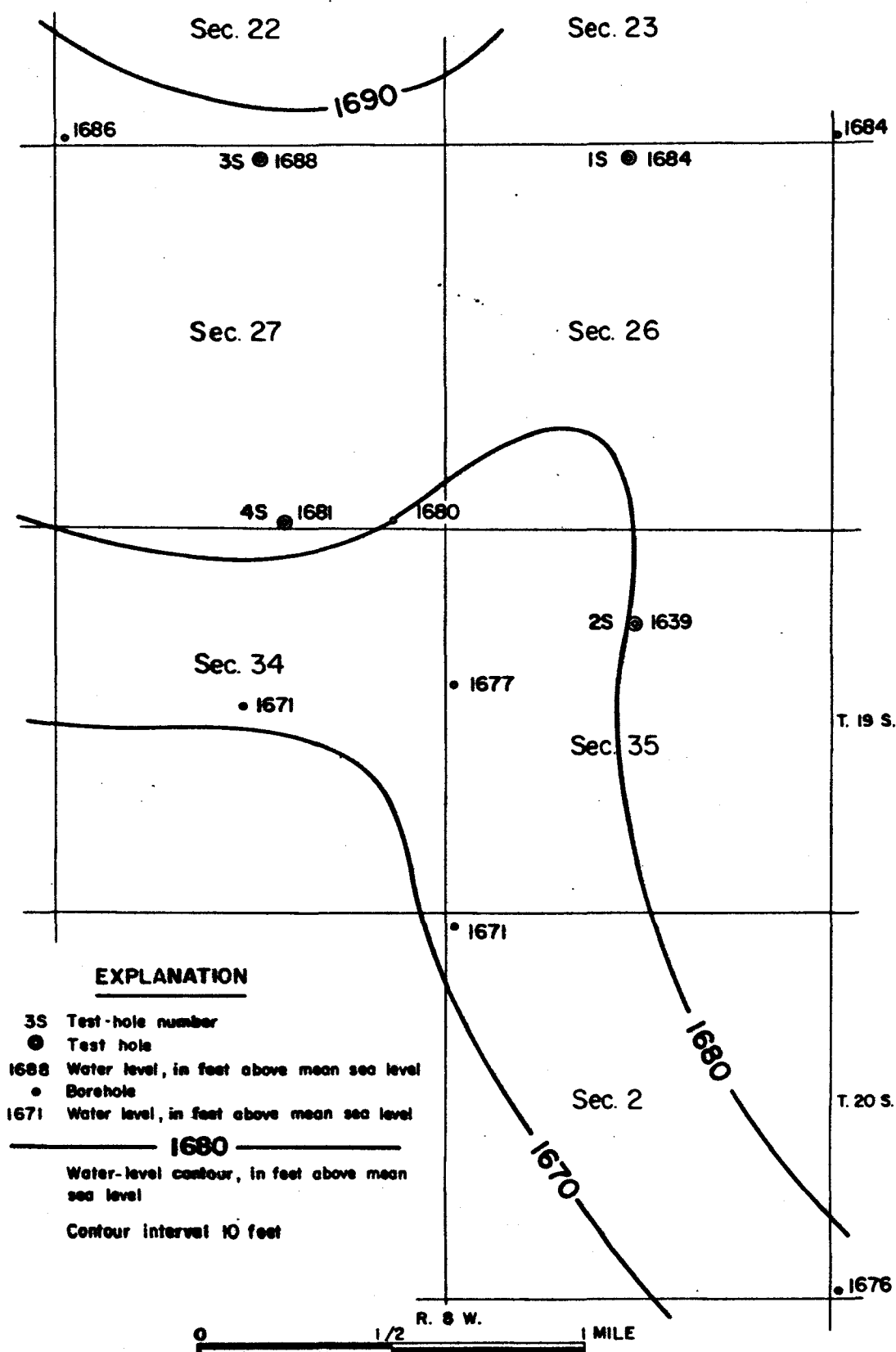


Fig. 9--Potentiometric surface in beds of sandstone in the Kiowa shale near Lyons, Kansas.

downward leakage, then over the long period of geologic time the hydrologic head in the aquifer should have reached an equilibrium with the remainder of the Kiowa Formation. Since the hydraulic head is anomalously low and if the sandstone is considered a completely isolated body then there is a strong argument for downward leakage of water. Several oil and gas wells have been drilled within a few hundred yards of the site of test hole 2S.

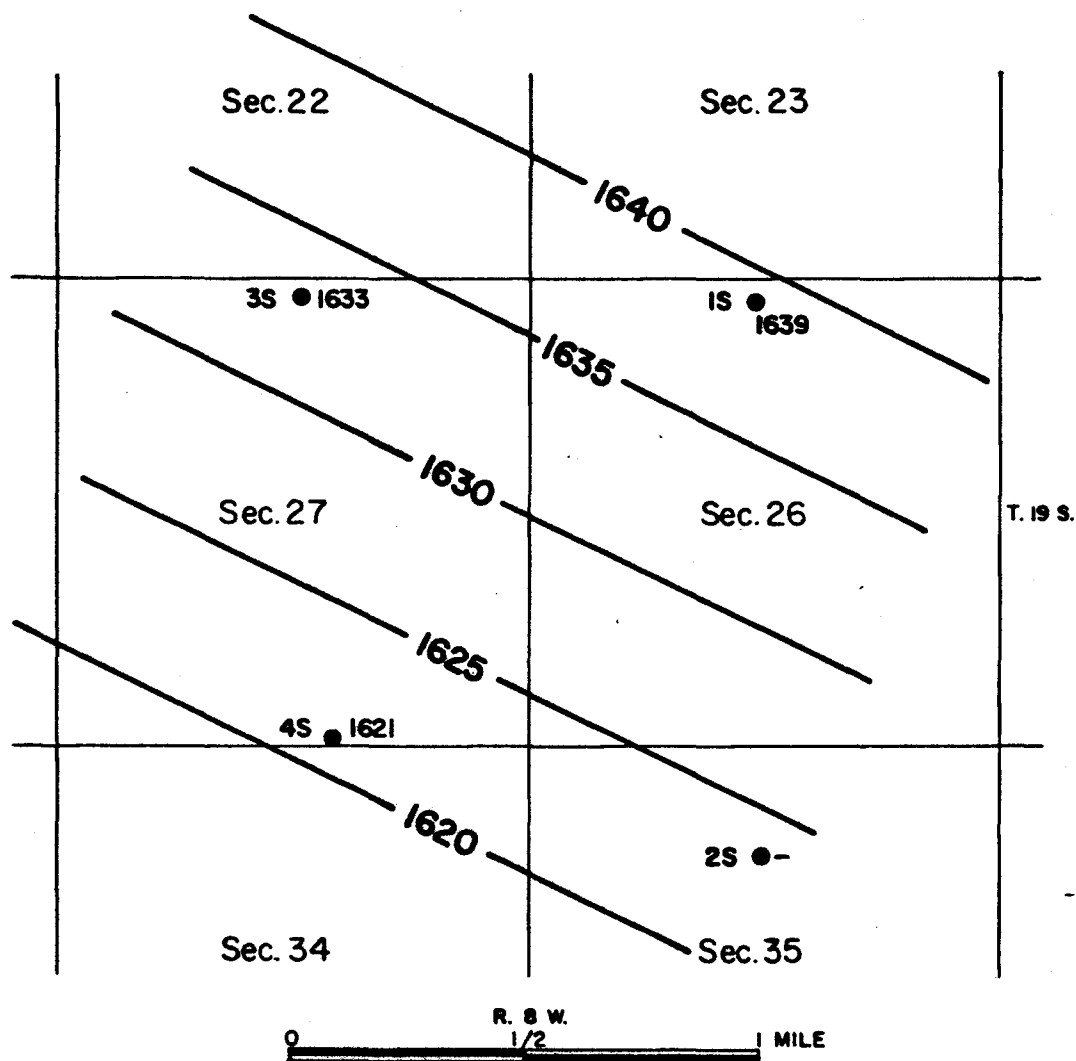
If the sandstone aquifer in test hole 2S is considered to be in very poor hydraulic connection with other aquifers in the Kiowa due to lensing or facies changes in the Kiowa Formation, an argument can be presented for lateral discharge from the aquifer. In this case the sandstone bed in test hole 2S would have to have hydraulic connection with a point of discharge outside the site area but isolated or very poorly connected from more permeable sandstone beds in the Kiowa. Decreasing hydraulic potentials with depth in the area indicate recharge to the deeper aquifers by downward percolation of water. The Kiowa shale above and below the sandstone tested in test hole 2S is not completely impermeable but does have a much lower permeability than the sandstone tested in test hole 2S. If a point of discharge for water from this sandstone is present than a pressure sink could be explained at the site of test hole 2S. Presently data to prove or disprove this is not available.

Figure 10 shows contours on the potentiometric surface as determined by hydraulic potentials measured in the Stone Corral Formation in three test holes. Hydraulic potential was not measured in test hole 2S because of very low transmissivity and the extremely long time required to reach static conditions. The contours indicate a ground-water gradient of about 14 1/2 feet per mile southwestward. Water may be discharging from this aquifer into an early Pleistocene buried valley underlying Cow Creek Valley southwest of Lyons.

GEOLOGY AND HYDROLOGY OF THE STUDY AREA

During the field work for this investigation, 38 test holes were drilled by the State Geological Survey (Table 2) to obtain geologic and hydrologic information in an area about 10 miles by 12 miles. The data collected were more concentrated toward the repository site (Fig. 11). Drill cuttings were examined in the field by a geologist and a log was prepared. These logs are given at the end of this report (Appendix A). Static water levels in the open hole were obtained and a map showing the water table in the unconfined aquifers was prepared (Fig. 11).

In addition to the 38 test holes drilled by the State Geological Survey, 2 holes were drilled by the U.S. Army Corps of Engineers. In the first of these holes, cores were obtained from the surface to the total depth of 1,300 feet. In the



EXPLANATION

3S Test-hole number
 ● Test hole
 1633 Water level, in feet above mean sea level

———— 1635 ————
 Water-level contour, in feet above mean sea level

Contour interval 5 feet

Fig. 10--Potentiometric surface in Stone Corral Formation near Lyons, Kansas.

TABLE 2.--RECORDS OF WELLS SALT WATER - RICE COUNTY, KANSAS

PRINCIPAL WATER-BEARING BED(S)																			
WELL (1)	OWNER OR USER	DEPTH OF WELL (FEET) (2)	DIAM. OF WELL (FT OR IN)	C T A YOS PEI EN C (3)	CHARACTER OF MATERIAL (4)	GEOLOGIC SOURCE	LIFT AND POWER (5)	USE (6)	WATER LEVEL DEPTH BELOW LSD FT) (7)	DATE OF MEAS.	ALT. OF LAND SURF. (FT)	C D H A E T M A (8)	REMARKS (9)						
19 7W 19000	STEWART RIFE	58.5	60	R	SS	KIOWA SH	JET,E	D,S	51.1	9-70	1754		5GPM						
19 7W 20333	VERVON RIFE	61.4	7	G	SS	KIOWA SH	SUB,E	D,S	45.2	9-70	1750	C	6GPM R						
19 7W 20030	G. GERMAN	60	R 6	G	SS	KIOWA SH	JET,E	D,S	40.2	9-70	1740		5GPM R						
19 7W 30303	HOWARD BYARD	52.8	48	R	SS	KIOWA SH	JET,E	D,S	44.5	9-70	1743	C	20GPM E						
19 7W 31000	IRVING DRESHER	60	R 42	R	SS	KIOWA SH	JET,E	D,S	28.9	9-70	1716	C	10GPM R						
19 8W 8000	J. E. COOK	21.3	48	R	SS AND ST	DAKOTA FM		N	20.1	9-70	1706								
19 8W 13000	KANS GEOL SURVEY	112.	5	N	SS AND CL	KIOWA SH	N	T	42.5	9-70	1752								
19 8W 14A33	JACK JANSSEN	65	R 6	I	SS	PLEISTOCENE SER	JET,E	D,S	44.1	9-70	1758	C	10GPM R						
19 8W 14000	KANS GEOL SURVEY	90.	5	N	SS AND CL	KIOWA SH	N	T	42.0	9-70	1748	C							
19 8W 14000	KENNETH KNIGHT	58.7	6	G	SS	PLEISTOCENE SER	SUB,E	D,S	29.8	9-70	1740	C	20GPM R						
19 8W 160A0	JESSE H. DRESSEL	68	R 36	R	SS	KIOWA SH	JET,E	D,S			1732		8GPM R						
19 8W 20000	JOE GILGOOD	64.9	6	I	SS	KIOWA SH	N	N			1710								
19 8W 20000	JOE GILGOOD	50	R 42	R	SS AND ST	KIOWA SH	JET,E	D	22.5	9-70	1710	C	5GPM R						
19 8W 21303	R. I. MCKINNIS	54	R 6	I	SS	PLEISTOCENE SER	JET,E	D,S	40	R 9-70	1722		10GPM R						
19 8W 22333	KANS GEOL SURVEY	75.	5	N	SS AND CL	KIOWA SH	N	T	41.4	9-70	1737								
19 8W 22000	KANS GEOL SURVEY	195.	5	N	SS AND GR	PLEISTOCENE SER	N	T	42.3	9-70	1734	C							
19 8W 22000	KANS GEOL SURVEY	105.	5		SS	KIOWA SH		T	48.8	10-70	1734	C							
19 8W 23A3A	W. H. POLAND	68	R 6	G	SS	KIOWA SH	JET,E	D,S			1747		5GPM R						
19 8W 24000	KANS GEOL SURVEY	205.	5	N	SS AND GR	KIOWA SH	N	T	43.0	9-70	1731	C							
19 8W 263AA2	KANS GEOL SURVEY	135.	7	S	SS	PLEISTOCENE SER	CY,G	T	61.	1-71	1747	C							
19 8W 263AA3	KANS GEOL SURVEY	316.	7	S	SH,DOL,GYP	KIOWA SH	CY,G	T	109.	1-71	1747	C							
19 8W 26000	KANS GEOL SURVEY	180.	5	N	SS	STONE CORRAL FM	N	T	33.8	9-70	1729	C							
19 8W 27AA3	KANS GEOL SURVEY	176.	5	N	SS AND GR	PLEISTOCENE SER	N	T	33.8	10-70	1725	C							
19 8W 27A33	KANS GEOL SURVEY	145.	5	N	SS,DOL,GYP	KIOWA SH	N	T	27.5	12-70	1733								
19 8W 27A33	KANS GEOL SURVEY	150.	7	S	SS	STONE CORRAL FM	CY,G	T	44.5	1-71	1733	C							
19 8W 27A33	KANS GEOL SURVEY	315.	7	S	SH,DOL,GYP	PLEISTOCENE SER	CY,G	T	93.	1-71	1733	C							
19 8W 27000	KANS GEOL SURVEY	300.	5	N	SS,DOL,GYP	KIOWA SH	N	T	31.0	12-70	1713								

Table 2.--Records of wells and test holes in the Lyons area.

TABLE 2.--CONTINUED

WELL (1)	OWNER OR USER	DEPTH OF WELL (FEET) (2)	DIAM. OF WELL (FT OR IN)	PRINCIPAL WATER-BEARING BED(S)			LIFT AND POWER (5)	USE (6)	WATER LEVEL		ALT. OF LAND SURF. (FT) (8)	C D H A E T M A (8)	REMARKS (9)
				T A YOS PFI E N G (3)	CHARACTER OF MATERIAL (4)	GEOLOGIC SOURCE			DEPTH BELOW LSD FT) (7)	DATE OF MEAS. (7)			
19	8W 27DC32	KANS GEOL SURVEY	135.	7	S SS	PLEISTOCENE SER							
19	8W 27DC33	KANS GEOL SURVEY	300.	7	S SH,DOL,GYP	KIOWA SH	CV,G	T	34.3	1-71	1713	C	
19	8W 27DDD	KANS GEOL SURVEY	90.	5	N SS AND GR	STONE CORRAL FM	CV,G	T	94.4	1-71	1713	C	
						KIOWA SH		T			1719	C	
19	8W 27DD02	KANS GEOL SURVEY	150.	5	N SS	PLEISTOCENE SER	N	T	41.9	10-70	1722	C	
19	8W 283B3	KANS GEOL SURVEY	165.	5	N SS AND CL	KIOWA SH	N	T	37.2	9-70	1718	C	
						PLEISTOCENE SER							
19	8W 28CD3	EUGENE PETERMAN	64 R	18	T SS AND SD	KIOWA SH	N	N	38.4	9-70	1711		10GPM R
19	8W 28CD32	EUGENE PETERMAN	42 R	6	T SD, ST, CL	PLEISTOCENE SER	SUB,E	D,S			1710	C	10GPM R
19	8W 29DDD	KANS GEOL SURVEY	90.	5	N SD AND CL	KIOWA SH	N	T	27.3	9-70	1701		
						PLEISTOCENE SER							
19	8W 30AA3		33.5	40	R SD, ST, CL	PLEISTOCENE SER	N	N	14.2	9-70	1687		
19	8W 30DDD	KANS GEOL SURVEY	130.	5	N GR AND CL	PLEISTOCENE SER	N	T	11.5	9-70	1678		
19	8W 313B3	KANS GEOL SURVEY	75.	5	N GR AND CL	PLEISTOCENE SER	N	T	32.7	8-70	1703	C	
19	8W 32DD3	KANS GEOL SURVEY	105.	5	SD, GR, CL	PLEISTOCENE SER		T	42.6	9-70	1693	C	
19	8W 343B3	KANS GEOL SURVEY	90.	5	N SH AND CL	KIOWA SH	N	T			1710		
						PLEISTOCENE SER							
19	8W 343DD	KANS GEOL SURVEY	129.	5	SS AND CL	KIOWA SH		T	28.6	9-70	1700	C	
						PLEISTOCENE SER							
19	8W 34CDA	KANS GEOL SURVEY	97.	4	SS AND CL	KIOWA SH		T	32.7	10-70	1700	C	
						PLEISTOCENE SER							
19	8W 353AA	KANS GEOL SURVEY	112.	5	N SS AND GR	KIOWA SH	N	T	15.4	12-70	1699		
						PLEISTOCENE SER							
19	8W 353CC	KANS GEOL SURVEY	120.	5	N SS AND CL	KIOWA SH	N	T	27.9	12-70	1705		
						PLEISTOCENE SER							
19	8W 353DA2	KANS GEOL SURVEY	135.	7	SS	KIOWA SH		T	41.	12-70	1710		
19	8W 353DA3	KANS GEOL SURVEY	271.	7	SH,DOL,GYP	STONE CORRAL FM		T	90.	12-70	1710		
19	8W 353DA4	KANS GEOL SURVEY	82.	5	N SS AND CL	KIOWA SH	N	T	22.3	2-71	1701	C	
						PLEISTOCENE SER							
19	8W 36CCC	ROGER CALDWELL	105 R	4	G SS	KIOWA SH	JET,E	D			1737	C	6GPM R
19	8W 36CC32	ROGER CALDWELL	85 R	6	T SS	KIOWA SH	SUB,E	S			1736		20GPM R
19	9W 13DDD	KANS GEOL SURVEY	120.	5	SS AND CL	KIOWA SH		T	40.0	9-70	1732	C	
						PLEISTOCENE SER							
19	9W 14CCC	KANS GEOL SURVEY	90.	5	SS	KIOWA SH		T	42.0	9-70	1725	C	
						DAKOTA FM							
19	9W 22ADD		54.5	42	R SS	DAKOTA FM	CV,W	S	47.2	9-70	1727		
19	9W 23CDD	FRANK HOYT	85 R	8	T SS	KIOWA SH	JET,E	D,S			1722		5GPM R
						DAKOTA FM							
19	9W 24CCA	COLIN D. HOYT	90 R	12	T SS	DAKOTA FM	T,LPS	I	51.3	9-70	1735		100GPM R
						KIOWA SH							

TABLE 2.--CONTINUED

WELL (1)	OWNER OR USER	DEPTH OF WELL (FEET) (2)	DIAM. OF WELL (FT OR IN)	PRINCIPAL WATER-BEARING BED(S)		LIFT AND POWER (5)	USE (6)	WATER LEVEL		ALT. OF LAND SURF. (FT) (7)	C D OF H A F T M A (8)	REMARKS (9)
				CHARACTER OF MATERIAL (4)	GEOLOGIC SOURCE			DEPTH BELOW LAND SURF. (FT) (7)	DATE OF MEAS. (7)			
20 8W 18DDD	KANS GEOL SURVEY	150.		SD AND GR	PLEISTOCENE SER		T	10.1	8-70	1657	C	
20 8W 20AAA	KANS GEOL SURVEY	105.	5	SD AND GR	PLEISTOCENE SER		T	11.2	8-70	1651	C	
20 8W 20CCA		65.0	14	I SD AND GR	QUATERNARY SYS ALLUVIUM	T.D	I	15.4	9-70	1664		
20 8W 22AA	CECIL TOBIAS	59.1	12	I SD AND GR	QUATERNARY SYS ALLUVIUM	T,NG	I	15.6	9-70	1644		850GPM R
20 8W 22CBA		56.3	16	I SD AND GR	QUATERNARY SYS ALLUVIUM	T,D	I	10.8	9-70	1649		
20 8W 23AA	CECIL TOBIAS	59 R	12	I SD AND GR	QUATERNARY SYS ALLUVIUM	C,NG	I	12.4	9-70	1638		475GPM R
20 8W 23ABA	CECIL TOBIAS	50 R	8	I SD AND GR	QUATERNARY SYS ALLUVIUM	C,E	D	13.0	9-70	1638	C	10GPM R
20 8W 23ABA	CECIL TOBIAS	25 R	6	SD AND GR	QUATERNARY SYS ALLUVIUM	C,E	S			1638		
20 9W 14DDD	KANS GEOL SURVEY	178.	5	SD AND GR	PLEISTOCENE SER		T	11.3	8-70	1671	C	
20 9W 16DDD	KANS GEOL SURVEY	150.	5	N SR AND CL	PLEISTOCENE SER		T	53.5	8-70	1724		
20 9W 22AAA	KANS GEOL SURVEY	150.	5	SD AND GR	PLEISTOCENE SER		T	11.6	8-70	1674	C	

(1) WELL-NUMBERING SYSTEM DESCRIBED IN TEXT.

(2) MEASURED DEPTHS OF WELLS GIVEN IN FEET AND TENTHS BELOW LAND SURFACE/ R, REPORTED/ E, ESTIMATED.

(3) B, BRICK/ C, CONCRETE/ G, GALVANIZED/ I, IRON, BLACK/ N, NONE/ O, OIL BARREL/ P, PLASTIC/ R, ROCK/ S, STEEL/ T, TILE/
A, ALUMINUM/ E, CONTACT SPRING/ H, FRACTURE SPRING/ U, SOLUTION SPRING.(4) SS, SANDSTONE/ LS, LIMESTONE/ SH, SHALE/ DO, DOLOMITE/ GYP, GYPSUM/ SD, SAND/ GR, GRAVEL/ ST, SILT/ CL, CLAY/
AL, ALLUVIUM/ IG, IGNEOUS/ META, METAMORPHIC.(5) METHOD OF LIFT--C, CENTRIFUGAL/ CY, CYLINDER/ T, TURBINE/ B, BUCKET/ AL, AIRLIFT/ EC, ENDLESS CHAIN/ SUB, SUBMERSIBLE/
N, NONE.
TYPE OF POWER--E, ELECTRIC/ H, HAND/ W, WIND/ G, GASOLINE/ NG, NATURAL GAS/ LPG, LIQUID PETROLEUM GAS/ D, DIESEL/ T, TRACTOR/
IC, INTERNAL COMBUSTION.

(6) D, DOMESTIC/ S, STOCK/ I, IRRIGATION/ ID, INDUSTRIAL/ PS, PUBLIC SUPPLY/ O, OBSERVATION/ N, NONE/ T, TEST/ COM, COMMERCIAL.

(7) MEASURED DEPTHS GIVEN IN FEET AND TENTHS / R, REPORTED/ E, ESTIMATED/ P, PUMPING/ +, FEET ABOVE LAND SURFACE.

(8) C, COMPLETE/ P, PARTIAL/ L, CHLORIDE/ K, CONDUCTANCE/ A, SERIES OF COMPLETES/ S, SERIES OF PARTIALS/
D, SERIES OF COMPLETES AND PARTIALS/ B, BACTERIOLOGICAL/ E, BACTERIOLOGICAL AND COMPLETE/ R, RADIOCHEMICAL.(9) YIELD--GPM, GALLONS PER MINUTE/ GPD, GALLONS PER DAY/ R, REPORTED/ E, ESTIMATED.
DRAWDOWN--IN FEET.

TABLE 2.--CONTINUED

WELL (1)	OWNER OR USER	DEPTH			PRINCIPAL WATER-BEARING BED(S)			WATER LEVEL		ALT. OF LAND SURF. (FT)	C D W A F T M A (8)	REMARKS (9)
		OF WELL (FEET) (2)	OF WELL (IN) (3)	T A YRS PER EN G (3)	CHARACTER OF MATERIAL (4)	GEOLOGIC SOURCE	LIFT AND POWER (5)	USE (6)	DEPTH BELOW LSD (7)	DATE OF MEAS.		
19 9W 240042	CHILDS D. HOYT	59.3	8	3	SS	DAKOTA FM KIOWA SH	N	N	51.1	9-70	1735	
19 9W 24000	CHILDS HOYT	90.4	6	3	SS	DAKOTA FM KIOWA SH	SUB,E	D+S	50.4	9-70	1729	C 100GPM R
19 9W 35AAA	KANS GEOL SURVEY	150.	5	N	SH AND CL	KIOWA SH PLEISTOCENE SER	N	T			1719	
20 8W 1300	A. J. KIMPLE	90.8	6	3	SS	KIOWA SH	SUB,E	D+S	25.8	9-70	1717	20GPM R
20 8W 1080	A. J. KIMPLE	57.7	72	3	SS	KIOWA SH	SUB,E	D+S	38.5	9-70	1715	2GPM R
20 8W 1000	KANS GEOL SURVEY	115.	5		SS	KIOWA SH		T	31.5	9-70	1708	C
20 8W 2AAA	KANS GEOL SURVEY	150.	5	N	SS AND CL	KIOWA SH PLEISTOCENE SER	N	T	37.1	9-70	1735	
20 8W 2333	KANS GEOL SURVEY	135.	5		SS AND CL	KIOWA SH PLEISTOCENE SER		T	19.1	9-70	1690	C
20 8W 3AA3	DON ALDERMAN	57.8	6	3	SS	KIOWA SH	SUB,E	D	19.9	9-70	1685	C 15GPM R
20 8W 3AA32	DON ALDERMAN	57.8	6	3	SS	KIOWA SH	SUB,E	S	18.8	9-70	1690	10GPM R
20 8W 7AAA	KANS GEOL SURVEY	135.	5		SD AND GR	PLEISTOCENE SER		T	32.4	8-70	1678	C
20 8W 73A0		69.0	16	1	SD AND GR	QUATERNARY SYS ALLUVIUM	T,NG	I	18.2	9-70	1667	
20 8W 7333	KANS GEOL SURVEY	120.	5	N	SD, GR, CL	PLEISTOCENE SER	N	T			1691	
20 8W 8AAA	KANS GEOL SURVEY	105.	5		SD AND GR	PLEISTOCENE SER		T	28.9	8-70	1670	C
20 8W 8DAC		68.4	16	1	SD AND GR	QUATERNARY SYS ALLUVIUM	T,NG	I	19.8	9-70	1658	
20 8W 9AAA	DELBERT HOLLINGER	77.8	16	1	SD AND GR	QUATERNARY SYS ALLUVIUM	T,D	I	29.9	9-70	1665	800GPM R
20 8W 9AAC	AMERICAN SALT CO	76.	16	1	SD AND GR	QUATERNARY SYS ALLUVIUM	T,E	ID	28.4	9-70	1662	850GPM R
20 8W 11333	KANS GEOL SURVEY	90.	5	N	SD AND CL	KIOWA SH PLEISTOCENE SER	N	T	30.6	9-70	1692	
20 8W 12AA3	A. J. KIMPLE	125.8	6	3	SS	KIOWA SH	JFT,E	D+S	60.8	9-70	1743	1GPM R
20 8W 12003	EDWARD JANDA	64.8	6	1	SD AND GR	QUATERNARY SYS ALLUVIUM	JFT,E	D+S	30.0	9-70	1659	C 5GPM R
20 8W 13000	KANS GEOL SURVEY	91.	5		SD AND GR	PLEISTOCENE SER		T	10.5	8-70	1639	C
20 8W 14000	KANS GEOL SURVEY	75.	5		SD AND GR	PLEISTOCENE SER		T			1643	C
20 8W 15300	CECIL TOBIAS	66.0	15	1	SD AND GR	QUATERNARY SYS ALLUVIUM	T,E	I	14.9	9-70	1647	
20 8W 15030	W. E. LATTIMER	60.8	12	1	SD AND GR	QUATERNARY SYS ALLUVIUM	SUB,E	I	13.8	9-70	1647	342GPM R
20 8W 15000	KANS GEOL SURVEY	105.	5		SD AND GR	PLEISTOCENE SER		T	13.1	8-70	1650	C
20 8W 17DAC	JAMES MCALLISTER	38.3	16	1	SD AND GR	QUATERNARY SYS ALLUVIUM	T,LPS	I	15.7	9-70	1656	
20 8W 18000	KANS GEOL SURVEY	120.	5		SD AND GR	PLEISTOCENE SER		T	11.2	8-70	1666	C

second hole, cores were taken only through the salt section. Hydrologic testing of the upper part of the Corps of Engineer's holes was attempted; however, these tests were inconclusive and four holes were drilled to the base of the Stone Corral Formation at the corners of the repository site and were hydraulically tested. These tests are described in the preceding section of this chapter. In this section of Chapter 1, data from these 4 holes and 3 of the original 38 holes in which hydraulic heads were measured through packers are projected into a larger area in an attempt to predict hydrologic conditions in the confined aquifers.

On the repository site a generalized section of the rocks to a depth of about 300 feet would have about 30 to 40 feet of Pleistocene loess composed of silt and silty clay. Next below the loess is 75 to 130 feet of Kiowa Formation underlain by about 125 feet of Harper Sandstone and 12 to 18 feet of Stone Corral Formation. The Kiowa Formation was fully penetrated in many of the holes, but the Harper Sandstone and Stone Corral were fully penetrated in only the four holes near the corners of the repository site.

In the upland area, the unconfined water moves generally in a south-southwesterly direction toward the valley of Cow Creek. Contours bend upstream where they cross tributary streams and these streams act as a drain to the aquifer. Data on which the water table contours (Fig. 11) are based were collected during the fall of 1970 and, although neither Little Cow Creek or the creek located in the southeastern part of the repository site were flowing during this period, the contours indicate movement of water in the aquifer toward these two valleys. During this period evaporation and transpiration exceeded the amount of water discharged into the valleys and the streams did not flow.

In Cow Creek Valley water moves in a southeasterly direction toward the stream and down the valley (Fig. 11).

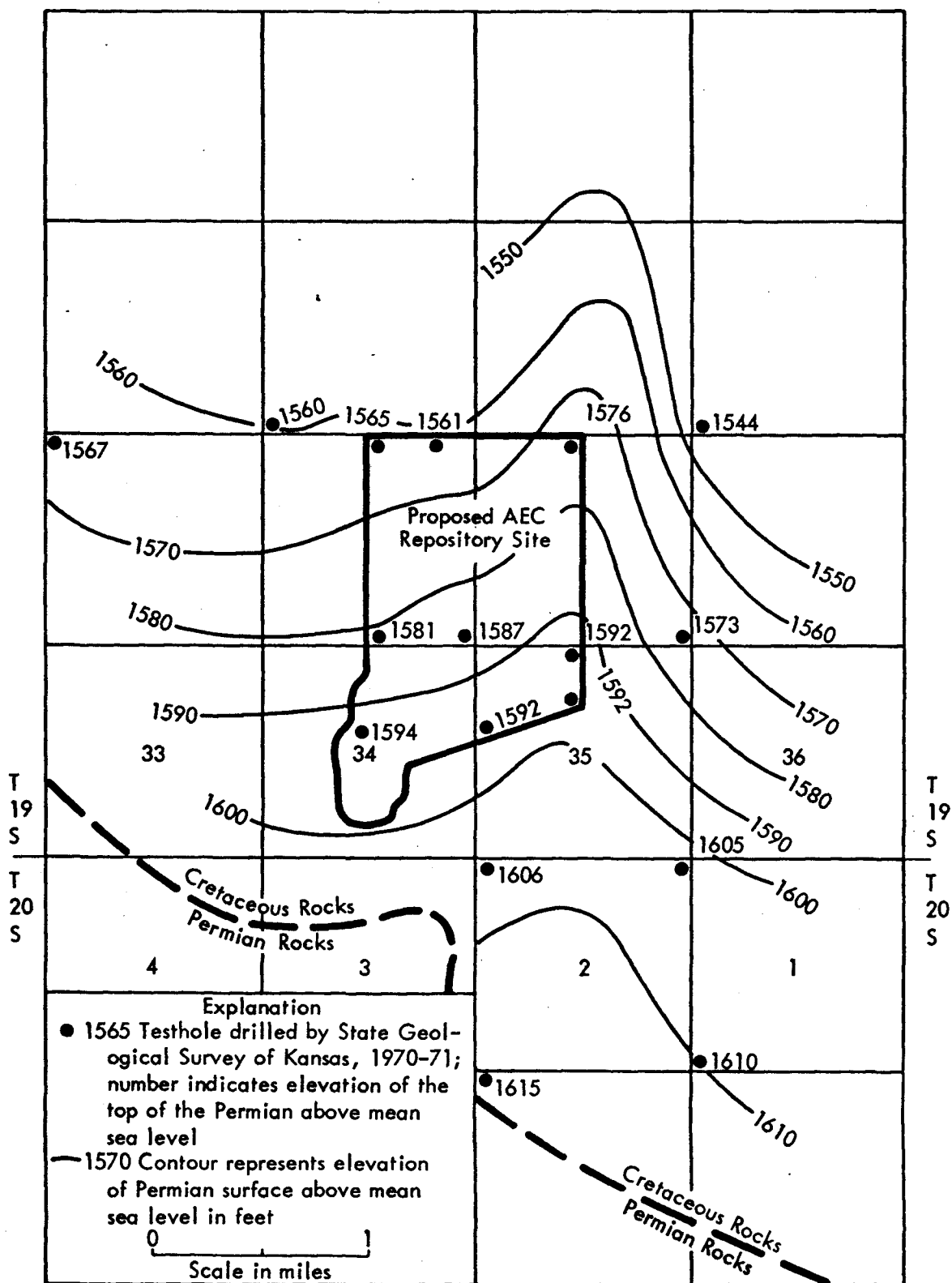
Data are not available on the aquifer in Cow Creek Valley or the Pleistocene silt aquifer in the repository site to determine the rate of movement of water in these aquifers under natural conditions; however, an estimate of these rates of movement can be made using data from other areas with similar deposits. Using a hydraulic conductivity (K) of 1,000 gallons per day per square foot, porosity (θ) of 20 percent and a gradient (I) of 4.5 feet per mile for the Cow Creek aquifer, water moves down valley at a rate of 0.56 feet per day. For the Pleistocene silt aquifer in the repository site using $K = 50$, $\theta = 30\%$, and $I = 10$ the rate of movement is 0.04 feet per day. These aquifers are not homogeneous but are somewhat layered with some zones more permeable than others. The more permeable zones will transmit more water with generally greater velocities.

The bedrock map (Fig. 12, Pocket) represents the surface of the bedrock beneath the Pleistocene deposits in the study area. North of the valley wall of Cow Creek, the bedrock unit immediately below the Pleistocene deposits is the Kiowa Formation. In Cow Creek Valley and in part of Little Cow Creek, the Harper Sandstone is the bedrock unit next below the Pleistocene deposits (Fig. 13, Pocket). The contours indicate that the bedrock slopes south-southwestward toward Cow Creek Valley. The contours bend sharply up Little Cow Creek Valley where this stream has cut into the bedrock surface. Contours bend upstream in the area of the small stream along the eastern side of the repository site. In about this same area the contours on top of the Permian bedrock (Fig. 14) indicate a topographic high. The contours bend sharply to the north and indicate a small ridge pitching toward the north. Both the Permian surface and the Kiowa surface in this area are unconformable with the overlying beds. The contours on the Permian surface indicate a general slope almost due north whereas the Kiowa surface slopes south-southwestward (Fig. 13-14).

Sandstone beds in the Kiowa Formation are the principal aquifers of the bedrock units in the area. Figure 15 is an isopachous map that shows the distribution of the total thickness of sandstone units in the Kiowa. Sandstone occurs in thin layered beds and in massive units in the area. The massive units are more permeable than the layered units and will yield more water per unit of thickness. Figure 15 shows the percent of massive sandstone to total thickness of sandstone in test holes in the repository and surrounding area. In this area the quantity of water which may be available to a well is dependent on the total thickness of sandstone and the percentage of massive sandstone to thin-bedded or layered sandstone. In test hole 2S the total thickness of sandstone was less than 10 feet all of which was thin-bedded sandstone. In this test hole the hydraulic conductivity from the test was 0.76 gallons per day per square foot (gpd/ft²). In test hole 4S the total thickness of sandstone was near 20 feet. In this test hole 66% of the sandstone was massive and the hydraulic conductivity was 8.8 gpd/ft². Similar results could be expected in other test holes in the area. Test hole 19-8W-26ddd had more than 50 feet of sandstone 89% of which was massive. In this test hole it was estimated that between 50 and 100 gpm could be obtained from a properly constructed well. One mile south of this test hole in test hole 20-8W-2aaa less than 10 feet of sandstone was present and only 33% of the total thickness is massive sandstone. The yield from a well at this point would probably be only a few gallons per hour. Test drilling in the area indicated that the amount of sandstone in the Kiowa diminished toward the southeast from the repository site although the total thickness of Kiowa was about normal in the area. Many farmers in this area have difficulty in locating an adequate water supply. South and southwest of the repository site the Kiowa

Map Showing Configuration of the Permian Surface

R 8 W



R 8 W

Fig. 14--Map showing configuration of the Permian Surface.

thins and is entirely removed near the valley wall of Cow Creek. In this area dependable water supplies are locally difficult to obtain. Because the individual beds in the Kiowa and especially the sandstone beds pinch and swell and locally are entirely absent, it is difficult to predict over appreciable distances the probable yield of a well in the Kiowa. Test hole 2S illustrates the rapidity with which sandstone beds may change in thickness and lithology. In this test hole less than 10 feet of Kiowa was sandstone and none of this was massive. In test holes, some little more than 1/4 mile away, in all directions from test hole 2S, appreciable thicknesses of sandstone were present (Fig. 15). Figure 15 indicates that the thickness of massive sandstone is greatest east and northwest of the repository site. Therefore, consistent with the idea that the massive sandstone yields significantly larger quantities of water than the interbedded sandstone, greater transmissivities may also be expected east and northwest of the site.

In the area of this study, data on the lithology and hydraulic characteristics of the Stone Corral Formation were obtained from only the four test holes drilled near the corners of the repository site. In test holes 1S, 2S and 4S the Stone Corral was about 18 feet thick and consisted of an upper dolomite about 1 foot thick underlain by about 1 foot of shale which was underlain by several feet of anhydrite and gypsum with some dolomite. The lower 4 or 5 feet of the Stone Corral in these holes was hard massive dolomite. In test hole 3S the total thickness of the Stone Corral was about 12 feet. In this hole the lower massive unit was largely absent. Hydraulic conductivity of the Stone Corral in the four test holes ranged from an estimated 0.001 gpd/ft² in test hole 2S to 6.9 gpd/ft² in test hole 3S. The Stone Corral Formation contains fractures some of which have been filled with gypsum. Water probably moves through the Stone Corral through these fractures. Possibly some solution of gypsum has occurred; however, the low transmissivity values obtained on the formation indicate that solution has been only minor and probably local in occurrence. On the outcrop where the total thickness of the Stone Corral is about 8 feet the gypsum and anhydrite has been removed. Test hole 3S was pumped at a rate of 1.5 gpm during the test. In test holes 1S and 4S the pumping rate was less than 1/4 gpm and test hole 2S could not be pumped. The 1.5 gpm pumping rate from test hole 3S is probably the maximum, or near the maximum, quantity of water that could be obtained in the repository site area.

WATER QUALITY

Water samples were obtained from 31 test holes and 13 domestic supply wells in the area. In three test holes more than one isolated aquifer was sampled. Standard chemical and radioactive analyses were performed by the Kansas State

Generalized Map Showing Total Thickness of Kiowa Sandstone
and Percent of Massive to Thin-bedded Layers

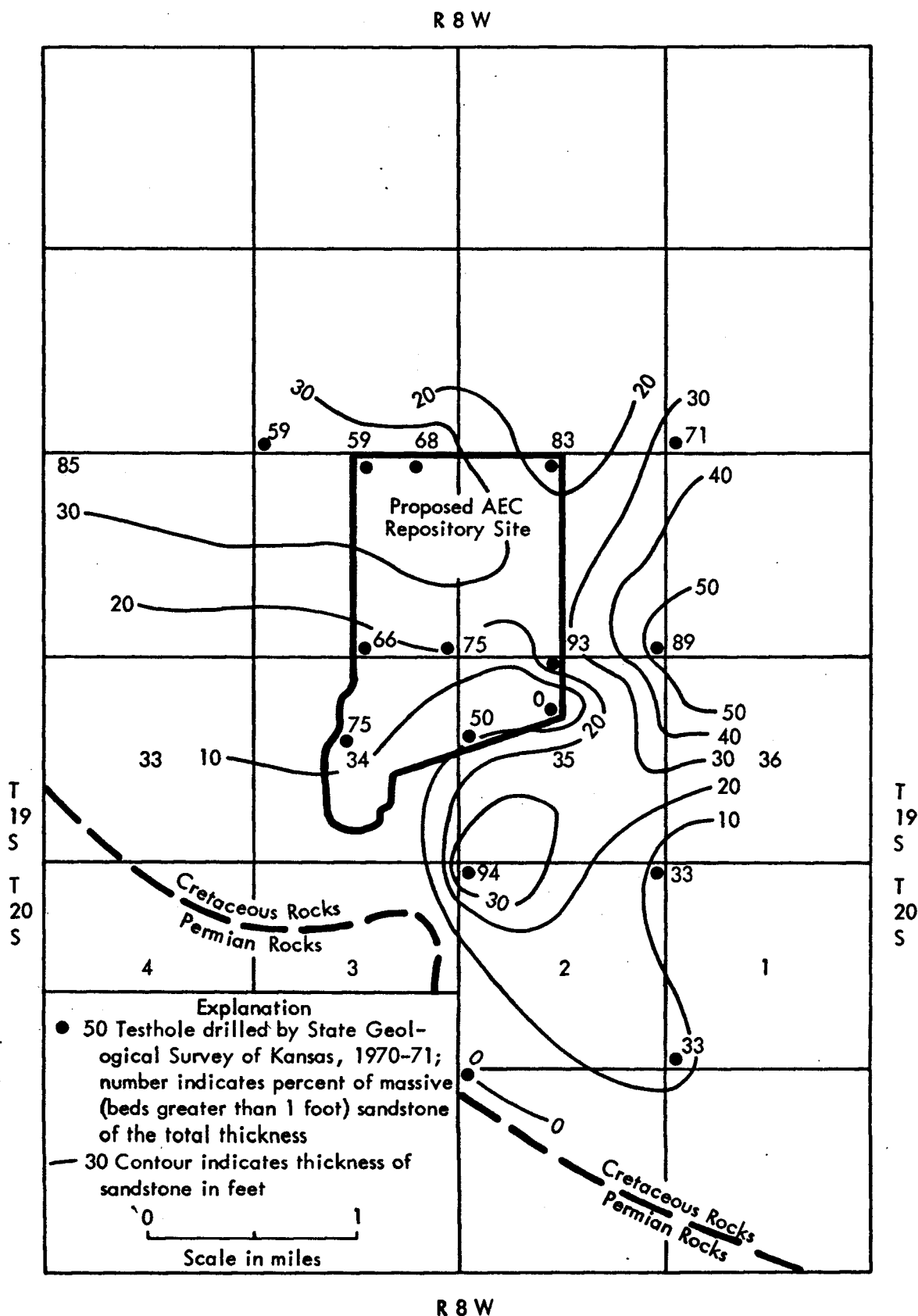


Fig. 15--Generalized map showing total thickness of Kiowa sandstone and percent of massive to thin-bedded layers.

Department of Health while the Kansas Geological Survey completed trace element analyses on all water samples from test holes. Standard chemical analyses only were performed on the samples from domestic supply wells. In addition, the U.S. Geological Survey collected water samples during their hydrologic testing on the repository site for standard chemical, radiochemical, tritium, and carbon-14 analyses. Preliminary chloride concentrations were determined for most samples from field measurements.

Results of the standard chemical analyses (Table 3, Pocket) and trace element analyses (Table 4) are available at the present time. The radiochemical and carbon-14 analyses are not complete and the results will be available at a future date.

Most water samples were taken from test holes and wells open to aquifers their entire length. At a few locations on and near the repository site, samples were obtained from sandstone aquifers isolated from shallow unconsolidated deposits. Samples from isolated Kiowa Formation and Stone Corral Formation aquifers were obtained at three locations on the repository site.

Unconsolidated Deposits and Kiowa Formation

The standard chemical analyses show that water collected from shallow unconsolidated deposits and the Kiowa Formation is generally similar, and is usually a very hard calcium bicarbonate type. A few scattered samples indicate a softer sodium bicarbonate type. The similar water types may indicate that water has comparative freedom of movement both laterally and vertically between these aquifers. All water samples from these aquifers range from 250 ppm (parts per million) to 656 ppm in dissolved solids except those from locations 20-8W-12ccb, 20-8W-13ccc, 19-9W-14ccc, 19-8W-34bdd, 19-8W-34cda, and 19-8W-27abb2, and show nothing unusual in their chemical composition.

Water samples from 20-8W-12ccb and 20-8W-13ccc contained total dissolved solids of 1,200 ppm and 1,704 ppm, respectively. Chloride contents are 492 ppm and 770 ppm. These test holes lie within an area of high chloride concentration which has been known for several years. The source of chloride is apparently the surface operations of a nearby active salt mine.

The sample taken at 19-9W-14ccc contained dissolved solids of 1,500 ppm and chloride concentration of 750 ppm. The high concentrations are probably caused by brine from oil wells in the immediate vicinity.

At test hole 19-8W-34bdd, which is near the north shaft of the salt mine on the proposed repository site, and test hole 19-8W-34cda, which is 1/4 mile south of 19-8W-34bdd,

dissolved solids are 54,940 ppm and 3,410 ppm, respectively. Chloride concentrations are 30,900 ppm and 1,860 ppm. Surface operations at the time when the mine was active are very likely responsible for this contamination. Sample No. 70238 discussed in the trace element analyses corresponds to location 19-8W-34bdd.

The sample from location 19-8W-27abb2 will be discussed later.

Stone Corral Formation

Three water samples were obtained from the Stone Corral Formation. Standard chemical analyses indicate the water is of poor quality with total dissolved solids ranging from 5,880 ppm to 6,430 ppm. Sulfate and chloride concentrations are very high, and the water type is sodium chloride. The high sulfate concentration may be explained by the solution of gypsum which is abundant in the formation. The high chloride content may be the result of the considerable depth and low permeability of the Stone Corral Formation in this area. Over most of eastern Kansas water increases in chloride content under similar conditions. It is also possible that small salt deposits within the Stone Corral have been dissolved by the ground water.

At locations 19-8W-26baa, 19-8W-27abb, and 19-8W-27dcc water samples were collected from both isolated Stone Corral and Kiowa Formations. At locations 19-8W-26baa and 19-8W-27dcc the Kiowa samples were calcium and sodium bicarbonate water types and similar to most other Kiowa Formation water samples. However, the Kiowa Formation water sample at 19-8W-27abb was a sodium chloride type and similar in most respects to Stone Corral water. No known oil wells are nearby for the introduction of brine in this area, and even other Kiowa Formation water samples showing chloride contamination do not correlate well in other respects with Stone Corral water. Because the piezometric level of the Stone Corral Formation is as high as the depth the water sample was collected from in the Kiowa Formation, vertical mixing of the water between the two formations during this test is suggested. Open fractures such as those noted within the Kiowa Formation might allow this localized upward movement to take place.

Procedure for trace element analyses

Trace element analyses were performed in the following way (O. K. Galle, Kansas Geological Survey). Upon being received in the laboratory, the water was filtered through a 0.4 μ membrane filter to remove any suspended material. Five hundred ml of the filtered water (to which 10 ml of HCl was added) was then evaporated down to a volume of approximately 10 ml, transferred to a 50 ml volumetric flask, and diluted to the mark with distilled, deionized water. All

trace elements with the exception of strontium, were determined on these concentrated solutions. Strontium was determined on an unconcentrated sample that was diluted 8 ml to 10 ml.

One sample (No. 70238) contained approximately 30,000 ppm sodium. Owing to the high sodium content, a different sample preparation method was used. After the sample was filtered, a 200 ml aliquot was taken and the pH adjusted to 4.5. This was then passed through an ion exchange column containing Dowex A-1 chelating resin. The pH of the column was also 4.5. The purpose of passing the water solution through the ion exchange resin was to extract the trace metals from the highly saline solution. The bivalent trace metals are retained on the resin and the other ions such as sodium pass through the exchange resin and are discarded. After all of the solution had passed through the resin, the column was rinsed with a buffer solution to eliminate any sodium which remained on the resin. The trace metals were then eluted from the resin by passing 1N HCl through the column. The eluant was collected in a 50 ml volumetric flask, diluted to the mark and analyzed in the same manner as all other samples.

All trace elements were determined by standard atomic absorption spectrophotometry methods for water analysis. Additional details on methods can be obtained by reference to the publications by Galle, et. al. (1968) and Galle (1970).

Examination of the analytical results (Table 4) indicates that with the exception of Sample No. 70238, the trace element content of all samples is well below the maximum concentration of the elements found in treated water of public supplies of the 100 largest cities in the United States (Durfor, C.N., and Becker, E., 1964). Largest differences between the Kiowa and Stone Corral Formations are that silica is present in smaller concentrations in the Stone Corral while strontium increases in concentration. Also, lead is present whereas it is not detectable in most Kiowa water samples. Nothing unusual or abnormal in the geology of the area is indicated by the trace element analyses.

UTILIZATION OF WATER

Ground water is the principal source of water supply for municipal, industrial, irrigation, stock and domestic use in the Lyons, Kansas area. All of the large supplies of water are obtained from alluvial deposits in the Arkansas River Valley, Cow Creek Valley or Little Cow Creek Valley near its junction with Cow Creek. Yields of several hundred gallons per minute are generally available in this area and locally yields of more than 1,000 gpm are obtained. Water from these alluvial deposits is generally suitable for most uses, but in local areas it has been contaminated by sodium chloride from salt-plant wastes or possible from oil-field brines.

Table 4.--Trace elements in water from shallow holes.

Field No.	KGS No.	Depth ft.	Mn	Fe	Co	Ni	Cu	Zn	Si	Sr	Li	Pb
20-8W-13ccc	70193	50-55	.007	.044	.022	.015	.009	.068	12.9	1.39	.020	N.D.
20-8W-14cc	70194	29-32	.004	.030	.010	<.001	.006	.060	9.3	.041	.009	N.D.
20-8W-15ccc	70195	30-36	.007	.032	.009	.006	.006	.108	9.2	.035	.008	N.D.
20-8W-20aaa	70217	20-26	.010	.033	.005	.008	.008	.033	10.3	.357	.009	N.D.
20-9W-22aaa	70218	19-25	.008	.034	.010	.014	.011	.051	11.4	.881	.012	N.D.
20-8W-7aaa	70219	79-85	.004	.042	.007	.011	.012	.078	3.9	.668	.018	N.D.
20-8W-18ddd	70220	49-55	.006	.030	.008	.015	.014	.076	8.7	.774	.011	N.D.
20-8W-8aaa	70221	59-65	.008	.025	.007	.011	.017	.083	12.1	.697	.017	N.D.
20-9W-14ddd	70222		.006	.025	.007	.010	.010	.054	10.9	.403	.010	<.01
20-8W-18ccc	70223	49-55	.008	.026	.007	.019	.010	.025	9.2	.630	.010	<.01
19-8W-14ccc	70224	69-75	.008	.034	.009	.006	.007	.017	11.5	.591	.008	N.D.
19-8-31bbb	70225	58-64	.026	.057	<.001	.005	.010	.036	13.5	.881	.032	N.D.
19-9W-13ddd	70226	99-105	.037	.032	.013	.004	.005	.019	9.4	.803	.032	N.D.
19-8W-26ddd	70229	99-104	.011	.033	<.001	.010	.006	.047	14.0	.392	.012	N.D.
19-8W-27ddd	70230	90	.037	.053	.012	.002	.011	.025	11.1	.599	.017	N.D.
19-9W-14ccc-	70231	59-65	.015	.073	.011	.014	.020	.023	11.5	.884	.016	<.01
20-8W-2bbb	70232	99-105	.011	.019	<.001	.002	.006	.011	15.1	.580	.017	N.D.
19-8W-32ddc	70233	79-85	.010	.021	.005	.009	.010	.020	12.5	.543	.017	N.D.
19-8W-24ccc	70234	109-115	.074	.023	<.001	<.001	.007	.009	5.9	.799	.030	N.D.
19-8W-22ccc	70235	119-125	.022	.056	.004	.001	.004	.009	6.6	.524	.019	N.D.
20-8W-1ccc	70237	99-105	.084	.040	.005	<.001	.007	.041	5.2	2.002	.040	<.01
19-8W-34bdd	70238	79-85	.049	.477	<.025	.086	.027	.932	*N.D.	5.912	*N.D.	N.D.
19-8W-28bbb	70239	99-105	.015	.045	.002	.016	.020	.016	9.1	.486	.011	<.01
19-8W-27dcc2	71006	62-74	.073	.089	<.001	.008	.005	.020	4.41	.832	.033	.01
19-8W-27dcc3	71007	266-284	.272	.096	.034	.081	.013	.064	1.39	11.4	.174	.04
19-8W-27aab3	71016	186-198	.067	.168	.042	.071	.017	.023	1.56	14.9	.182	.04
19-8W-26baa3	71017	296-315	.196	.140	.033	.061	.016	.040	1.49	11.2	.187	.03
19-8W-27aab2	71018	90-126	.155	.070	<.001	.013	.010	.027	2.34	1.77	.056	<.01
19-8W-26baa2	71019	106-126	.087	.111	N.D.	.011	.006	.039	3.33	1.09	.034	<.01

N.D. - Not detected

* - Sample unconcentrated due to high Cl concentrations in ppm (parts per million)

The location of the Lyons municipal wells are shown on Figure 11. The locations of 42 industrial, irrigation, stock and domestic wells inventoried during this investigation and the location of 38 test holes drilled by the State Geological Survey are also shown on this figure.

In the remainder of the Lyons area outside the area where water is available from the alluvial deposits in the valleys of Arkansas River, Cow Creek and Little Cow Creek water is obtained for stock and domestic use from Pliestocene silts and sandstones in the Kiowa Formation which underlie the uplands north of the alluvial valleys. The Pleistocene silts generally have a low hydraulic conductivity and yields may range from a few gallons per minute to only a few gallons per hour. The sandstone aquifers in this area are lenticular. These lenticular sandstone bodies may not have great lateral continuity and potential yields of wells from the sandstones may range widely in this area. In an area where little or no sandstone is present water to supply domestic and stock wells is not available. In other areas where thick massive sandstones are present, potential yields up to 100 gpm may be available.

SUMMARY

Bedrock units cropping out and underlying the surface in the report area range in age from the Early Permian Ninnescah Shale to the Late Cretaceous Carlile Shale. Not all the rock units which are present in other parts of central Kansas are present in the report area or at the repository site. Some were never deposited and others were removed during long periods of weathering in post-Permian and post-Cretaceous time. The principal bedrock aquifers in the report area are the Kiowa Formation and the Dakota Formation. Only the Kiowa is present at the repository site. The Tertiary is represented in the area by a soil caliche developed during the period near the end of Cretaceous deposition and pre-Pleistocene deposition.

Pleistocene deposits mantle much of the area. These deposits are fluvial and aeolian in origin. Large quantities of water are available from the fluvial deposits. Smaller quantities of water are available locally from the aeolian deposits in the area north of Cow Creek Valley.

Four test holes were drilled near the corners of the repository site and injection or swabbing tests were made to determine the transmissivity, hydraulic conductivity, and hydraulic potential of the Kiowa sandstone and the Stone Corral Formation. Hydraulic conductivity (K) of the Kiowa sandstones penetrated by the tested holes ranges from 0.76 gpd/ft² to 8.8 gpd/ft². The higher value K was obtained from massive sandstone and the low value from thinly bedded sandstone. Hydraulic conductivity of the Stone Corral ranged from 0.001 gpd/ft² to 6.9 gpd/ft². Most of the water from

the Stone Corral is probably obtained from fractures in the dolomite.

A potentiometric map of the Kiowa Formation indicates a ground-water gradient toward the southwest and closely resembles the potentiometric surface in the overlying Pleistocene deposits. In test hole 2S the hydraulic potential appeared to be anomalously low and was not used in preparation of the potentiometric map. It is concluded that the casing in this test hole was well cemented and that the measurements obtained during the test were valid. The anomalously low potential in this hole may be due to leakage downward through fractures or an old drill hole to some lower rock unit or the sandstone may be very poorly connected to other sandstones in the Kiowa but may have hydraulic connection to a discharge point in the subsurface near where the Kiowa has been eroded out.

The potentiometric surface on the Stone Corral indicates a ground-water gradient toward the southwest. Measurements of hydraulic potential in isolated intervals of the test holes indicate that hydraulic potential decreases with depth. This means that any vertical hydraulic connection will allow water to move from the surface deposits downward and into underlying formations.

Large quantities of water are generally available from the alluvial deposits in Cow Creek Valley and small quantities are generally available from the aeolian deposits north of Cow Creek Valley. Quality of water from these deposits generally is suitable for most uses except in local areas where contamination from salt-producing operations or oil-field brines has occurred in the past.

The bedrock surface slopes generally toward the south and southwest in the area. The Permian surface below the Kiowa slopes generally toward the north. Sandstones in the Kiowa Formation are the principal aquifers in the bedrock units.

RECOMMENDATIONS

Additional hydrologic tests should be made outside the repository site to determine the hydraulic characteristics of the sandstones in the Kiowa Formation and of the dolomite in the Stone Corral Formation. The anomalously low hydraulic potential in test hole 2S indicates a need for more testing in this area. A determination of the cause of the low potential in this area is needed.

As hydraulic potential decreases with depth and water can possibly move downward, it would be advisable to test and understand the hydraulic characteristics of some of the more permeable rocks that underlie the salt body.

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Chapter 2

STATUS REPORT OF SIX MONTH STUDY OF THE SUBSURFACE ROCKS AT THE PROPOSED SITE FOR THE NATIONAL RADIOACTIVE WASTE REPOSITORY AT LYONS, RICE COUNTY, KANSAS

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Introduction

A concerted effort was made during the limited study period to accumulate all the available unpublished and published data previously generated on this area by the petroleum exploration and salt industry in Kansas. This accumulative process as well as the limited time for evaluation of data, preparation of illustrations, and manuscript, imposed serious restrictions on the completeness and quality of the report. There has been inadequate colleague review. For these reasons, this report should be considered as a preliminary status report rather than the complete authoritative study which the storage project merits. As project planning proceeds, continuing studies must be made.

In spite of the substantial number of oil and gas exploratory test holes near the Lyons Site, limited geologic information was available on the section from below the surface rocks to the top of the Pennsylvanian rocks. The two cores taken by the Corps of Engineers in the project area and the suite of "wire-line" geophysical logs on these holes greatly enhanced the quality of the subsurface information at the site. No detailed study of the area had been made prior to this endeavor.

Acknowledgements

Counsel and help was received from a number of people. Some of these are Shirley E. Paul, James L. Wall, Sharon K. Hagan, Robert F. Walters, Doris E. Zeller, Robert L. Dilts, Floyd W. Preston, Gary F. Stewart, Frank W. Wilson, and Kathryn I. Horton.

Culture

The proposed site for the national repository for radioactive waste materials is northeast of the town of Lyons, Rice County, Kansas. Rice County, Kansas includes an area of 720 square miles contained in approximately 20 townships in central Kansas. The county is located at the eastern edge

of the area designated as the Plains Border Section of the Great Plains Province. Population of Rice County is less than 12,250 of which slightly more than 4,300 live in the city of Lyons. As part of the Plains Border Section physiographically, Rice County is included in the erosional transitional belt between the receding High Plains to the west and the broadening Central Lowlands to the east. Most of Rice County is drained by the Arkansas River and its tributaries, Little Arkansas River and Cow Creek. A portion of northeastern Rice County is included in the Smoky Hill River drainage system. Figure 16 shows the topography and the location of the site in the immediate area of Lyons. The altitude at Lyons is about 1,700 feet above sea level.

About 25 inches of rainfall is expected each year in Rice County, fluctuating from low rainfall in January to a normal high in June. Rice County experiences a middle latitude continental type of climate with a moderately wide range of temperature.

A number of railroad lines pass through the county and it is well served by both federal and state highways. U.S. Highway 56 runs east-west through Lyons, and Kansas Highway 14 runs north and south. A number of buried oil transmission pipelines cross Rice County (Fig. 17).

Rice County's principal agriculture is wheat-growing with lesser acreages of sorghum, alfalfa and corn.

Mineral Resources

The mineral resources in the county (excluding groundwater as a mineral resource) consist of salt which has been produced commercially since 1887 and a rich history of oil and gas production since the early 30's.

The active salt mine in the area operated by American Salt Corporation is located about 2 miles south of the city of Lyons. A generalized north-south cross-section, (Fig. 18) through the state of Kansas (Taft 1946) shows the Hutchinson Salt Member in its relationship to the towns of Lyons, Hutchinson, and Kanopolis, Kansas. Each of these towns have a history of salt production.

Rice County has proved to be one of the most prolific oil producing counties in the state of Kansas (Fig. 19). To the end of 1968 more than 272.8 million barrels of crude oil had been produced from its fields and more than 42 billion cubic feet of gas (Beene, 1970). The bulk of the oil and gas production has been from the Arbuckle Group of carbonate rocks of Cambro-Ordovician Age (Fig. 20, Type Log, in Pocket) and from Middle Pennsylvanian rocks. In the immediate Lyons area,

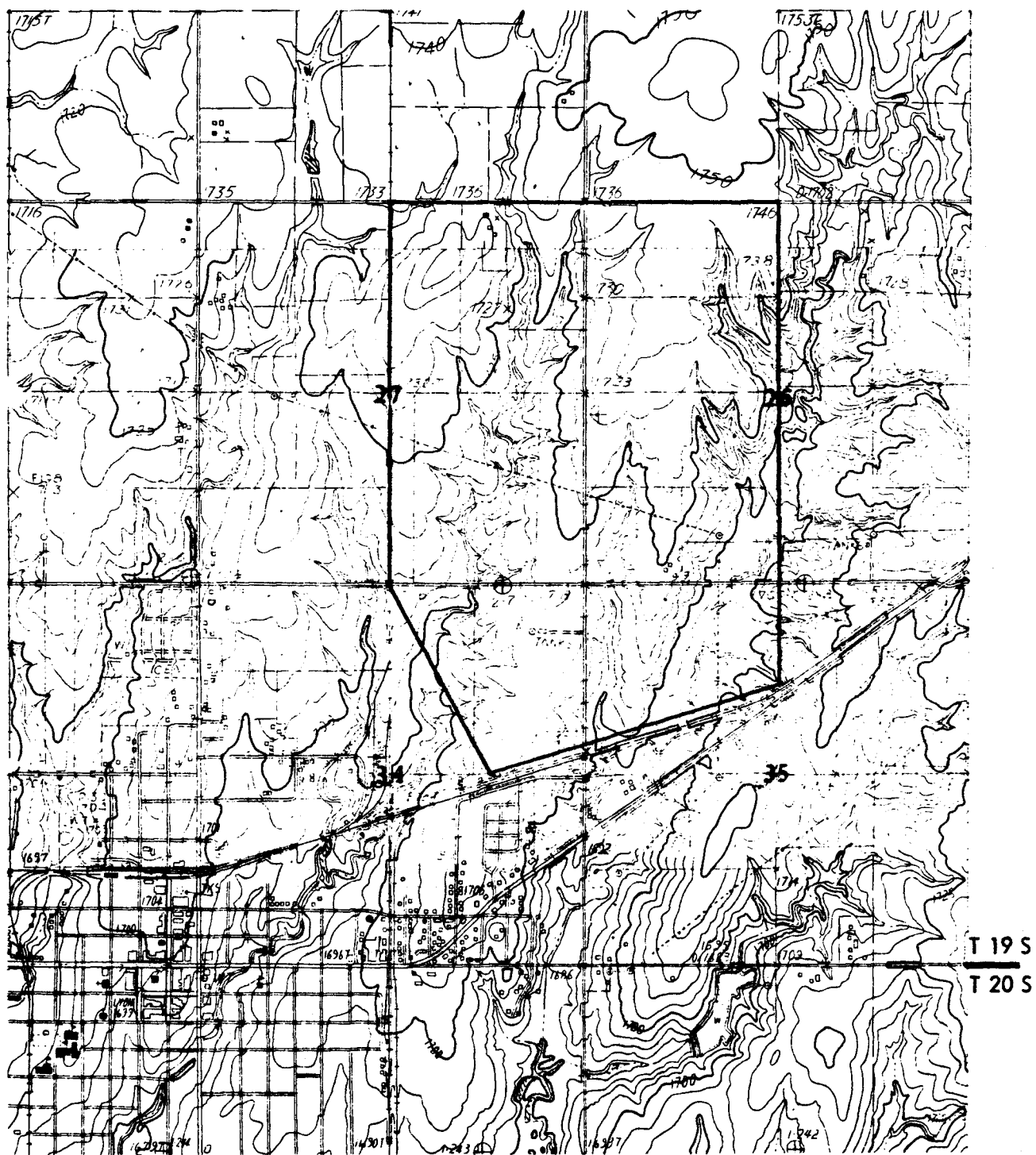


Fig. 16--Topographic map of proposed site.

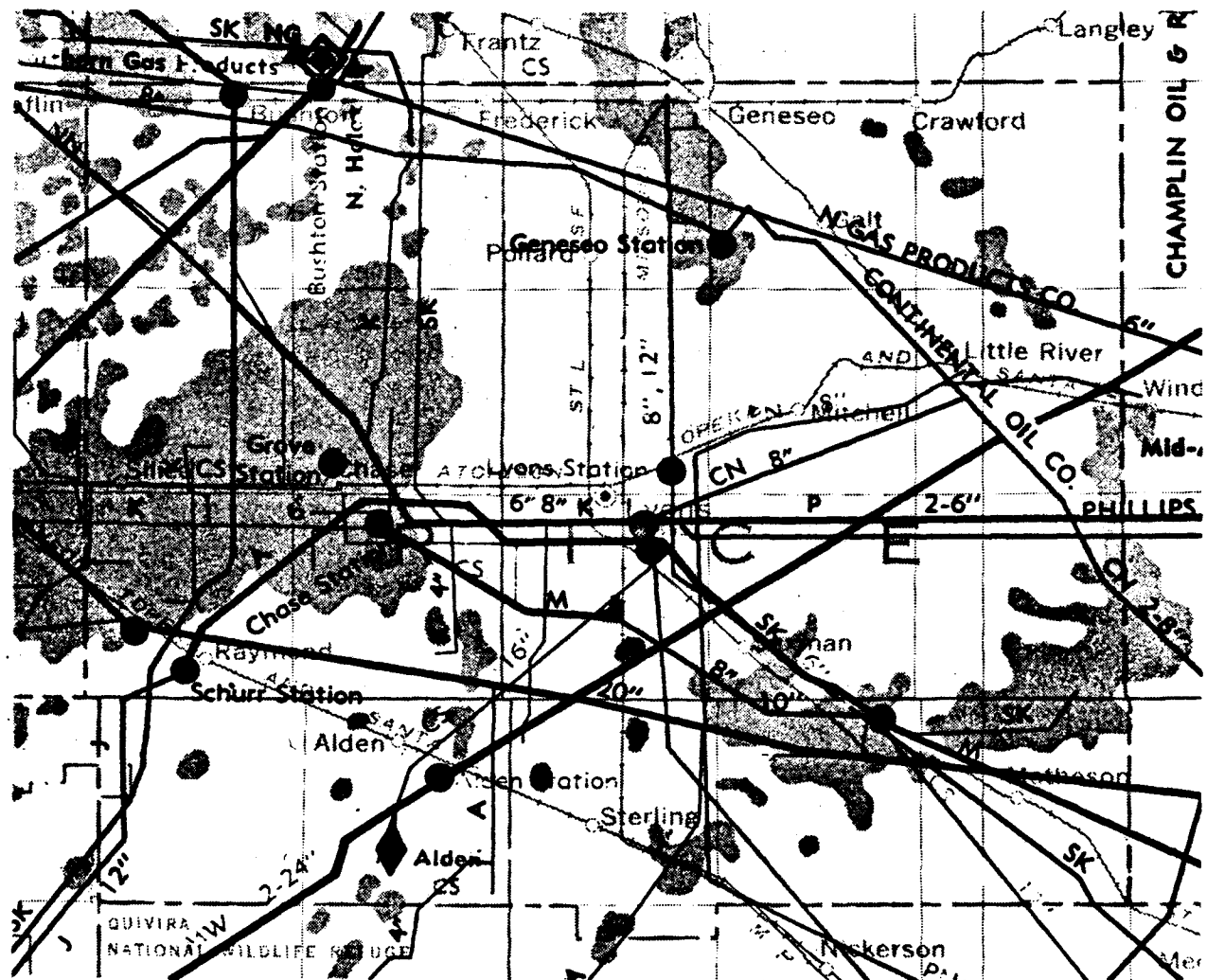


Fig. 17--Pipelines in Rice County (adapted from Oros, 1963).

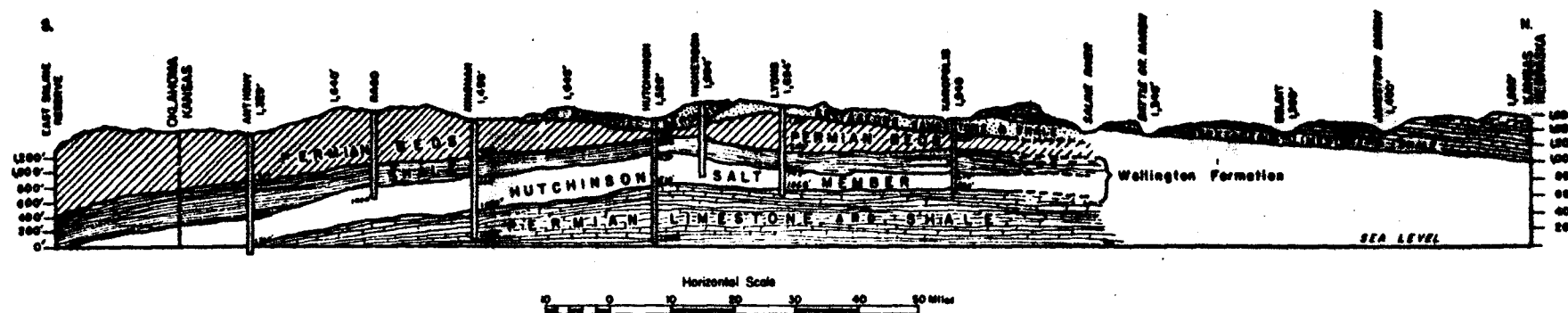


Fig. 18--Generalized north-south cross-section of salt beds from early records (from Taft, 1946).

the largest oil field, the Lyons West field (Fig. 19) produces from early Mississippian sandstone (4.1 million bbls. cum.). The Lyons Townsite pool (21,000 bbls. cum.) within the proposed repository site area consists of one active well. The depleted Lyons Gas Field (Ordovician, Arbuckle and Simpson) located in the southeastern portion and to the south and east of the proposed site has particular structural significance.

Exploration in the city of Lyons in 1888-1889 brought Rice County the distinction of being the first in western Kansas in which commercial deposits of oil and gas were revealed. The first gas well in western Kansas, (the Lyons Gas, Oil, and Mineral No. 1 Lyons), was drilled in the southeastern part of the city (Fig. 21), a few blocks east of the public square (Ver Wiebe, 1939). At a depth of only 1,230 feet from the surface gas was discovered in the Chase Group of Permian Age. This gas was piped to town and used for a "long time" in the Interstate Hotel and in some local residences. A rock salt section was uncovered in this exploratory effort in the thickness of 275 feet at a depth of 780 feet from the surface. This dual discovery served as the beginning of two prosperous industries for the state of Kansas; salt, and oil and gas in this region. Koester (1934) reported the specific location of the discovery well of gas at the NE corner of the SE 1/4, NW 1/4 of Sec. 34, T. 19S, R. 8W. In our opinion this location is incorrect. The location as shown on Figure 21 is judged correct. A second exploratory hole, the Jack Brisbane No. 2 Lyons, was reported drilled about one mile west of the No. 1 hole (in Sec. 33). Brisbane apparently found gas at about the same depth but there are no records available as to whether or not the gas was ever put to use. The Chase gas production has been referred to as the "Lyons" gas field. Several months after the first well had been placed on production it was ruined by "premature" explosion which burned the hotel. The Rice County gas industry then laid dormant for over thirty-five years.

The Lyons Gas Field, east of the city, was officially opened in 1937 in Sec. 35, T. 19S, R. 8W with gas production from the Arbuckle Group (Ordovician) at approximately 3280 feet depth. The structural high was outlined by earlier "core-drilling" to the Chase rocks. "Core-drilling" in the exploration for oil and gas refers to small diameter drilled and unplugged boreholes. The location of these "core-drill" holes (courtesy of Robert F. Walters) are given on Figure 22 (Pocket). The initial capacity of the Lyons (Arbuckle) discovery well was 150 million cubic feet per day of "sour" gas which had to be treated before it could be sold. One sweet gas well in the Simpson (Ordovician) was completed in the field. According to Ver Wiebe (1941), the Lyons pool had 11 producing gas wells which were located on a tightly folded and faulted anticline trending north-south (Fig. 23).

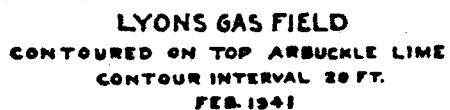


Fig. 23--Structure on top of the Arbuckle in the Lyons Gas Field (after Ver Wiebe, 1941).

Cumulative gas production from the field (abandoned 1960) through the end of 1959 accounted for more than 14 billion cubic feet. To the west of Lyons occurs the most important oil field of the immediate area, the Lyons West Field (Fig. 24). To the end of 1965 the Lyons West (early Mississippian "Kinderhook" field) had 101 producing wells in it and had produced more than 1.9 million barrels of oil. A stratigraphic pinch-out traps the oil. At the end of 1969, there were five secondary recovery and pressure maintenance operations in the Lyons West field (Dilts, SDP 49, 1970). Data on these projects (Table 5, Pocket) include information on the shallow source of water for repressuring, the injection pressures, and results of repressuring.

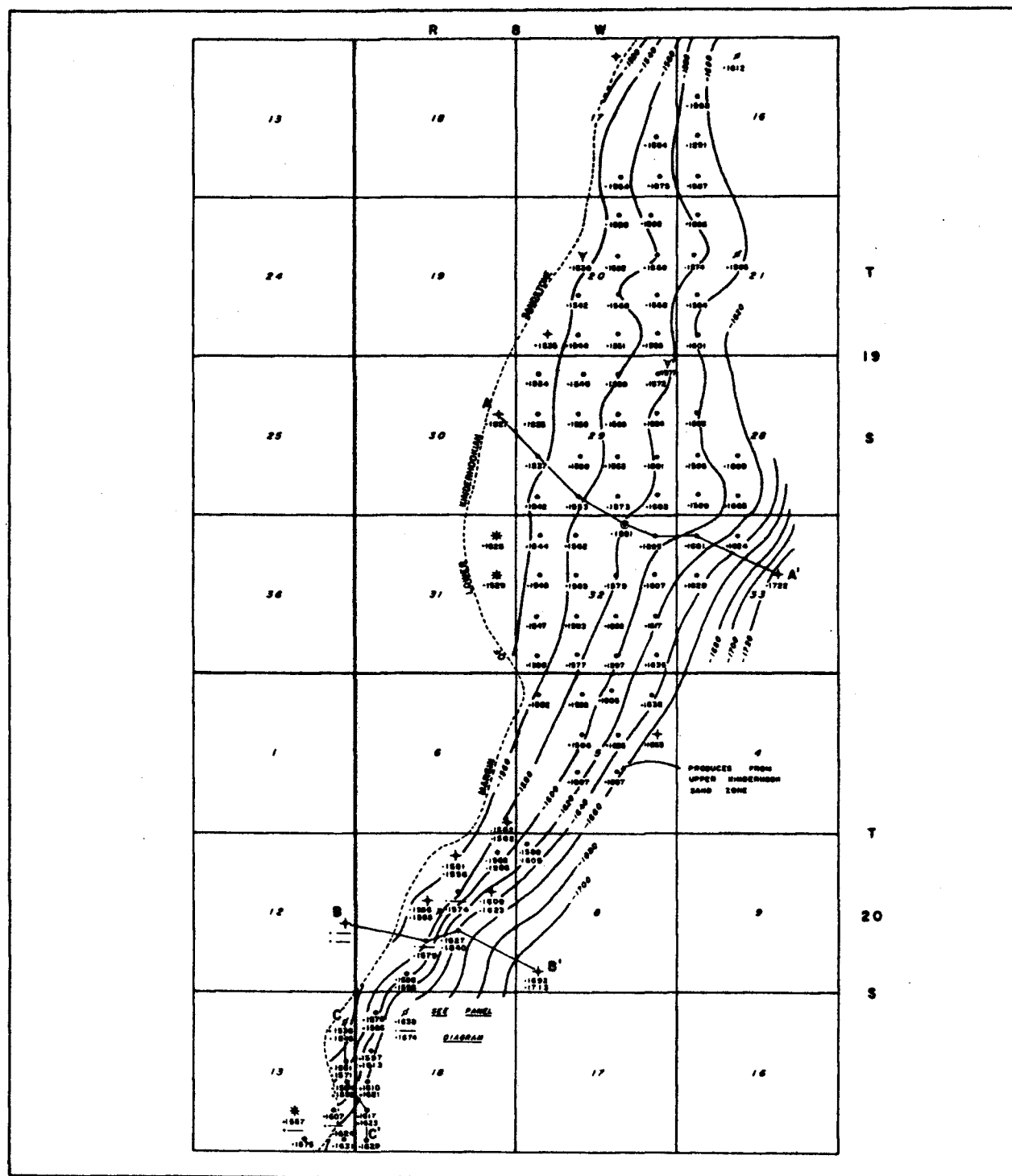
Rice County has been one of Kansas's leading twenty oil producing counties for the last twenty years and considerable amounts of brine (connate water) is produced with the oil. It is common oil field practice here to dispose of this brine either in the producing zone or in deeper porous zones. The disposal zone preferred by most operators is in the Arbuckle Group of Ordovician Age.

The proposed Lyons storage site is located in the center of an important active oil-, gas-, and salt-producing area of Kansas.

Source and Quality of Geological Data

Knowledge of the geological history of the deeply buried rocks here stems from a vast amount of geologic data accumulated during the search for oil and gas. Geological information on the rock section from the surface rocks to the top of the Pennsylvanian carbonate rocks is meager. Pennsylvanian rocks are found at a depth of approximately 2,000 feet in the county. Few radioactivity logs or electric logs were run in the shallow salt-bearing section of the upper 2,000 feet of section. On the type log (Fig. 20, Pocket), gamma ray-neutron characteristic "kicks" on the graphs are unique for each lithology. Limestone is abbreviated ls. and shales abbreviated sh. in the nomenclature column. The Hutchinson Salt (from about 800 feet to 1,080 feet on this log in Sec. 20, about 2 miles NE of Lyons) is easily discernible in this type of logging. Gamma ray-neutron logs are especially useful in delineating the salt section and when available were used in preference to other types of logs in preparation of subsurface data in this report.

Logging techniques utilizing the unique electrical and radioactive characteristics of stratified sedimentary rocks were not in general use in Kansas until after the depression years. Therefore records of the early wells in the Lyons area are those kept by the drillers. These are descriptions of the types of rock material encountered during the drilling.



KEY

- PRODUCING OIL WELL
- DISCOVERY WELL
- ⊘ ABANDONED OIL WELL
- ⊘ TEMPORARILY ABANDONED WELL
- ★ GAS WELL
- ▽ SALT WATER DISPOSAL WELL
- ⊕ DRY HOLE

SCALE



LYONS WEST FIELD, Rice County, Kansas

KINDERHOOKIAN SANDSTONE STRUCTURE
CONTOUR INTERVAL - 20'

BY

ARLEN E. EMM
NOVEMBER, 1964

Fig. 24--Map of the Lyons West field showing the stratigraphic trap formed by westward pinch-out on the Central Kansas Uplift.

Early exploration for salt provided only a limited number of cores. For these reasons the quality of control points on the various structural maps and isopachous maps in the pocket of this report is of a high degree of reliability in those fields that are of more recent vintage. A lower degree of reliability prevails in such areas as the now abandoned (1960) Lyons Gas Field. The locations of all known holes regardless of depth are shown on all structure and isopachous maps, although some were not used in contouring because of lack of reliable geologic data. The work maps showing control points are filed with the material accumulated for this project.

The steel casing in some early wells must certainly have long since deteriorated. The very real possibility exists that, in spite of our careful checking of all available well records and history of exploration in the county, other wells have been drilled, plugged or abandoned and not plugged and were not recorded. The old "core-drill" holes near the site (Fig. 22, Pocket) certainly were never cased or plugged. In all probability, they have closed up during the elapsed time since being drilled and do not pose a threat to the integrity of the site.

Regional Setting

The proposed location of the repository site is on the southeast flank of the Central Kansas Uplift. The Central Kansas Uplift (Fig. 25) is the dominant structural feature in central Kansas. It is of post-Mississippian to pre-middle Pennsylvanian age. The dominant pre-Mississippian structural feature (Fig. 26) of the area is the Central Kansas Arch which connects the Ellis Arch with the Chautauqua Arch. A west-east cross-section (Fig. 27) from the Central Kansas Uplift across the Nemaha Anticline (Edmond and Goebel, 1954) in an area somewhat north of Rice County shows the overlap of Pennsylvanian rocks over lower Paleozoic rocks onto the uplifts. Other cross-sections centering on Lyons are indexed in Figure 28. These cross-sections (Figs. 29, 30, 31, 32, 33) are presented as various scales, with the largest scale (Fig. 33) presenting the most detail on the rock sequence containing the bedded salt deposits. Details of the structural and stratigraphic development of the Salina Basin and part of the Sedgwick Basin are given in Lee (1956).

Stratigraphy

The stratigraphic units recognized in Rice County are presented in Figure 20, a type log of Rice County. The location of the general-type log is in Sec. 20, T. 19S, R. 8W, a few miles northwest of the proposed site. Known oil and gas zones, gas storage zones and salt-water disposal zones are indicated. Unfortunately, the gas zone from the Chase Group was omitted.

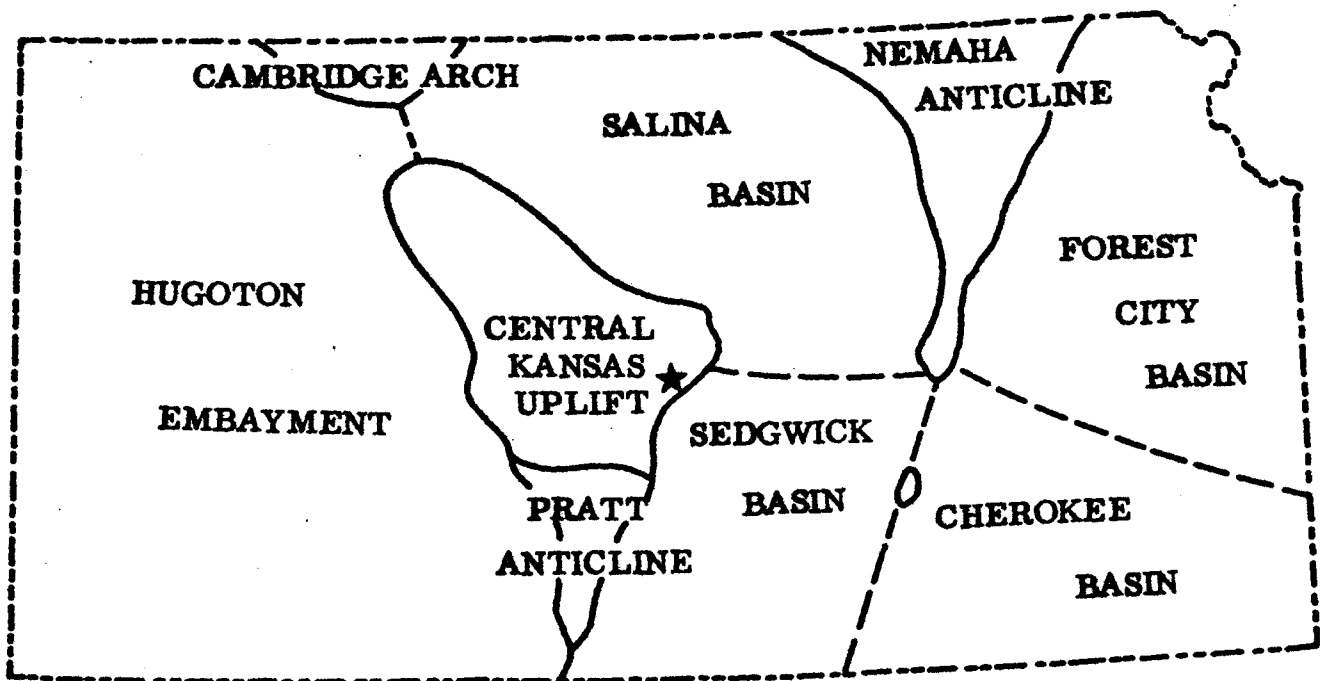


Fig. 25--Post-Mississippian structural provinces in Kansas.

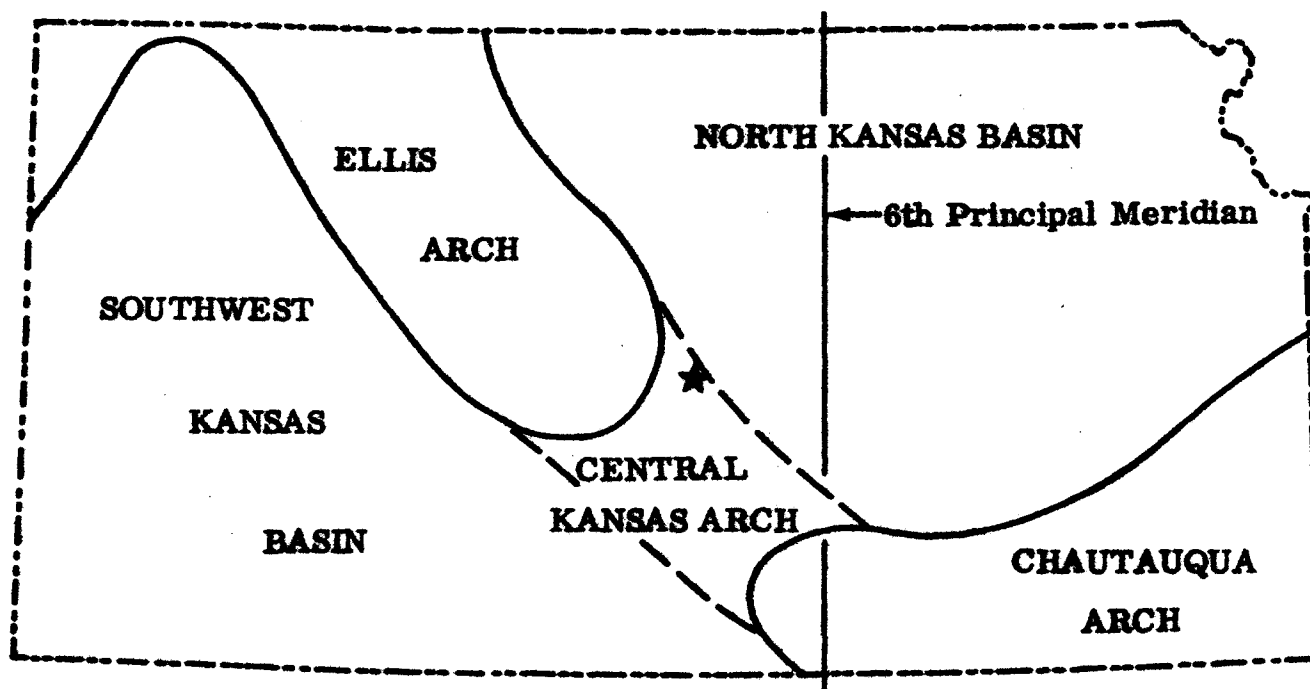


Fig. 26--Pre-Mississippian structural provinces in Kansas. The site is located on the boundary between the Central Kansas Arch and the North Kansas Basin.

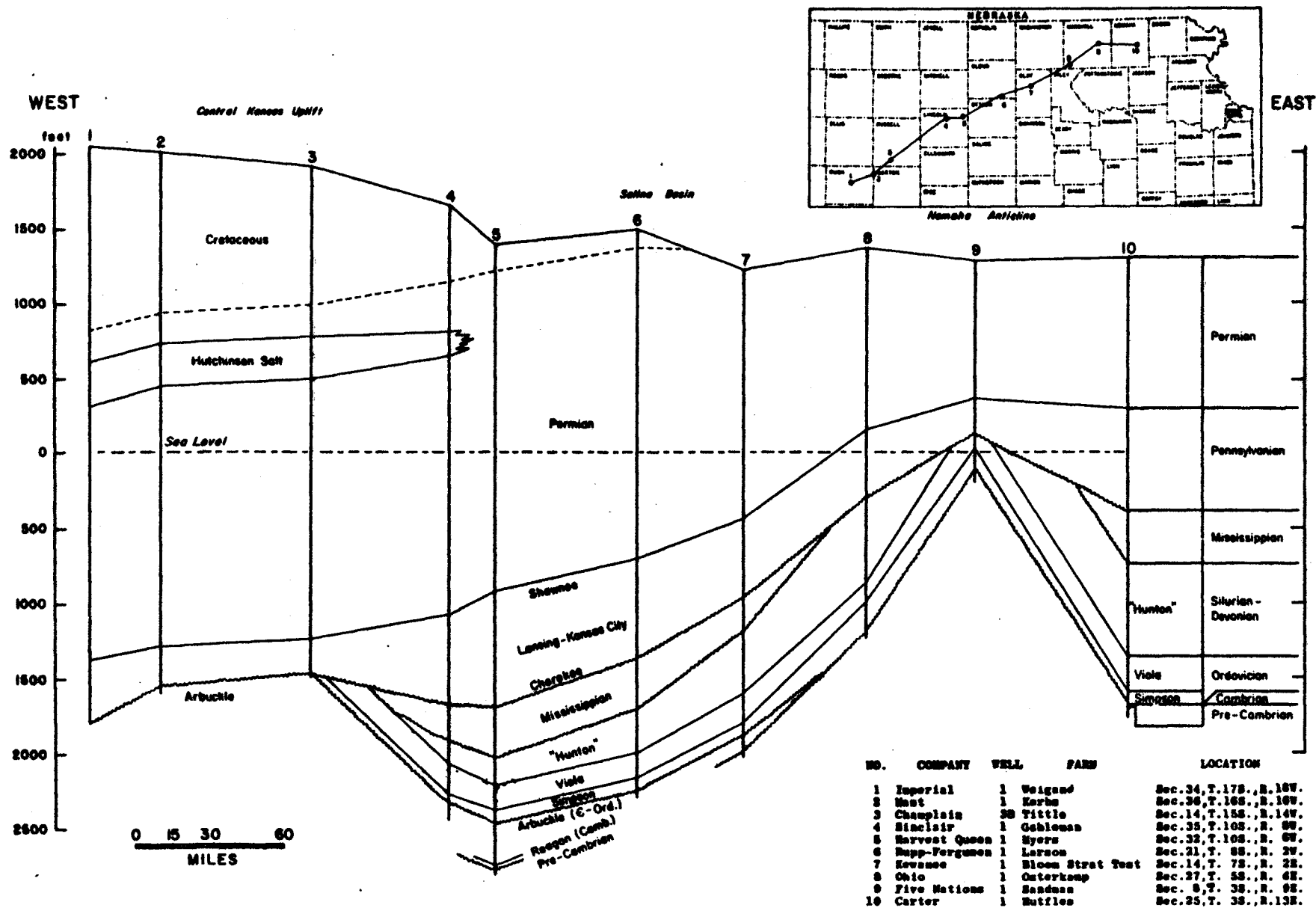
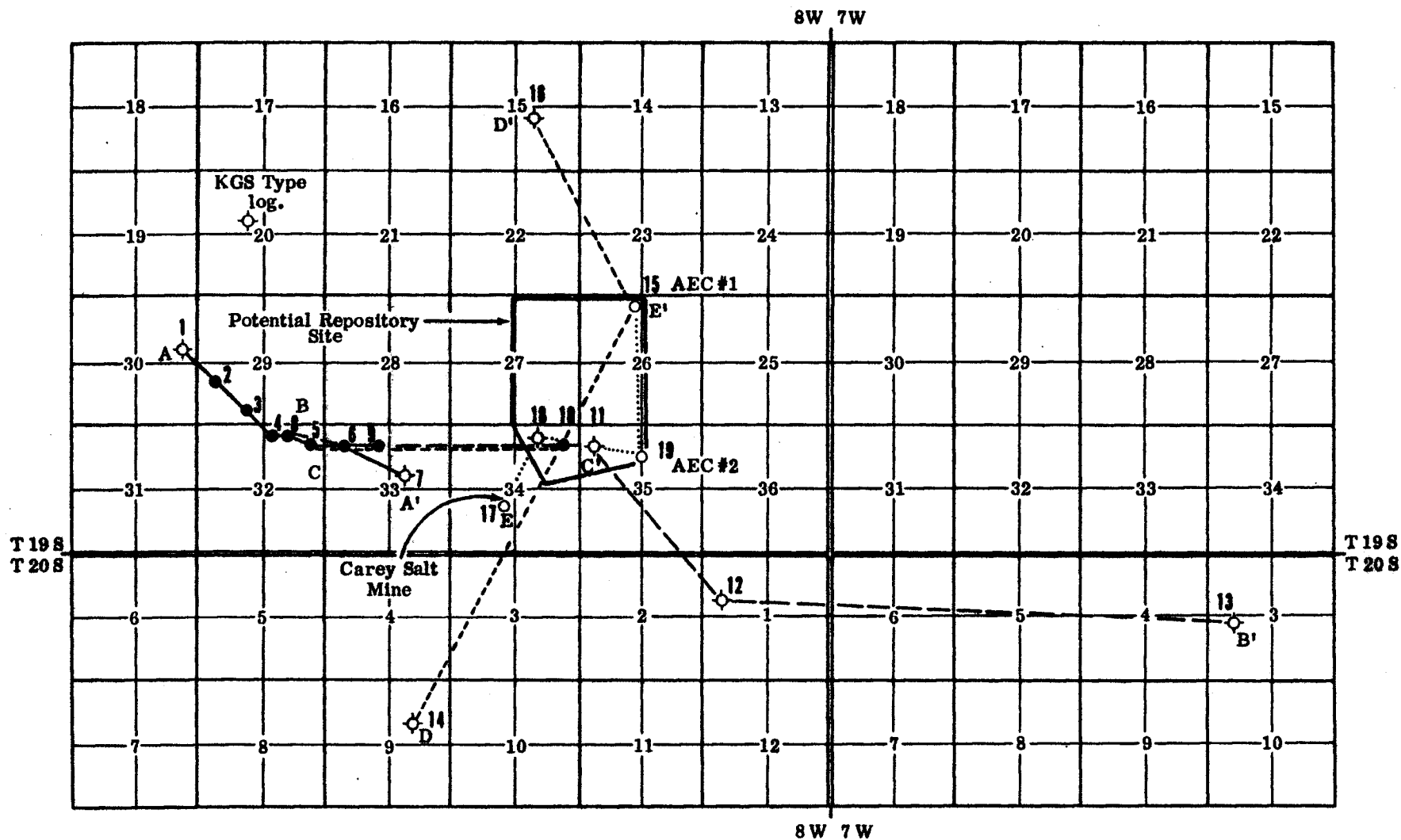


Fig. 27--Cross-section from Rush County to Nemaha County, Kansas showing stratigraphic units and thickness from the Central Kansas Uplift across the Salina Basin and over the Nemaha Anticline.



INDEX MAP TO CROSS SECTIONS

Well Numbers		Portion of Section
A-----A'	1 to 7	Pennsylvanian to Ordovician
B-----B'	8, 9, 11-13	Base of Salt to Ordovician
C-----C'	5, 6, 10, 11	Surface to Chase Gp. (Perm.)
D-----D'	14, 10, 15, 16	Surface to Chase Gp. (Perm.)
E.....E'	17-19, 15	Salt Section to Chase Gp. (Perm.)

Fig. 28--Index map to cross-sections centering on Lyons, Kansas.

Precambrian crystalline rocks or the Rice Formation (Precambrian?) of indeterminate thickness occur in the county at depths ranging from 3,700 feet on the west to 4,100 feet on the east. Precambrian rocks (Fig. 34) west of the town of Lyons (Scott, unpublished manuscript, 1968) are quartzite "granite" and schists. At Lyons and to the north-east, meta-sedimentary rocks older than late Cambrian age are recognized. This unit of possible Precambrian age is known as the Rice Formation. Regionally extensive in the Salina Basin, the Rice Formation is composed of feldspatic sandstone, red and green sandy micaceous shale which is unconformably overlain by the LaMotte Sandstone of late-Cambrian age. The Rice Formation attains a thickness of more than 700 feet in central Ellsworth County to the north of Lyons and locally in the Salina Basin exceeds 1,600 feet in thickness. Beneath Lyons, the Rice Formation is believed to rest upon Precambrian crystalline rocks but no borehole has yet provided verification of this belief. In Rice County, Scott reports minor amounts of limestone and dolomite interbedded with feldspatic sandstone and shale in the Rice Formation. The Cambro-Ordovician Arbuckle Group and the Rice Formation are not separated by an impermeable unit. The Rice does not take brine from disposal wells as readily as the Arbuckle.

The LaMotte or Reagan Sandstone (Upper Cambrian) with a thickness of 0-40 feet lies unconformably above the Precambrian rocks (Fig. 20). The Cambro-Ordovician Arbuckle Group made up of cherty dolomite exceeds 150 feet in thickness. The overlying Simpson Group (Middle Ordovician) consisting of sands and shales, (0 to 50 feet in total thickness) is set off by unconformities below and above. The Middle Ordovician Viola Limestone (0 to 50 feet thick) seemingly is conformable on 0 to 40 feet of Maquoketa Shale (Upper Ordovician). No Silurian, or Lower or Middle Devonian rocks are known in the county. The Devonian-Mississippian sequence (0 to 85 feet thick) is unconformable above the Upper Ordovician rocks. The "Misener Sandstone" or "Kinderhook sands" are erratically occurring basal units of the Chattanooga Shale of late Devonian-early Mississippian age. Mississippian marine carbonate rocks range from 0 to 200 feet in thickness in the eastern one-third of the county. The zero Mississippian (excludes Chattanooga) isopachous line (Fig. 35) marks the limits of the major post-Mississippian structural provinces. The "Pennsylvanian basal conglomerate" marks the angular unconformity (Fig. 20) between early Middle Pennsylvanian marine rocks and older Paleozoic units. About 1,200 feet of cyclic marine and non-marine rocks make up the Pennsylvanian sequence in the county. Lower Permian rocks are disconformable upon the Pennsylvanian. The Gearyan Stage (Admire, Council Grove and Chase groups) comprises a sequence of up to 750 feet of dominately carbonate rocks. An evaporite and red shale sequence of the Summer Group (Lower Permian) includes below, the Wellington Formation (about 650 feet thick) with its middle rock salt member, the Hutchinson Salt and above,

DISTRIBUTION OF PRECAMBRIAN ROCKS
IN RICE CO. (adapted from Scott, Denison,
and Lidiak, Unpubl. manuscript 1968)

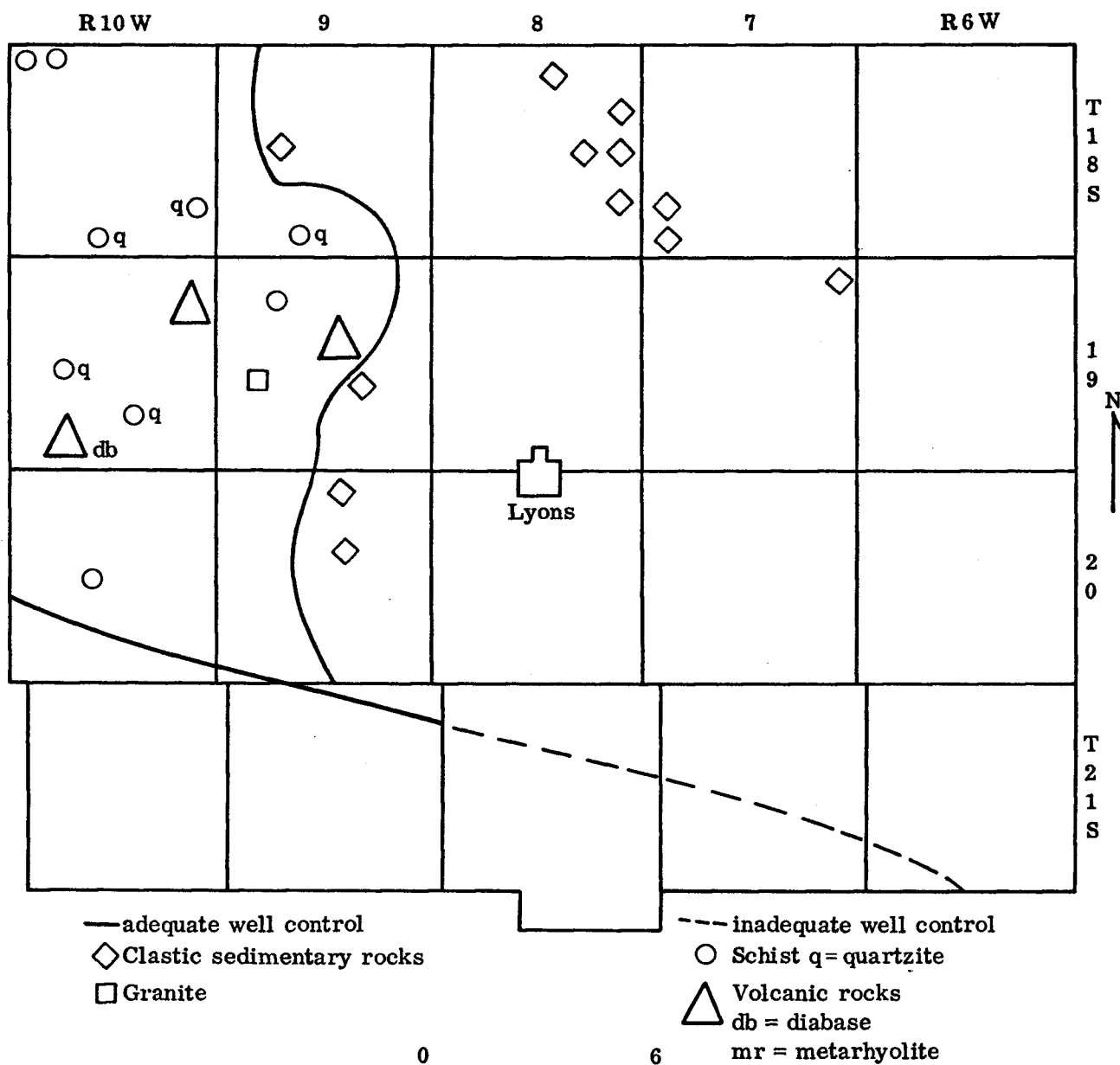


Fig. 34--Distribution of Precambrian rocks in Rice County.

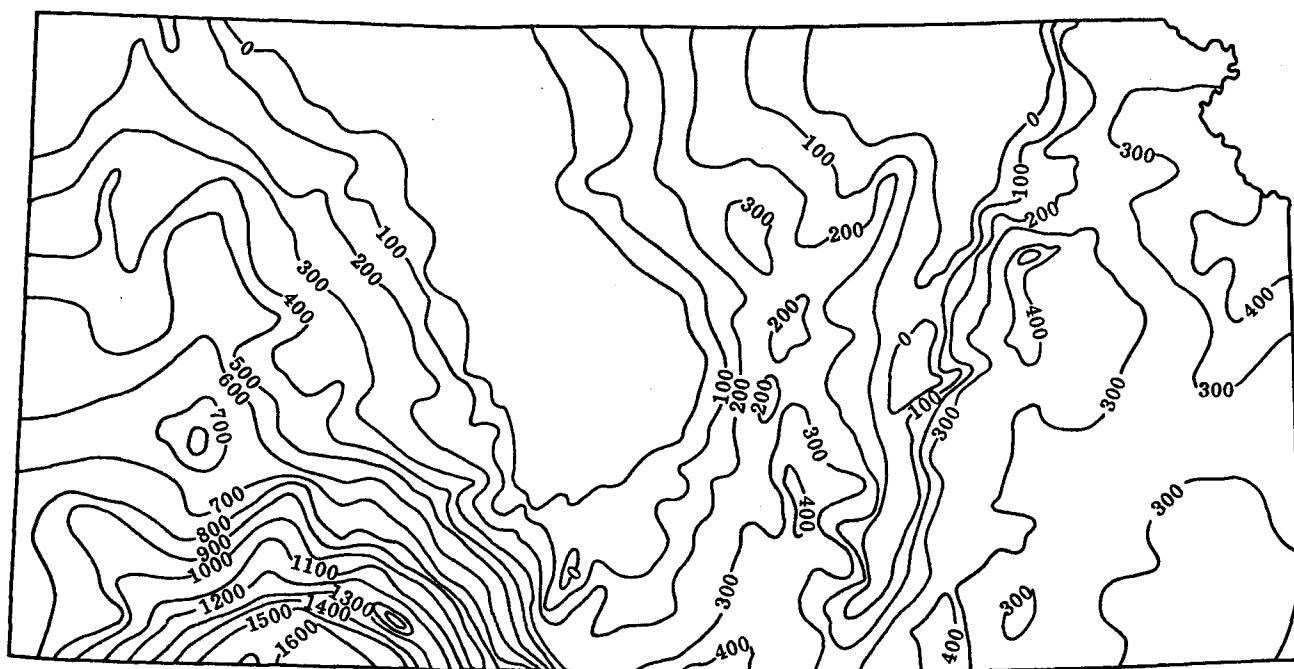


Fig. 35--Isopachous map of Mississippian rocks (excludes Chattanooga-"Kinderhook") in Kansas (from Goebel, unpublished manuscript, 1971).

the Ninnescah Shale with the top marked by the Stone Corral Formation. The Lower Permian, Harper Sandstone (up to 200 thick) and Cretaceous Cheyenne Sandstone, Kiowa Shale and Dakota Formation are recognized in the county. The lithologic description of the AEC Core Hole No. 1 (Fig. 36, Pocket) as plotted by Robert F. Walters provides details of the Cretaceous and some of the Permian rocks present at the proposed site.

The characteristics of the rock section from the top of the Chase to the surface at Lyons are more pertinent to the proposed storage projects than the deeply buried rocks. Therefore more details are herein given.

The Hutchinson Salt Member is included in the rocks of the Wellington Formation. Rocks of the Wellington Formation are poorly exposed in a broad north and south trending strip which extends entirely across the state of Kansas from Summer and Cowley counties on the Oklahoma boundary line to Washington and Marshall counties on the northern boundary with Nebraska. The Wellington Formation was named by Cragen in 1885 for exposures near Wellington, Summer County, south-central Kansas. The Wellington Formation includes all the beds above the Herington Limestone Member of the Nolans Limestone and below the Ninnescah Shale.

Surface exposures of the Wellington consist of gray to greenish gray somewhat silty shales having some conchoidal fractures. There are some beds of brownish red, maroon and purple shales particularly in the upper part of the formation and many of the shale units are somewhat calcareous. Numerous thin and lenticular silty limestones, generally less than 15 feet thick and dolomitic, occur throughout the section and a few discontinued beds of gypsum are also exposed. The thick section of salt which is exploited in the subsurface, is of course removed in surface exposures. Solution of this salt and gypsum at or near the surface has produced rather steeply dipping small scale structures at many localities. Swineford (1955) reported that beds of middle Wellington gypsum are exposed in the vicinity of Wichita in Sedgwick County, southeast from Rice County. There is some indication that the Hutchinson Salt grades into gypsum toward the south and east (Bass, 1929, p. 101), that the original margin of the salt basin passed through Summer County (Bass, 1926, p. 94) and that the city of Wichita is not far from the margin. A remnant of a thin-bedded gypsum is exposed in a stream bank (Sec. 3, T. 27S, R. 1E) in Sedgwick County. Thinly laminated green and gray shales and calcareous shales assigned by Swineford to the Middle Wellington Formation crop-out in a stream bank (Sec. 15, T. 24S, R. 1E), in Harvey County. This is one of the lowermost sections in which the brine shrimp (Cycicus) is found.

At the outcrop, the uppermost part of the Wellington section is characterized by numerous thin beds of earthy argillaceous limestone and dolomite. It is at the top of the Wellington Formation of Kansas at which the principal change in color from gray to red takes place. This is marked by the Milan Limestone Member.

A detailed study of the Wellington Formation which outcrops in south-central Kansas was made by Ver Wiebe (1937). He reported that only the Hollenberg Limestone (a limestone 50 feet above the base of the Wellington) is recognized with confidence in the subsurface west of the outcrop. Ver Wiebe distinguished five zones in the subsurface based on lithologic changes which he correlated with the outcrops. These five zones in descending order are: "upper gray beds", "red beds", "middle-gray beds", "salt beds", and "anhydrite beds". Lee (1956) was able to recognize Ver Wiebe's units in the subsurface in the Salina Basin. He noted that the top of the Nolans Limestone of the Chase Group, the first carbonate of consequence below the Wellington, was a definite reference datum. The contact of the "anhydrite beds" with the overlying "salt beds" is transitional. Also the contact of the salt beds with the "middle-gray beds" is transitional.

The thick beds of salt in the Hutchinson Salt Member are clearly revealed by gamma ray logs and inferentially by comparison in electric logs. Lee found it convenient to divide the Wellington Formation into three members in the subsurface; the "anhydrite-beds" of Ver Wiebe at the bottom the "salt-beds" or Hutchinson Salt Member in the middle and an unnamed member at the top comprising the "middle-gray beds", "red-beds" and "upper-gray beds" of Ver Wiebe's classification. These anhydrite beds at the base of the Wellington (known also as the Pearl Shale) consist of a sequence of gray shale interbedded with anhydrite beds. As revealed by the AEC core holes, No. 1 and 2 taken at the proposed site, the Hutchinson Salt Member, the "salt-beds" of Ver Wiebe, is an evaporite zone consisting of salt (halite interstratified with beds and laminae of anhydrite, and probably co-precipitated mixtures of both. Lee reported that the salt beds are believed to thin somewhat irregularly toward the margins of the basin where together with the anhydrite they intermingle with shale washed into the basin from a low border area. Lee felt that the salt and much of the associated anhydrite near the outcrop belt had been dissolved by surface waters for a distance of "20 to 30 miles downdip." In the areas of the outcrop, removal of the salt has caused slump structures in the overlying cover of insoluble rocks. Lee noted that the combined thickness of Wellington rocks above and below the salt sequence (exclusive of the Hutchinson Salt Member) is essentially constant whatever the thickness of the salt. With this evidence Lee proposed that the salt basin must have been formed by downwarping in the

area after the deposition of the "anhydrite beds" of Ver Wiebe and ceased to develop after the deposition of the salt. Lee theorized that inasmuch as the thickest salt beds and therefore the area of greatest downwarping overlies, in part the crest of the previously rising Central Kansas Uplift that it was clear that the arching of the uplift was interrupted at this time if not earlier by the downwarping of the salt basin. Lee reported that inasmuch as the unleached salt areas show no definite thinning toward the southeast it seems probable that at least half of the original salt body has been lost by erosion and leaching. Dellwig in Chapter 3 of this report, discusses the extent of the salt basin.

Sinkholes, Solution, and Salt Front

The solutional history of the eastern edge of the Hutchinson Salt is important to the integrity of the proposed storage site. Sinkholes, undrained depressions and other subsidence features are relatively common along the solution front of the Hutchinson Salt where it occurs in the shallow subsurface in east-central Kansas. Geological studies available to appraise this question include [The Wellington Formation of Central Kansas] Walter A. Ver Wiebe, (1937) and [The Petrography of Upper Rocks in South-Central Kansas] Ada Swineford, (1955). Another important reference is [Kansas and the Nation's Salt] Robert Taft, (1946). The general belief of these workers is that the salt beds extended farther eastward and that the present eastern boundary is largely the edge left by the dissolving away of the eastern portion. During mapping in the field Ver Wiebe noticed that the beds at the horizon of his Annelly gypsum (in the middle unit within the salt section) and those above it were characterized by local deformation. He mapped, in many cases, dips ranging between 15 and 30 degrees at the surface. It was Bass' suggestion that the sharper eastern edge of the salt has been produced by the fact that the original salt deposit was subjected to erosion; the edges therefore do not mark the original shoreline of the salt that was first laid down. A possible cause of this effect was cited as the solution of the salt by groundwaters followed by circulation of resulting solutions; the original beds would therefore have extended further eastward.

North of Great Bend in Barton County (west of Rice County) is located the Cheyenne Bottoms. This surface feature considered by some early workers to be the result of solution of beds (salt? or chalk?) at undetermined depths and subsequent subsidence. Fent (1950) however, suggested that the Cheyenne Bottoms are the result of emplacement of thick Pleistocene alluvial fill in an earlier Pleistocene valley. As such its origin would have no bearing on the proposed site.

Wilson (1971) described subsidence affecting a newly constructed section of Interstate Highway 70 in western Russell County. This is nearly a hundred miles west of the solution front of the Hutchinson Salt and about 50 miles west of Lyons. Communication along abandoned oil well holes established that sinking had occurred in a range of from 9 to 20 feet at the locality. Subsidence here began in 1954 and additional study recently has showed a sinking rate of about a foot a year. Wilson concluded that the subsidence resulted from solution of salt by fresh water flowing downward from the Dakota or Cheyenne Sandstones either through or along the side the well casings. The dissolved salt he suggests was probably being discharged into the former producing horizons at a depth of approximately 3,000 feet here. An area of 1,000 feet in diameter was found to be subsiding. Well log analysis led him to the conclusion that approximately 50 feet of upper salt was missing but that no cavity existed. Apparently, then, the overlying strata had sagged as the salt was dissolved.

Thickness and Extent of Salt Section

Kulstad's (1959) map of the Hutchinson Member of the Wellington Formation (Fig. 37, Pocket) indicates a thickness in Rice County of from less than 250 feet to more than 400 feet. Although Kulstad's map was published in 1959, the map was prepared in the middle 50's. It does not include the drilling which accompanied the surge of LPG storage projects in salt. Kulstad's work map (Fig. 38) shows the low level of reliability of geological data along the eastern edge of the salt in McPherson County. Our isopachous map of the area in the vicinity of Lyons (Fig. 39, Pocket) depicts the salt section of slightly more than 250 feet in AEC Core Hole No. 2 to more than 320 feet to the southwest and east. The salt section thins over the Lyons (Ordovician) Gas Field (Sec. 35) within the study area; the salt section is generally thicker toward the southwest.

The percentage of salt to non-salt in the core holes is in the range of 70% to 75% salt and from 30% to 25% non-salt. Kulstad's 1959 map indicates an excess of 80% salt near Lyons. Also, a band of greater than 80% salt trends northwest-southeast of Lyons.

On Kulstad's thickness map the zero line of salt is generally north-south through McPherson County. Probably this is incorrect. In sections 29 and 30, T. 19S, R. 4W, McPherson County, the salt section is utilized by the National Cooperative Refinery Association, Cities Service Oil Company, and Skelly Oil Company for liquified natural gas storage. This location is approximately 36 miles east of the proposed repository at Lyons. At the LPG storage sites, the salt section is encountered at about 400 feet from the surface and is more

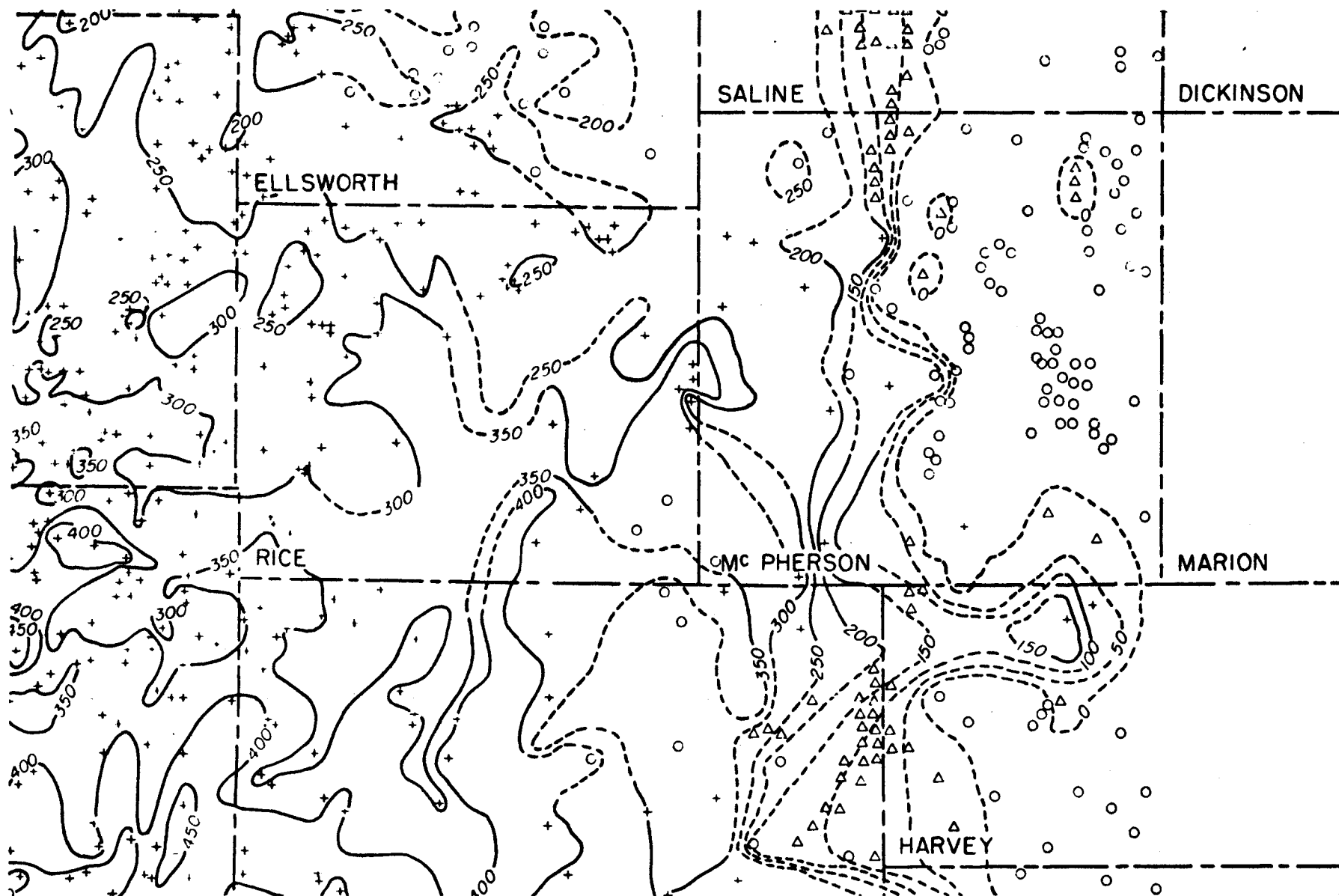


Fig. 38--Map showing thickness of salt in area of Rice County. Circular control points indicate driller's logs. Note general absence of salt in eastern McPherson County (from Kulstad, unpublished manuscript, 1962).

than 250 feet thick. Progressively eastward from this site to Range 1E (the eastern boundary of McPherson County, a distance of about 25 miles) a thinner salt section is found closer to the surface. In Sec. 27, T. 19S, R. 1E it is at least 100 feet thick. East of Range 1E, fresh water is reported in the Chase Group of rocks which outcrop here.

Erosion has removed an estimated 900 feet of Permian rock (above the Chase) and younger rocks between the proposed repository site and the farthest eastward subsurface preservation of the salt section.

Seismology

The proposed repository site in central Kansas is in an area commonly referred to as part of the Continental Stable Interior. Here earthquakes are recorded as infrequent and of low intensity. The site lies within Zone 1 (expected minor damage) according to Algermissen (1969). Merriam's 1963 map, (Fig. 40) shows the relationship of Kansas earthquakes epicenters to major Pre-Desmoinesian-post-Mississippian structural features. Merriam reported that only 43 earthquakes have been recorded since 1811 in Kansas and only 24 of these had epicenters inside the state borders. Of interest in the illustration is the location of only two epicenters (1932, and 1942) on the Central Kansas Uplift, in Ellis County, to the west of Rice County. Both of these were I to III or low intensity (in Mercalli units). To the east of Lyons, in 1927 at McPherson in McPherson County, an earthquake of an intensity of IV to VI is recorded. Dellwig (1956) reported a minor earthquake in Barber County, Kansas, on the border with Oklahoma. A history of the earthquakes having occurred in Kansas seems to indicate that they have not been numerous nor frequent. They are recorded back to 1811 but this is a relatively short period of time in which to measure the regularity of earthquakes. These records may give an erroneous impression.

As part of the Continental Stable Interior of the United States, Kansas probably was never subjected to as intense earthquakes as those known in the mobile belts of the Continental crustal rock (Merriam, 1963). The reported focal depths of earthquakes which have affected Kansas in the past are relatively shallow ranging from approximately 16 to 38 miles. The hypocenters seemingly were located above the Mohorovicic discontinuity within the granitic crustal section. Available data seems to indicate that the Lyons site is relatively free of destructive earthquakes.

Records of Faulting

Some authors (Merriam, 1963 and Cole, 1962, Ver Wiebe, 1939, Brewer, 1965) have mapped faults in the Precambrian and or Paleozoic section in Rice County near the vicinity of the proposed site. Merriam's 1963 map (Fig. 41) showing the location

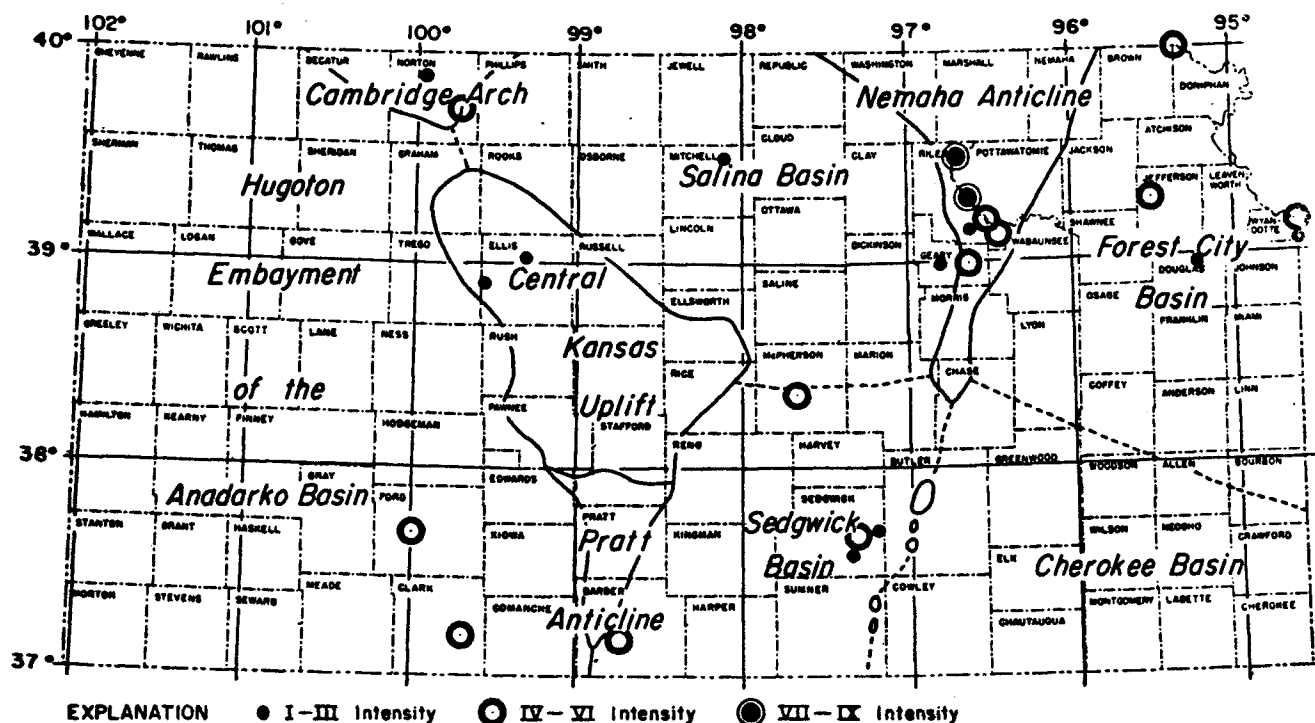


Fig. 40--Map showing the relationship of Kansas earthquake epicenters to major Pre-Desmoinesian-post-Mississippian structural features (from Merriam, 1963).

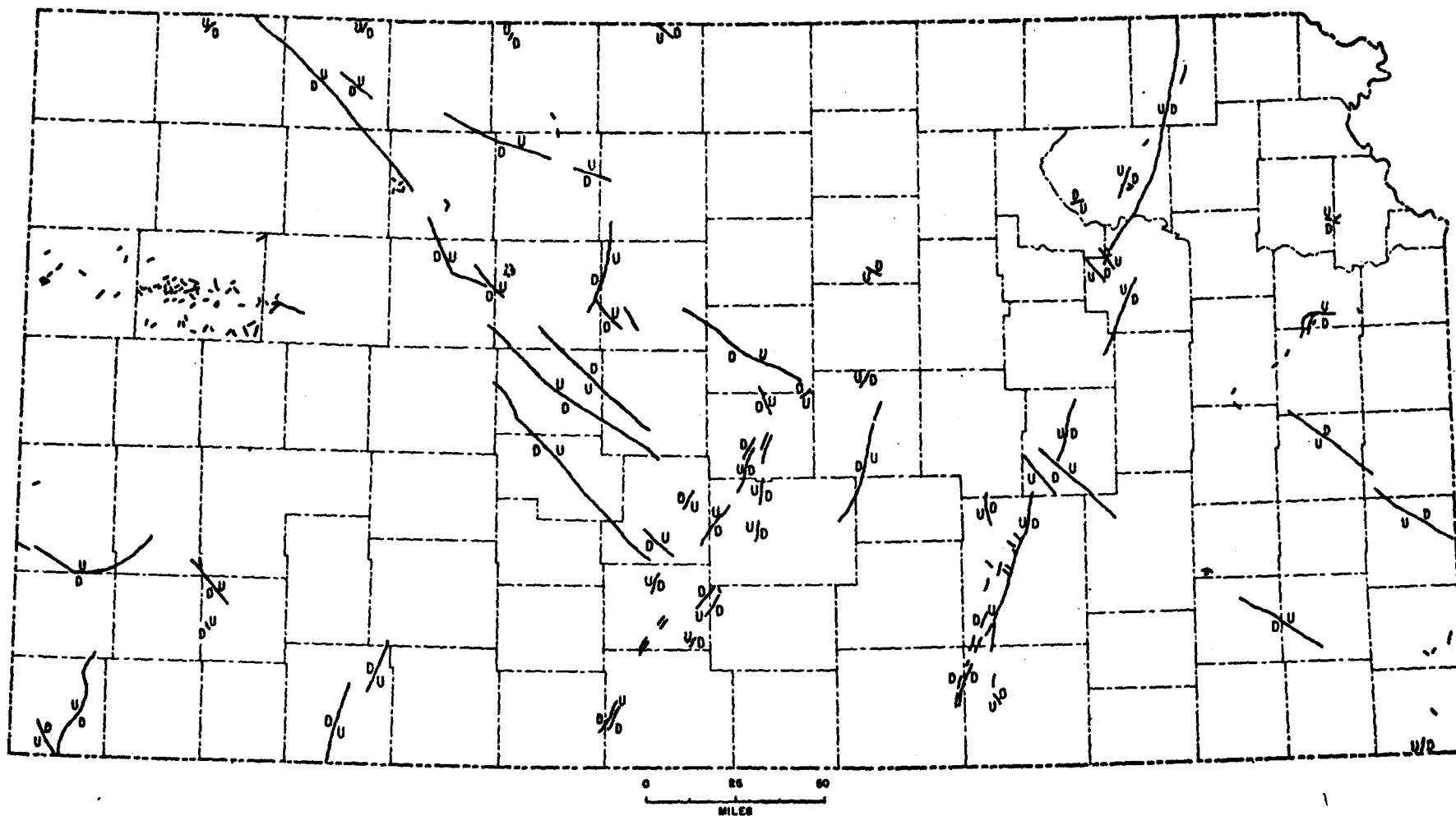


Fig. 41--Map showing the location of some faults in Kansas,,
assembled by Merriam (1963) from published literature.

of some faults in Kansas was assembled from the published literature. Both northeast-southwest-trending faults and northwest-southeast-trending faults are recorded across Rice County. The individual literature sources were not cited. There was no easy access to the data on the individual faults. Therefore, no appraisal of this reported faulting relative to the site is possible. Cole's map showing the configuration on top of the Precambrian (Fig. 42) indicates a number of faults in Rice County. The scale of the map prohibits projection directly into the proposed repository site. Many of the faults recorded by Cole represent projection of structure downward from the Ordovician rocks. There is inadequate well control to accurately locate and verify the faults. An early interpretation of the structure of the Lyons Gas Field (Fig. 23) by Ver Wiebe showed faulting in the Ordovician rocks. Brewer's field study of the Tobias oil field, southwest of Lyons shows faulting in the Ordovician rocks. Our Figure 43 (Pocket), the configuration on top of the Arbuckle (Ordovician) rocks, shows complex faulting (adapted from Brewer) in the area of the Tobias field. The faulting could not be projected onto the Lansing structure map (Fig. 44).

Cross-Sections Centering on Lyons

The location of five stratigraphic cross-sections, pertinent to the Lyons area, are indexed in Figure 28. The cross-section (A-A') of the (Pennsylvanian-Ordovician) rock units under the Lyons West field (Fig. 29) shows that the Mississippian reservoir rocks form a stratigraphic wedge of clastic-detrital sands and shales on the flank of the Central Kansas Uplift. Certainly, the Mississippian rocks once extended further westward but were removed by late Mississippian-Middle Pennsylvanian erosion.

Cross-section B-B' (Fig. 30) from the base of the salt section to the Ordovician rocks extends the lower Paleozoic rocks eastward. At this vertical and horizontal scale there is little evidence of faulting in the region. Several periods of uplift and erosion are recorded in the Ordovician sequence by the local absence of some units and the general thinning westward toward the Central Kansas Uplift. Well No. 12 (Shell No. 1 Welsh) shows the structure on the Ordovician rocks on the eastern side of the Lyons Gas Field.

Cross-section C-C' (west to east) and D-D' (south to north) (Figs. 31, and 32) show the sequence from the surface to the top of the Chase rocks (Permian). There is good lateral continuity at this scale of those stratigraphic units of special significance to the project.

Cross-section E-E', (Fig. 33), generally from south to north, includes the two core holes drilled by the AEC on the eastern corners of the project site. At this large scale, there is excellent correlation between the two core holes.

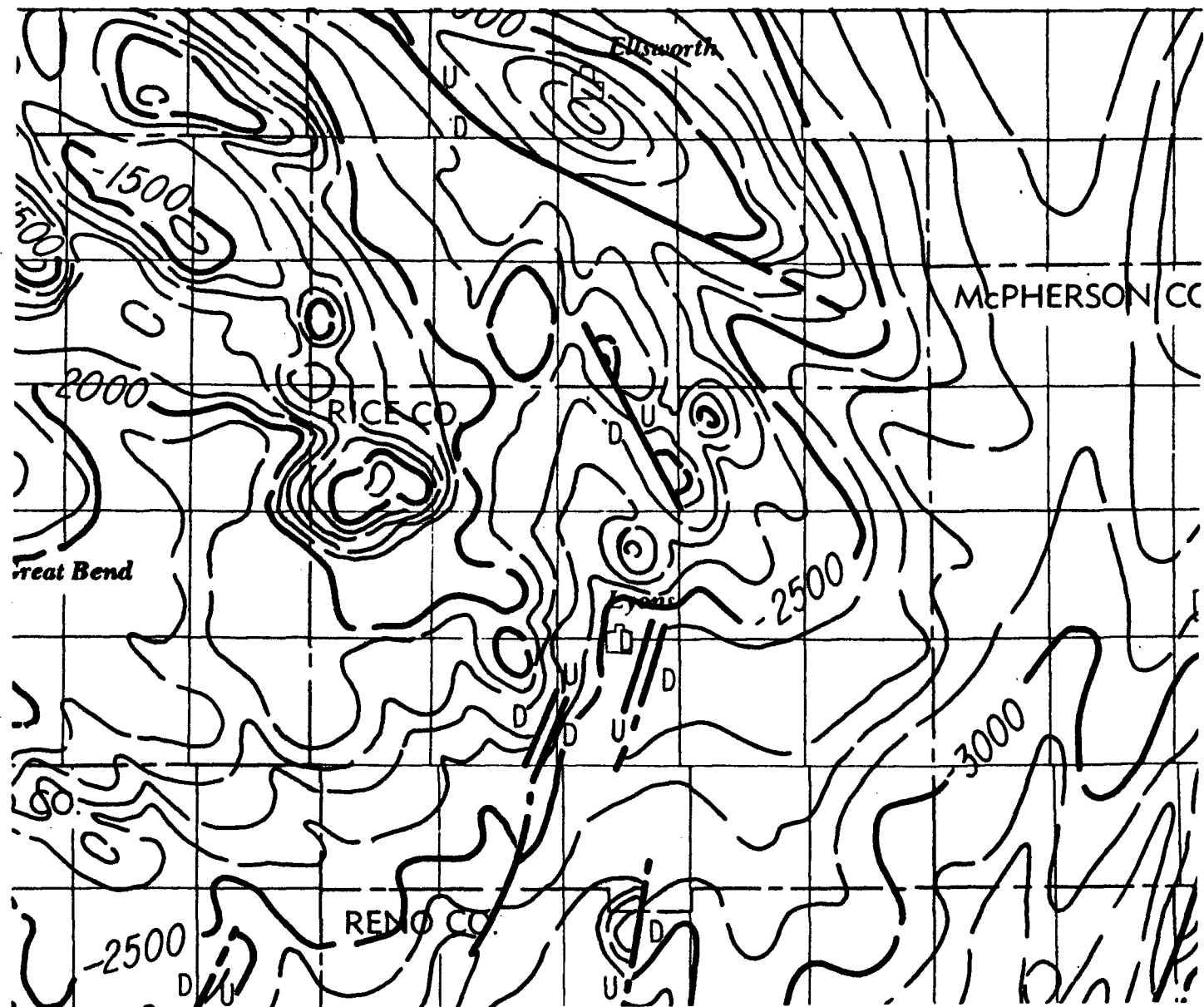


Fig. 42--Configuration on top of the Precambrian rocks in Kansas
(from Cole, 1962).

Some key-beds are described here (Dellwig 1971, Chapter 3, this report) and cross-indexed to Figures 45 and 53. The "wire-line" log of the No. 2 Stockham is "less than excellent", and only rough correlation can be made with it. A "wire-line" log run at the same intensity level as those on the core holes probably would reveal the same fine details. In all probability the lithologic units carry through this area of the project site. The correlations into the Carey Shaft "wire-line" log is reasonably good. Key-beds (17, 18, and 19) are indicated on each log across the cross-section.

A structure map (Fig. 45) on top of bed No. 18 (the future mine floor) shows a high of +740 feet, relative to a sea level datum, at AEC No. 2 and a low at Carey Shaft of +695 feet. The floor slopes from No. 2 core hole northward to No. 1 and less so to the west at the No. 2 Stockham hole.

Structure

Of the recognizable subsurface units, the base of the Stone Corral, top of the salt section, top of the Chase Group (Nolans Limestone), top of the Lansing Group, and top of the Arbuckle Group are in common use by the petroleum exploration industry in construction of subsurface structural contour maps. Merriam (1955) showed that structure maps of the Stone Corral reflected Pennsylvanian structure in central and western Kansas. Lee (1956) utilized structure maps in his Salina Basin study, which included Rice County. Structure maps were prepared for this report on the above listed marker beds (Figs. 46, 47, 22, 44, and 43, Pocket). Several unconformities (Fig. 20) separate the Ordovician (Arbuckle) rocks from the Permian (Stone Corral). Nevertheless, most of the structures observed on the Arbuckle map are reflected also in the Stone Corral map, except where the Stone Corral is absent. It outcrops in the northeastern part of the county. The common association of oil and gas reservoirs with structural highs is used as an exploration guide by the Petroleum Industry. Near the area of the proposed site, the Lyons West field, because it forms a stratigraphic rather than a structural trap, is not reflected as a structural positive area on the structural maps.

The structure contour map on the base of the Stone Corral (Fig. 46) shows the flank of a positive structural high over the Lyons (Ordovician) Gas Field (Sec. 35). The westward dip, apparent on the eastern margin of the study area, is seen to shift toward the northwest in the northwestern part of the area investigated. An elevation of about +1490 above a sea level datum, on the east declines to a +1300 feet to the northwest. The map shows a closure of more than 70 feet on the Lyons Gas Field structure.

The structure map on top of the salt section (Fig. 47, Pocket) shows a configuration similar to the Stone Corral map.

19a-8w, Rice Co.

Structure on Future Mine Floor (#18)

thickness of lower salt zones

#17-appro. roof of future mine

#18- future floor of salt mine

#19-shale break approx. 5' below present salt mine floor

B.S.- base of salt

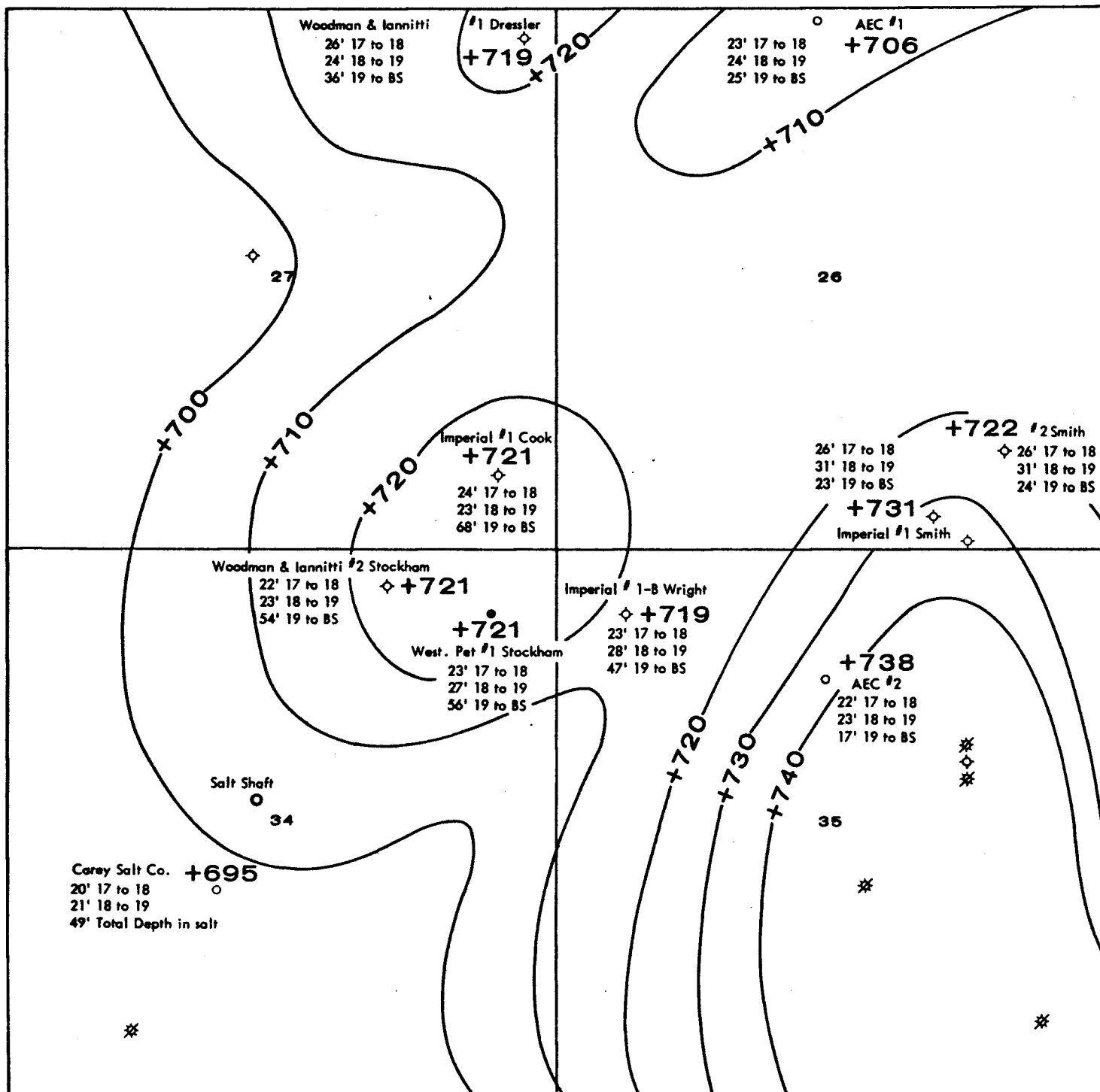


Fig. 45--Structure map on bed no. 18 (the future mine floor),
Lyons, Kansas.

Along the eastern edge of the study area the strike is north and south, and the top beds of the salt dip gently westward. In the northwestern part of the study area the surface (+840 strikes northeast-southwest and dips northwest. At the site the top of the salt is at less than +930 subsea level at AEC No. 1 and greater than +940 at AEC No. 2. The Lyons (Ordovician) Gas Field structure (50 feet of closure) is evident in Sec. 35.

In Figure 22, (Pocket), the top of the Chase Group occurs at a +580 feet elevation above a sea level datum, along the eastern margin of the study area, and the Nolans Limestone dips westward. Along the western margin the limestone occurs at +420 feet, 160 feet lower than east of the site. Closure on the tight structure of the Lyons Gas Field exceeds 40 feet. "Core-holes" to the Chase rocks verify the structure.

The structure on top of the Lansing Group (Fig. 44), contoured at 25 foot intervals, is found at a sea level elevation of from -1175 to -1200 feet on the west to a -1225 feet on the southeast. At core hole No. 2, the elevation is a -1100 feet. The Lyons Gas Field structure is evident in Sec. 35.

The structure on top of the Arbuckle contoured at 100 foot intervals (Fig. 43) shows a regional dip from -1500 feet below sea level on the northeast to -2200 on the southeast. The edge of the Central Kansas Uplift is at about the -1600 foot contour line. The irregular surface due to Karst (Walters, 1946) is evident. The tightly closed anticline forming the Lyons Gas Field is prominent in Sec. 35. Some geologists would choose to fault the northwestern side of the anticline in that the dip exceeds 6°.

In Kansas, locally mapped subsurface anticlines fit into a regional picture. This implies some common fact in the origin. Because mapped structures are present in older beds, it is assumed that these structures are tectonic or are related to tectonic rather than surficial movements. In the area of study surrounding the proposed repository site, there is a definite relationship of the structure at one horizon to that at another, as well as the position and arrangement of strata. This in itself strongly suggests vertically controlled structural movement such as upwarping combined with differential compaction and possible draping of beds over positive structures. This type of structural configuration (Merriam, 1963) is identified as "Plains-type folding." Reflection in the various beds of the folded structure with depth was recognized by Powers as early as 1925; he summarized concerning the structural geology of the Mid-Continent, that closure on key horizons in the Kansas subsurface increases downward from as little as five feet in Pennsylvanian beds to more than 400 feet in Ordovician beds.

Seemingly, the forces which caused "Plains-type folding" in Kansas are forces which were transmitted through the rigid

basement (including the Rice Formation), and the structures seen in the overlying beds are the local result of the vertical relief of these stresses.

The structural maps presented in this report (Pocket) show that there has been mild structural deformation, of the Plains-type, dominated by vertical movement in the region recurrent in the Paleozoic and into the Mesozoic. Structural development here consisted mostly of vertical movement and gentle warping which extended over long periods of time except for the relatively short geologic lapsed time during the formation of the Central Kansas Uplift. The Central Kansas Uplift formed during post-Mermacian and early Middle Pennsylvanian time. The pebbles and large boulders of limestone and brecciated chert of the "Pennsylvanian Conglomerate" attest to the intensity of erosion which removed several hundred of feet of Mississippian carbonate rocks on the Central Kansas Uplift and resulted in an angular unconformity between Pennsylvanian and Lower Ordovician rocks. Mississippian rocks were removed in the area of the Lyons Gas Field structure, also, (Fig. 48).

Within the area studied, the isopachous map of the salt section (Fig. 39) displays a thinning of the salt section in areas over structural highs. This is especially evident in the eastern part of the site at the abandoned Lyons Gas Field. Also, the structural maps of the area (Figs. 46, 47, 22, 44, and 43) exhibit a close correlation of structural highs on the base of the Stone Corral, the salt section, the Chase Group, (all Permian), the Lansing (Pennsylvanian), and the Arbuckle (Ordovician). The absence of reliable marker beds younger than the Stone Corral in the area, preclude dating the structural changes here as younger than early Permian. West of the area studied, structures in younger rocks reflect crustal adjustments more recent than early Permian (Lee, 1956).

Comparison of the self-potential-lateral logs of the Carey Salt Company (AEC shaft hole) with a gamma ray-neutron logs of the AEC No. 1 and AEC No. 2 core holes in cross-section E-E' (Fig. 33) reveals that the non-salt beds of the salt section have good continuity in the middle of the section. There is less lateral continuity between beds at the very top and the very bottom of the salt section (below the mined area). There is no evidence of faulting in the salt section revealed in the study of logs of holes in the study area.

Study of a number of logs within the area seemingly reveals that locally, where the salt section thins, the loss of section could have been both at the top and the bottom of the section. Dellwig (1971, Chapter 3, this report) reports no evidence of post-depositional solution of the top of the salt section. Topographic irregularities of the depositional surface of the lower salt beds could have been a factor in the non-continuity of the lower beds in the salt section.

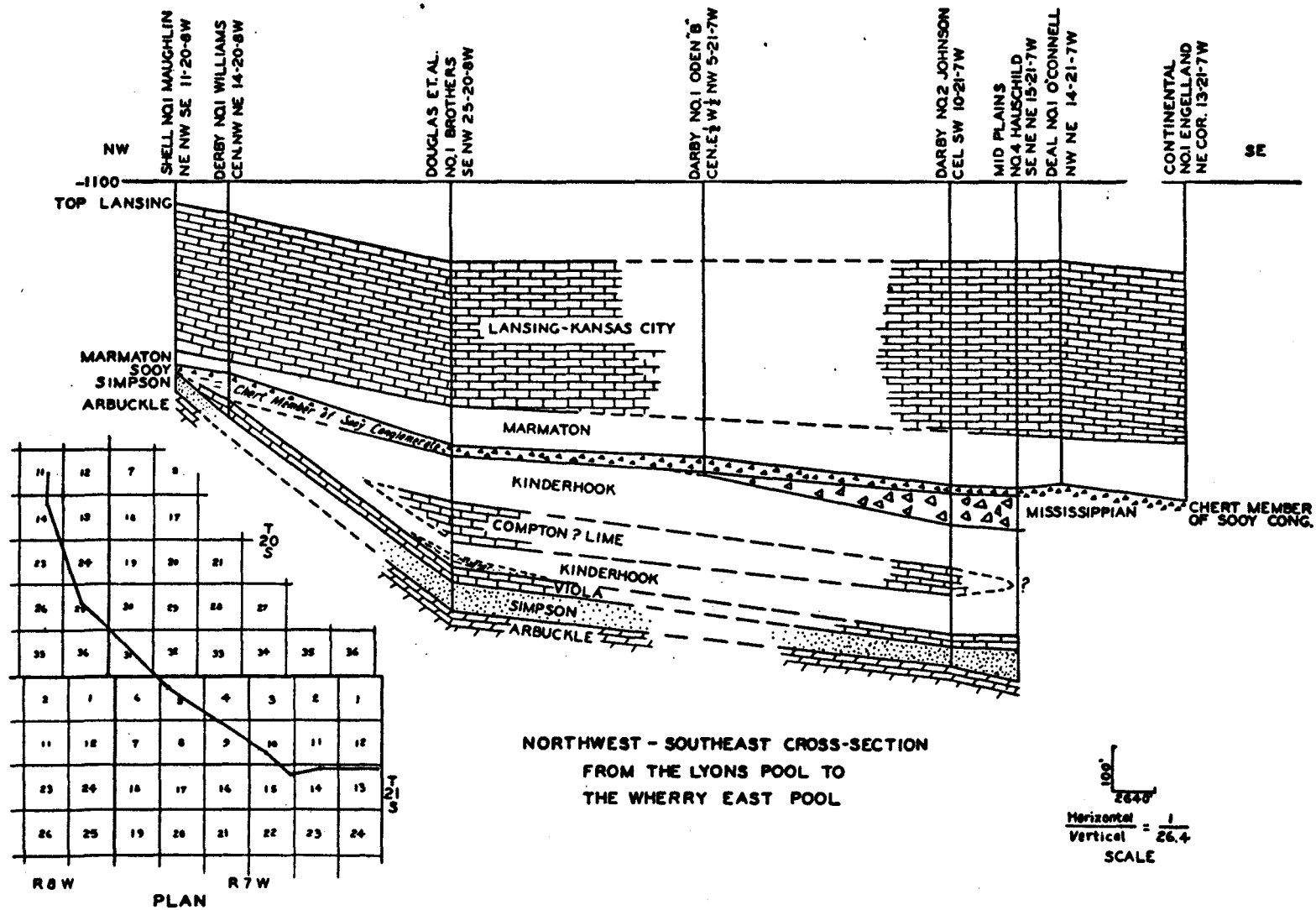


Fig. 48--Cross-section from the Lyons Gas Field to the Wherry East Field (from McNeil, 1941). Note the thinning and absence of the Mississippian rocks (11-20-8W) over the Lyons Gas Field structure.

Some salt flowage away from areas of structural highs, in response to recurrent uplifting is also a feasible but not favored interpretation. Such an interpretation would be in disagreement with Lee (1956) who reported (Rooks Co.) salt flowage toward anticlinal structures resulting in thicker salt sections at structural highs. There are no records of salt forming domes in the Kansas salt beds. However, neither has there been a regional study of the Kansas salt beds examining the question, of why they have not formed salt domes.

Geologic and Physical Features of Cores

Some of the cores from the site are cut by high-angle fractures. Some of the fissures in anhydrite, gypsum and shale are filled with salt, others in shale are filled with gypsum or anhydrite. Some fissures are fresh, containing no obvious secondary mineral deposit. Some of the high-angle fractures are above the salt section, others are below. Possibly the fresh fractures are due to the coring process which would have the tendency to form high-angle torsion fractures. Regardless of the origin of the fissures and fractures, they are a potential avenue of communication between shallow water-bearing sand reservoirs and the salt section. In addition to the water available from the water reservoirs, it must be kept in mind that the moisture held in the shales (Tables 6 and 7) is an appreciable amount, which upon heating would enhance solution along the fractures and fissures as well as along the interbeds of shale, anhydrite and gypsum. Undoubtedly, the water content of the core-plugs (Tables 6 and 7) is abnormally high due to contamination by the brine-saturated coring and core cutting procedures. Also, exposure of rock salt to humid air causes changes in the moisture content of the rock salt. Regardless, there is an appreciable quantity of water available in the porous and permeable thin interbeds of shale and gypsum beds within the salt section.

Under many conditions, dry salt (Aufrecht and Howard, 1961) may be sufficiently permeable to allow appreciable flow of non-aqueous fluids such as gaseous and liquid hydrocarbons. These workers report the moisture content of central Kansas salt as from 0.05 to 0.08 percent. These values are lower than the indicated porosity of salt. The average porosity of Hutchinson Salt is 1.0 percent, the average permeability is 5.7 millidarcies (Aufrecht and Howard). These workers concluded that dry salt at shallow depths is permeable and porous; much of the permeability is along shale bands in the salt.

During the examination of the 35 mm color photos of each foot of the cores it was observed that within the salt section, many of the thin beds of clay, shale, gypsum or anhydrite were faulted with displacements in the magnitude of 1/4 inch to

Table 6

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

Page No. 1**CORE ANALYSIS RESULTS**

KANSAS STATE GEOLOGICAL SURVEY AND

Company UNION CARBIDE CORPORATION Formation _____ File CP-1-7338
 Well AEC LYONS REPOSITORY NO. 1 Core Type DIAMOND Date Report 2-8-71
 Field _____ Drilling Fluid _____ Analysts BOYLE
 County RICE State KANSAS Elev. _____ Location _____

Lithological Abbreviations

SAND - SD SHALE - SH LIME - LM	DOLOMITE - DOL CHERT - CH GYPSUM - GYP	ANHYDRITE - ANHY CONGLOMERATE - CONG FOSSILIFEROUS - FOSS	SANDY - SDY SHALY - SHY LIMY - LMY	FINE - FM MEDIUM - MED COARSE - CSE	CRYSTALLINE - XLN GRAIN - GRN GRANULAR - GRNL	BROWN - BRN GRAY - GRV VUGGY - VVG	FRACTURED - FRAC LAMINATION - LAM STYLOLITIC - STV	SLIGHTLY - I VERY - V/ WITH - W/
--------------------------------------	--	---	--	---	---	--	--	--

SAMPLE NUMBER	DEPTH FEET	PERMEABILITY MILLIDARCYS		POROSITY PER CENT	RESIDUAL SATURATION PER CENT PORE		GRAIN DENSITY	Wb ₁	Wb ₂	°F. TEMP.
		PERM. MAX.	PERM. 50°		OIL	TOTAL WATER				
7	210.9	0.2		23.7	0.0	84.6	2.72	20.1	1.4	700
8	241.9	5.4		26.4	0.0	81.8	2.72	21.6	1.8	700
9	280.1	<0.1		24.0	0.0	86.4	2.74	20.7	3.3	600
10	293.2	<0.1		22.7	0.0	88.8	2.75	20.2	3.4	600
11	304.0	0.3		28.3	0.0	96.0	2.61	27.2	13.2	200
12	312.6	0.1		19.2	0.0	95.0	2.78	18.2	3.8	300
13	316.5	1.1		22.7	0.0	92.1	2.77	20.9	2.1	700
14	325.6	0.5		28.7	0.0	96.0	2.62	27.6	8.7	300
15	347.8	0.1		30.1	0.0	97.4	2.77	29.3	3.7	500
16	362.8	0.2		22.6	0.0	86.7	2.71	19.6	1.3	700
18	425.7	<0.1		23.1	0.0	85.3	2.76	19.7	2.0	700
19	459.7	<0.1		22.2	0.0	83.4	2.74	18.5	1.9	700
25	594.4	0.1		22.9	0.0	86.0	2.74	19.7	3.0	600
27	631.2	<0.1		12.4	0.0	89.2	2.73	11.1	2.7	700
28	647.2	<0.1		18.8	0.0	90.6	2.82	17.0	4.0	600
29	675.2	0.8		21.5	0.0	86.1	2.71	18.5	2.9	700
31	710.9	<0.1		16.7	0.0	70.4	2.65	11.8	2.0	700
33	752.4	<0.1		17.6	Tr	71.5	2.70	12.6	4.5	700
35	791.1	<0.1		16.1	Tr	66.5	2.67	10.7	4.1	600
37	814.9	0.3		14.0	0.0	73.2	2.59	10.2	2.0	600
39	839.0	<0.1		3.1	0.0	44.4	2.18	1.4		
43	879.8	<0.1		1.6	0.0	57.0	2.17	.9		
44	905.6	<0.1		24.9	0.0	98.6	2.70	24.6	4.6	300
45	918.6	<0.1		0.6	0.0	36.6	2.49	0.2	0.7	1100
47	946.1	0.1		1.4	0.0	41.2	2.49	0.6		
48	946.1	<0.1		1.7	0.0	35.3	2.19	0.6		
49	959.2	0.1		4.0	0.0	68.7	2.57	2.7	0.4	1000
51	989.8	<0.1		0.4	0.0	48.1	2.24	0.2		
53	1032.2	<0.1		0.5	0.0	55.4	2.16	0.3		
55	1062.5	1.0		17.0	0.0	78.8	2.76	13.4	6.4	700
59	1093.7	<0.1		5.4	0.0	66.7	2.86	3.6		
61	1115.9	<0.1		24.5	0.0	96.9	2.70	23.7		
63	1136.0	<0.1		0.7	0.0	95.0	2.95	0.67		
67	1173.0	<0.1		24.4	0.0	93.0	2.72	22.7	7.0	700
69	1182.0	<0.1		19.7	0.0	60.5	2.67	11.9	7.9	800
71	1207.1	<0.1		16.1	0.0	68.1	2.71	11.0		
73	1219.6	<0.1		19.2	0.0	73.6	2.84	14.1	4.4	700
75	1226.8	<0.1		16.4	0.0	77.4	2.75	12.7	3.9	900
78	1249.3	<0.1		2.5	0.0	53.2	2.91	1.3	1.3	1200
79	1252.2	<0.1		13.0	0.0	78.2	2.78	10.2	2.7	700
80	1264.2	9.6		21.4	0.0	58.4	2.83	12.5	2.8	700
81	1282.4	0.1		10.4	0.0	78.4	2.62	8.2	1.8	1100
82	1291.3	<0.1		14.8	0.0	83.0	2.74	12.3	5.7	700

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Petroleum Reservoir Engineering
DALLAS, TEXAS

Page No. 1**CORE ANALYSIS RESULTS**

KANSAS STATE GEOLOGICAL SURVEY AND

Company UNION CARBIDE CORPORATION Formation _____ File CP-1-7339
 Well AEC LYONS REPOSITORY NO. 2 Core Type DIAMOND Date Report 2-8-71
 Field _____ Drilling Fluid _____ Analysts BOYLE
 County RICE State KANSAS Elev. _____ Location _____

Lithological Abbreviations

SAND-SG SHALE-SH LIME-LM DOLOMITE-DOL CHERT-CH GYPSUM-GYP ANHYDRITE-ANHY CONGLOMERATE-CONG FOSSILIFEROUS-FOSS SANDY-SOY SHALY-SHY LIMY-LMY FINE-FN MEDIUM-MED COARSE-CSE CRYSTALLINE-XLN GRAIN-GRN GRANULAR-GRNL BROWN-BRN GRAY-GY VESSEY-VSEY FRACTURED-FRAC LAMINATION-LAM STYLOLITIC-STY SLIGHTLY-VERY-V/ WITH-W/

SAMPLE NUMBER	DEPTH FEET	PERMEABILITY MILLIDARCYS		POROSITY PER CENT	RESIDUAL SATURATION PER CENT PORE		GRAIN DENSITY	Wb1	Wb2	°F. TEMP.
		PERM. MAX.	PERM. 90°		OIL	TOTAL WATER				
1	743.2	Δ0.1		23.3	0.0	82.7	2.71	19.3	9.0	700
3	772.6	Δ0.1		0.4	0.0	15.4	2.17	.06		
4	788.4	0.8		16.1	0.0	74.4	2.64	12.0	8.7	800
5	806.5	Δ0.1		0.6	0.0	31.5	2.16	0.2	0.07	900
7	836.2	Δ0.1		0.8	0.0	14.0	2.16	0.1		
9	874.8	0.2		24.9	0.0	83.2	2.69	20.7	10.4	700
10	890.2	Δ0.1		0.7	0.0	23.4	2.17	0.16		
11	902.4	Δ0.1		1.7	0.0	28.5	2.45	.48	2.6	700
13	932.5	Δ0.1		1.8	0.0	54.9	2.19	.99		
15	981.6	Δ0.1		0.5	0.0	9.4	2.23	.05		
17	1004.0	Δ0.1		2.4	0.0	46.4	2.81	1.11	1.5	700
19	1033.2	Δ0.1		3.9	0.0	64.0	2.90	2.5		
21	1051.2	Δ0.1		0.4	0.0	10.0	2.93	.04		
23	1072.2	Δ0.1		0.8	0.0	25.0	2.93	.20		
25	1099.5	Δ0.1		0.2	0.0	21.7	2.94	.04		

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1/8 inch. The structures, seemingly, are all normal faults. No faults (in this examination) were observed in the salt portion of the salt section. Probably, these faults are early diagenetic and were caused by non-tectonic forces.

Recommendations

1. Study thus far of the subsurface section below the salt reveals the paucity of adequate rock information. No continuous core is available. We strongly recommend that in order to establish base line information on rocks and fluids below the salt we must have a continuous core and a suitable suite of geophysical logs to the Precambrian. Certainly, the project as now conceived, with containment of canisters in the lower part of the salt section will cause long-term heating effects below the salt as well as above the salt. Undoubtedly, the heat will cause dehydration of the evaporites and shales and result in low-grade metamorphism both below and above the salt section.
2. We strongly recommend that the monitoring system include a program of relocating and cementing old abandoned holes in the area at least every ten years.
3. This report has brought to light the need to update the work of Kulstad (1959) on the distribution and quality of salt to the east and north of the project area. It is recommended that additional investigation be made of the extent of solution of the top of the salt section in a widespread area as well as the rate of solution along the salt front. Fent's (1970) report to the AEC does not include study of gamma ray-neutron logs from the petroleum industry. An appreciable amount of new subsurface geological data along the margins of the salt body is now available and this information should be evaluated in the above suggested, recommended study.
4. A study should be undertaken to consider the possible thermal effects of undiscovered small pockets of Chase gas in reservoirs below the salt section at and near the project site.
5. A study of the Kansas salt beds should be undertaken to answer the question why Kansas salt beds have not formed domes. A question to be answered is whether or not thinning of salt on structural highs of the salt section reported herein and the thickening over structural highs reported by Lee (1956) are in fact incipient forms of subregional salt flowage.
6. It is recommended as part of the long-term monitoring system that an initial topographic map of small contour interval be made. Precisely located benchmarks with exact elevations must be erected at the project.

7. It is recommended that the monitoring system include monitoring of the location of the canisters many years after burial.
8. It is recommended that clay mineral studies (Table 8, memo from Bauleke, August, 1970, Pocket) of the core be undertaken to establish base-line mineralogical identification.
9. Utilizing the cores, studies of the fossil content and environment of depositions of the sediments (Table 9) should be pursued.
10. Evaluation of salt beds elsewhere in Kansas should be appraised as to possible alternate or future repository sites.
11. Base-line data on the quality of surface run-off waters need to be recorded.
12. Geophysical surveys of the proposed site, especially those methods measuring gravity, should precede use of the salt beds as disposal zones.

Table 8

Memo To: Ed Goebel

From: M. P. Bauleke

Subject: Proposed Clay Mineral Analysis of the AEC Cores
from the Lyons Salt Mine Area.

Date: August 13, 1970

1. X-ray identification for type of mineral present.
(Complete with glyceration and thermal processing as required.) Routinely done on -2μ composite but would divide into smaller fractions if required.
2. Differential Thermal Analysis of clay minerals to establish their thermal decomposition behavior. This could also be done under various pressures and atmospheres.
3. pH of clay-water suspensions.
4. Particle size analysis of the fraction below 44μ . I assume someone else will do analysis above 44μ .
5. Bulk density of clay as received from the core.
6. Slaking characteristics of clay - ability of the particles to be wetted by water.
7. Fired color of clay samples.
8. Correlation between changes in X-ray diffraction pattern, DTA pattern and bulk density with variations in pressure and temperature; temperatures up to a maximum of 400°F . and loads varying according to depth of material.

Table 9

Paleontologic Examination of Selected Footages of Atomic Energy
Commission Hole #1, NE NE NE NW Sec. 26, T 19 S, R 8 W, Rice
County, Kansas

Due to limited time available for examination, only the intervals indicated as fossiliferous in the core description were investigated.

Kiowa Formation

- 107.9 feet: Concentration of large pelecypod shells (up to 2" in length) in the black shale (not limestone as indicated by well log)
- 136.5-
137.5 feet: Crustacean fragments; high-spined gastropods (Turritella), low-spined (pulmonate) gastropods; tiny nuculinid pelecypods, scattered pelecypod prisms; ostracodes; holothurian sclerites (?); pyrite, selenite, malachite (?) in dark grey to black shale
- 143.5 feet: Same as above, but with integuments of crustaceans, leg appendages; fish scales and bone fragments
- 145.0 feet: Tiny pelecypods (largest 1" across hinge line); fish scales and bone fragments; much selenite, disseminated and as aggregates; holothurian sclerites; cyprid ostracodes
- Nolans Limestone
- 1285 feet: Algae, bryozoans, crinoid stems, brachiopods (?)

No spores or seeds or plant remains were seen in any of the shales examined.

The environment of deposition of the Kiowa represented in this well, as indicated by the fauna and its state of preservation, was offshore in brackish water (bay). Conditions during diagenesis were highly acidic. All that remains of what I believe to have been an extensive fauna are casts and molds of pelecypods, with occasional thin remnants of the outside shell layer, or finely comminuted shell material. Extremely tiny shells (microfossil size) and fish scales are fortuitously preserved. The black shale contains aggregates of

Table 9 (con'd.)

2

pyrite and selenite, much of it discretely crystallized, but for the most part it consists of platy clay minerals and disaggregated shell materials. All particles are oriented horizontally, making this a highly fissile, unctuous shale. There is little or no cementing material, and the shale goes into suspension rapidly upon agitation in water.

Doris E. Zeller

February 26, 1971

Dr. Doris E. Zeller
Micropaleontologist
Subsurface Geology Section

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Chapter 3

STUDY OF SALT SEQUENCE AT PROPOSED SITE OF THE NATIONAL RADIOACTIVE WASTE REPOSITORY AT LYONS, KANSAS

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INTRODUCTION

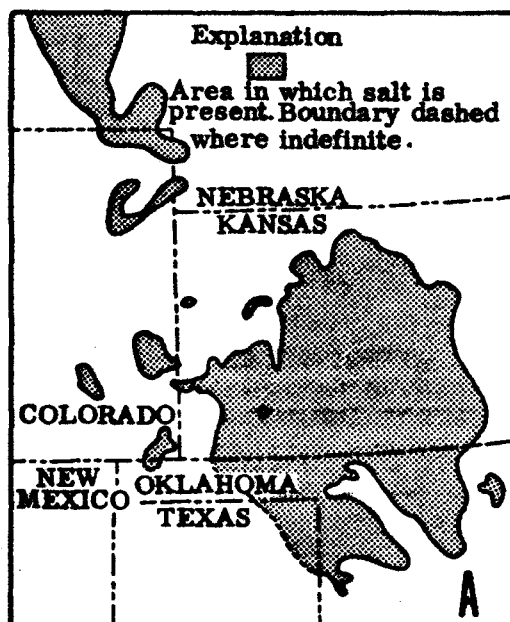
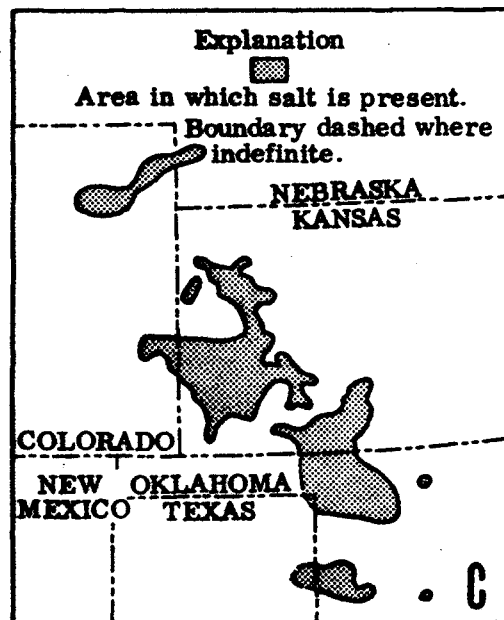
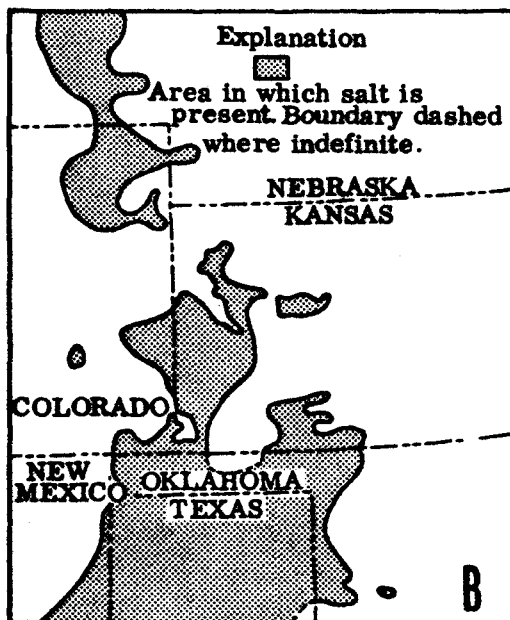
The area underlain by the Permian salt beds, the Wellington Formation, the Ninnescah Shale and the Nippewalla Group are relatively well defined (Fig. 49). Knowledge of details of stratigraphy, depositional features and structures, and physical properties of the salt of the Hutchinson Member of the Wellington Formation is confined to the eastern portion of the basin where the salt section has been exposed through mining and core drilling. Extensive subsurface data from the entire basin have been evaluated most recently by Kulstad (1959), this having resulted in the production of a map showing thickness of the salt-bearing unit and the percentage of salt in the unit throughout the Kansas portion of the basin (Fig. 37, Pocket). Stratigraphy of the salt unit proved to be local, as many key units could be correlated only over short distances.

Detailed studies in the mines at Kanopolis (Green, 1963) and at Lyons and Hutchinson (Dellwig, 1963) indicated that correlation of major units and some minor units in the salt section could be accomplished throughout each of the mine areas. Subsequent drilling of the Atomic Energy Commission test holes confirmed this observation in the Lyons area.

HUTCHINSON SALT BASIN

Early work on the Hutchinson Salt was limited, with the first map showing the thickness and extent of the salt being published by Bass in 1926 (Fig. 50). This map was the basic data source for the Hutchinson salt until 1959 having undergone only minor modifications of extent or thickness by a number of workers. Sufficient data have long been available for the recognition of the basin margin environment of deposition as described by Sloss (1953), this being more recently confirmed by Kulstad (1959) and Dellwig (1963) as the result of detailed as well as regional studies. Kulstad's conclusions were based on his study of the salt throughout the state, whereas Dellwig based his conclusions primarily on the study of the salt as exposed in the mines at Hutchinson, Lyons and Kanopolis.

This most recent comprehensive study of the Hutchinson Salt Member (Kulstad, 1959) was based primarily on "electric"



0 50 100 150
Scale in miles

A. Salt beds in the Wellington Shale.

B. Salt beds in the Ninnescah.

C. Salt beds in the Nippewalla.

Fig. 49--Distribution of Permian salt beds in Kansas and adjacent areas (after Mudge, 1967).

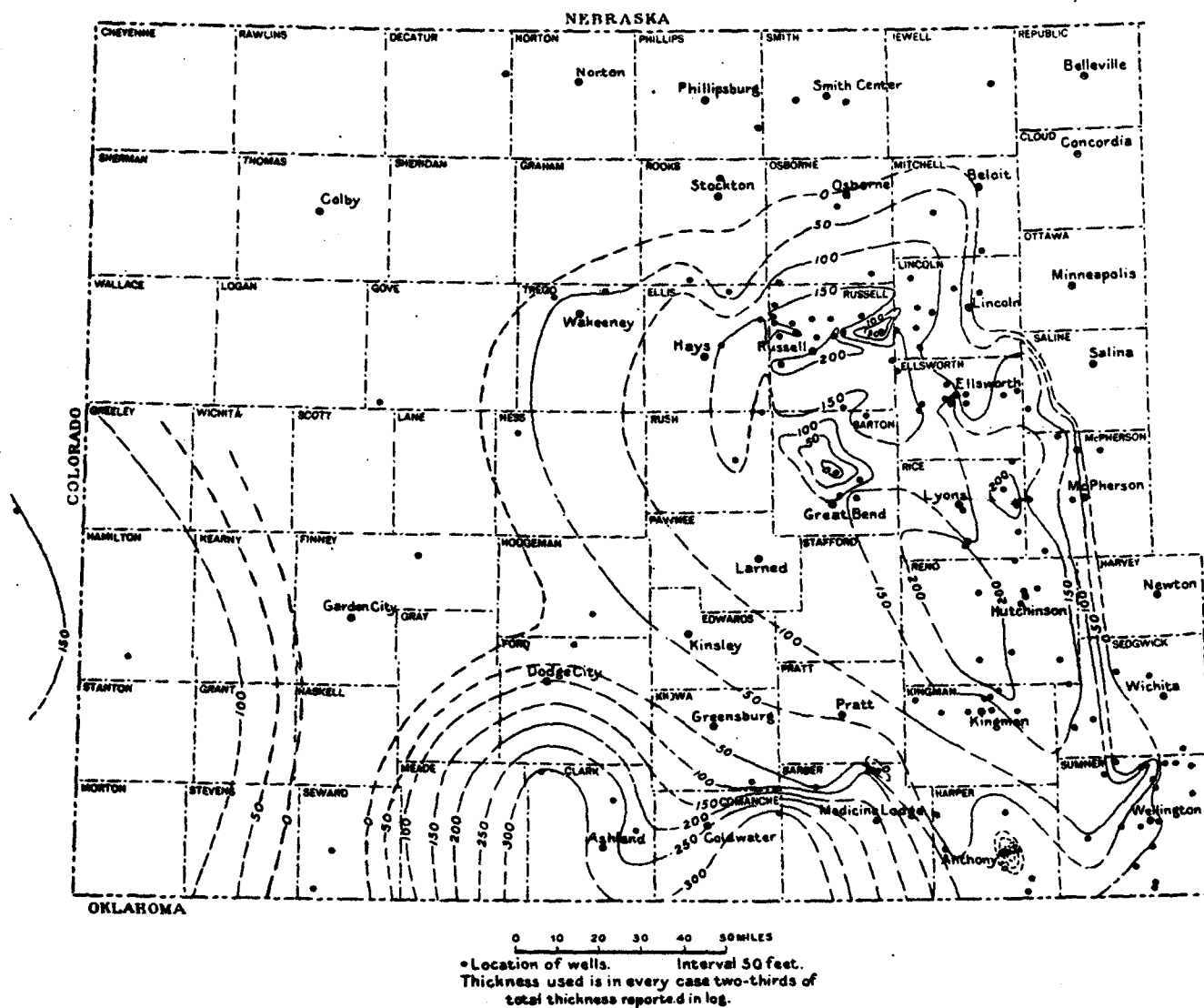


Fig. 50--The 1926 map (Bass) of the thickness of salt beds as shown in well records.

logs although some detailed study of mine sections in the eastern part of the basin was included. For evaluation of the Wellington salt as a repository for radioactive waste, the results of this investigation are significant primarily in evaluating the desirability of the marginal portion of the basin (as compared with the more central portion of the basin) as the disposal site.

(1) Kulstad's map (Fig. 37, Pocket) not only reveals an increase in depth of the salt to the south and west but also a decrease in the percentage of salt in the evaporite section. Accompanying this change is a change of the insoluble content from predominately shale in the marginal areas to anhydrite in the more central basin area.

(2) The salt consists of a succession of layers. The area underlain by any single bed is small compared to the area underlain by the entire salt unit, indicating a continual shifting of the locus of deposition. Correlation (based entirely on logs) also indicates that individual strata are imbricate and have an oblique relationship to the upper and lower boundaries of the salt unit as a whole.

(3) Key beds can be correlated only for short distances. In studies of mine areas, correlation of key beds offers no problem but it is important to note that one should not expect to project local stratigraphic units from marginal areas (Hutchinson, Lyons and Kanopolis mines; AEC holes) toward the basin center and anticipate an increase in thickness or improvement in quality of a salt unit as might be the case in a basin center deposit such as the Salina salt of the Michigan basin. Although projection of data from the marginal areas does not appear productive, it would be expected that more distant from the margin of the basin greater uniformity and purity in saline as well as non-saline beds might reasonably be expected. However, sufficient data are not available at this time for suggestion of an additional or alternate site.

DISPOSAL SITE STRATIGRAPHY AND SEDIMENTOLOGICAL IMPLICATIONS

Extent of Salt Deposition

The position of the proposed disposal site near the margin of the salt basin is well documented by the study of Kulstad, and has been verified in this as well as earlier studies by Dellwig. The actual position of the original eastern margin of the basin is of concern only in the determination of the rate of migration of the margin of the salt body westward. Lee (1956) proposed a 20 to 30 mile westward migration of the eastern margin of the salt beds, although this writer is of the opinion that considerably less salt

has been removed from the eastern and northern margins of the deposit.

Although evidence is sparse and local, the results of a study near Clearwater, in south-central Kansas (east side of the salt basin) strongly support this contention (Fig. 51). At Clearwater, where a number of cores were available for study, correlation of three cores oriented along an east-west line indicated an erosional surface at the top of the salt sequence across which, with angular unconformity, the overlying shale was deposited. The projection of the base of the salt sequence eastward to the intersection of easterly projection of the unconformity at the top of the salt should indicate that position at which the eastern edge of the salt basin was located at the time of deposition of the overlying shale. It is recognized, of course, that the salt may have originally extended farther to the east but was removed prior to the deposition of the overlying shale. In this area the contact between the salt and the overlying shale is clean and sharp and there is no indication of post shale-deposition solution of the salt and collapse of the overlying shale unit.

In the area presently under investigation, the lower-most salt-shale-anhydrite sequence of AEC Hole 1 is greater in thickness than in Hole 2, although all units correlate relatively well (Fig. 52). The thinning of the units in Hole 2 presumably is related to the positioning of Hole 2 on the flank of a structural high, the topographic relief of this structure at the initiation of salt deposition apparently being reflected in the salt sequence. Insufficient data prevents a study such as that in the Clearwater area. However, as in the Clearwater area, there is no indication at the top of the cores of solution of salt following deposition of the overlying shale.

Mechanics of Deposition

Kulstad's map not only shows extreme irregularity in thickness but also in the percentage of salt in the thickness indicated. It is recognized that this percentage is based on the interpretation of "electric" and other "wire-line" logs and in some cases drillers' logs, but even considering this, variations appear to be extreme. If one considers the large percentage of clay which is contained within the sequence, and the marginal position of the deposit relative to the basin as a whole, one might easily visualize the addition of fresh water to the basin waters from the marginal regions as a contributing factor to the irregularity in thickness as well as variations in composition and sedimentary structure. The solution of salt with the addition of such water, may have resulted in the creation of channels, this in turn effecting a degree of instability which would permit the slump of

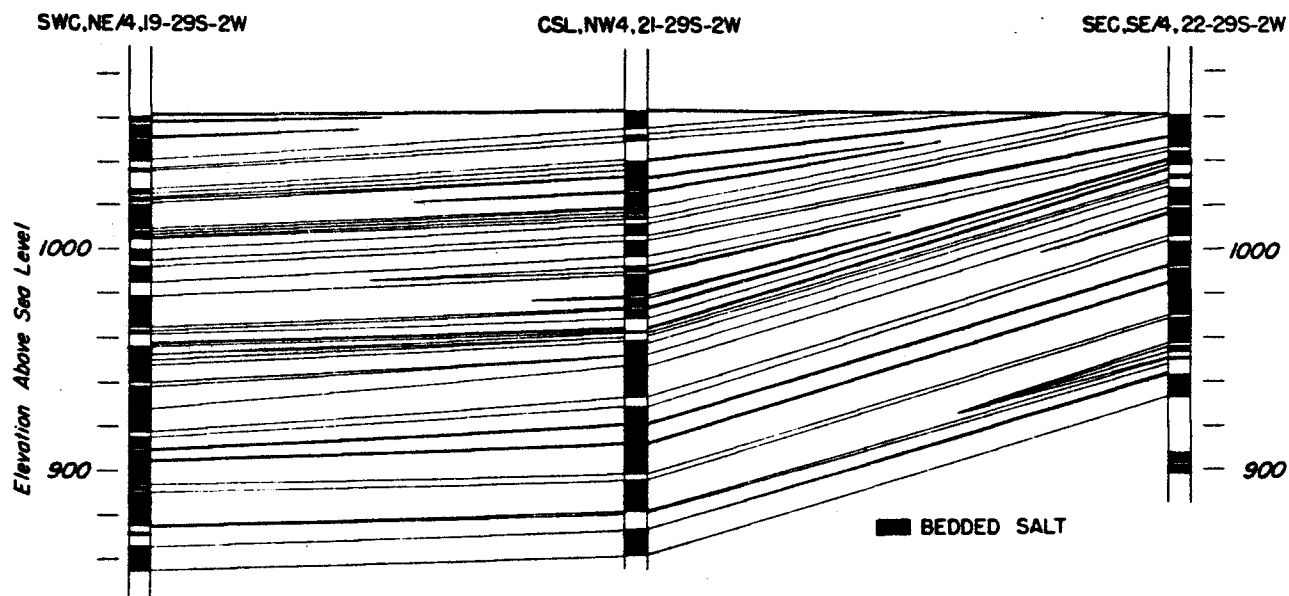


Fig. 51--Generalized section of cores showing the unconformity at the top of the Hutchinson salt between 0.5 and 4.5 miles west of Clearwater, Sedgwick County, Kansas (from Dellwig, 1956).

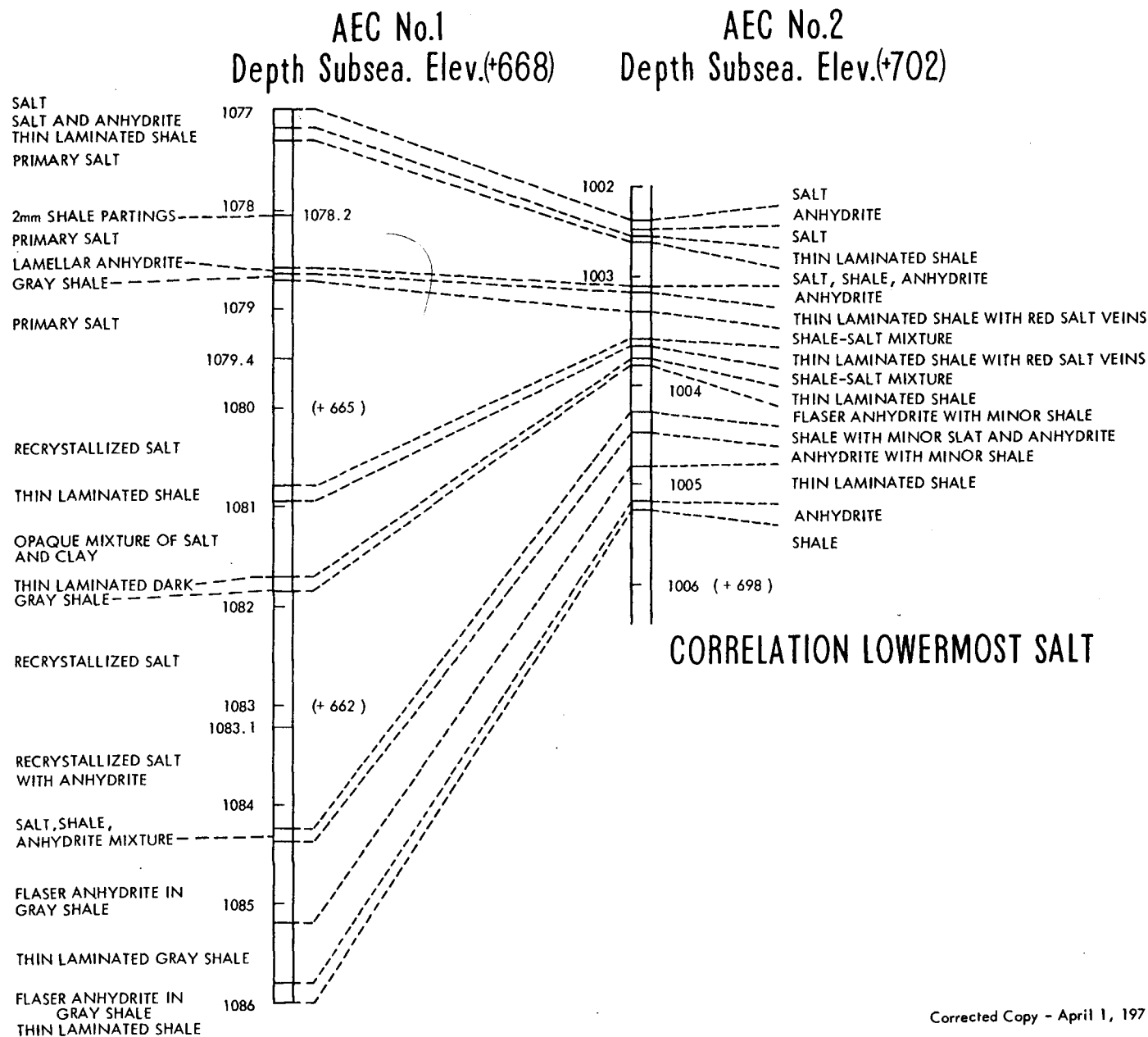


Fig. 52--Correlation by L. F. Dellwig of lithologic units of lower portion of section between coreholes at the proposed site.

earlier deposited sediment. The core from AEC Hole 1 contains a number of units of sedimentary breccia. In some units fragments are large and show little evidence of transport, whereas in other units fragments are relatively small and suggest longer transport or perhaps lesser consolidation at the time of brecciation. With periodic shifting of the channels, the slump would occur at different stratigraphic horizons and thus one would not expect to correlate breccia zones from core to core. Evidence has been presented as the result of studies elsewhere (Dellwig, 1963) that there may have been periodic subareal exposure of some of the salt and thus fluctuation in water level in the basin. This also would tend to promote the development of discontinuities, particularly in the marginal regions of the basin.

DETAILED DESCRIPTION OF AEC CORE 1

AEC Core 1 has been examined and described in detail. In general compared to other bedded deposits the salt tends to be relatively impure with a high percentage of recrystallization which occurred prior to, or during, lithification. Nowhere in the core was there evidence of post-diagenetic recrystallization. In addition to a high percentage of impurities and extensive recrystallization, there was noted extensive development of sedimentary breccias and other slump features. Breccia zones and zones in which the bedding deviates significantly from the horizontal, are confined between horizontally bedded sediments (shale, anhydrite or salt). In some instances dipping or brecciated beds are overlain unconformably by horizontal strata. In other instances the change from dipping to horizontal beds, or from breccia to normal bedding, is transitional in a few tenths (or less) of a foot. In some breccia zones there has been sufficient reworking of the fragments to develop bedding. Zones of inclined bedding or breccia similarly show varied relationships with underlying sediments, relationships which range from sharp unconformities to thin zones of gradational change. The periodic repetition of such zones throughout the section, bounded above and below by horizontal beds, indicated development during the depositional process as opposed to post depositional solution and collapse. This movement, as previously mentioned, is the expected result of the addition of fresh water into a shallow brine basin.

CORRELATION BETWEEN AEC CORE 1 AND CORE 2

Correlation of major as well as minor units in AEC Core 1 and AEC Core 2 (Figs. 52, 53, Pocket) was achieved not only in the storage and in the mining zones but also in the sequence at the base of the salt unit and in the salt up to approximately 35 feet above the 17 foot parting (Figs. 52, 53). Correlation in the zone of storage is excellent, the thickness of the unit between the mine floor and the 17 foot parting being almost

identical in both cores. Both the base of the storage unit and the 17 foot parting correlate well in so far as position is concerned. At the base of the storage unit the correlation lithologically is excellent, but this is not the case in the 17 foot parting, which in Core 1 is well bedded shale and in Core 2 consists of a breccia zone. Near the top of the storage unit excellent correlation of several minor units suggests basin stability at the time of deposition of that portion of the salt sequence, and thus one should expect the units to persist throughout the proposed disposal site.

Above the 17 foot parting and extending up to the proposed roof of the mine, correlation is more difficult. Most units correlate relatively well, but lithologic dissimilarities are noted frequently. However, with the exception of one zone in Core 1 at depth between 1,028 and 1,028.6 feet (Fig. 54), no major discontinuities in the mine and storage area were observed. At this depth in Core 1 brecciation of salt and the rotation of a portion of a shale bed to near vertical suggests faulting. No evidence of this was found in Core 2.

From the proposed roof to the top of the salt section major lithologic changes can be easily correlated (Fig. 33), although in detail, individual salt beds lack in uniformity. Below the storage level correlation of minor units also becomes more difficult, and in fact cannot be achieved at a depth greater than 4 or 5 feet below the present mine floor except in the basal salt sequence.

There is no question but that the best quality and most uniformly deposited salt in the entire sequence is in the zone which has been previously mined (Carey, and Lyons mine) and in which storage of the canisters has been proposed.

STRUCTURE

The discovery of what appeared to be a fault in the salt section in AEC Hole 1 prompted the preparation of a structural contour map on top of the future mine floor of the salt (Bed No. 18), and the thicknesses between key beds were calculated and plotted (Fig. 45). This map gave no indication of any major break in the section or of any abrupt change in attitude which might result from faulting. However, these data do not deny the possibility of a local fault with small displacement as mentioned above. If such a fault does exist it is not believed that it disrupts the continuity of the salt section.

CONCLUSIONS

The cores from AEC test holes along with mine data, indicate that the salt zone proposed for the storage of radioactive waste (considering thickness, purity and uniformity) is the best zone in the salt section in the Lyons

area. Major units and some minor ones correlate well throughout the area. The isopachous and structure contour map (Fig. 45) give no suggestion of structural discontinuities. Contact between the salt and the overlying shale indicates that the integrity of the salt has not been violated since the deposition of the overlying shale. Keeping in mind depth and salt thickness requirements, insufficient data are available to propose a more satisfactory site elsewhere in the basin. No structural problems are anticipated.

Because of the ease of correlation of major units and the loss of continuity in many minor ones, no need for additional core holes is visualized, except perhaps at the shaft location. Major discontinuities are as easily and precisely defined on "electric" logs as through study of cores, and sufficient data are also available in existing AEC cores and in the Lyons mine to establish the quality of the salt section proposed for waste disposal.

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Chapter 4

HEAT TRANSFER

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The problem of modeling heat flow and subsidence before and during waste storage is of paramount importance. The level of work presently being done by ORNL is a logical and adequate initial step in analysis of the problem. However, apparently limited manpower together with the seemingly unfamiliarity with modeling techniques mitigate against obtaining a sufficiently realistic solution in time to influence key decisions in the project. Seemingly, those working on the project at ORNL are unfamiliar with the extensive petroleum engineering and hydrology oriented research papers in the area of heat and fluid flow.

Although the type of calculations performed by ORNL personnel are correct for their model, a realistic answer may not have been reached for the following reasons:

1) The stratigraphic section has been overly simplified. As an example; in a hypothetical 100-foot laminated section of salt and shale, all the shale and all the salt are lumped for computational purposes. This type of calculation will give a distribution in time and space markedly different from the real case. Would one expect heat flow in a laminated system to be anything like that in a single thick layer system?

The simplification outlined in (1) above can easily be eliminated by solving the difference equations other than explicitly (see, for example, references 3, 4, 5, 7, 11, 16, 17, 18, 19, 20). The explicit solution technique has a rigid stability constraint (2, 3, 17, 19, 20), that is:

$$k \left\{ \frac{1}{(\Delta x)^2} + \frac{1}{(\Delta y)^2} \right\} \Delta t \leq 1/2$$

where k = heat conductivity
 Δx = mesh size in x direction
 Δy = mesh size in y direction
 t = time step

The above constraint requires that in order to model short space intervals (thin beds) one has to use small time steps. To model large time intervals with small space steps takes a

prohibitive amount of computer time using an explicit technique!

2) The strength of the source terms (heat flow rate per canister) is not known by ORNL personnel. Although this is understandable since the canisters have not been manufactured, it should be kept in mind that assuming all canisters will be of equal and constant strength is unrealistic. The temperature distribution as found by the heat flux calculations can be considered as maximum values only if maximum source values are chosen, not representative or average values.

3) The assumption that the thermal properties of the media are independent of temperature has not been substantiated!!

4) The analytic solution for the heat-flow distribution is of no value as it assumed a single homogeneous and isotropic medium.

5) The numerical solutions to the differential equations were performed in one- and two-dimensions for both the steady and unsteady cases. Although it is readily conceded that one- and two-dimensional calculations are quite good in problems that exhibit symmetry, it is not conceded that this particular problem exhibits any symmetry. ORNL has not demonstrated the capability of solving the three-dimensional non-steady or steady state problem. Three dimensional numerical techniques are available in the literature (see for example, 1, 4, 6, 8, 10, 12, 14).

The crucial problem is not the transient heat flow problem but rather the interaction of subsidence, thermal expansion and heat flow effects as they occur over the life of the disposal facility. It is this interaction of heat flow, plastic flow of salt, subsidence and thermal expansion that could be responsible, potentially, for breaking the seal of overlying beds permitting entry of surface or subterranean waters. In order to adequately investigate the problem the best theoreticians and mathematical modelers available in heat flow and rock mechanics should be assigned the research task, and even then a realistic solution may not truly be possible.

Brief mention is made of a mine-management program in ORNL-4584, UC-41-Health and Safety. We feel strongly that significant effort needs to be expended in developing this computer program into one which can be used to determine the day-by-day hole spacing program for "pot" holes in the salt room floors and for selection of optimum safe room sizes. Included as part of this program should be an inventory function for identifying the location and radionuclide make-up of each pot stored. Because of the long period for which such information may be needed (possibly

several hundred years), special care needs to be given to the form and type of storage facility for the pot-inventory data. Such information will be extremely valuable if it is necessary to retrieve the pots.

The management program cannot be a meaningful reality until the combined heat flow, plastic salt flow, and overburden stress-strain problem referred to earlier is a working reality.

Several alternatives are suggested below to accelerate the search for an appropriate solution to this latter problem.

The alternatives proposed are:

1) That greater effort be made by the modeling group at ORNL. This would require that at least two and possibly three full time, highly competent people be added who are familiar with numerical solutions to partial differential equations and who have backgrounds in heat or fluid flow. At least one and maybe two more rock-mechanics people should be retained either as employees or consultants to assist in problem formulation.

2) That ORNL contract, through one of the many excellent modeling and simulation firms, to have this work done. Organizations from whom bids for this work could be requested include:

- a. International Computer Applications, Ltd.
1209 Rio Grande
Austin, Texas 78701
- b. D. R. McCord and Associates
1949 N. Stemmons Freeway
Dallas, Texas 75207
- c. H. K. Van Poolen and Associates
Littleton, Colorado 80120
- d. Scientific Software Corp.
5300 So. Ulster
Englewood, Colorado 80110

3) That funds be given to the state of Kansas to contract the problem using one of the agencies given in (2) above, or to solve the problem with their own personnel and any additional personnel necessary to expedite a rapid solution. In addition, a group consisting of Drs. Halepaska, Green, Willhite, and possibly others in the State Geological Survey and other departments of The University of Kansas should serve as project monitors or liaison personnel to see that the work is being performed properly.

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Chapter 5*

Section A

ENERGY STORAGE AND RADIATION DAMAGE EFFECTS IN ROCK SALT

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INTRODUCTION

Radiation damage effects and processes associated with the high energy radiation flux produced by the nuclear wastes still remain the least thoroughly investigated of all of the anticipated potential problems which might arise in the salt mine disposal facility. There has been a general tendency to assume that radiation effects would be of relatively small magnitude and that they could be compensated by overdesign of safety factors in the engineering calculations. This approach is entirely satisfactory for a feasibility study and a pilot experiment of the nature of the Salt Vault investigation. The principle is clearly not a satisfactory mode of operation in the final design of the disposal site because it assumes that every possible problem has been recognized and that limiting values can be assigned to each of these problems.

The report of investigations which follows does not contain evidence which indicates that radiation effects are so severe that they preclude the use of salt mines for nuclear waste disposal. In fact, it is likely that such waste disposal facilities are safer than any currently in use and are the safest of those which have been proposed from the standpoint of radiation effects. Nevertheless, specific problems have been uncovered which must be taken into account in site design. Furthermore, only through a full scale research investigation of radiation damage effects in all components of the disposal site will it be possible to assign realistic

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values to potentially hazardous effects. The present state of knowledge about radiation effects on the salt and on the waste container material is not adequate to assure the safe operation of the disposal facility.

EXPERIMENTAL MEASUREMENTS

Research groups operating at both Oak Ridge National Laboratory and The University of Kansas together with the Kansas State Geological Survey have been engaged in investigations of energy storage in radiation damaged salt. Initially the data obtained by the two groups were in poor agreement but this proved to be the result of variations in the samples which the individual groups had selected for their studies. After identical samples were furnished for control measurements, differences were resolved and essential agreement was obtained on the standard samples. The ORNL group has used an electron accelerator as its radiation source and has performed its analysis by solution calorimetry. At The University of Kansas, irradiations have been made using heavy particles such as protons or alpha particles from a Van de Graaff accelerator. Energy storage measurements have been made in all irradiated samples by differential thermal analysis, (DTA).

In addition to the measurements made on material irradiated at both laboratories, several samples of gamma irradiated salt were obtained from the experiments conducted at Project Salt Vault (Bradshaw and McClain). The ORNL group obtained values of under 10 cal. per gram on the samples which they studied. Different samples taken from other test holes and analyzed at The University of Kansas showed energy storage of approximately 10 to 50 cal. per gram. Because of the differences between the values obtained by the ORNL and Kansas groups, standard samples were prepared from irradiated salt taken from Hole IV at 9'6" and 11'. The ORNL group tested these samples by solution calorimetry and found that they could detect no stored energy in either sample. When splits of the same samples were analyzed by differential thermal analysis at the Kansas State Geological Survey, identical results were obtained if the integrated heat flux between 100° C and the melting point is considered. Specifically, the sample from Hole IV at 9'6" showed an exotherm from 100 to 400° C and an endotherm from about 400 to 785° C which has approximately the same total area. In this case, the energy released in the low temperature range is absorbed in the higher temperature range and the total integrated value from 100 to 785° C is essentially zero. Similar results were obtained in a DTA test of the Hole IV, 11' sample. In this case, the exotherm extended from 100 to about 500° C and was followed from 500 to 750° C by a strong endotherm. As before, the total energy storage from 100 to melting is essentially zero, exactly as reported in the solution calorimetry measurements made at ORNL.

After concluding these tests, the sample from Hole IV, 11' was examined under a microscope and the strongly colored

grains were selectively concentrated for a separate DTA test. In this case, the sample enriched in the dark blue material was found to show a total energy storage of 6 cal. per gram. The main exotherm occurs between 120 and 500° C with a smaller endotherm from 500 to 625° C. From 625° C to the melting point, there are several small exotherms and endotherms, but the main release clearly occurs between 120 and 500° C.

Three factors account for the previous differences in the energy storage reported by the ORNL and Kansas research groups in evaluating the Project Salt Vault samples. First, solution calorimetry requires samples which are over 100 times larger than those used for DTA. This results in an average value for a large sample and does not provide information about the maximum possible energy stored in individual grains within the sample. The ORNL group never had an unaltered, highly colored sample which was large enough to permit solution calorimetry measurements to be made.

Second, all of the data obtained by DTA in the first preliminary report were limited to the interval from 50 to 475° C. At that time, as was stated in that report, all studies were confined to the low temperature range and the appearance of endotherms in the range above 475° C had not been investigated. Finally, there was a conscious effort on the part of the Kansas investigators to select from the available samples those crystals which appeared to show the maximum radiation damage. Only by this means is it possible to obtain valid information about the maximum energy storage which is attainable by gamma irradiation of rock salt. Without such data, meaningful engineering calculations of heat release by the discharge of stored energy cannot be made. For this reason, all of the values shown in Fig. 55, are for measurements made between 100 and 750° C and are from crystals which show the maximum amount of blue color. When possible, those portions of the samples which were not highly colored were rejected.

It should be pointed out that solution calorimetry provides an accurate indication of the total energy stored in crystals between room temperature and the melting point but that it furnishes no information about the activation energy of the specific defects which cause the energy storage. DTA techniques, on the other hand, are capable of providing specific data about the energy release. Such data are of particular usefulness in the evaluation of the effect of release of stored energy on the thermal profile of the storage site.

Figure 55 provides a summary of all of the other data obtained at the Kansas State Geological Survey for the other gamma irradiated samples from the Project Salt Vault operation at the Lyons Mine. In this diagram samples designated as squares were measured as small single crystals. Those designated as circles were powdered. The data indicate that a rough correlation can be made between electron spin.

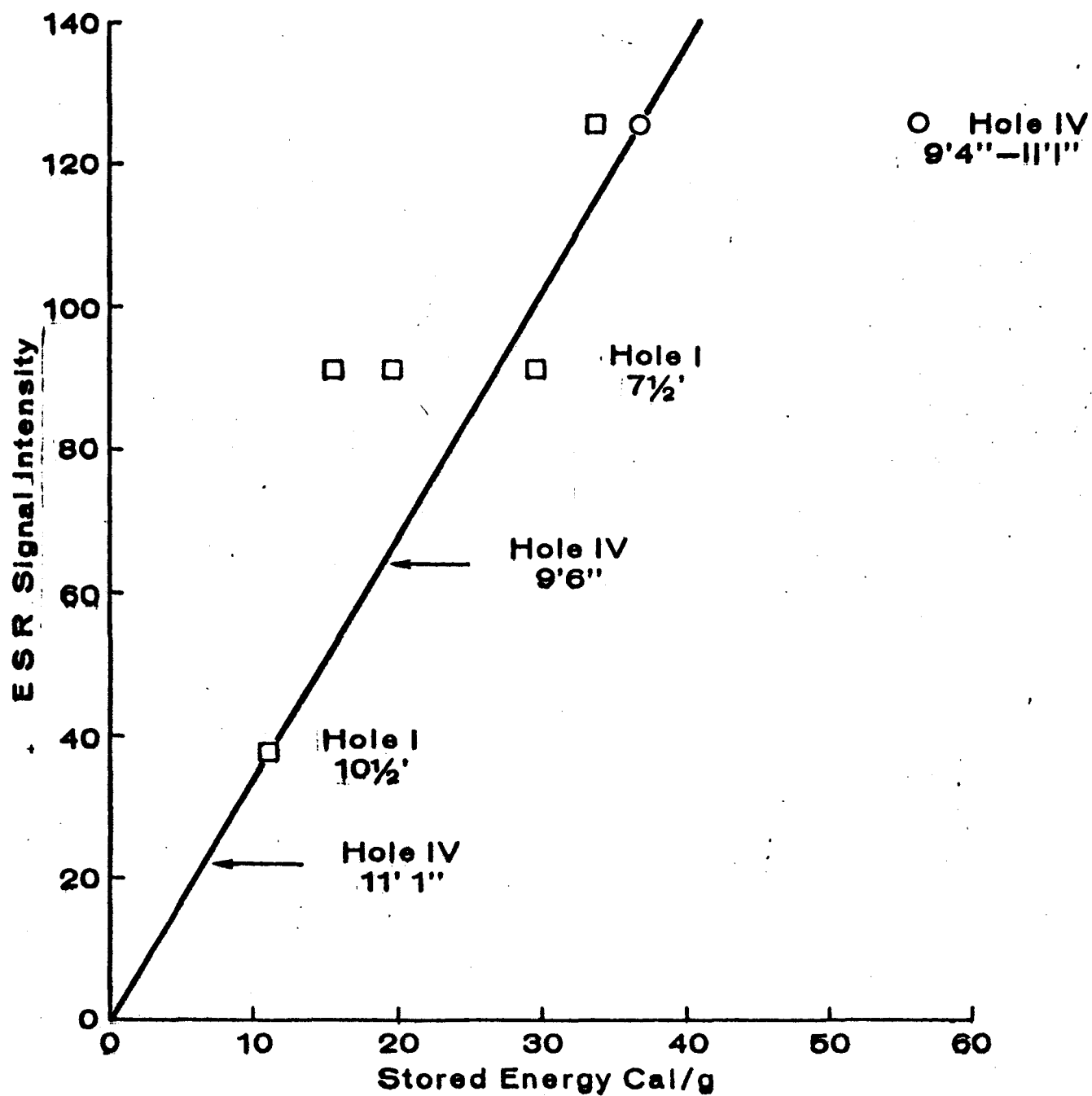


Fig. 55--Relationship of energy storage to electron spin resonance signal strength.

resonance signal strength and stored energy measured by differential thermal analysis. The two data points for Hole IV are projected values based upon this assumption. The three points obtained for Hole IV 9'4" - 11'1" are thought to have received approximately 9×10^8 rad total gamma dose during the Project Salt Vault experiment.

The second part of this chapter (Section B) is devoted to a specific investigation of the effect of particle radiation upon salt and other alkali halides. It should be noted here, however, that samples of salt irradiated with protons from a Van de Graaff accelerator can show energy storage as high as 100 cal. per gram. As long as the waste containers maintain their integrity, only very small quantities of salt will be subjected to high energy, heavy particle radiation. Nevertheless, the values obtained by proton irradiation do provide an indication of the potential capability of salt to store energy. Furthermore, the fact that the gamma ray irradiations performed as part of Project Salt Vault yield values in the range from 10 to 50 cal. per gram suggests that gamma radiation might approach the same energy storage limits as heavy particle radiation.

There is evidence that some of the irradiated samples from Project Salt Vault have already undergone local release of stored energy. Our study indicates that most, though not all, of the stored energy is located in the highly colored salt.

Photographs of thin-sections of salt from Hole IV are shown on Plate I, Figs. 1, 2. Both samples were obtained by chipping fragments from the inner wall of Hole IV after removal of the reactor fuel elements and heaters. (Plates for both sections of this chapter are located together with the plate explanations at the end of the chapter.) Plate I, Fig. 1, is an illustration of a region of highly colored salt adjacent to an area from which the color has been bleached either by heating or by recrystallization, perhaps caused by migration of small quantities of water along fracture lines. The location on the hole wall from which the sample was obtained is not known precisely, but it was collected between 9'4" and 11'11".

Figure 2 on Plate I is an example of the type of salt from Hole IV at 9'6" which shows nearly complete bleaching of the highly colored salt but little evidence of solution recrystallization. It is this sample which shows no energy storage when tested by solution calorimetry and DTA. Apparently most of the stored energy which was originally present has been discharged by heating in the last 90 day period of the Salt Vault study in which wall temperatures in the hole reached 195° C. As indicated above, the samples illustrated in Figures 1 and 2 were taken directly from the inner wall of Hole IV and were subject to strong heating by electric heater coils. The fact that the samples could be readily broken loose by chipping suggests that they may have become partially

detached from the surrounding salt mass during the irradiation and heating experiment. If this were the case, the individual crystalline masses may have been in poor thermal contact with the walls and could have reached temperatures substantially higher than 195° C especially if they were immediately adjacent to some of the heater units which were operated in the holes.

The practical problem which arises from energy storage in salt lies in the potential capacity of the material to undergo rapid thermal excursions through sudden release of the stored energy. The nature of such a thermal excursion can be postulated from known data. The specific heat of salt at 100° C is 0.271 cal. per gram and can be considered to be roughly 0.25 at 300° C. The release of 80 cal. per gram would cause the temperature in the affected region to rise from 300° C to about 620° C. Such a thermal excursion would be confined to the region where the energy storage occurred and could take place only if the release temperature were reached by some process of heating from a source external to the damaged salt, for example, heat from the radioactive waste containers themselves. Scanning electron microscope photographs of unirradiated, irradiated and bleached salt crystals are shown in Plates II and III.

The extent to which energy storage in salt may constitute a hazard in the practical aspects of the Lyons site for radioactive waste disposal has not been adequately evaluated. It has been argued that the rapid energy release of 100 cal. per gram will not constitute a significant hazard and that the entire problem can be ignored. At a conference at Oak Ridge held on October 8, 1970 it was implied that even 1000 cal. per gram could perhaps be tolerated. It should be pointed out, however, that any energy release in excess of 125 cal. per gram would result in melting of substantial quantities of salt. For this reason we do not feel that sufficient evidence has been presented to justify either of these conclusions.

POTENTIAL HAZARDS NEAR RADIOACTIVE WASTE CONTAINER

It is possible to envisage a number of hazardous phenomena that might occur at or near the individual waste container sites. These are, of course, only conjectures and may not be serious problems. However, we feel these potential hazards cannot be dismissed without careful research and documentation.

The total energy stored in salt via radiation damage is insignificant compared to the total thermal energy produced by the waste containers and will not affect the gross temperature distribution of the mine. However, a sudden release of energy may cause melting of salt around the container. The amount of salt affected corresponds to the gamma penetration which is about four feet from the surface of the container. A sudden rise in temperature could cause an explosive effect due to sudden thermal expansion. It is well known that salt releases water rather violently when heated above 280° C. This could add to the explosive effect.

Since the salt around the waste container is being continuously heated and irradiated, the energy storage and release process might occur periodically. A release might occur once or twice a year for about three years until the salt has reached maximum temperature. The melting and/or explosions might cause the container to migrate to a lower depth in the mine, possibly to a shale layer. The radiation damage and high temperature characteristics of shale would then become an important factor. Problems in the mine floor may develop, such as subsidence due to melting of the salt or bulge due to explosive heaving.

It is speculated that the waste container's metal cover may deteriorate as early as six months after emplacement in the mine. The radioactive waste is contained in a glass or ceramic silicate material which, as indicated by ORNL, may break up into relatively small pieces. Any disturbance due to temperature excursions in the vicinity of the container would enhance the deterioration of the glass or ceramic. The end result would be a large number of small radioactive particles available for migration in the salt. If the particles are relatively heavy, downward migration might occur due to localized melting. If the particles are relatively light or quite small, there may be upward migration. It is well known that water will migrate towards the pot, so that water will be available. The waste particles, if suspended by turbulent boiling water, will migrate along with the cavity. The upward migration is caused by deposition of salt from saturated brine at the cavity bottom and the dissolution of salt by condensed water at the cavity top.

The solid waste breakup may expose the salt to a significantly higher radiation dose. The expected total dose from a six inch purex pot is 2×10^{10} rads. Indications are that this number is based on the assumption that considerable self absorption will occur but if the solid material breaks up, self absorption will decrease. Based on the container dimensions and gamma radiation length, the elimination of self absorption could increase the total dose by a factor of two or three. Furthermore, the disintegration of the waste container would expose the salt to bombardment by particle radiation, thereby increasing the possibility of energy storage.

In general, heat conductivity of crystalline solids is reduced if they are subjected to irradiation. High concentrations of trapped, radiation induced defects, can cause a reduction in heat conductivity of as much as a factor of 50 in some materials (Dienes and Vinyard, 1957). The potential significance of this effect and its influence upon heat transfer from the containers to the surrounding salt has, so far as we can determine, not been considered in any of the heat flow calculations. The principal effect would be the tendency to increase the thermal gradient from the container outward and to raise the temperature of the waste container itself. It is also

known that gamma irradiation can change the mechanical properties of salt (Agullo-Lopez and Levy, 1964). The primary effect is that of radiation embrittlement with a large increase of yield stress. This factor could contribute positively to site safety but it must be considered in site design.

Finally, intense gamma radiation will cause some actual chemical breakdown of rock salt and associated impurities. These radiolysis effects could result in the formation of new chemical compounds with some of the radioactive elements in the waste containers. For example, plutonium forms water soluble chloride complexes under oxidizing conditions. Any chlorine which might be released could leach plutonium from the waste containers, especially after the disintegration of the glass. The presence of even small quantities of water will tend to disperse the plutonium complexes. The extent to which this process constitutes a hazard is dependent upon the degree to which the salt beds continue to exist as a truly closed system.

ENERGY STORAGE IN WASTE CONTAINER MATERIAL

According to current plans, the radioactive waste will be incorporated by fusion directly into glass or ceramic cylinders at the fuel processing plants. The exact composition of the waste containers has not been determined but they are expected to consist of approximately 30% radioactive isotopes and 70% inert binding material. Glass mixtures of phosphate and borosilicate as well as some high silica ceramics are currently being tested. The test program is designed to provide information about the structural strength and chemical stability of the material but so far as is known, no studies of energy storage from radiation damage effects are underway. Such investigations should be undertaken as soon as possible because glass and ceramic materials most probably are capable of storing substantially more energy than are comparable masses of salt.

Measurements of energy storage in proton irradiated iron magnesium silicate (olivine) and in common glass (microscope cover glass) were made by Zeller, Dreschhoff and Kevan in 1969. Approximately 200 cal. per gram were found in the iron magnesium silicate and about 100 cal. per gram in the glass. Both samples were irradiated as powders in a copper sample holder attached to a liquid nitrogen dewar. Owing to the extremely poor heat conductivity of powder samples in vacuum, it is most likely that the upper layer of the powder reached a temperature in excess of 100° C. Although temperatures in the waste containers will be in excess of 300° C at the time of emplacement, it must be anticipated that substantial energy storage will occur. Furthermore, unlike the surrounding salt, the waste containers will be subjected to heavy particle as well as gamma radiation. The efficiency of gamma rays for defect production and consequently energy storage is very low

(Van Bueren, 1960) when compared to the effectiveness of heavy particles. Thus, the possibility of energy storage in the material of the waste containers is proportionately larger than that in the salt. In view of the fact that we have detected energy storage in the range of approximately 10 to 50 cal. per gram in the most heavily damaged salt from the Project Salt Vault experiment, it appears reasonable to expect two to four times these values in the waste container material.

Release of stored energy and the accompanying thermal excursions can be expected to be most troublesome in the period immediately after the emplacement of the waste containers in the mine floor. This is true because the waste containers will be cooled during transit to the mine site and immediately after emplacement through contact with the cool salt in the mine floor. During the period when the containers are coolest, they may be able to store energy which will be released periodically as their surroundings are heated and their own interior temperature rises.

Under the worst circumstances, the internal temperature of the containers might rise high enough to permit temporary partial melting of the glass or ceramic. At these times, some melting of the surrounding salt would occur and shifting of the waste containers might result. Substantial shifts in container position after emplacement would make retrieval virtually impossible. If such melting and recrystallization cycles were repeated frequently enough, a type of "zone refining" could occur within the glass or ceramic so that specific radioisotopes would tend to be enriched locally within the waste containers. If fissionable isotopes were concentrated by this process, they might tend to develop local hot spots which could accelerate greatly the disintegration of the individual casks.

It is our opinion that the potential hazard due to energy storage in silicate and salt has been under-estimated. For example, the November, 1970 report from the National Academy of Sciences - National Research Council ("Disposal of Solid Radioactive Wastes in Bedded Salt Deposits" by the Committee on Radioactive Waste Management) indicates that a sudden release of 500 cal. per gram by the silicate would be acceptable. This conclusion is based on the fact that this quantity of energy would raise the temperature of the salt five feet from the container by only 2° C. The report fails to consider the more important fact that the temperature rise of the silicate would be 2000° C, enough to essentially vaporize the metal container and its contents. The report also indicates that energy storage in salt would not exceed 20 cal. per gram. As far as we can ascertain, this figure constitutes only a guess and is not in agreement with the data provided in this report.

SUMMARY AND RECOMMENDATIONS

Radiation damage effects in both salt and in glass or ceramic waste container material can cause significant quantities of energy to be stored. Gamma irradiated salt from Project Salt Vault shows energy storage amounts from 10 to 50 cal. per gram. Proton irradiated salt which has been cooled during the irradiation can release as much as 100 cal. per gram. Glass and ceramic materials can be expected to store appreciably larger amounts of energy than that found in salt. The fact that the waste container material is directly exposed to particle radiation causes it to accumulate stored energy much more rapidly than the gamma irradiated salt.

Thermal excursions will be most pronounced during the heating phase of any of the site components and they will be least likely to occur as the mine area cools. Solid material which is maintained at high temperature is less able to store energy than it can at low temperature. The approximate nature of the energy release curves for rock salt are known but no research on the glass or ceramic container materials is currently available.

The following recommendations for research are considered the minimum requirements consistent with a practical evaluation of site safety with respect to energy storage and radiation damage.

- 1) A careful examination of the irradiated salt from Project Salt Vault should be made. All of the necessary samples for this type of study are still present in the Lyons mine and could be obtained either by core drilling or by channeling into one of the holes used for the radiation experiment. Most of the answers to problems related to energy storage in rock salt could be obtained by a systematic study of this material. Only questions related to the effect of heavy particle radiation on salt could not be investigated by examination of the irradiated salt which surrounds the test holes.
- 2) Limits of maximum possible energy storage should be determined by particle irradiation of salt. Once these data have been obtained, practical assessment of the potential problem caused by energy storage in the salt can be made.
- 3) It is probable that the waste container material presents a greater safety hazard with respect to energy storage than does the salt itself. For this reason, energy storage capabilities of the various types of waste container material must be tested. Particle irradiations should be made and energy release curves

should be established for all of the various mixtures which are being considered.

- 4) Measurements of the thermal conductivity of highly irradiated salt should be made throughout the range of temperatures which will be encountered at the disposal site. Calculations of heat flow and gradients in the irradiated salt should be corrected for the observed variation in conductivity.

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Chapter 5

Section B

ENERGY STORAGE AND CHARGE TRAPPING IN HEAVY PARTICLE IRRADIATED ALKALI HALIDES

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INTRODUCTION

Many of the physical properties (electrical and thermal conductivity, color, luminescence, diffusion, mechanical strength) of solids are determined by imperfections in the crystal lattice. In order to investigate the physical behavior of solid matter, it is frequently desirable to introduce imperfections in a controlled way. This can be done most simply by radiation which can be applied independent of temperature.

Exposure of alkali halides to ionizing radiation produces many types of lattice defects, because energetic radiation has the capability of displacing atoms from their equilibrium positions in a lattice. A thorough investigation of the plastic behavior of gamma-ray irradiated sodium chloride crystals using color-center measurements and examination of the effects of mechanical stress has been conducted by Agullo-Lopez and Levy (1). Kobayashi (2) used highly energetic charged particles (350 MeV protons) to make extensive studies of stored energy together with the electrical conductivity and color-center formation in sodium chloride.

When high energy protons traverse matter, most of their kinetic energy is used up in excitation and ionization processes. The ejected electrons in turn can produce atomic displacements, because in addition to causing further ionization, they undergo elastic scattering at electrons and nuclei. The cross section is proportional to Z (atomic number) for scattering at electrons and Z^2 for the scattering at nuclei. The range of 350 MeV protons is several centimeters in sodium chloride, so that they are not stopped in a crystal a few millimeters thick. The interaction of electromagnetic radiation (gamma-rays) with the lattice is mainly by transfer of momentum to the atomic electrons.

Therefore, in both cases, it is possible to get a relatively homogeneous defect distribution in the irradiated crystalline material. If, however, charged particles are stopped in the crystal under irradiation, completely different conditions will arise. At lower particle energies, especially

near the end of the particle's path, elastic (hard sphere) collisions will prevail producing heavy disturbance in the lattice within a very small region.

ENERGY STORAGE MEASUREMENTS BY DIFFERENTIAL THERMAL ANALYSIS

Single crystals of optical grade pure sodium chloride were bombarded with 1 MeV protons from a Van de Graaff accelerator. The irradiations were made at low temperature by cooling with liquid nitrogen and at room temperature by cooling with water.

Lattice defects are thermally unstable. The annealing of defects can be observed directly by means of Differential Thermal Analysis (DTA). The change in internal energy introduced by the release of stored energy can be measured versus temperature. A constant heating rate is used for annealing the sample. Recovery of the crystal lattice is characterized by one or several activation energies, which are dependent upon the lattice structure and the properties of the surrounding lattice atoms.

In Figure 56, the energy release curves for three different proton fluxes (irradiated at 77° K) are shown. The total number of protons incident on each sample was $6.7 \times 10^{16} \text{ cm}^{-2}$ in all three cases. 107 cal. per gram are released between 50° C and 475° C in the sample subjected to the lowest proton flux. This and all following values are considered to be accurate within + 15%. For the sample which received the proton flux of $7 \times 10^{12} \text{ cm}^{-2} \text{ sec}^{-1}$, the amount of stored energy is 86 cal. per gram, and 70 cal. per gram are released in the case of the proton flux, $9.3 \times 10^{12} \text{ cm}^{-2} \text{ sec}^{-1}$. The fact that the lowest proton flux results in the highest amount of stored energy most probably reflects the temperature attained within the irradiated volume of the target during the bombardment. Higher fluxes result in higher temperatures and thus produce less total energy storage within the temperature range from 50° C to 475° C.

Similar to this result is the DTA curve of alpha particle irradiated sodium chloride, which had been exposed to a flux of $5.4 \times 10^{12} \text{ cm}^{-2} \text{ sec}^{-1}$ and an integrated flux of $5.6 \times 10^{16} \text{ cm}^{-2}$. The penetration depth for the relatively low He^{++} energy of 1.5 MeV was only approximately 7 microns, so that the energy deposition occurred in a very thin layer, which gives a value of 24 cal. per gram of stored energy.

Proton bombardment of a NaCl crystal at room temperature resulted in 19.6 cal. per gram stored energy observed between 150° C and 400° C after an exposure to 3.4×10^{16} protons cm^{-2} at a particle flux of $3.3 \times 10^{12} \text{ cm}^{-2} \text{ sec}^{-1}$.

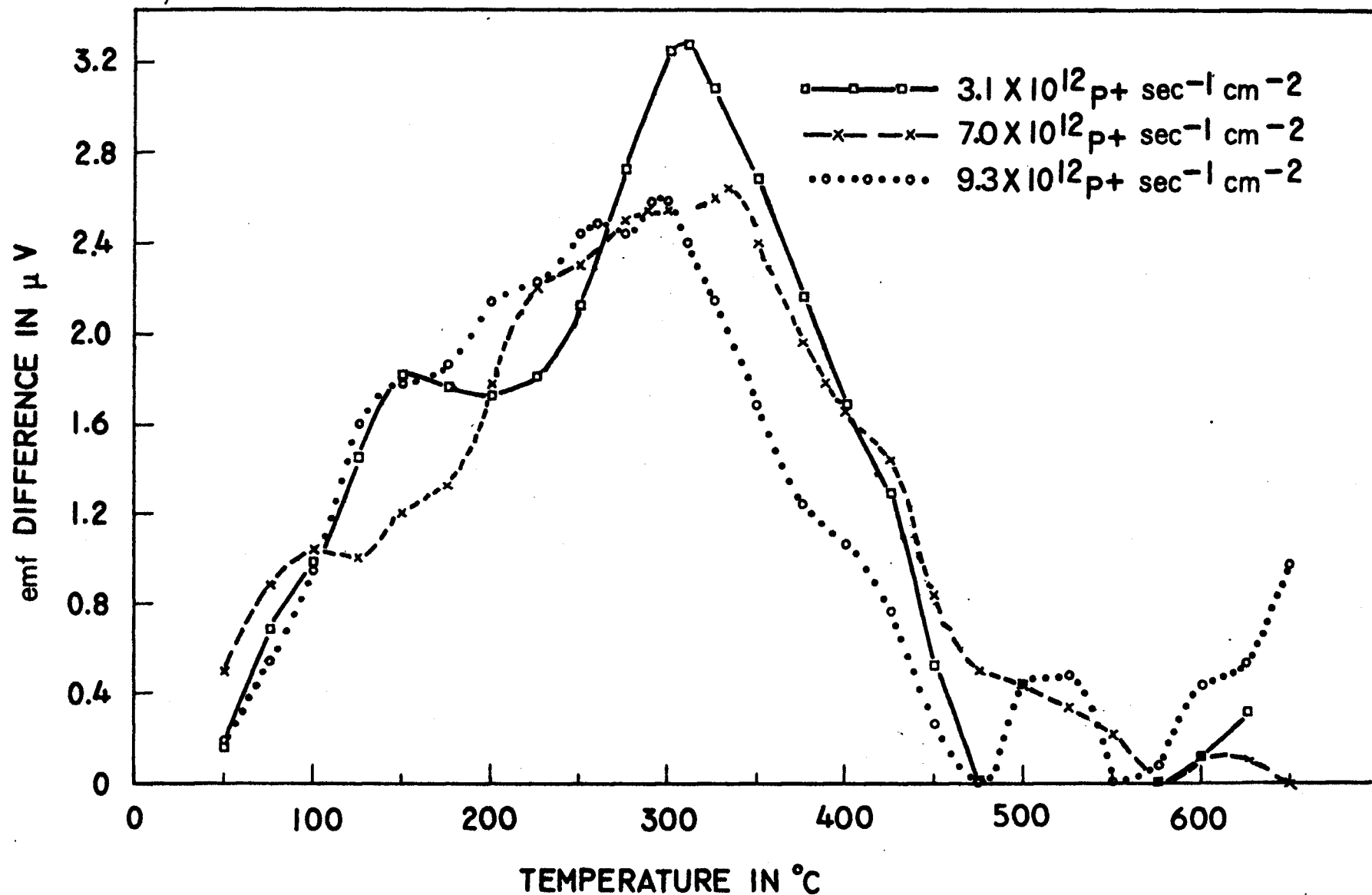


Fig. 56--Flux dependency for stored energy in sodium chloride.

(Dreschhoff, 1971)

Because each sample consisted of irradiated and unirradiated material, all energy storage data have been corrected for the sample weight of the irradiated portion of each sample used for the DTA measurements. After determination of the actual penetration depth of the particles, it was possible to calculate the true volume affected by the radiation.

Because of the complex annealing behavior and because of its dependence on particle fluxes, the investigation was extended by studying the distribution of stored energy in the irradiated part of the NaCl crystal which had been exposed to 3.1×10^{12} protons $\text{cm}^{-2} \text{sec}^{-1}$ at an energy of 1 MeV, resulting in a penetration depth of 22 microns.

By using a microtome, it was possible to slice off 6 micron thick layers from the irradiated surface of the crystal, and the stored energy release up to the temperature of 500° C for each layer was measured. Marked changes in the annealing spectrum with depth were observed. The uppermost layer shows energy release in the interval of 150° C to 350° C, with a distinct peak at 175° C and a broad peak with a shoulder rising to the maximum value at 300° C. The layer from 6 to 12 microns continues to show some energy release at 300° C, a small peak at about 350° C, and a small but distinct peak at 475° C is developing, which in the next layer appears much stronger. The third layer also shows a well developed peak at 170° C. Moreover, this region from 12 to 18 microns contains about 35% of all of the stored energy. No energy release occurs at 300° C and 350° C. The fourth layer from 18 to 24 microns shows again a distinct peak at 350° C in the higher temperature region and around 100° to 175° C.

It is assumed that the difference in the nature of the lattice damage is reflected in the energy release spectra. Additional and very interesting information is gained by heating the samples of 6 micron thick layers up to the melting point. For the first three layers, the DTA curves show a slow decrease before entering the strong endotherm which accompanies the actual melting process. The fourth layer also exhibits the same general behavior, however, a few degrees before the melting starts, there is a small but very sharp rise in the sample temperature which subsequently falls off very rapidly. This peak could not have been observed if the entire volume of the irradiated material had been used.

A strong dependence exists between the stored energy and the particle flux as well as the total incident particle dose. The very complex relaxation behavior, however, especially if investigated in successive thin layers of the bombarded crystal surface, suggested that a direct examination of the irradiated part of the crystal should be made.

DIRECT OBSERVATION OF THE IRRADIATED CRYSTALS

These experiments were conducted by two separate methods. In both cases, alkali halide crystals were bombarded by heavy charged particles. If the crystal was to be examined by optical methods, it was cleaved perpendicular to the bombarded surface and a thin-section was prepared. Standard petrographic thin-section grinding techniques were used except that oil rather than water was used to suspend the abrasive. The thin-sections were then examined by a polarizing petrographic microscope. Subsequently, a number of the irradiated crystals were also examined by means of the scanning electron microscope. In all cases, the crystals were cleaved perpendicular to the bombarded surface and then etched for 30 seconds in methyl alcohol which contained 0.02% water. The relative variations in solubility of the material on the cleavage surface is assumed to reflect the degree of lattice damage which is present at that point.

As can be seen in Figure 3 and 4 of Plate I, the particle irradiated portion of NaCl crystals are deep blue in color. However, if the crystals are cooled with liquid nitrogen during the bombardment, they develop a bright yellow color which they maintain after termination of the irradiation. If kept in the dark, below 0° C for a few days, the color changes to green and if exposed to daylight at room temperature, the samples often become blue.

The absorption of light in these colored crystals indicate the type of color centers which are present.

The F-center is the simplest trapped-electron center in alkali halides and absorption of the visible light produces the bright yellow appearance of the NaCl crystals. The blue color, however, is determined by the absorption and scattering of the light waves by small particles of colloidal sodium metal. The scattering cross section of the fine colloidal particles is wavelength dependent. A particle diameter up to 200 Å will give a red color to the crystal and for a diameter between 400 and 800 Å, the crystal color is blue (3). The green color of the NaCl crystal is a combined effect of the F-band (yellow) and the blue color of the colloidal sodium.

The process which produces the yellow color in the NaCl crystals, causes the development of a reddish-purple in KCl crystals and a very deep blue of KBr crystals. The tendency for alkali halide crystals to develop coloration as a result of particle irradiation has been known for a long time and has been the subject of extensive study. If the particle penetration depth in the material is much greater than the actual thickness of the crystal, the particles pass completely through and the F-center distribution and therefore the coloration is more or less uniform throughout. If, however, the

particles are stopped within the crystal, the color distribution is not uniform along the particle path. On Plate IV in Figure 1, 2, 3, thin-sections are shown of NaCl, KCl and KBr. Protons of about 2 MeV had entered the crystal surface from the top. These photomicrographs show the actual penetration depth in profile. Three zones are clearly visible. The upper region shows strong color center development (mainly colloidal metal). Beneath this zone, an optically transparent layer is present, which is followed by a dark, deeply colored third zone. It should be mentioned, that in the case of KBr, the colorless upper surface layer of 5 microns is thought to be the result of introduction of water or oxygen, which can destroy the F-centers and consequently the blue color. The same three zones which are visible in transmitted light can also be found in the etch patterns which can be made visible by the reflected electron beam of the scanning electron microscope. Figure 1 and 2 of Plate V represent the damage caused by about 1×10^{16} protons cm^{-2} with an initial energy of 2 MeV. It is clear from these pictures that aggregation into clusters of the simpler defects has taken place. This cluster formation is also well developed in a NaCl crystal, which had been bombarded with about 1.8 MeV protons and a total dose of about 1×10^{16} cm^{-2} . This is shown in Figure 1 and 2 on Plate VI.

Crystals which have been irradiated at room temperature develop a yellowish-brown color, which does not turn readily into blue after exposure to daylight. This color probably also results from the simultaneous presence in the crystal of F-centers and some colloidal sodium. In irradiations performed at room temperature, however, the color is distributed throughout the irradiated part of the crystal and no colorless layer near the end of the particle path is developed.

Two different types of experiments represented by the photomicrographs have been conducted to investigate the optically clear region shown in Figure 3 and 4 of Plate I. First, in Figure 3, a NaCl crystal had been cooled to liquid nitrogen temperature and subjected to bombardment by 2 MeV protons. The radiation caused the upper part of the area which was penetrated to become colored and this is in turn followed by the colorless and the darker, terminal layer. After completion of the proton irradiation, the crystal was subjected to further bombardment by deuterons of the same energy, (2 MeV). Because of their larger mass compared to that of the protons, their velocity is lower and their penetration is less, so that they are stopped within the colored region produced by the protons. Despite the previous F-center formation by the protons, the deuterons show a bleached zone near to their stopping site. The same is true for 2 MeV alpha particles which have the least penetration power. However, the energy of the alpha particles was unstable during the bombardment, so that the whole stopping region appears lighter in color. This same crystal has also been studied with the

electron microscope and all three stopping regions are visible in Figure 1, Plate VIII.

A second experiment was conducted in which an NaCl crystal was first irradiated with 1 MeV protons and then subsequently bombarded with 2 MeV protons. In this case both irradiations were equal in total dose to about 0.7×10^{16} particles. The results of the experiment are shown on Plate I, Figure 4. Even after the bombardment with 2 MeV protons, the colorless region corresponding to the stopping zone of 1 MeV protons remains clearly visible. The structure of this layer can be best seen by examining the same crystal under the scanning electron microscope. Clusters of nearly 400 mμ diameter (Plate VII) have formed at some sites at the 1 MeV terminal line.

The appearance of the colorless layer as well as the terminal dark line marking the end of the particles path was completely unexpected and no reference reporting its existence has been found. These structures can be especially well seen in Figures 1, 2, 3 of Plate V. Figure 3 shows the unique etching behavior of the terminal darker layer, which appears now as a continuous groove and in the upper part of the picture there is a marked difference in the etching characteristics of the transition zone between the colored portion of the crystal and the uncolored layer. This uncolored region is either a phenomenon of low temperature or rapid cooling. The crystal shown in the scanning electron microscope photographs on Plate VI was irradiated at room temperature. In this case, the region which should correspond to the transparent zone is conspicuously absent.

The last dark line can not be attributed merely to a much higher color center density than that present in the upper part of the irradiated crystal. All color can be bleached after heating the sample to 200° C for 25 minutes. This is illustrated in the proton irradiated NaCl crystal shown in Figure 4, Plate IV. The crystal still shows the terminal layer. Crystals have been heated to a temperature of 350° C for 20 minutes and then examined under polarized light. The region of the terminal zone shows strong birefringence. If the irradiation is conducted with alpha particles and the same annealing process had been applied, no birefringence can be seen.

NaCl crystallizes in the cubic system and is isotropic. Therefore, it does not show birefringence under normal circumstances. If, however, regions within the crystal are subjected to stress, birefringence is frequently developed in the stressed zones. It is important to note that the birefringence does not tend to develop in the crystals as a result of the irradiation alone but requires subsequent heat treatment. Furthermore, crystals irradiated with alpha particles do not show birefringence while those irradiated with protons developed this

characteristic in the terminal layer after heating in all of the crystals which were examined.

The terminal layer apparently represents the actual stopping region of the protons. It is roughly 2 microns in thickness and probably constitutes a region of displacement spikes which are formed at the end of the particle's path through the crystal. It is also a region where positive charge is accumulated during the irradiation.

If the irradiation is conducted at liquid nitrogen temperature, most of the protons are probably prevented from diffusing out of the stopping region. The implanted particles may act as chemical impurities and the terminal layer remains clearly visible even after heating. There is strong evidence that protons are retained in the NaCl lattice. H atoms on negative ion vacancy sites (U_3 centers) have been detected by ESR studies (4). In addition, hydride ions have been observed in CaF_2 at room temperature (5). Because chemical bonds may develop between some of the incident protons and lattice atoms even at low temperature, NaH may be formed during the irradiation. The attraction between the sodium cation and the hydrogen anion is very strong (6) and heat treatment will enhance the formation of NaH, which in local areas could result in the partial development of the NaH lattice. The crystal lattices of both NaCl and NaH are cubic and as pure crystals would show no birefringence. The lattice constant for NaH is, however, much smaller than that for NaCl and a local intergrowth or partial replacement of Cl by H in some unit cells could result in stress and cause the observed birefringence in the terminal layer after heating to 350°C . Apparently HCl does not form from these irradiations. No characteristic HCl infrared absorption bands were developed in any of the irradiated NaCl crystals which were tested.

The presence of a concentrated region of displacement spikes in the terminal layer causes this region to be more highly disordered than the adjacent areas in the crystal. Ion vacancies and implanted hydrogen are both present in significant concentrations. Indirect evidence for the presence of this disorder is furnished by another heating experiment which was conducted with proton irradiated NaCl crystals. In this experiment, the crystals were annealed stepwise by heating to 180° , 350° , 500° and 650°C . Between each step, the crystals were cooled and examined under a microscope. The formation of minute bubbles in or immediately adjacent to the terminal layer could be observed after the 350° or 500°C heating. Bubble formation occurs at the lower temperature in crystals which have been subjected to a very high total particle dose. Initially, the bubbles are very small and round but heating to higher temperatures results in the formation of larger bubbles which have a rectangular cross section which is greater than the thickness of the terminal layer. Presumably,

the bubbles contain hydrogen gas, but there is no experimental evidence for this conclusion. Bubble formation takes place at nucleation sites and these can be provided by the presence of displacement spikes.

If the colorless region was developed by thermal bleaching which was caused by elevated temperatures at the end of the particle's path, it would be most pronounced in the room temperature irradiations. (Some earlier observations which were made on whole crystals produced misleading results because of optical effects related to differences in refractive index between the irradiated and unirradiated regions. These effects were eliminated through the use of thin-sections.)

The transparent layer is not developed if the total particle dose is too low. For example, 10^{14} protons cm^{-2} produce coloration but do not develop the transparent zone in NaCl, KCl or KBr. For this reason, it might be argued that the effect is a kind of radiation bleaching. The fact that room temperature irradiations at high integrated flux do not produce the effect eliminates this also as a potential explanation.

The effect of stress upon F-center or colloidal sodium distribution could also be considered as a possible cause of the transparent layer. If this were the case, experiments in which 1 MeV irradiations are followed by 2 MeV irradiations should result in a broadening of the transparent zone below the terminal layer for the 1 MeV protons. Since this does not occur, it appears that simple stress cannot be the cause of the transparent layer.

The development of a layered structure is especially striking in the case of alpha particle bombardment and it is not fully understood. In addition, the scanning electron microscope photograph shows a very low concentration of defects or defect clusters. Actually, this is in good agreement with the optical characteristics which can be seen in the thin-sections. The degree of coloration produced by 2×10^{16} alpha particles cm^{-2} is much less than that resulting from a similar dose of protons. (Plate VIII, Fig. 2)

This investigation has shown that the distribution of energy stored in the lattice by stopped particles can be divided into distinct layers, if the particles are monoenergetic. It appears that the energy storage is related to the profile of energy loss to the lattice along the particle path. The defect production throughout the irradiated portion of the crystal results in significant changes in the mechanical and optical properties. The heaviest damage is concentrated in the terminal layer and can contribute to the extensive alteration of the mechanical properties in this region. Further studies are currently in progress to determine whether electrical charge effects may be in part responsible for the development of the transparent layer above the terminal zone.

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EXPLANATION OF PLATE I

Figure 1 - Magnification X 38

Photomicrograph of a thin section of salt irradiated during the Project Salt Vault study. (Hole IV 9'4" to 11'11") The dark blue colored region shows a high concentration of colloidal sodium metal. This portion of the crystal also exhibits the maximum energy storage. In this thin section, the transparent zones which parallel cleavage fractures are probably regions of local recrystallization caused by water migrating along the cleavage planes.

Figure 2 - Magnification X 38

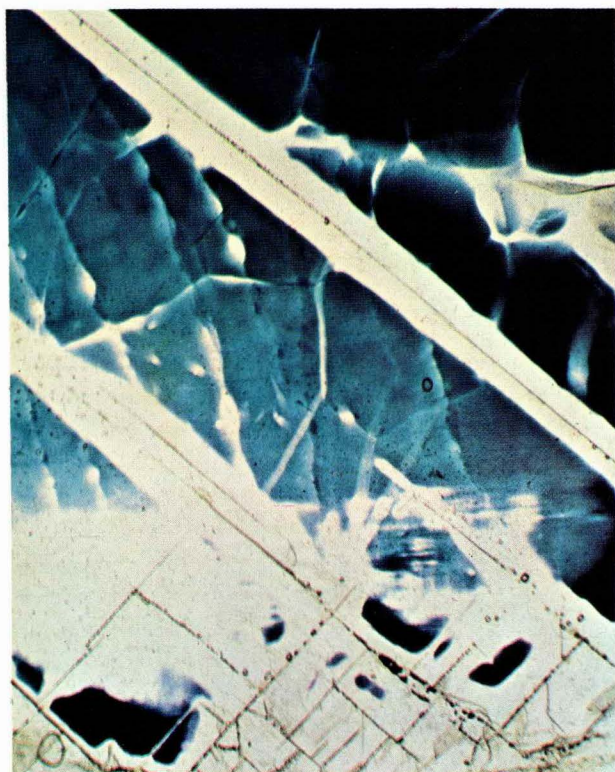
Photomicrograph of a thin section of salt irradiated and partially bleached during the Project Salt Vault experiment. (Hole IV 9'6") This crystal is thought to have been bleached during the heating experiment at the end of the Salt Vault Study. There is no clear evidence of recrystallization by water moving along channels and the general structure of the primary salt is retained.

Figure 3 - Magnification X 480

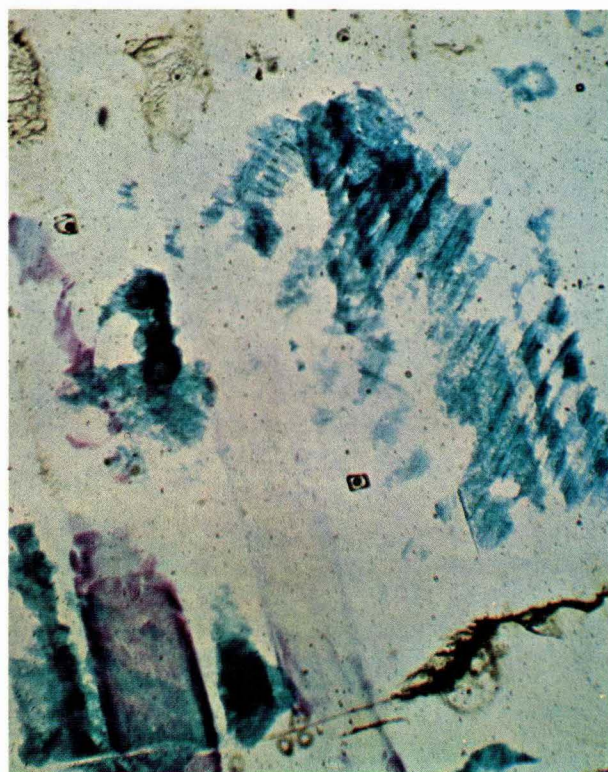
Thin-section of an NaCl crystal which has been bombarded by 2 MeV protons, deuterons and alpha particles at liquid nitrogen temperature. The upper surface of the crystal through which the particles entered is on the upper left of the colored region and the protons stopped in the narrow dark band at the lower right. The transparent region below the dark terminal layer caused by the protons is the unirradiated portion of the crystal. The damage caused by the alpha particles is visible in the light blue region nearest the surface. The light blue band below the center of the irradiated zone is the stopping region for the deuterons. The total deuteron dose is only about one eighth that of the proton dose. The narrow brownish-yellow fringe at the lower edge of the terminal layer may result from a local concentration of F-centers.

Figure 4 - Magnification X 480

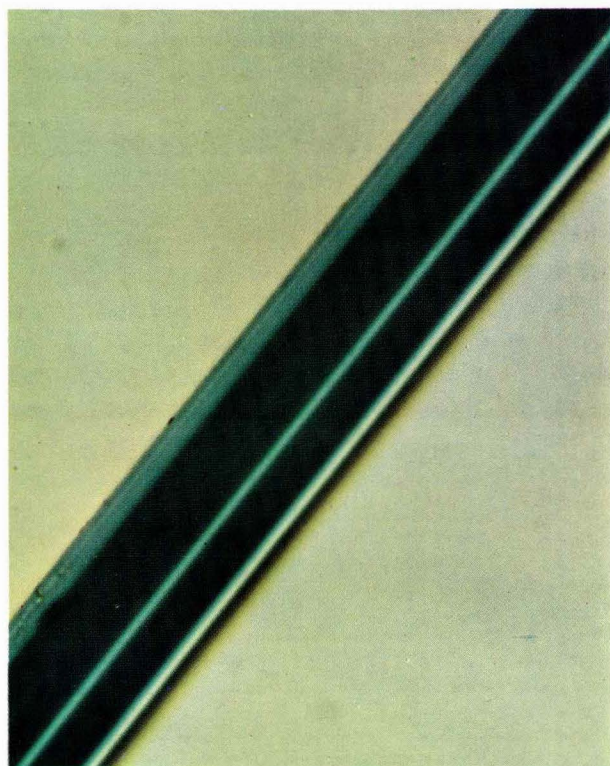
Photomicrograph of a thin section of a crystal irradiated with protons at liquid nitrogen temperature. The protons entered the crystal surface from the upper left. The region to the right below the colored band is the unirradiated portion of the crystal. In this case, the crystal was first irradiated with 1 MeV protons and then subsequently irradiated with 2 MeV protons. The bleaching effect which the 1 MeV protons had upon the crystal is retained even though the 2 MeV protons passed through this region. The transparent region and terminal layer are clearly visible.



1



2



3

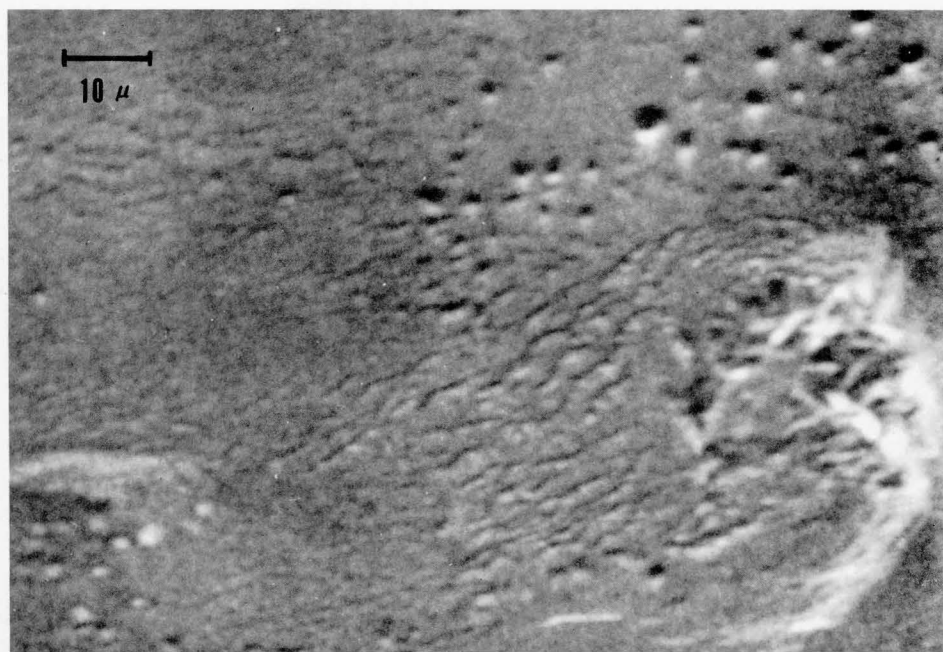


4

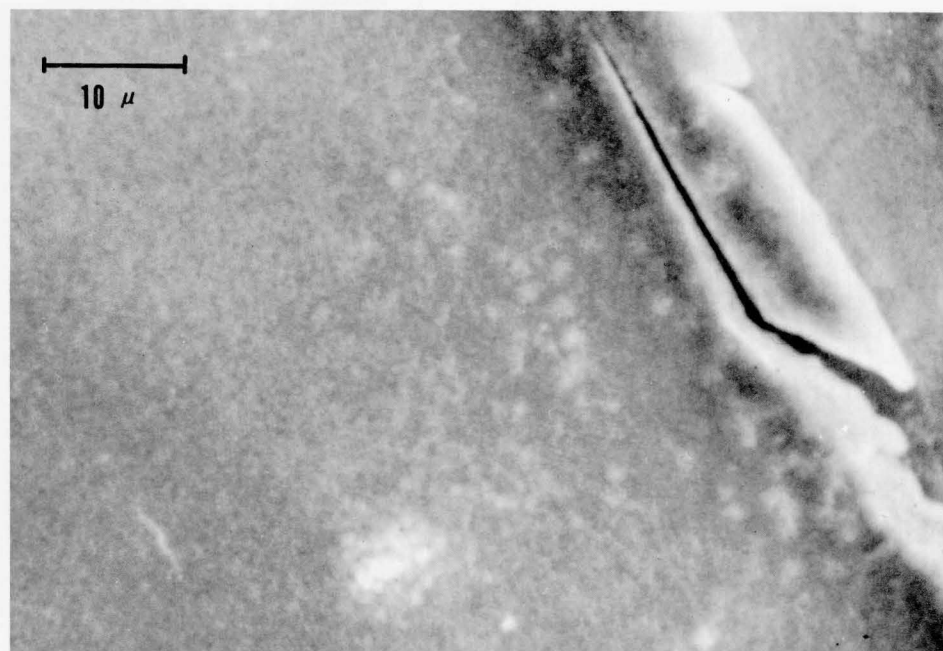
EXPLANATION OF PLATE II

Figures 1 and 2

Scanning electron microscope photographs of etched cleavage surfaces of two unirradiated crystals of salt from the Lyons Mine. Both surfaces show generally low relief. The presence of small mounds, as seen in Figure 1, is typical of some surface areas. Figure 2 shows very low relief over most of the surface, but there is a tendency for the mound-like structures to be concentrated in the area parallel to the fracture.



1



2

EXPLANATION OF PLATE III

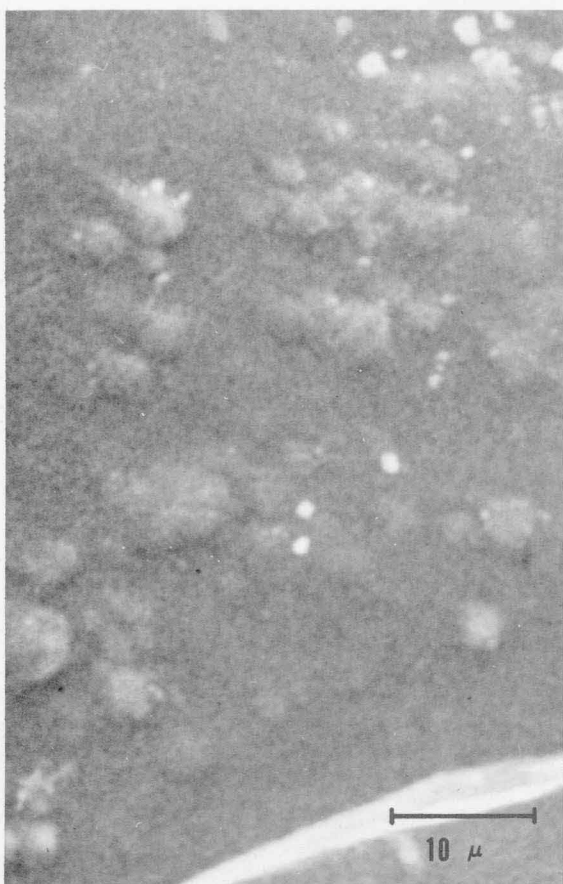
Figure 1

Scanning electron microscope photograph of bleached region adjacent to the highly colored area shown in Figures 2 and 3. The etching characteristics of the bleached regions differ from those of both the colored areas and the unirradiated salt. Mound-like structures are present on the surfaces and the general relief is higher than that shown by unirradiated cleavages which were subjected to the same etch conditions. Deep pitting which is present in the immediately adjacent colored area is not developed. The mounds may represent regions where substantial restoration of the lattice to its most stable form has already taken place.

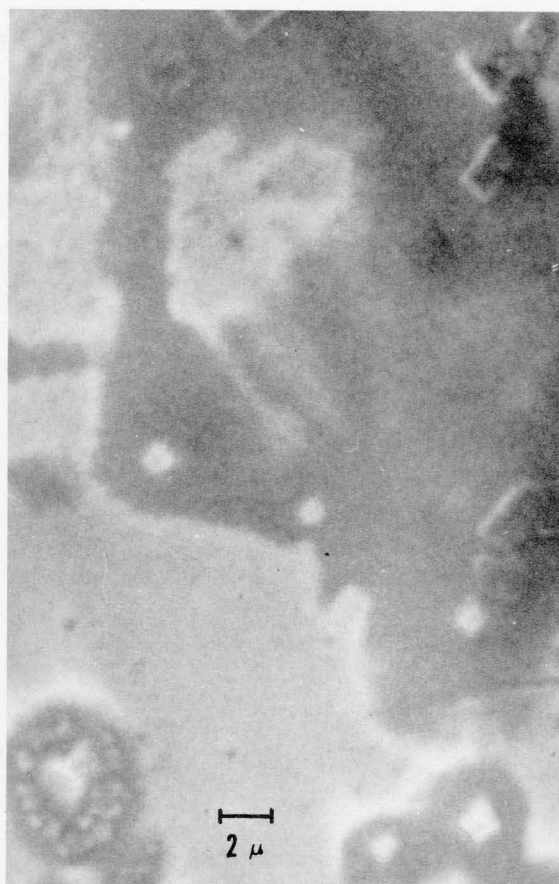
Figures 2 and 3

Scanning electron microscope photographs of an etched cleavage surface of a strongly colored region in a crystal from Hole IV, 9'6". The surface in figure 3 shows a complex structure and deep pitting not present in either the bleached regions of this crystal or in unirradiated crystals of Kansas salt. The deep pitting is assumed to arise mainly from local concentrations of defects which were caused by the irradiation. In general, the local solubility of the salt at any given point on the surface of the crystal is thought to be directly related to the degree of lattice disorder, either from impurities or from radiation damage. Since the stored energy is also related to the degree of lattice disorder, these photographs provide an indication that the distribution of stored energy in this region of the crystal is highly irregular.

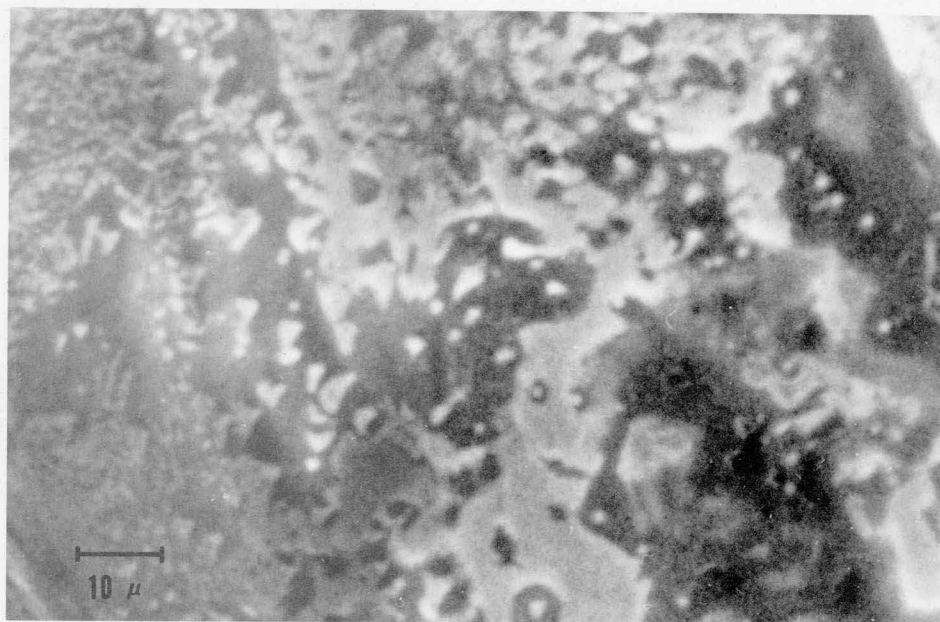
Figure 2 is an enlarged view of the lower central portion of figure 3. Small euhedral crystals are visible along the right side of the enlargement.



1



2



3

EXPLANATION OF PLATE IV

Figure 1

Photomicrograph of a thin-section through the irradiated portion of a NaCl crystal. The crystal was cooled to liquid nitrogen temperature during the irradiation with protons of approximately 2 MeV energy. The granules scattered through the photograph are grains of the abrasive used to grind the thin-section.

Figure 2

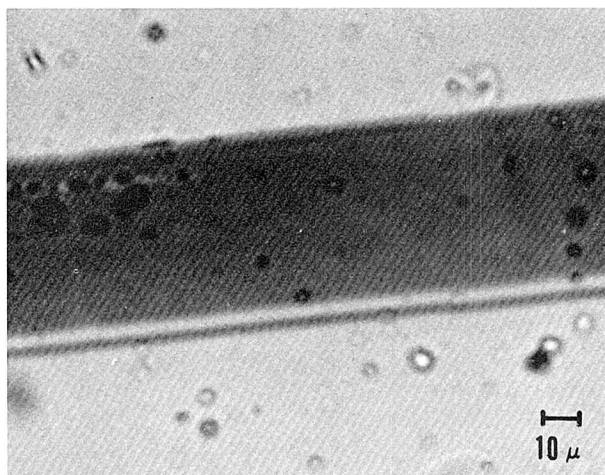
Photomicrograph of a thin-section through the irradiated portion of a KCl crystal. The crystal was cooled to liquid nitrogen temperature during the irradiation with protons of approximately 2 MeV energy. The granules scattered through the photograph are grains of the abrasive used to grind the thin-section.

Figure 3

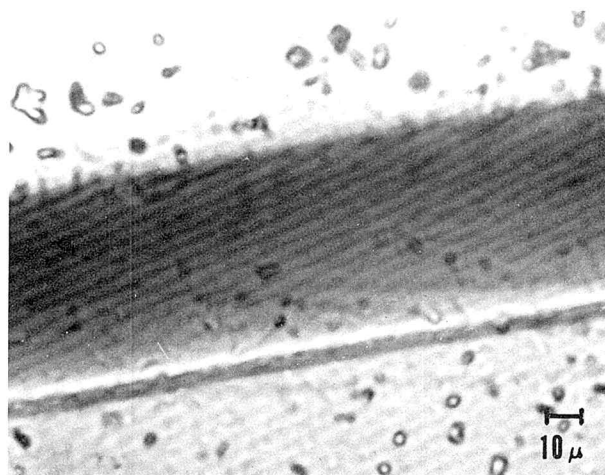
Photomicrograph of a thin-section through the irradiated portion of a KBr crystal. The crystal was cooled to liquid nitrogen temperature during the irradiation with protons of approximately 2 MeV energy. The granules scattered through the photograph are grains of the abrasive used to grind the thin-section.

Figure 4

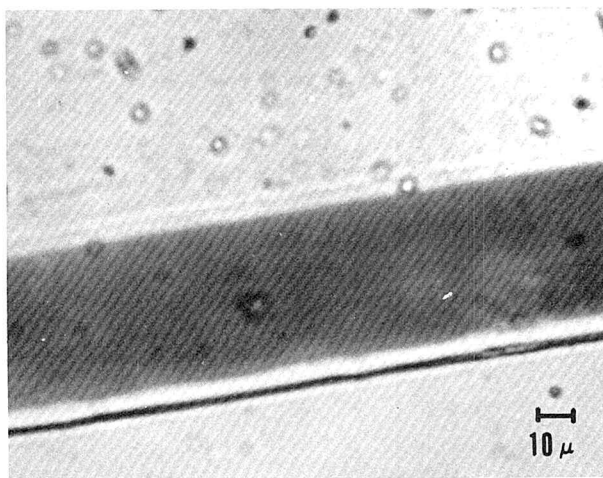
Photomicrograph of a thin-section through an irradiated portion of an NaCl crystal which has been subsequently subjected to heating to 200° C. The color has been completely removed but the terminal zone remains clearly visible. The light band below the terminal zone most probably results from an optical effect related to the excessive thickness of this particular thin-section.



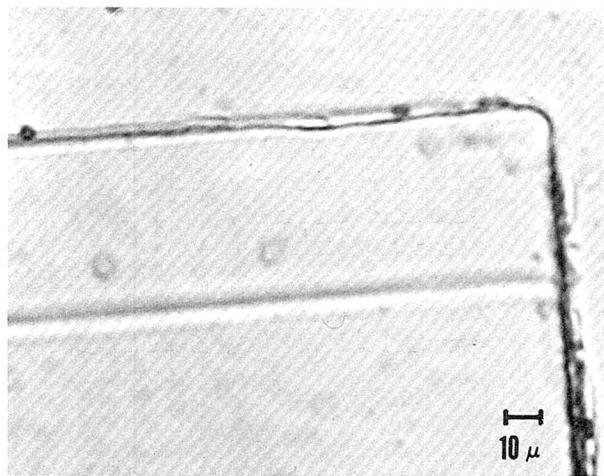
1



2



3



4

IV

EXPLANATION OF PLATE V

Figure 1

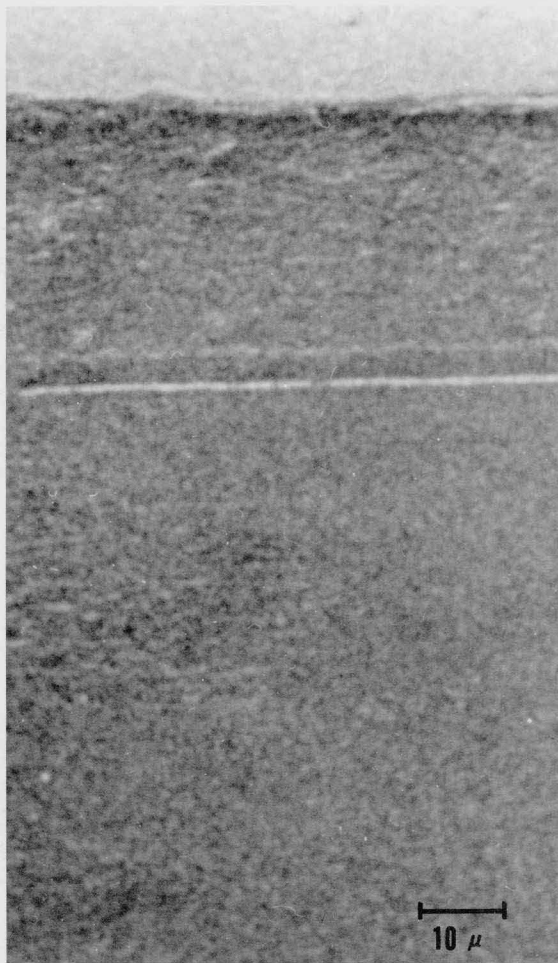
Scanning electron microscope photograph of the etched cleavage surface of a proton bombarded NaCl crystal. The three zones which are present in the thin-sections are also visible in this photograph. The upper colored zone is characterized by an irregularly etched region which appears to show the development of cluster formation by the defects. The transparent zone is separated from the colored region by a small, somewhat discontinuous groove and the terminal layer is clearly marked by a deep continuous groove.

Figure 2

Increased magnification of a portion of the area shown in Figure 1.. The groove which represents the terminal layer is at the bottom of the picture.

Figure 3

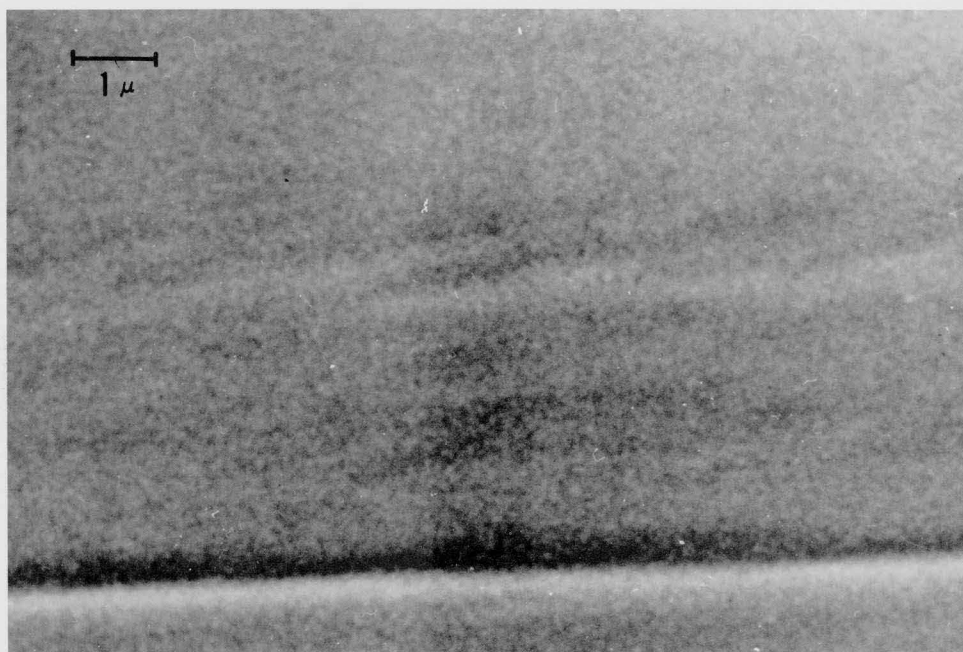
Scanning electron photomicrograph of the boundry between the upper colored region and the transparent zone in an etched NaCl crystal irradiated with 2 MeV protons at liquid nitrogen temperature. The deep groove is present at the site of the terminal layer.



1



2



3

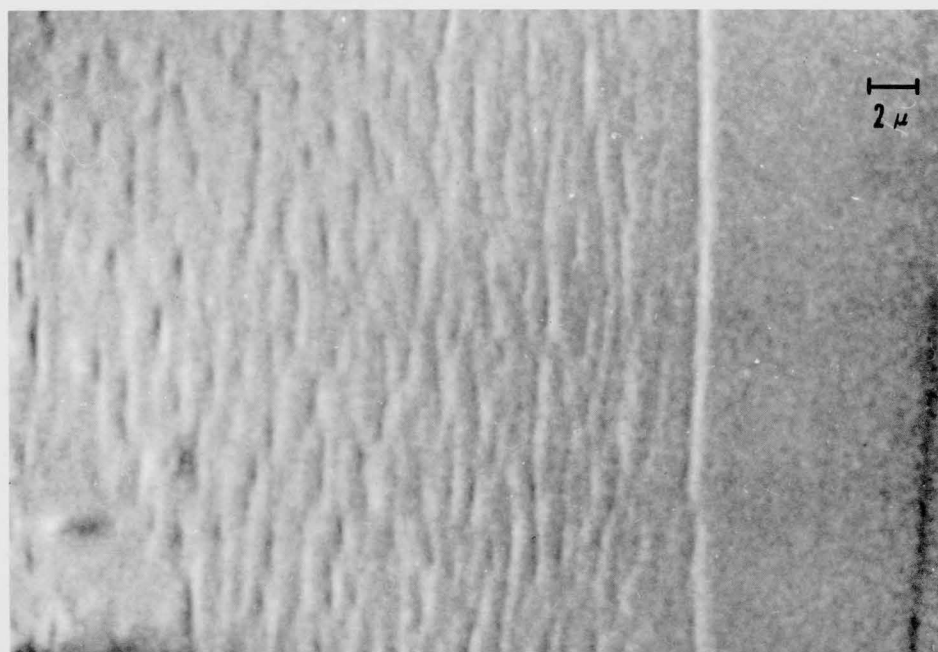
EXPLANATION OF PLATE VI

Figure 1

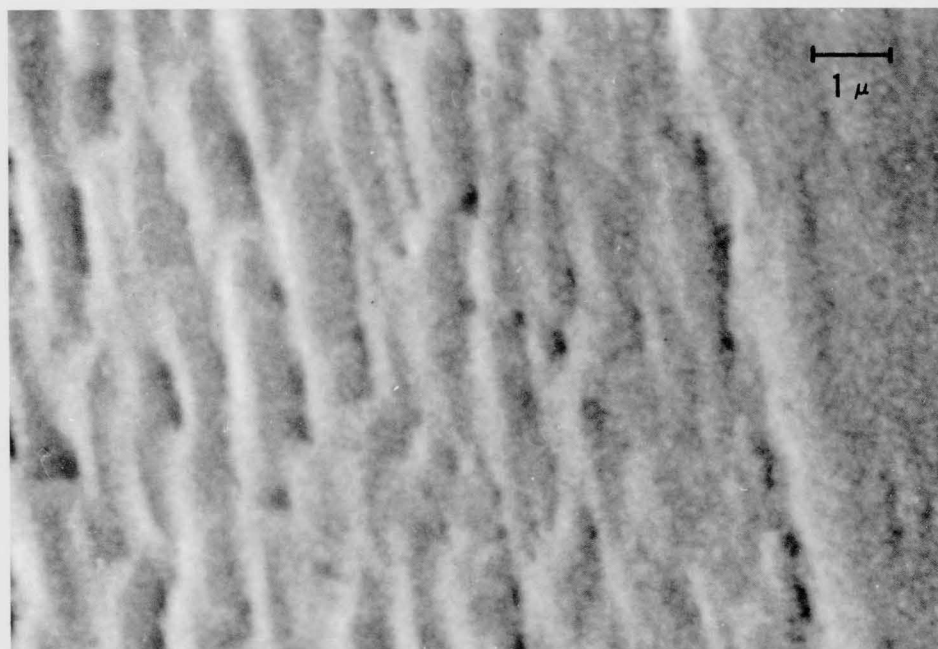
Scanning electron microscope photomicrograph of the etched cleavage surface of a NaCl crystal irradiated with 1.8 MeV protons at room temperature. In this crystal, the bombarding protons entered from the left and stopped in the area of the vertical groove in the right portion of the photograph. Aggregation of defects to produce clusters is more marked in this crystal than in those shown in Plate V which were irradiated at liquid nitrogen temperature. Note particularly the absence of any zone which would correspond to the transparent layer. This layer is not developed in crystals irradiated at room temperature.

Figure 2

Increased magnification of a portion of figure 1 showing the detail of the defect cluster structure.



1



2

VI

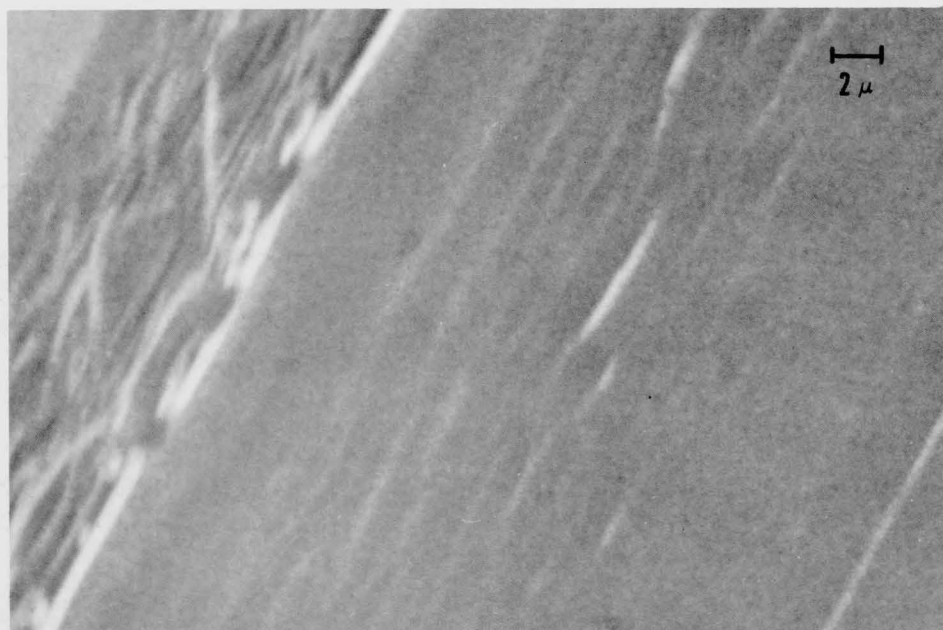
EXPLANATION OF PLATE VII

Figure 1

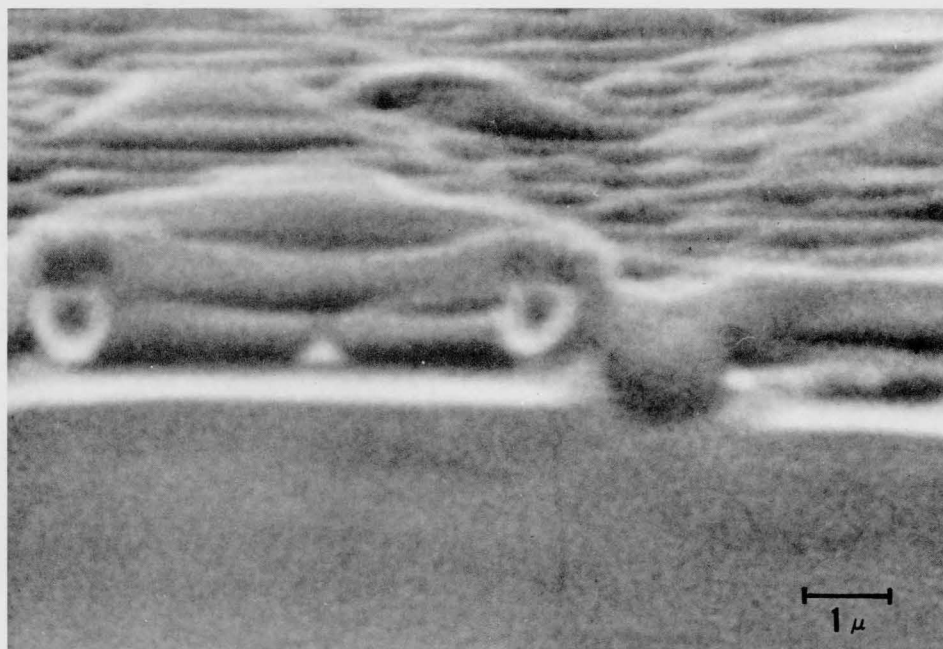
Scanning electron microscope photomicrograph of an etched cleavage surface of a crystal which has been first bombarded with 1 MeV protons and subsequently with 2 MeV protons. (The same crystal is shown in optical thin-section in Plate I, figure 4.) In this case, the protons entered the crystal from the upper left and grooves are developed by etching at the site of the stopping regions of both the 1 MeV and 2 MeV protons. Of special interest is the development of defect clusters in the 1 MeV zone.

Figure 2

Increased magnification of the left hand portion of figure 1 along the groove caused by the 1 MeV protons.



1



2

VII

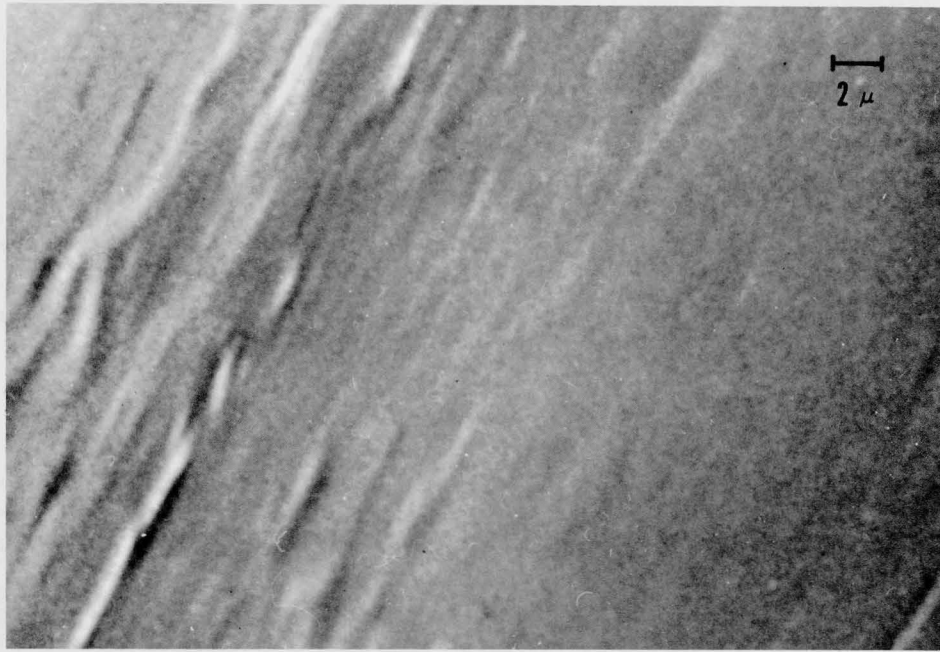
EXPLANATION OF PLATE VIII

Figure 1

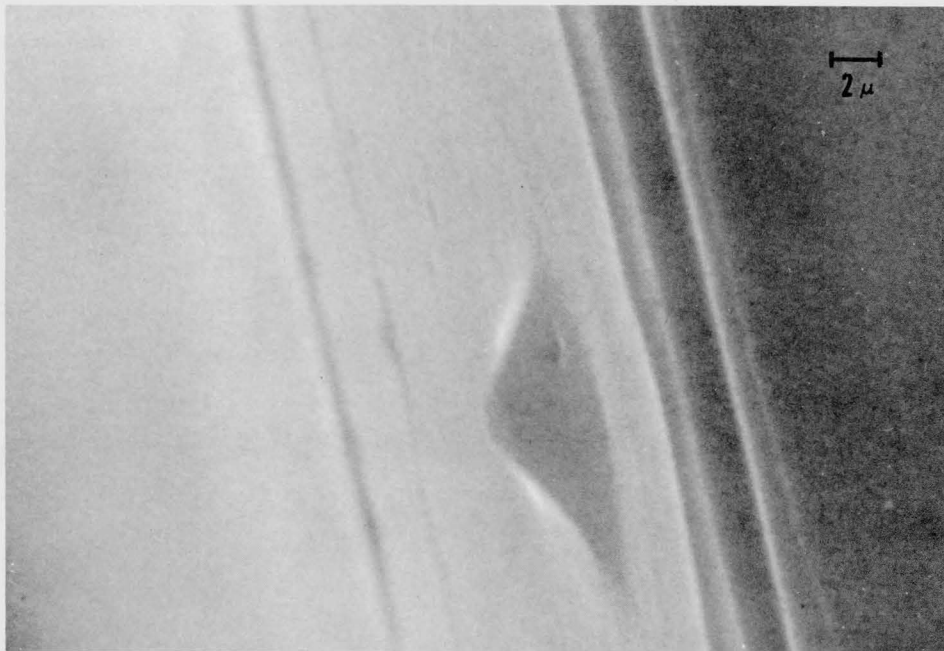
Scanning electron microscope photomicrograph of an etched surface of the crystal shown in Plate I, figure 3. The particles entered from the upper left and the groove caused by the terminal layer developed by the 2 MeV protons is present in the lower right corner of the photograph. The stopping region of the deuterons and the discontinuous groove caused by the 1 MeV protons is visible. Much of the relief in the upper portion of the crystal is probably related to the development of defect aggregation and cluster formation.

Figure 2

Scanning electron microscope photomicrograph of the etched surface of an alpha particle irradiated NaCl crystal. The scale indicated on this photograph is in error. One micron is equal to 9 mm in the photograph. The unusually deep groove at the end of the particle path shows a complex structure which is not completely understood.



1



2

VIII

APPENDIX A
Drilling Logs

19-8W-13ddd Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec. 13, T.19S., R.8W.; 10' west and 45' north of stop
(Location)
sign which is in NE cor. of Sec. 24 - on edge of field in extreme SE
corner of sec. 13

9/2/70; depth to water, 42.5 feet;
(Date)

altitude of land surface 1752 feet.

	Thickness, feet	Depth, feet
soil, black	5	5
Quaternary-Pleistocene		
(Loveland and Peoria Formations undifferentiated)		
clay, noncalcareous, gray	4	9
clay, noncalcareous, gray; streaks of tan clay	7	16
clay, noncalcareous, grayish-brown; caliche from 25' to 26'	10	26
clay, calcareous, brown; contains thin layers of caliche at 30, 39, 44, 48 to 49, 56 to 57, 59, 64, 71 to 73, 76, 77, 87 to 88 and 90 feet.	67	93

Cretaceous-Comanchean

Kiowa Formation

sandstone, fine, black, iron stained, hard	2	95
sandstone, silty, yellowish tan	2	97
shale, clayey, gray with yellowish streaks	7	104
shale, clayey, dark gray	8	112

19-8W-14ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW Sec. 14, T.19S., R.8W.; 150' east and 10' north of
(Location)

center of road intersection

9/2/70; depth to water, 42.0 feet;
(Date)

altitude of land surface 1748 feet.

	Thickness, feet	Depth, feet
<u>Quaternary-Pleistocene</u>		
<u>Loveland and Peoria Formations undifferentiated</u>		
silt, noncalcareous, dark brown	5	5
silt, slightly calcareous, reddish brown	6	11
clay, calcareous, brown; contains thin layers of caliche at 11' to 12', 25', 27', 40', 42', 43'	33	44
<u>Cretaceous-Comanchean</u>		
<u>Kiowa Formation (?)</u>		
sandstone, fine, tan to black, iron cement and stain; a few soft clayey layers	8	52
<u>Kiowa Formation</u>		
shale, clayey, gray to tan; and siltstone, tan, in thin layers	12	64
shale, clayey, dark gray weathered to yellowish brown	13	77
shale, clayey, dark gray; contains thin layers of hard tan sandstone	13	90

19-8W-22BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NW NW sec, 22, T. 19S., R. 8W; 18' west and 30' south of _____
(Location)
telephone pole in NW sec, corner - about 30' east in road ditch _____
from edge of highway pavement _____
9/1/70; depth to water, 41.4 _____ feet;
(Date)
altitude of land surface 1737 _____ feet.

	Thickness, feet	Depth, feet
soil, black	1	1
<u>Quaternary-Pleistocene</u>		
<u>Loveland and Peoria Formations undifferentiated</u>		
silt, noncalcareous, dark brown	3	4
clay, calcareous, brown; contains thin layers of caliche at 9', 12 to 13', 15 to 16', 18 to 19'.	18	22
clay, slightly calcareous, grayish brown; caliche at 24, 27, 30, 32 to 33 and 38 to 41 feet.	29	51
<u>Cretaceous-Comanchean</u>		
<u>Kiowa Formation</u>		
sandstone, fine, tan, iron stained	2	53
shale, clayey, light brown to tan; contains thin layers of tan, sandy, siltstone	15	68
shale, clayey, dark gray	7	75

19-8W-22ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW Sec. 22, T.19S., R.8W.; 50' north and 10' west of orange
(Location)

right-of-way post in SW section corner

9/14, 15/70 depth to water, 42.3 feet;
(Date)

altitude of land surface 1734 feet.

	Thickness, feet	Depth, feet
soil, brownish black	3	3

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

silt, slightly calcareous, reddish brown; contains caliche at 12' and 15'	14	17
clay and silt, calcareous, slightly sandy, brown; contains much caliche throughout.	8	25
clay, calcareous, brown; contains thin layers of caliche throughout from 45' to 57'.	32	57
clay, very calcareous, caliche brownish light gray.	4	61
gravel, fine, clayey, chert and "ironstone" fragments.	1	62

Cretaceous-Comanchean

Kiowa Formation

siltstone, tan to brownish black	3	65
shale, slightly calcareous, clayey, light gray to tan; contains thin layers of fine sandstone from 62 to 65', 67, 69, 72 and 74 feet.	13	78
sandstone, fine, reddish brown to tan; tightly cemented and very hard from 78 to 80'; inter- bedded with thin layers of light gray shale.	14	92
shale, noncalcareous, clayey, dark gray; con- tains selenite and pyrite; contains sandstone at 98 to 98.5', 100 to 100.5', 103 to 105', 110', 112', 114 to 115' and 117 feet.	25	117
shale, noncalcareous, gray	5	122
sandstone, fine, gray, very hard from 122-124'	5	127

19-8W-22ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

	Thickness, feet	Depth, feet
shale, noncalcareous, dark gray; contains Selenite and pyrite; contains streaks of laminated tan to brown shale from 128-135'; contains thin sandstone from 129' to 130', 132' to 132.5', 136', 138', 142', 146', 151', 154', 157', and 164'.	47	174

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

shale, light gray	15	189
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Chikaskia Sandstone Member

shale, silty, reddish brown	6	195
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19-8W-24ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW SEc. 24, T.19S., R.8W.; 150' north of center of road
(Location)

intersection in east road shoulder--on north side of field drive.

9/10/70; depth to water, 43.0 feet;
(Date)

altitude of land surface 1731 feet.

	Thickness, feet	Depth, feet
soil, black	1	1
<u>Quaternary-Pleistocene</u>		
<u>Loveland and Peoria Formations undifferentiated</u>		
silt, slightly calcareous, grayish brown; contains thin layers of caliche from 7 to 11', 14 to 15', 22' and 29'.	29	30
clay, slightly calcareous, slightly sandy, grayish brown; contains thin layers of caliche throughout.	30	60
gravel, fine, clayey; contains black "ironstone" fragments.	1	61
<u>Cretaceous-Comanchean</u>		
<u>Kiowa Formation</u>		
siltstone, reddish brown to brownish tan	3	64
shale, clayey, light gray to tan and brown; contains thin layers of sandstone from 67 to 69' and 72 to 74'.	10	74
sandstone, quartz, fine, brown	6	80
shale, clayey, dark gray; contains thin streaks of sandstone at 83 to 85', 91', 94', 98' and 101 feet.	20	103
sandstone, fine, gray, very hard	2	105
sandstone, fine, gray, medium hard; contains thin layers of dark gray shale with abundant selenite, lignite and pyrite.	17	122
shale, laminated bentonitic, grayish brown	6	128

19-8W-24ccc

(Well No.)

Sample _____ log of test hole _____ augered drilled

in _____

(Location)

_____; depth to water, _____ feet;
(Date)

altitude of land surface _____ feet.

Thickness,
feetDepth,
feet

shale, clayey, blocky, black; contains thin
layers of sandstone from 135 to 137', 150' to
152' and 176 to 177 feet.

49

177

shale, clayey, dark gray with a brownish cast

10

187

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

shale, light greenish gray

11

198

Chikaskia Sandstone Member

shale, reddish brown; contains some
siltstone.

7

205

19-8W-26DDD

Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE SEc. 26, T.19S., R.8W.; 25' west and 20' north of large
(Location)
cottonwood tree in SE Section corner--Tree is within triangle made by
township roads and U.S. 56.
9/9/70; depth to water, 33.8 feet;
(Date)
altitude of land surface 1729 feet.

	Thickness, feet	Depth, feet
soil, black	1	1
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, slightly calcareous, dark brown	8	9
clay, calcareous, brown; contains thin layers of caliche at 10', 12'-13' and 14'.	6	15
clay, very calcareous, slightly sandy, brown; caliche from 22' to 23'.	13	28
clay, very calcareous, light gray to brown; caliche from 33'-34.	8	36
Cretaceous-Comanchean		
Kiowa Formation		
siltstone, sandy, tan to reddish brown	4	40
shale, slightly calcareous, clayey, light gray to brown; thin layer of sandstone from 52'-53'	13	53
shale, noncalcareous, brownish gray; contains thin layers of sandstone at 61', 64', 68', 69', 72' and 74'.	21	74
shale, noncalcareous, clayey, dark gray	6	80
sandstone, fine, shell fragments, dark brown	18	98
sandstone, fine, brown, very hard	1	99
sandstone, fine, brown, loosely cemented	19	118
sandstone, fine, gray, loosely cemented	12	130
shale, clayey, dark gray; contains thin layers of sandstone from 139'-143', 144'-145' and 149'-149.5'.	26	156

19-8W-26000 Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

shale, silty, light greenish gray

6

162

Chikaskia Sandstone Member

shale, reddish brown; contains siltstone

18

180

from 162'-169'.

19-8W-27aab Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NE NE Sec 27, T.19S, R.8W; In center of abandoned drive to
(Location)

barnyard 28 feet south of centerline of E-W section road

10/5, 6/70; depth to water, 33.8 feet;
(Date)

altitude of land surface 1725 feet.

	Thickness, feet	Depth, feet
soil	1	1
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, noncalcareous, reddish brown	4	5
silt, noncalcareous, clayey, reddish brown	5	10
silt, slightly calcareous, reddish brown; contains thin layers of caliche at 12'	22	32
gravel, fine to medium; composed of caliche, dark sandstone and ironstone fragments	6	38
Cretaceous-Comanchean		
Kiowa Formation (?)		
sandstone, fine, brown, hard	4	42
sandstone, fine, light tan, soft to hard	2	44
shale, clayey, yellow	6	50
Kiowa Formation		
shale, clayey, medium gray; contains several thin (.1 to .3 foot) hard streaks, probably ironstone and sandstone	25	75
shale, medium dark gray; streaks of medium hard sandstone throughout	5	80
sandstone, fine, gray, hard to very hard	5	85
shale, medium, light gray, soft; contains thin beds of sandstone and siltstone	5	90
shale, clayey, dark gray; contains thin streaks of sandstone	15	105
sandstone, very fine, gray; hard to very hard at 118 1/2'; interbedded with shale, clayey, medium gray	14	119

19-8W-27aab

Sample

log of test hole

augered drilled

(Well No.)

in

(Location)

(Date)

; depth to water,

feet;

altitude of land surface

feet.

Thickness,
feetDepth,
feet

shale, medium dark gray; contains pyrite and
hard sandstone layers at 125'-125 1/2' and
130'-130 1/2'

12

131

shale, noncalcareous, clayey, dark gray,
uniform character

33

164

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

shale, noncalcareous, light blue-gray

4

168

Chikaskia Sandstone Member

shale, silty, brownish red

7 1/2

175 1/2

19-8W-27ABB Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NW NE Sec. 27, T.19S., R.8W.: 100' east of railroad and 50' south of section
(Location)
road in the field; 20' south and 50' east of corner fence post.

12-1-70; depth to water, 27.5 feet;
(Date)
altitude of land surface 1733 feet.

	Thickness, feet	Depth, feet
soil, black	2	2
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, noncalcareous, slightly sandy, brown	5	7
silt, slightly calcareous; light brown; contains thin layers of caliche at 7', 8', 11', 17', 23' and 25'	33.5	40.5
gravel, fine; contains fragments of chert, black "ironstone" and caliche	5	41
Cretaceous-Comanchean		
Kiowa Formation		
sandstone, fine, medium hard to hard, brown; contains grayish brown and pinkish brown clay shale	4	45
sandstone, fine, very hard near top, brown	6	51
shale, clayey, light grayish brown	6	57
shale, clayey, gray; contains thin hard layers of sandstone or pyrite	5	62
shale, clayey, dark gray; contains thin hard layers of sandstone or pyrite throughout	28	90
sandstone, fine, medium hard to hard, gray; contains dark gray clay shale from 92'-94'	6	96
shale, clayey, dark gray; contains thin layers of sandstone at 99', 102', 103' and 104'	14	110
sandstone, fine, medium hard to hard, gray; contains layers of dark gray shale at 114'-115', 118'-119', and 124'-125'; very hard thin shell bed with pyrite at 124'	17	127
shale, clayey, dark gray; contains thin sandstone or pyrite at 133', 146' and 148'	41	168
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		

19-8W-27ABB Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

	Thickness, feet	Depth, feet
shale, silty, light whitish gray	6	174
shale, silty to sandy, light greenish gray	5	179
Chikaskia Sandstone Member		
siltstone, soft, reddish brown	7	186
shale, reddish brown	4	190
siltstone, clayey, soft, red; contains shale from 210'-214'	33	223
shale, reddish brown	14	237
siltstone, reddish brown to greenish gray	3	240
shale, silty, reddish brown	11	251
siltstone, clayey, reddish brown to light greenish gray	11	262
shale, clayey, reddish brown to greenish gray	24	286
Stone Corral Formation		
dolomite, hard, grayish brown	1	287
shale, light greenish gray; and gypsum, soft, white	5	292
dolomite, sandy, crystalline, medium hard, gray; contains thin (?) layers of anhydrite	6	298
Ninnescah Shale		
shale, very clayey, dark reddish brown; contains soft, white gypsum	2	300
shale, very clayey, dark reddish brown and greenish gray	45	345

19-8W-27DCC Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SE Sec. 27, T.19S., R.8W.; about 600' east of railroad track and 30' north
(Location)

of center of section road in field; due north of old water well in field on south side of road

12-2-70; depth to water, 31.0 feet;
(Date)

altitude of land surface 1713 feet.

	Thickness, feet	Depth, feet
soil, black; and clay, gray	5	5
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, calcareous, brown; contains thin layers of caliche	21	26
at 7', 8', 9.5', 11', 16', 21' and 26'		
clay, calcareous, brown	25	51
Cretaceous-Comanchean		
Kiowa Formation		
shale, clayey, light gray to brown; contains a thin	12	63
layer of sandstone at 61'		
sandstone, fine, soft to medium hard, iron cemented,	10	73
brown to blackish brown; thin layer of gray shale		
at 72'		
sandstone, fine, very hard, dark brown	2	75
shale, clayey, dark gray; contains sandstone from 77' to 78',	51	126
79' to 80', 104' to 105', 111' to 112' and many other		
thin layers; pyrite and selenite interspersed throughout		
shale, clayey, dark gray; contains abundant lignite and pyrite	6	132
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		
shale, light blue gray	5	137
siltstone, light greenish gray	7	144
Chikaskia Sandstone Member		
siltstone, clayey, reddish brown	6	150

19-8W-27DCC Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

	Thickness, feet	Depth, feet
shale, very silty, reddish brown	7	157
siltstone, slightly sandy, streaks of shale, reddish brown	22	179
shale, silty, reddish brown	61	240
siltstone, clayey, reddish brown to gray	16	256
shale, reddish brown	3	259
siltstone, reddish brown	7	266
Stone Corral Formation		
dolomite, finely crystalline, soft, gray	2	268
gypsum, soft, white; and shale, clayey, light gray; may contain some anhydrite	6	274
dolomite, finely crystalline, soft, gray	5	279
dolomite, finely crystalline, very hard, gray	5.5	284.5
Ninnescah Shale		
shale, light greenish gray	3.5	288
shale, clayey, reddish brown	6	294
shale, clayey, light greenish gray to reddish brown	6	300

19-8W-27DDD Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec 27, T. 19S, R. 8W; 100' west and 15' north of center

(Location)

of road crossing on north road shoulder

9/8/70

(Date)

; depth to water, _____ feet;

altitude of land surface 1719 _____ feet.

	Thickness, feet	Depth, feet
soil, dark brownish black	3	3
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, calcareous, slightly sandy, dark brown	4	7
clay, calcareous, slightly sandy, brown; contains thin layers and nodules of caliche at 9', 12', 17', 19', 22' and 27'	23	30
clay, calcareous, brown to reddish brown; contains coarse sand and a few black pebbles	10	40
clay, calcareous, brown; caliche from 40'-41'	9	49
gravel, fine; contains black ironstone and caliche fragments	1	50
Cretaceous-Comanchean		
Kiowa Formation (?)		
sandstone, fine, brownish black	2	52
Kiowa Formation		
shale, clayey, light gray with brown streaks	4	56
sandstone, fine, tan to brown; tightly cemented and very hard at 67' and 71'	18	74
shale, clayey, dark gray; contains thin layers of gray sandstone at 78', 80' and 86'	16	90

19-8W-28BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NW NW Sec 28, T. 19S, R. 8W; 60' east and 20' north of power

(Location)

pole in NW section corner; drilled on road shoulder

9/24/70; depth to water, 37.2 feet;
(Date)

altitude of land surface 1718 feet.

	Thickness, feet	Depth, feet
roadfill and soil, black	4	4
<u>Quaternary-Pleistocene</u>		
<u>Loveland and Peoria Formations undifferentiated</u>		
silt, noncalcareous, reddish brown	7	11
silt, slightly calcareous, brown; contains caliche from 11' to 12'	10	21
clay, slightly calcareous, silty, brown; con- tains thin streaks of caliche from 21' to 23', 36', 40', 46', 53' and 55'	36	57
clay, calcareous, light gray; interbedded with gravel composed of caliche, sandstone, and "ironstone" fragments	2	59
<u>Cretaceous-Comanchean</u>		
<u>Kiowa Formation (?)</u>		
sandstone, quartz, fine, dark brown, iron, cemented, hard	5	64
<u>Kiowa Formation</u>		
sandstone, quartz, fine, brown to tan, soft; contains thin streaks of tan to light gray shale	14	78
shale, noncalcareous, clayey, dark gray; contains thin streaks of gray sandstone at 81', 84' to 85', 87' and 89'	18	96
sandstone, quartz, fine, slightly, calcareous, light gray; soft to medium hard; contains streaks of dark gray shale from 101' to 106'	15	111
shale, noncalcareous, clayey, dark gray to black; contains selenite and pyrite; contains	40	151

19-8W-28BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

Thickness,
feet

Depth,
feet

thin streaks of very hard shelly sandstone
at 113', 117' and 119'; softer sandstones
are present at 129' to 130', 131' and 136'

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

siltstone, sandy, light gray

9

160

Chikaskia Sandstone Member

siltstone, sandy, reddish brown

5

165

19-8W-29ddd Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec. 29, T.19S., R.8W.; 120' due north of power pole in _____
(Location)

SE section corner with telephone line transformer at the base _____

9/1/70 _____; depth to water, 27.3 _____ feet;
(Date)

altitude of land surface 1701 _____ feet.

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

	Thickness, feet	Depth, feet
silt, noncalcareous, dark brown	4	4

clay, calcareous, slightly sandy, brown; contains thin layers of caliche at 7 to 8', 12', 13' to 15', 18', 22' and 26' to 30'.	33	37
--	----	----

clay, calcareous, slightly sandy, grayish brown; contains thin layers of caliche at 37', 39', 42', 45' to 46', 51', 55' to 58' and 59' to 60'.	24	61
--	----	----

gravel, fine; contains fragments of "ironstone", caliche and weathered light gray to yellow shale.	7	68
--	---	----

Cretaceous-Comanchean

Kiowa Formation

shale, noncalcareous, clayey, yellowish brown to light gray; contains thin layers of reddish brown siltstone	5	73
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shale, noncalcareous clayey, light gray with tan streaks	12	85
--	----	----

shale, noncalcareous, clayey, dark gray	5	90
---	---	----

19-8W-30ddd Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec. 30, T.19S., R.8W.; 18' south and 50' west of bddc and
(Location)
white post on NW corner to drive - 150' west of bridge on north
shoulder.

9/1/70; depth to water, 11.5 feet;
(Date)
altitude of land surface 1678 feet.

	Thickness, feet	Depth, feet
roadfill	2	2
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
clay, noncalcareous, slightly sandy, gray	5	7
silt, noncalcareous, reddish brown with gray streaks	8	15
clay, noncalcareous, brown; contains thin layers of caliche from 15' to 16', 19 to 21', and 29' to 30'.	15	30
clay, slightly calcareous, slightly sandy, gray; caliche from 39' to 40' and 42' to 43'.	15	45
clay, slightly calcareous, slightly sandy, grayish brown; contains thin layers of caliche at 63 to 64', 69 to 70' and 76 to 77'.	60	105
gravel, fine, black "ironstone" fragments and chert prominent.	11	116
clay, noncalcareous, sandy, gray	2	118
gravel, fine	1	119

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale, calcareous, reddish brown	9	128
siltstone, reddish brown	2	130

19-8W-31BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NW NW Sec. 31, T.19S., R.8W.; 80' south and 9' east of center
(Location)
of intersection.

8/31/70; depth to water, 32.7 feet;
(Date)
altitude of land surface 1703 feet.

Thickness,
feet

Depth,
feet

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

silt, noncalcareous, dark brown	6	6
silt, noncalcareous, sandy, brown	9	15
clay, very calcareous, slightly sandy, grayish brown; contains layers of caliche at 15' to 16' and 28' to 30'.	22	37
clay, calcareous, gray; caliche from 37' to 38'	6	43
gravel, fine, sandy; and clay, calcareous, yellowish tan.	10	53
clay, slightly calcareous, dark gray with yellowish streaks.	10	63
gravel, fine; contains black ironstone fragments	3	66

Cretaceous-Comanchean

Kiowa Formation

shale, noncalcareous, clayey, light gray	3	69
siltstone, reddish brown and tan	6	75

19-8W-32DDC

(Well No.)

Sample _____ log of test hole _____ augered drilled

in SW SE SE Sec. 32, T.19S., R.8W.; On west side of entrance to _____

(Location)

Kewanee oil road which is .2 mile west of SE Section corner-On north
side of highway on right-of-way.9/16/70; depth to water, 42.6 _____ feet;
(Date)

altitude of land surface 1693 _____ feet.

Thickness,
feetDepth,
feet

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

silt, noncalcareous, dark reddish brown 6 6

silt, noncalcareous, clayey, slightly sandy, 8 14
reddish brown

clay, noncalcareous, sandy, grayish brown 7 21

clay, calcareous, slightly sandy, brown; thin 9 30
layers of caliche throughoutclay, noncalcareous, very sandy, grayish brown; 36 66
contains streaks of fine to coarse sand and
fine gravel from 55' to 60'.clay, slightly calcareous, compact grayish 38 104
brown; contains caliche at 66', 89' and
100' to 104'.

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale, reddish brown 1 105

19-8W-34BBB

(Well No.)

Sample _____ log of test hole _____ augered drilled

in NW NW NW Sec. 34, T.19S., R.8W.; 200' east and 15' south of center
 (Location)
 of road intersection in south road shoulder-Just east of stockyard
 drive.

9/9/70 _____; depth to water, _____ feet;
 (Date)

altitude of land surface 1710 _____ feet.

Thickness,
feet

Depth,
feet

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

silt, calcareous, dark brown	4	4
clay, calcareous, slightly sandy, brown to light gray; contains thin layers and nodules of caliche at 5, 7, 10, 19, 26, 29, 31, 34, 39 and 52-53', very uniform composition throughout.	57	61

Cretaceous-Comanchean

Kiowa Formation

siltstone, tan to reddish brown; interbedded light gray clay shale	5	66
shale, slightly calcareous, clayey, light gray to tan	18	84
shale, noncalcareous, clayey, dark gray	6	90

19-8W-34BDD Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE NW Sec. 34, T.19S., R.8E.; W-SW of gate to salt mine 250' --
(Location)
60' due west of old mine office.

9/23/70; depth to water, 28.6 feet;
(Date)
altitude of land surface 1700 feet.

	Thickness, feet	Depth, feet
fill	1	1
soil, dark brown	2	3
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, noncalcareous, reddish brown	11	14
silt, slightly calcareous, reddish brown, clayey; caliche from 22' to 24' and 36' to 37'.	26	40
Cretaceous-Comanchean		
Kiowa Formation (?)		
sandstone, quartz, fine, brown, medium hard to soft; very hard from 46' to 46.5'.	12	52
shale, reddish brown	1	53
Kiowa Formation		
shale, light gray to tan; contains thin layers of fine, silty, yellowish tan sandstone	9	62
shale, clayey, dark gray; contains selenite, pyrite and sparse lignite; gray, fine sandstone from 71' to 72', 79' and 83' to 84'.	22	84
shale, clayey, dark gray, ~~is~~ fissile, black	22	106
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		
shale, light greenish gray; contains thin layers of fine silty sandstone.	8	114

19-8W-34BDD Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

Thickness,
feet

Depth,
feet

Chikaskia Sandstone Member

siltstone, sandy, reddish brown;
contains thin layers of shale.

15

129

19-8W-34CDA Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE SE SW Sec. 34, T.19S., R.8W.; on 3rd street at railroad in field just north

(Location)

of powerline and 150' west of railroad--1/4 mile south of salt mine

10-16-70; depth to water, 32.7

(Date)

feet;

altitude of land surface 1700 feet.

Thickness,
feet

Depth,
feet

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

silt, clayey, dark grayish brown

3

3

silt, brown to tannish brown

9

12

silt, tan brown; contains some small caliche nodules

10

22

silt, tan brown

7

29

silt, tan brown; contains small caliche nodules

6

35

silt, brown; contains some caliche

6

41

silt, clayey, tan brown

11

52

Cretaceous-Comanchean

Kiowa Formation

shale, clayey, brownish gray and dark gray to black;

45

97

contains some sandstone from 65' to 70'

19-8W-35BAA Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE NE NW Sec. 35, T. 19S., R. 8W.; on south road shoulder 115' east of Owl Creek

(Location)

bridge and .4 mile east of northwest section corner

12-3-70; depth to water, 15.4

(Date)

feet;

altitude of land surface 1699 feet.

	Thickness, feet	Depth, feet
roadfill	2	2
Quaternary		
Recent		
soil, sandy, black to grayish black	6	8
clay, sandy, gray; intermixed pebbles and sandstone fragments from 13' to 15'	16	24
Loveland and Peoria Formations undifferentiated(?)		
gravel, medium; contains fragments of chert, brown sandstone and caliche, and intermixed greenish gray clay	3	27
Cretaceous-Comanchean		
Kiowa Formation		
shale, clayey, dark gray	9	36
shale, clayey, light gray	3	39
sandstone, fine, medium soft, iron cemented, brown; thin layers of light gray shale interspersed throughout	15	54
sandstone, fine, medium soft to hard, gray; thin layers of gray shale from 10' to 13'; some pyrite and lignite	14	68
shale, clayey, dark gray	3	71
sandstone, fine, shells, pyrite, medium hard, gray	2	73
shale, clayey, dark gray to black	34	107
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		
shale, light blue gray	5	112
shale, silty, light greenish gray		

19-8W-35BAA

(Well No.)

Sample

log of test hole

augered drilled

in

(Location)

(Date)

; depth to water,

feet;

altitude of land surface

feet.

Thickness,
feetDepth,
feet

Chikaskia Sandstone Member

shale, reddish brown

8

120

19-8W-35BCC Sample _____ log of test hole _____ ~~augered~~ drilled
(Well No.)

in SW SW NW Sec. 35, T.19S., R.8W.; 75' north of railroad track on east road shoulder.
(Location)

12-3/4-70 ; depth to water, 27.9 _____ feet;
(Date)
altitude of land surface 1705 _____ feet.

	Thickness, feet	Depth, feet
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, noncalcareous, brown	9	9
clay, noncalcareous, brown	6	15
clay, slightly calcareous, brown; contains caliche from 18' to 19', 22' to 23' and 24'	9	24
clay, slightly calcareous, gray; contains thin layers of caliche throughout	15	39
clay, calcareous, brown; contains thin layers of caliche throughout and a layer from 44' to 45'	17	56
gravel, fine; contains fragments of caliche, chert, and brown sandstone	1	57
Cretaceous-Comanchean		
Kiowa Formation		
sandstone, fine, yellowish brown	2	59
shale, clayey, light gray with yellowish brown streaks; contains thin layers of fine, iron cemented, yellowish brown sandstone at 62', 64', 67' and from 69' to 71'	12	71
shale, clayey, dark gray; thin sandstone at 74' and 79'	12	83
sandstone, fine, hard, gray; interspersed shells, pyrite, lignite	3	86
shale, clayey, dark gray to black; contains hard sandstone from 90' to 91' with abundant pyrite	27	113
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		
shale, light blue-gray	7	120

19-8W-35BDA4 Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE SE NW Sec. 35, T.19S., R.8W.; 4' due north of 19-8W-35BDA2 and 12' northeast
(Location)

of 19-8W-35BDA (Corps of Engineers No. 2).

1-19-71 ; depth to water, 22.3 feet;
(Date)

altitude of land surface 1701 feet.

Thickness,
feet

Depth,
feet

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

clay, slightly calcareous, brown; contains abundant caliche nodules 6 6

clay, slightly calcareous, brown to dark brown; contains a few large caliche nodules 5 11

clay, slightly calcareous, silty, reddish brown 8 19

clay, calcareous, light grayish brown; contains abundant caliche 14 33

Cretaceous-Comanchean

Kiowa Formation

shale, clayey, light greenish gray; contains some pinkish brown clay shale from 35' to 40'; contains fine red brown sandstone from 35' to 35.5' and fine yellow brown sandstone from 37.5' to 38' 7 40

shale, clayey, light gray to yellowish brown; contains 3" layers of sandstone at 48', 52' and 57' 18 58

shale, clayey, dark gray; contains 2-3" layers of fine gray sandstone and/or pyrite at 60.5', 63', 66', 70.5' and four layers as above between 73' and 75' 18 76

shale, clayey, dark gray to black; contains four 2" layers of sandstone or shell beds and one thin layer of lignite 6 82

19-9W-13DDD Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec. 13, T.19S., R.9W.; 100' north and 10' east of stop
(Location)

sign in SE Section corner--on road shoulder

9/3/70 ; depth to water, 40.0 feet;
(Date)

altitude of land surface 1732 feet.

	Thickness, feet	Depth, feet
Quaternary-Pleistocene		

Loveland and Peoria Formations undifferentiated

silt, noncalcareous, dark brown	6	6
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silt, noncalcareous, dark reddish brown	3	9
---	---	---

clay, calcareous, sandy, brown; contains thin layers of caliche at 15' and 29'.	21	30
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clay, calcareous, brown; contains thin layers of caliche throughout at about 2' intervals from 30' to 45', also 52', 54' and 56' to 57'.	33	63
--	----	----

Cretaceous-Comanchean

Kiowa Formation (?)

sandstone, fine, tan, iron stain; contains thin layers of shale.	8	71
--	---	----

Kiowa Formation

shale, clayey, light gray to tan; contains thin layers of medium hard to hard, tan to reddish brown sandstone throughout.	20	91
---	----	----

sandstone, fine, dark gray	7	98
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shale, clayey, dark gray; contains thin layers of sandstone from 98' to 104' and 106' to 108'	22	120
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19-9W-14ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW Sec. 14, T. 19S., R. 9W.; 100' east and 20' north of center
(Location)
of road crossing - in north road ditch

9/3/70; depth to water, 42.0 feet;
(Date)

altitude of land surface 1725 feet.

Quaternary-Pleistocene

Loveland and Peoria Formations undifferentiated

	Thickness, feet	Depth, feet
silt, calcareous, brown	5	5

clay, very calcareous, grayish brown; contains layers of caliche at 7', 9', 10', 12', and 13'-14'.	13	18
--	----	----

Cretaceous-Comanchean

Dakota Formation

Sandstone, fine, tan, hard	3	21
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shale, sandy, gray to tan	4	25
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sandstone, fine, black to brown; iron stained, hard.	4	29
--	---	----

(Kiowa Formation (?))

sandstone, quartz, fine, grayish white to tan, loosely cemented; thin streaks of tan to gray clay shale throughout.	24	53
---	----	----

sandstone, maroon to black, hard; streaks of light gray to tan sandy clay shale.	6	59
--	---	----

sandstone, brown to tan, loosely cemented; streaks of light gray shale interbedded	9	68
--	---	----

sandstone, quartz, fine, white, very loosely cemented and soft.	2	70
---	---	----

Kiowa Formation

shale, clayey tan to light gray	14	84
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shale, clayey, dark gray	6	90
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19-9W-35aaa Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE NE NE Sec. 35, T.19S., R.9W.; 170' west and 12' south of center
(Location)
of road intersection

8/27/70 _____; depth to water, _____ feet;
(Date)
altitude of land surface 1719 _____ feet.

	Thickness, feet	Depth, feet
Quaternary-Pleistocene		
Loveland and Peoria undifferentiated		
clay, noncalcareous, sandy, dark reddish brown	6	6
clay, noncalcareous, slightly sandy, brown	6	12
clay, very calcareous, grayish brown; contains caliche at 12' and 24'.	16	28
clay, calcareous, brown with gray streaks; contains caliche at 37' and 47'.	22	50
clay, calcareous, slightly sandy, reddish brown; contains caliche at 63' and 78'.	31	81
gravel, fine to coarse; contains chert and black "ironstone" fragments.	8	89
Cretaceous-Comanchean		
Kiowa Formation		
shale, noncalcareous, clayey, brownish gray	7	96
siltstone, dark brown	5	101
shale, noncalcareous, clayey, dark gray; con- tains selenite, marcasite, thin layers of hard gray sandstone.	31	132
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		
shale, light gray	3	135
shale, reddish brown	2	137
shale, light gray; contains some siltstone	8	145
Chikaskia Sandstone		
shale, reddish brown; contains red siltstone	5	150

20-8W-1ccc

(Well No.)

Sample _____ log of test hole _____

augered drilled

in SW SW SW Sec. 1, T.20S., R.8W.; Just inside fenceline and 150'

(Location)

north of yellow pipeline marker in SW section corner.

9/21/70; depth to water, 31.5

(Date)

feet;

altitude of land surface 1708 feet.

	Thickness, feet	Depth, feet
soil, black	1	1
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
clay, noncalcareous, dark brown	3	4
clay, calcareous, light reddish brown	2	6
clay, calcareous, reddish brown to tan; and caliche, algal with ironstone fragments.	2	8
Cretaceous-Comanchean		
Kiowa Formation		
sandstone, fine, calcareous, gray, soft, streaks of gray shale.	2	10
shale, noncalcareous, light gray	2	12
shale, noncalcareous, clayey, tan to light gray; contains thin layers of tan to reddish brown sandstone.	6	18
shale, noncalcareous, clayey, light gray; contains sandstone from 25' to 26' and thin layers of dark gray shale from 36' to 44'.	26	44
sandstone, fine, brown to grayish brown, very hard.	2	46
shale, slightly calcareous, clayey, brown to dark gray.	4	50
sandstone, fine, brownish gray, medium hard	2	52
shale, noncalcareous, clayey, dark gray to black; contains layers of fine, gray sandstone at 56', 61', 64' to 65', 69', 73', and and 76' to 78'; abundant selenite at about 79'.	46	98

20-8W-1ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

Thickness,
feet

Depth,
feet

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

shale, noncalcareous, light greenish 2 100
gray.

siltstone, sandy, light greenish gray; 9 109
contains thin shale layers.

sandstone, very fine, light greenish gray 2 111

Chikaskia Sandstone Member

siltstone, reddish brown 4 115

20-8W-2aaa Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE NE NE Sec. 2, T.20S., R.8W.; 20' north and 20' west of pole in _____
(Location)

NE corner which braces transformer telephone pole in SE of Sec. 35

9/22/70; depth to water, 37.1 _____ feet;
(Date)

altitude of land surface 1735 _____ feet.

	Thickness, feet	Depth, feet
soil, brownish black	1	1
<u>Quaternary-Pleistocene</u>		
<u>Loveland and Peoria Formations undifferentiated</u>		
silt, noncalcareous, dark brown	2	3
clay, slightly calcareous, silty, brown; contains caliche from 3' to 4', 11' to 13' and many thin streaks from 21' to 29'.	26	29
clay, slightly calcareous, compact, grayish brown; contains thin streaks of caliche at 34' and 36' to 39'.	18	47
clay, calcareous, brown to tan; interbedded with caliche and "ironstone" fragments.	5	52
<u>Cretaceous-Comanchean</u>		
<u>Kiowa Formation</u>		
shale, noncalcareous, clayey, light gray with tan streaks; very hard, fine, iron cemented, brown sandstone from 69' to 70' and 72.5' to 73'.	26	78
shale, noncalcareous, clayey, dark gray	4	82
sandstone, quartz, fine, calcareous, gray, medium hard.	3	85
shale, noncalcareous, clayey, dark gray	2	87
sandstone, quartz, fine, calcareous, gray, hard	1	88
shale, noncalcareous, clayey, dark gray to black; contains fragments selenite and pyrite; thin sandstone or concretions at 92', 94', 98', 102', 111', 114', 122', and 124'.	42	130

20-8W-2aaa Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____ (Location)

_____; depth to water, _____ feet;
(Date) _____
altitude of land surface _____ feet.

 Thickness, feet | Depth, feet |

Permian-Cimarronian

Harper Sandstone

Kingman Sandstone Member

shale, light greenish gray	12	142
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sandstone, very fine, silty, light greenish gray	5	147
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Chikaskia Sandstone Member

shale, reddish brown	3	150
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20-8W-2BBB

(Well No.)

Sample _____ log of test hole _____ augered drilled

in NW NW NW Sec. 2, T.20S., R.8W.; 20' east and 50' south of light pole
(Location)which is on north side of entrance to KP&L substation--in their
storage area.9/16, 17/70; depth to water, 19.1 _____ feet;
(Date)

altitude of land surface 1690 _____ feet.

	Thickness, feet	Depth, feet
<u>Quaternary-Pleistocene</u>		
<u>Loveland and Peoria Formations undifferentiated</u>		
silt, noncalcareous, dark reddish brown	4	4
silt, noncalcareous, sandy, brown; contains thin layers of caliche at 5', 8' and 13'.	18	22
silt, slightly calcareous, slightly sandy, clayey, reddish brown to brown; nodular caliche throughout.	15	37
clay, calcareous, grayish brown; caliche at 37' and 41'.	8	45
<u>Cretaceous-Comanchean</u>		
<u>Kiowa Formation</u>		
sandstone, quartz, fine, calcareous light gray, very hard.	4	49
sandstone, quartz, fine, calcareous brown, very soft.	12	61
sandstone, fine, calcareous, brown to gray, medium hard.	6	67
sandstone, quartz, fine, calcareous, brown, very soft.	3	70
sandstone, quartz, fine, calcareous, gray, hard	2	72
sandstone, quartz, fine, brown to tan, medium hard.	4	76
shale, noncalcareous, clayey, dark gray; con- tains thin layers of sandstone at 79', 81' and 84'.	8	84
<u>Permian-Cimarronian</u>		
<u>Harper Sandstone</u>		
<u>Kingman Sandstone Member</u>		
shale, noncalcareous, light greenish gray	9	93

20-8W-2BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in _____
(Location)

_____; depth to water, _____ feet;
(Date)
altitude of land surface _____ feet.

	Thickness, feet	Depth, feet
siltstone, sandy, light greenish gray; contains thin layers of greenish gray shale.	24	117
shale, noncalcareous, light greenish gray; contains gypsum and/or anhydrite fragments.	4	123
siltstone, sandy, light greenish gray	8	131
Chikaskia Sandstone Member		
shale, noncalcareous, silty, reddish brown	4	135

20-8W-7aaa Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE NE NE Sec. 7, T.20S., R.8W.; 45' south and 6' west of fence
(Location)
corner post at SW corner of road crossing

8/24/70; depth to water, 32.4 feet;
(Date)
altitude of land surface 1678 feet.

	Thickness, feet	Depth, feet
Quaternary		
Pleistocene and Recent undifferentiated		
soil, noncalcareous, dark brown	3	3
silt, slightly calcareous, slightly sandy, gray to brown.	5	8
silt, slightly calcareous, slightly sandy, reddish brown; caliche at 12'.	5	13
sand, very fine, silty, tan	12	25
sand, fine to coarse, slightly clayey, light gray.	15	40
sand, medium to coarse; contains quartz and feldspar; thin clay from 42' to 44'.	10	50
sand, fine to coarse, light gray	6	56
gravel, fine to medium	2	58
clay, noncalcareous, slightly sandy, light gray.	7	65
sand, fine to coarse; contains thin layers of fine gravel.	15	80
gravel, fine, sandy	6	86
clay, noncalcareous, tan	2	88
gravel, fine, sandy	4	92
clay, noncalcareous, slightly sandy, light brownish gray	37	129
gravel, fine	3	132
Permian-Cimarronian		
Harper Sandstone		
Chikaskia Sandstone Member		
shale, medium to dark red	13	135

20-8W-7BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NW NW Sec. 7, T.20S., R.8W.; 7' south and 22' east of gate
(Location)
corner post at SE corner of road intersection.

8/25/70 ; depth to water, _____ feet;
(Date)
altitude of land surface 1691 _____ feet.

	Thickness, feet	Depth, feet
<u>Quaternary</u>		
Pleistocene and Recent undifferentiated		
soil, black	1	1
clay, slightly calcareous, dark reddish brown	6	7
clay, slightly calcareous, slightly sandy, brown	4	11
clay, noncalcareous, brownish gray	4	15
clay, noncalcareous, sandy, dark gray to brown	11	26
clay, noncalcareous, brown	6	32
sand, medium to coarse, sparse fine gravel, thin layers of light brown clay.	20	52
clay, noncalcareous, slightly sandy, grayish brown to light gray.	15	67
clay, sandy, light gray; sand cemented at 67' to 68' and 71'-72'.	8	75
sand, medium to coarse; and gravel, fine to coarse; contains thin layers of tan to brown clay from 85' to 90'.	15	90
clay, calcareous, sandy, light grayish brown, caliche from 101' to 102' and 103' to 105'.	22	112
gravel, fine, contains fragments of caliche and "ironstone".	3	115

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale, reddish brown and greenish gray 5 120

20-8W-8aaa Sample log of test hole augered drilled
(Well No.)

in NE NE NE T.20S., R.8W.; 75' due west of power pole with phone cable
(Location)
marker at base on SW corner of road intersection

8/26/70; depth to water, 28.9 feet;
(Date)

altitude of land surface 1670 feet.

	Thickness, feet	Depth, feet
<u>Quaternary</u>		
<u>Pleistocene and Recent undifferentiated</u>		
clay, noncalcareous, dark reddish brown	4	4
clay, slightly calcareous, gray; thin layer of sand at 7'.	3	7
clay, noncalcareous, gray to reddish brown	8	15
clay, slightly calcareous, brownish gray	5	20
sand, medium to coarse, tan	6	26
clay, noncalcareous, sandy, tan	4	30
sand, very fine to coarse; thin layer of gray clay from 30' to 35'; thin gravel at 52'.	27	57
gravel, fine to medium; and sand medium to coarse.	3	60
gravel, fine to coarse, sandy; thin layer of gray clay throughout.	16	76
clay, very calcareous, light brownish gray; and caliche.	7	83
clay, slightly calcareous, light brownish gray; thin layers of caliche from 83'-86'.	16	99
gravel, fine to medium; contains "ironstone" fragments.	4	103

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale, reddish brown 2 105

20-8W-11BBB Sample _____ log of test hole _____ augered drilled
(Well No.)

in NW NW NW Sec. 11, T.20S., R.8W.; About 400' south of northwest
(Location)

section corner and just south of farmhouse drive on east side of road.
Inside pasture 10' east and 5' south of corner

9/22/70; depth to water, 30.6 fence post. feet;
(Date)

altitude of land surface 1692 feet.

	Thickness, feet	Depth, feet
soil, black	1	1
Quaternary-Pleistocene		
Loveland and Peoria Formations undifferentiated		
silt, noncalcareous, dark brown	3	4
silt, noncalcareous, light reddish brown	8	12
silt, slightly calcareous, light reddish brown, very sandy.	3	15
sand, quartz, fine	9	24
clay, calcareous, brown, very sandy; contains thin layers of caliche throughout.	9	33
clay, noncalcareous, gray, slightly sandy	13	46
clay, slightly calcareous, grayish brown; contains caliche from 46' to 48'.	9	55
clay, slightly calcareous, reddish brown, compact.	11	66
Cretaceous-Comanchean		
Kiowa Formation		
shale, clayey, tan to light gray	11	77
Permian-Cimarronian		
Harper Sandstone		
Kingman Sandstone Member		
siltstone, clayey, light greenish gray	11	88
Chikaskia Sandstone Member		
siltstone, reddish brown	2	90

20-8W-13ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW Sec. 13, T.20S., R.8W.; 31' east and 8' north of the
(Location)

northend of the east culvert at road intersection

8/11/70; depth to water, 10.5 feet;
(Date)

altitude of land surface 1639 feet.

	Thickness, feet	Depth, feet
roadfill	3	3
Quaternary		
Pleistocene and Recent undifferentiated		
silt, grayish brown; contains some fine to medium sand	5	8
silt, grayish tan; contains much very fine sand.	5	13
sand; and gravel, fine to coarse; contains thin layers of grayish green clay with black spots.	11	24
sand and gravel, fine to coarse, gray	13	37
clay, yellow and gray	3	40
sand and gravel, fine to coarse	19	59
Permian-Cimarronian		
Harper Sandstone		
Chikaskia Sandstone Member		
shale and siltstone, red	6	65
shale, red; streaks of siltstone from 88' to 91'.	26	91

20-8W-14ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW Sec. 14, T.20S., R.8W., on section line on east side of
curves--20' NW of a double 8" hackberry tree. (Location)

8/12/70; depth to water, _____ feet;
(Date)
altitude of land surface 1643 _____ feet.

Quaternary

Pleistocene and Recent undifferentiated

	Thickness, feet	Depth, feet
soil, grayish black	3	3
silt, sandy, tan	5	8
silt and clay, slightly sandy, medium light gray.	5	13
gravel and sand, medium to coarse, gray and red (arkosic).	17	30
gravel and sand; streaks of yellow clay throughout.	27	57

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

	Thickness, feet	Depth, feet
shale, red	18	75

20-8W-15ccc

(Well No.)

Sample-----log of test hole-----augered drilled

in Sw SW SW Sec. 15, T.20S., R.8W.; .1 mile east of road intersection

(Location)

in center of field entrance on north side of road.

8/13/70; depth to water, 13.1 feet;
(Date)

altitude of land surface 1650 feet.

Thickness,
feetDepth,
feet

Quaternary

Pleistocene and Recent undifferentiated

soil, black 3 3

clay, silty, medium gray 2 5

clay, sandy, tan 3 8

clay, sandy, medium gray 5 13

clay, silty and sandy, tannish gray 5 18

sand and gravel, arkosic 12 30

silt and clay, sandy, yellow buff and light gray. 4 34

gravel and sand, arkosic; streaks of yellow 18 52
sandy clay throughout and layer from 46' to 48'.

silt, clayey, light tan to light grayish tan 8 60

silt, sandy, light gray to tannish gray 5 65

silt, sandy, light tannish gray to pinkish 12 77

silt, sandy, light tannish gray; contains 13 90
abundant caliche.silt, sandy, light tan to tannish gray; con- 4 94
tains some gravel.gravel and sand, arkosic and black sandstone 4 98
and caliche fragments.

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale, red with some green mottles 7 105

20-8W-18ccc Sample _____ log of test hole _____ augered drilled
(Well No.)

in SW SW SW Sec. 18, T.20S., R.8W.; 84' east and 28' north of center
(Location)
of road intersection.

8/18/70; depth to water, 11.2 feet;
(Date)
altitude of land surface 1666 feet.

Thickness,
feet

Depth,
feet

Quaternary

Pleistocene and Recent undifferentiated

soil, sandy, brownish gray 2 2

silt, very sandy, tan 10 12

sand and gravel, arkosic; layer of tan silt 21 33
from 22' to 24'.

silt and clay, sandy, light gray and light 12 45
yellowish tan; contains streaks of sand and
gravel.

sand and gravel, arkosic 12 57

clay and silt, yellowish tan 3 60

silt and clay, pinkish tan 12 72

silt and clay, calcareous, medium gray 7 79

silt and clay, noncalcareous, blue-gray; con- 10 89
tains thin layers of calcareous medium
gray clay.

silt and clay, calcareous, pinkish tan; con- 16 105
tains thin layers of caliche throughout.

silt, calcareous, tan; contains thin layers 15 120
of caliche throughout.

20-8W-18ddd Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec. 18, T.20S., R.8W.; 24' west and 18' north of center
(Location)

of road intersection

8/18/70 ; depth to water, 10.1 feet;
(Date)

altitude of land surface 1657 feet.

Thickness,
feet

Depth,
feet

Quaternary

Pleistocene and Recent undifferentiated

soil, brownish black 3 3

silt and clay, slightly sandy, light brownish gray 10 13

clay and silt, dark blue gray 1 14

sand and gravel, arkosic, interbedded with blue gray sandy clay from 15'-20'; coarse gravel at 28'-29'. 16 30

sand and gravel, arkosic; interbedded with thin yellow to buff clay layers from 33' to 45'. 26 56

silt and clay, light tan; gravel and sand from 59' to 60'. 4 60

silt and clay, light tan to pinkish tan; contains thin layers of sand and gravel. 10 70

silt and clay, light tan; contains .2 foot layers of caliche at 70', 72', 73' and 78'. 16 86

silt and clay, light greenish gray streaked with black. 8 94

silt and clay, pinkish tan 11 105

silt and clay, pinkish tan to grayish tan; thin layers of caliche throughout 26 131

silt and clay, grayish red; some caliche; contains gravel with "ironstone" fragments. 6 137

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

siltstone and shale, dark red 13 150

20-8W-20aaa Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE NE NE Sec. 20, T.20S., R.8W.; 45' south and 12' west of center
(Location)

of road intersection on west road shoulder

8/17/70; depth to water, 11.2 feet;
(Date)

altitude of land surface 1651 feet.

	Thickness, feet	Depth, feet
Quaternary		
Pleistocene and Recent undifferentiated		
soil	3 1/2	3 1/2
silt, slightly sandy, tan	3 1/2	7
silt, sandy, light tannish gray	4	11
gravel and sand, arkosic; contains light blue gray, sandy silt from 12' to 15'.	15	26
silt and clay, sandy, yellowish tan	7	33
sand and gravel, arkosic	19	52
clay, silty, grayish tan with cream white spots	5	57
clay and silt, calcareous, grayish tan to pinkish tan.	30	87
silt, calcareous, reddish tan; contains a little caliche.	6	93
gravel, black; contains ironstone, quartz and caliche fragments.	10 1/2	103 1/2
Permian-Cimarronian		
Harper Sandstone		
Chikaskia Sandstone Member		
siltstone, reddish brown	1 1/2	105

20-9W-14ddd

(Well No.)

Sample _____ log of test hole _____

augered drilled

in SE SE SE Sec. 14, T.20S., R.9W.; 185' west and 24' north of center
(Location)

of road intersection

8/19/70; depth to water, 11.3
(Date)

feet;

altitude of land surface 1671 feet.

Thickness,
feetDepth,
feet

Quaternary

Pleistocene and Recent undifferentiated

soil, grayish black 3 3

silt, tan to light gray 3 6

sand and gravel, arkosic 9 15

gravel and sand, fine to coarse 17 32

silt and clay, yellowish buff and light gray 2 34

sand and gravel, arkosic; thin light gray clay 11 45
streaks throughout.gravel and sand; streaks of noncalcareous 18 63
yellow buff and light gray clay.silt and clay, calcareous, light grayish tan 17 80
to tan.silt and clay, calcareous, light grayish tan; 17 97
contains caliche from 78' to 80' and 89' to 91'.

silt and clay, noncalcareous, pinkish tan 45 142

silt and clay, calcareous, yellow brown and 6 148
grayish tan.sand and gravel, contains "ironstone" frag- 25 173
ments; cemented.

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale and siltstone, red 5 178

20-9W-16DDD Sample _____ log of test hole _____ augered drilled
(Well No.)

in SE SE SE Sec. 16, T.20S., R.9W.; 135' north and 36 feet west of
(Location)

center of road intersection--In Township storage yard.

8/21/70; depth to water, 53.5 feet;
(Date)

altitude of land surface 1724 feet.

	Thickness, feet	Depth, feet
<u>Quaternary</u>		
Pleistocene and Recent undifferentiated		
soil, gray to brown	3	3
silt, slightly sandy, reddish brown, soft	22	25
silt, noncalcareous, slightly sandy, reddish gray brown, medium hard.	20	45
silt and clay, calcareous, light tan to cream; contains a little caliche.	15	60
silt and clay, noncalcareous, reddish to reddish gray.	10	70
silt and clay, calcareous, reddish to light grayish red, contains caliche.	70	85
silt and clay, calcareous, light gray mottled with red; contains caliche.	16	101
silt and clay, slightly calcareous, grayish red	9	110
silt, calcareous, slightly sandy, reddish gray	10	120
silt and clay, calcareous reddish tan; contains a little caliche.	15	135
silt and clay, calcareous, sandy, gravelly, reddish tan.	5	140
gravel, fine to medium, sandy; contains fragments of caliche and red siltstone and sandstone.	2	142

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

shale, dark reddish brown	8	150
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20-9W-22aaa Sample _____ log of test hole _____ augered drilled
(Well No.)

in NE NE NE Sec. 22, T.20S., R.9W.; 145' west and 8' south of center
(Location)
of road intersection.

8/20/70; depth to water, 11.6 feet;
(Date)
altitude of land surface 1674 feet.

Quaternary

Pleistocene and Recent undifferentiated

	Thickness, feet	Depth, feet
roadfill and soil	4	4
silt, calcareous, light greenish gray	4	8
sand and gravel, arkosic	7	15
sand, medium to coarse; and gravel, fine to medium, arkosic.	17	32
silt and clay, sandy, light gray to yellowish buff.	10	42
sand and gravel, fine to coarse, arkosic	5	47
clay, calcareous, sandy, light greenish gray and pinkish; contains caliche nodules throughout.	23	70
silt and clay, calcareous, pinkish	13	83
silt and clay, noncalcareous, pinkish gray and light greenish gray.	15	98
clay and silt, calcareous, medium gray and dark gray.	8 1/2	106 1/2
gravel, abundance of caliche, light grayish tan	3 1/2	110
clay and silt, calcareous, light greenish gray and pinkish tan.	4	114
silt and clay, calcareous, reddish tan	14	128
gravel, clayey; contains caliche and "iron-stone" fragments.	13	141

Permian-Cimarronian

Harper Sandstone

Chikaskia Sandstone Member

siltstone, calcareous, red	1/2	141 1/2
shale, noncalcareous, red.	8 1/2	150