UNDERGROUND STORAGE OF LIQUID PETROLEUM PRODUCTS IN McPHERSON COUNTY, KANSAS

June, 1956

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This is a brief report on an investigation of the practice of storing liquid hydrocarbons in controlled underground cavities in McPherson County, Kansas. The geologic conditions of the area, the technique of developing storage and the operational methods and procedure are discussed. Special attention was given to possible ground water pollution hazards associated with underground storage practices of existing and proposed installations. A summary of the report and conclusions are presented.

Acknowledgements

The authors wish to thank Dr. Mark Jewett and Kenneth Walters of the State Geological Survey; Mr. G. H. Billue of Security Underground Storage; Mr. Willis Waterman, Consulting Geologist; Messrs. J. W. Taylor, Gage Lee, Charles Moore, Howard Andrews, and other members of the staff of the National Cooperative Refinery Association, and J. Y. Haslam of Skelly Oil Company for the time and effort spent in discussing the various problems and techniques of underground storage development and operation. Data and information incorporated in this report were obtained largely from interviews with these people. Their cooperation was very much appreciated.

Introduction

The storing of liquid products in controlled cavities underground has been practiced for a number of years. The first installation was developed at Ranken, Texas in 1949 for the purpose of storing anhydrous ammonia. Since that time more than 500 million gallons (12 million bbls) of underground storage capacity exists in the Mid-Continent region. Texas, Louisiana, Oaklahoma and Kansas use a salt formation for the cavity development and storage.

The storing of liquid petroleum gas in Kansas in the Hutchinson salt member of the Wellington formation was initiated by National Cooperative Refinery Association at Conway. The first storage cavity was completed and put in use in March, 1953. At the present time NCRA has five storage cavities with a total capacity of a little over 9½ million gallons (232,592 bbls). Skelly Oil Company's installation located just a mile west of NCRA has eight storage cavities in use with a combined storage of 11 million gallons (263,299 bbls). Both installations store only liquid petroleum gas. The Skelly installation stores propane gas (Skelgas) while NCRA has butane, propane and Iso butane stored under ground.

Underground storage facilities for liquid petroleum gas serves several purposes. The principle advantages are conservation of petroleum products and economy. In addition there may be considerable military value in storing large quantities of petroleum products underground where they are less accessible to enemy attack and strategically located for emergency use.

Liquid petroleum gas such as propane, butane, and LPG are produced during the refining of crude oil. The demand for these products is seasonable since the principle use is for domestic heating. To meet the seasonal demand it is necessary to store surplus gas produced during periods of low demands. This necessitates large storage facilities. Surface storage of the gas in high pressure containers is very expensive. It has been estimated that the cost of high pressure steel storage facilities above ground runs about $20. per barrel, whereas equivalant underground storage costs approximately $1. per barrel. Because of this expense it is reported that much of the gas produced prior to the use of underground storage was wasted during periods of low consumption.

Since large storage facilities can be constructed economically, underground, the industry makes use of underground storage for more effective utilization of transportation facilities. During periods of low consumption the product is moved from the refinery to storage areas much closer to the point of consumption. When consumption is heavy, the product is removed from storage and transported to the consumer over a much shorter route. In this manner the transportation facilities are kept in constant use during the year by hauling from refinery to storage areas in the summer and hauling from storage to the consumer in the winter. This results in much greater assurance of meeting the winter demand for the product as well as a reduced cost to the consumer.

Other advantages of underground storage to the petroleum industry are reduced maintenance cost for storage facilities, savings in the use of steel, and the elimination of many above ground operational hazards. The uniform temperature of the underground storage and the use of a column of salt brine for maintaining the necessary pressure to keep the gas in the liquid state are less hazardous than surface storage for operating personnel. The large capacity of the developed cavities (up to 50,000 barrels) and the ease of handling the product is of great value to the industry. The actual loss in storing the product in underground cavities is considered by the industry to be quite small as compared to above ground storage. Records of an actual test run on one of the early Texas installations gave results of 95% recovery on the initial use of the storage cavity and up to 99.7% recovery on continued use.

Area of This Report and Existing Facilities:

The two existing installations in McPherson County are located just west of the City of McPherson. They are operated by Skelly Oil Company and National Cooperative Refinery Association. The Skelly installation is located seven miles west of the city in the NW/4 NW/4 NE/4 Section 30-19-4W (see Plate #1). The installation includes 8 storage wells, (4 more are being developed) an Arbuckle disposal well, dehydrators for removing moisture from the stored gas and loading facilities for both trucks and rail transportation. The product stored is propane gas. The installation occupys an area of about 40 acres including the railroad loading facilities. (See Plate #2)

The National Cooperative Refinery Association installation is located about one mile east of the Skelly site and within the city limits of Conway. The legal description is the NW/4, SE/4, Section 29, Township 19S., Range 4W. The NCRA installation includes 5 storage wells (one additional well being developed at the present time), an Arbuckle disposal well and pumping equipment to transfer product from the storage location to the Refinery in McPherson (See Plate #3). All product is brought in and sent out through a pipe line. The Refinery at McPherson provides the other facilities for handling the product.

A water well owned jointly by NCRA and Skelly Oil Company is located about two miles east of the NCRA installations. SE/4 SE/4 NW/4 Section 27-19-4W). This well produces water from the McPherson formation (Equus beds) and is rated at 420 gpm. This well supplies the needed water for dissolution of the salt in developing storage.

Proposed Storage Facilities:

The Security Underground Storage, Inc. have made application for the installation of storage facilities in this same area. The product to be stored is jet fuel for the United States Air Force. The facilities required will be similiar to those in use by NCRA or Skelly Oil Company.

The proposed location for the storage site is about one mile southeast of the NCRA installation at Conway (See Plate #1). The location is the SE/4 SW/4 Section 28-19-4W. The disposal well application is for a shallow disposal zone into the Wellington formation at a depth of 415 feet below ground level. The location of the disposal well is to be the NE corner of the NW/4 NW/4 Section 34-19-4W. The water well for this installation will be located a quarter of a mile east of the disposal well in the NE corner of the NW/4 Section 34-17-4W (See Plate 1). Plate 4 shows proposed storage wells and facilities.

Geography and Geology of Storage Area:

The geographical requirements for underground storage are well satisfied in the area west of McPherson. Adequate transportation facilities, the Santa Fe Railroad and U.S. 50 N Highway, are present. The need of fairly large water supplies is provided by the proliferous water bearing characteristics of the McPherson formation (Equus beds). The Hutchinson Salt member of the Wellington formation is favorably located both as to depth and areal extent for developing controlled cavities. The close proximity of the NCRA Refinery added the initial impetus to the underground storage installation.

The actual storage facilities are developed by dissolution of a salt layer which underlies the area at a depth of 360 to 400 feet. This salt layer averages about 250 feet in thickness and is interbedded with thin shale stringers throughout. An idealized cross section (plate 5) is included to give proper prospective to the stratigraphy of the area. Plate 6 is an exact scale reproduction of the lithology of the part of the area. This cross section was prepared by Willis Waterman, Consultant for Mr. G. H. Billue of Security Underground Storage. The data for constructing this profile was obtained from radio-active logs run on test holes drilled across Sections 27 and 28. The use of radio-active logs is as exact as any method known for obtaining subsurface data.

Test hole logs and existing data indicate the installations of Skelly Oil Company, NCRA and the proposed storage cavities of Security Underground Storage, Inc. do not lie in the area underlain by the water bearing portion of the McPherson formation. The only material that could correlate as being of Pliestocene to Recent age (the McPherson formation is material of Pliestocene age) is the very thin mantil of silt and clay with some sandy clay that overlies the entire area. The thickness varies from a feather edge on the higher ground to possibly ten feet in the lower areas or draws. This material is not known to carry recoverable ground water in this immediate area.

The bed-rock formation in the area of Skelly and NCRA installation as well as the proposed storage cavities of Security Underground Storage is the Ninnescah Shale. This rock layer is predominately composed of a red silty shale with thin beds of gray and green shale. A few very thin stringers of impure Gypsum and Limestone as well as several thin silty sand layers are also present. The Ninnescah shale thins to a feather edge as it approaches the area underlain by the water bearing portion of the McPherson formation. A few domestic and stock water wells derive water from the silty sand stringers located at a depth of 60 to 85 feet near the base of the Ninnescah shale.

The entire area is underlain by the Wellington shale formation. This shale underlies the Ninnescah formation and forms the Bedrock where the Ninnescah pinches out. The water bearing portion of the McPherson formation is, therefore, underlain by the Wellington shale in this general area. The total thickness of the Wellington is about 700 feet. The area of underground storage has a 300 foot section of shale, varicolored in the upper part grading to a gray fissel shale; a few shaly lime stringers and some gypsum and anhydrite lenses are interbedded throughout this shale section.

The Hutchinson Salt member underlies the upper shale section of the Wellington formation. The Salt section is approximately 250 feet thick as indicated by cores obtained from test holes. This section has numerous thin lenticular shale stringers interbedded. These stringers, with one exception, vary from a few inches to more than a foot in thickness. One shale bed is about 5 to 8 feet thick and appears to be fairly consistant as to areal extent and depth encountered in the salt member. However, all the interbedded shale is very impure, containing gypsum, salt and anhydrite in varying amounts. The shale section below the salt is about 150 foot thick and is similiar to the shale overlying the salt member.

The Hutchinson Salt member of the Wellington formation has several zones that have very high permeability and porosity. In several drilling tests, actual cavities have been encountered. This area of natural cavities and high porosity is very likely due to the natural leaching of the salt zone by ground water. This leached area exists along an approximate north-south line from 25 miles north of the Storage area to a greater distance to the south. The numerous sink holes and larger depressions such as Inman Lake and the marsh area west of McPherson are the result of the dissolution of the Salt member and the gradual settlement of the over-burden into the leached area of the salt.

This fringe area along the eastern extent of the salt member has been used for oil field brine disposal. The first disposal well in this general area was put in use in September 1953. Since that date there are a total of 15 disposal wells using this zone for brine disposal.

The actual configuration of this "Lost Circulation" zone in the Wellington formation is not known. However, it is fairly well established that this zone of high porosity is rather narrow in width. The east to west boundry is limited to less than one-half mile in the area east of the Storage sites. Approximately sixteen miles to the north, this zone has about the same width. It does, however, broaden to around 1 to 1½ miles in width in Saline County, which is a distance of about 25 miles from the storage area. This broadening of the "Lost Circulation" zone is probably due to the leaching of the northern edge as well as the eastern edge of the Salt member. The Salt zone is likewise considerably thinner and less persistant in areal extent in the area of Saline County.

The Salt member has about the same thickness south of the storage area as it does at the storage sites. The "Lost Circulation" zone is known to exist three miles south of the storage area and is in use at this location for oil field brine disposal. The same zone has been encountered in the drilling of oil tests further south. It is reasonable to expect that this leached zone does exist along the entire length of the Eastern fringe of the Hutchinson Salt member of the Wellington formation. This leached zone is overlain by a shale section similiar to that encountered in the storage area and the shale appears to be fairly uniform in thickness throughout the North-South extent of the zone.

Techniques of Constructing Storage:

In developing underground storage it is important that the cavity be located at sufficient depth to avoid rupture. Liquid petroleum fuels such as propane, butane and L.P.G. exist in the gaseous state under normal temperature and pressure conditions. Since the fuels are stored in the liquid state, pressure must be maintained in the storage cavity. The oil industry considers that 1.0 to 1.1 psi subsurface pressure is exerted by each foot of overburden. For a margin of safety the industry, therefore, uses a minimum depth for storage of one foot for each 0.9 psi which may be exerted on the formation to avoid raising the overburden. As an example, propane has a vapor pressure of 200 psi at 100° F. Therefore, propane would have to be stored at a depth of at least 222 feet as based on vapor pressure considerations alone. A greater depth is necessary to allow for the additional pressure that must be exerted to move the product in storage operations. In practice in this area the storage temperatures are less than 100° F. and the storage depths are considerably greater than 200 feet.

Plate #7 is a cross-sectional sketch of a typical subsurface storage installation. The first step in construction consists of drilling into the salt formation and setting and cementing the surface pipe (A). Cementing of the surface pipe consists of circulating cement grout to the surface so that the annular space between the drilled hole and the pipe is completely filled. Next, the conductor string (B) is run into the holes to a depth approximately 8 feet below the seat depth of the surface pipe. The bottom of the conductor pipe establishes the roof of the storage cavity. The third or injection string of pipe (C) is set to the lower depth of the cavity to be developed. This pipe is set on a concrete footing at the base of the drilled hole. The pipe is perforated near the bottom to facilitate the injection of water into the storage formation during construction.

An important factor for successful storage is to maintain a salt section between the top of the cavity and the bottom of the surface pipe. Prior to actual dissolution of the salt to form a cavity, the annulus (space between pipe A and B) is filled with the petroleum product to be stored. As the cavity is formed, the petroleum product from this annulus spreads out to form a protective cap at the top of the cavity. This prevents contact of the brine with the roof and thus maintains a protective salt section between the product and the cement grout surrounding the surface pipe.

The storage cavity is developed by injecting fresh water through the injection string. The water circulates upward, taking salt into solution, and is discharged through the annular space between the conductor and injection strings (pipes B and C) to disposal facilities. In this manner a cavity is formed with the approximate shape shown on Plate 7.

The water used in developing the cavern is metered, and specific gravity determinations are made at hourly intervals to determine the percent saturation of discharged brine. By utilizing this data it is possible to compute the volume of developed storage. A barrel of storage volume is developed for each 6.1 barrels of saturated brine discharged. The rate of storage development is on the order of 100 days per 25,000 bbl. of storage capacity for existing installations. The rate of development is, however, dependent upon the capacity of the water system and the disposal system.

The largest, existing underground storage cavity in McPherson County has a capacity of 2,229,024 gallons. This is the N.C.R.A. No. 1 cavity which is the oldest one in use in the area. The average cavity size is about 1.5 million gallons. The following table shows the capacities of individual cavities at this time. Some of these are still under development.

Storage Cavity	Capacity in Gallons
NCRA No. 1	2,229,024
NCRA No. 2	2,149,140
NCRA No. 3	2,114,826
NCRA No. 4	1,895,596
NCRA No. 5	1,380,078
Skelly No. 1	1,354,668
Skelly No. 2	1,592,766
Skelly No. 3	1,639,344
Skelly No. 4	1,388,478
Skelly No. 5	1,386,084
Skelly No. 6	1,178,218
Skelly No. 7	1,050,000
Skelly No. 8	1,470,000

The cavities developed in the salt member range from about 85 feet in height to approximately 205 feet. The top surface of the developed cavities range from approximately 415 to 570 feet below the ground surface.

Operation of Storage Facilities:

Petroleum products stored at the NCRA installation are brought to the storage site by means of a 4 inch pipe line from the NCRA refinery located just south of the City of McPherson. Products stored at the Skelly installation are brought in by highway or railroad transportation. Facilities are provided at the storage area for loading and unloading trucks or railway cars.

In storage operation, the product is pumped through a piping system to any desired storage unit. The product is always injected into the annulus between pipes B and C. (See Plate No. 7) Since the storage cavity is filled with fluid, the input of product displaces brine upward through the injection pipe (C). The brine is then removed by a piping system to deep disposal facilities. Since the brine within the cavity has a greater density then the petroleum fuel, there is a physical separation of the brine and fuel within the cavity. As fuel is added the brine is lowered in the cavity. Fuel may be added until it reaches the perforations at the base of the injection pipe. The fuel is kept in a liquid state by the column of brine maintained in the injection pipe. The pressure exerted by this column of brine balances the pressure exerted by the confined fuel.

The removal of the fuel from storage is normally accomplished by the input of brine in to the injection pipe (C) and displacing the product through the annulus between B and C. The storage system is kept full of fluid at all times under normal operations. The reasons for this are (1) the cavity, as such, needs the support of the fluid to insure against possible caving of shale stringers and (2) the handling of the product, both on injection and removal is greatly simplified by having the system full of fluid. Saturated brine solutions must be used when removing fuel after the cavity has reached the maximum size intended or further dissolution will occur.

The proposed installation of Security Underground Storage, Inc. will differ in one respect from the existing installations. One of the requisites of the contract between the Air Force and Security Underground Storage, Inc. is that one storage cavity is to be equipped with a Reda submersible electric pump. This cavity will be filled with product (Jet Fuel) in the usual manner and then removed at a very high rate with the pump rather than by displacement with brine. It is anticipated that caving of the protruding shale stringers (as shown on Plate 7) will occur during the rapid removal of the product. This caving will probably cause severe damage to the pumping equipment; however, damage should be limited to the storage equipment in this particular cavity. It is very unlikely that the surface pipe or concrete grout seal will be damaged. The possibility that the overburden would collapse into the cavity is extremely remote considering the small size of the cavity compared with the overburden. Rapid removal of fuel with the Reda submersible pump is a feasibility study, and it does not constitute routine storage operation.

A pipe network carries displaced brine from the various storage cavities (both during development and storage operation) to subsurface disposal facilities. The principle unit is the disposal well. Single disposal wells, therefore, serve each of the existing storage installations. Plate 8 shows a cross-sectional drawing of a typical disposal well. The Skelly and NCRA disposal wells each discharge brine into the lower Arbuckle formation at a depth of about 4,200 feet.

The Skelly disposal well consists of the following strings of pipe:

a. <u>Surface pipe.</u> 165 feet of 13 3/8 inch. O.D. pipe cemented from seat depth to the surface.

b. <u>Intermediate string.</u> 730 feet of 9 5/8 inch O.D. pipe cemented from seat depth to the surface.

c. <u>Conductor string.</u> 4033 feet of 7 inch O.D. pipe cemented from seat depth upward to an undetermined elevation.

The National Cooperative Refinery Association disposal well has the following strings of pipe:

a. <u>Surface pipe.</u> 240 feet of 8 5/8 inch O.D. pipe cemented from seat depth to the surface.

b. Intermediate string. 3938 feet of 5 1/2 inch O.D. pipe. This string is cemented from seat depth upward to an undetermined elevation. In addition, this string is cemented from a depth of 683 feet below ground level to 480 feet below the surface.

c. Conductor string. 3975 feet of plastic coated, 2 7/8 inch O.D. tubing.

The surface pipe is placed for primary protection of fresh water. The intermediate string is placed through the salt section for protecting of the conductor string against salt action. The conductor strings carries the brine to the disposal formation. The NCRA disposal well also differs from the Skelly disposal well in that the annular space between the intermediate and conductor strings is filled with diesel fuel (A.P.I. 33). This is done to detect any leak which may develop in either the intermediate or conductor strings.

Construction features of the proposed Security Underground Storage disposal well differ considerably from the two existing disposal wells. As previously mentioned the Security Underground Storage Company well will inject brine into the "Lost Circulation" zone of the Wellington formation. This is a depth of about 400 feet compared with the Arbuckle injection which is approximately 4000 feet. This disposal well, because of its location with respect to the Equus Beds, will have 265 feet of surface pipe. A 265 foot depth is considered to be below the deepest portion of the Equus beds. The surface pipe will be 13 5/8 inch O.D. pipe, and it will be cemented from seat depth to the surface. The conductor string will be 8 5/8 inch O.D. pipe cemented from seat depth to the surface.

The proposed disposal well will have a sampling tube installed on the outside of the surface pipe. The sampling tube will terminate at the point where the casing leaves the sand and gravel of the Equus Beds and enters the shale formation. This tube will allow the sampling of water at the base of the aquifer. Another stipulation imposed on this shallow disposal well is the installation of a continuous recording device to record the static level of fluid in the disposal horizon. An upper limit is to be maintained and this level is not to rise above the deepest part of the Equus Beds. All brine injected into this well is to be by gravity at the well head.

Pollution from Underground Storage Operations:

Around May 1, 1956, propane pollution was detected in two water wells on the Ray Burns farm which is located about 1/2 mile north of the Skelly underground storage site. Shortly thereafter it was found that a domestic water well on the Skelly storage site was also polluted by propane. The exact location of the farm is the SE/4, 19-19-4W, McPherson County. Plate 1 shows the location of the farm with respect to the Skelly and NCRA storage sites. One of the Burns' wells is a domestic well located at the house and the other is a stock well located about 75 feet to the East of the house. The house well is a drilled and cased well and the other is a dug well. The wells are around 80 feet deep, and they derive water from the weathered contact zone at the base of the Ninnescah formation.

Gas samples were collected from the two wells on the Burns property and Podbieliniak analyses were performed by Mr. L. P. Aeschliman, Chief Chemist for the National Cooperative Refinery Association. The analyses were reported as follows:

Identification	House Well	Stock Well
Non-condensible (Air)	38.64%	71.75%
Ethane	2.29	0.31
Propane	58.07	27.44
Butane	1.00	0.50

Analyses based on air-free samples:

Ethane	3.74%	1.11%
Propane	94.64	97.13
Butane	1.62	1.76

The analyses indicate that the principle hydrocarbon consituent of the gas is propane. It was reported that the propane stored by the National Refinery Association is ethane free, since ethane removal is practiced at the refinery. Small amounts of butane are reported to be present in propane gas.

Following the initial detection of propane pollution of the above water wells, a joint investigative program was undertaken by Skelly Oil Company and NCRA. Samples were collected from wells in Conway, from an abandoned water well on the NCRA storage site, and from other water wells in the area. None of the additional wells tested were found to be polluted. The tests included a farm well approximately 1/2 mile north of the Ray Burns farm.

Because of pollution of the Burns' farm wells, Skelly Oil Company and NCRA provided a water supply free of gas pollution for Mr. Burns. Since then Skelly Oil Company has leased the Burns property and the Burns family has moved. One of the purposes of this action was to avoid the possibility of damage that might result if an explosion should occur.

In an attempt to determine the cavity or cavities which were causing pollution, pressure checks were made on storage cavities used for propane storage. This procedure consisted of applying 275 p.s.i. gauge pressure on the annulus containing the stored product at each cavity for a 72 hour period. Pressure recording instruments were used for a continuous and permanent record. Pressure checks were made on the N.C.R.A. number 1 and 2 cavities and on all eight of the Skelly cavities. These checks have been completed and both companies have reported that none of the pressure checks showed significant pressure reductions, thus indicating that the assumed storage leak is not detectable in this manner

Another phase of the investigation being made by the oil companies has been the installation of observation wells on the storage sites. Four such wells were constructed by NCRA around the periphery of the storage area and the abandoned water well, previously mentioned, is also being used for this purpose. These wells vary in depth from 80 to 95 feet. Skelly Oil Company has constructed 6 similar observation wells on the Skelly property. The latest information available indicates the propane pollution does exist in these wells, although testing is not complete. In addition, the Skelly observation wells have not provided any information that would indicate which storage cavity or cavities may be the source of the escaping gas.

One observation well on the NCRA property has shown indications of gas accumulation on an explosion meter. Attempts to collect a sufficient sample of gas from the well for gas analysis have been unsuccessful. At the present time the wells are being remodeled in an attempt to collect samples sufficient for gas analysis. It is the opinion of NCRA that present information does not justify any conclusions regarding pollution of the observation wells on the NCRA storage site.

Recent conversation by the writers with Mr. Gage Lee, Production Department, National Cooperative Refinery Association, Wichita, and Mr. J. Y. Haslam, Chief Engineer, Skelly Oil Company, Tulsa, Oklahoma, indicate that the exact source of the escaped gas has not been found. The No. 2 and No. 3 storage cavities on the Skelly property have been emptied, and it is assumed that these cavities are suspected. Both companies report that continued efforts are to be made to locate and correct the source of pollution. Skelly Oil Company reports that two additional observation wells are planned for construction on the Burns farm, and that the company plans to investigate more thoroughly the areal extent of the polluted area and to determine whether the quantity of escaping gas is increasing or decreasing.

Information obtained by the writers during this investigation indicate that the most likely weakness in storage construction is the escape of gas around the base of the surface pipe due to a poor cement job. This would not be possible if an impervious salt section is maintained between the roof of the cavity and the surface pipe. Therefore, it would appear that the detection of any gas (petroleum product) above the base of the surface pipe would indicate a defective cavity and the possibility of pollution. Such a test could be accomplished by flooding the storage unit with saturated brine and then running a radio-active log to determine if petroleum products do exist above the base of the surface pipe.

Summary and Conclusions

The practice of storing liquid petroleum products underground has been in use since late 1949 in the Mid-Continent region and since late 1952 in McPherson County, Kansas. At the present time there are two underground storage installations in operation in McPherson County. These installations are located near Conway, Kansas and are operated by the Skelly Oil Company and National Cooperative Refinery Association. Skelly Oil Company has 8 storage cavities in use and 4 cavities under construction with a total storage capacity of about 11,000,000 gallons. NCRA has 5 storage cavities having a total capacity of approximately 9,500,000 gallons. Propane, butane, and Iso butane are the petroleum products being stored. These products exist in the gaseous state under normal temperature and pressure conditions, but are stored under pressure in the liquid state.

The principle facilities involved in underground storage operations are the underground cavities, salt brine disposal wells, and fresh water wells. The storage cavities are located in the Hutchinson Salt member of the Wellington formation. The Salt section is about 250 feet thick, and it is interbedded with numerous, thin lenticular shale stringers. The top surface of developed cavities range from approximately 415 to 570 feet below the ground surface. Cavities are formed by pumping fresh water into the salt formation, dissolving the salt, and removing the water to disposal wells.

A third underground storage project is being undertaken by Security Underground Storage, Inc. The principle difference in the proposed project as compared with existing installations in McPherson County is that the product to be stored is jet fuel (a liquid at ordinary temperature and pressure) and that the salt water disposal well is to discharge into the "Lost Circulation" zone of the Wellington formation at a location in which the well penetrates the water bearing portion of the McPherson formation or "Equus Beds". The two existing disposal wells discharge to the lower Arbuckle formation at a depth of about 4200 feet which is considerably deeper than the "Lost Circulation" zone of the Wellington formation.

Underground storage of petroleum products has proved very satisfactory from the industry standpoint. Underground storage is reported to cost about $1.00 per barrel of capacity compared to around $20.00 per barrel for surface storage in steel containers. Because of reduced costs, much greater storage capacity is being provided for such products as propane, butane, and L.P.G. This permits the industry to conserve rather than waste these products during low demand periods.

The oil industry, in general, has a very good reputation for pollution prevention and abatement. With proper management the industry will operate without deliberately causing pollution. Storage areas are chosen to insure adequate thicknesses of salt and overburden for the injection pressures to be used, and the equipment used is new and is installed with the best known methods. It is reported that the few failures which have occurred in underground storage were contributed to faulty techniques in development. The principle weakness appears to be failure to maintain the roof of the cavity below the bottom of the surface pipe by means of the gas cap.

Storage losses are quite difficult to determine with accuracy, yet there should be considerable value in obtaining the most accurate information possible on all storage units. Initial losses appear to be as high as 4 to 5% due to the trapping of product beneath rock ledges within the cavity, etc. Subsequent losses are somewhat lower. As little as 0.3% has been reported. Skelly Oil Company and NCRA do not have accurate data on storage losses at their McPherson County installations; however, these losses were generally estimated at 1 to 2%. Some of these losses are due to sampling and testing and blow off due to maintenance of the gas cap in the roof of the cavity.

Conclusions relating to possible pollution hazards to fresh water supplies are listed below as follows:

1. The underground storage facilities for storing liquid petroleum products of Skelly Oil Company and National Cooperative Refinery Association as well as the proposed jet fuel storage facilities of Security Underground Storage, Inc. are not located under the water bearing portion of the McPherson formation (Equus Beds).

2. The brine disposal wells of Skelly Oil Company and NCRA are not located in the area underlain by the water bearing portion of the McPherson formation. Neither drilled hole encountered the McPherson formation. Both wells are completed to the lower Arbuckle formation and use this zone for the disposal of brine. Both are considered safe from a pollution standpoint.

3. The proposed location of the disposal well for Security Underground Storage, Inc. is located in the area underlain by the water bearing portion of the McPherson formation. This proposed location will penetrate about 135 feet of the "Equus Beds". The disposal horizon is the "Lost Circulation" zone of the Wellington formation. This zone has been in use for more than 2½ years by the oil industry for the purpose of brine disposal. The "Lost Circulation" zone of the Wellington formation carries fluid that is naturally highly mineralized. The addition of more mineralized water cannot conceivably harm the ground water carried in the formation. In addition, there are 15 wells presently in use that inject oil field brine into this zone, and no known pollution has resulted.

The injection of brine to this zone under gravity at the well head will create an injection pressure at the input zone equivalent to the height of the column of fluid maintained in the input string. This column could only be a hazard if the cement grout around both strings of pipe should fail. The fact that an upper limit for the static fluid level of the input zone is placed below the deepest portion of the fresh water aquifer eliminates the chance of mineralized fluid approaching the fresh water zone from the input formation. Any chance for pollution of the Equus beds by means of the disposal well, with these controls, is very remote. If pollution should occur, the installation of a sampling tube will provide for early detection. In view of controls provided, the disposal well is considered safe.

4. Propane pollution of three domestic water wells near the Skelly Oil Company underground storage installation has occurred. The source and cause of this pollution is not presently known, although it must be concluded that pollution originated from either the Skelly or NCRA underground storage installations. Both companies have undertaken an investigation to determine the source of the pollution and a joint program is being carried out to determine the extent of pollution as well as to protect those involved.

Information presently available indicates that the polluted area is limited in areal extent and that it will not harm the Equus bed water. The polluted aquifer is the weathered zone at the base of the Ninnescah formation. This aquifer serves as a source of supply for domestic consumption by individual users in the immediate area and for general farm use.

5. Insufficient data are available to justify definite conclusions as to the hazard or safety of underground storage from a pollution standpoint if it is recognized that occasional failures are possible in any industrial project. Pollution has occurred, yet many installations are reported to have been in use for several years in other areas without known pollution. Collection of additional data concerning storage construction techniques, operation and failures should be undertaken. It is clearly indicated that controls or safe guards should be established to minimize any pollution hazard and to detect pollution that may occur at the earliest possible time so that remedial measures can be undertaken. The following items are submitted for consideration as controls to safe guard underground storage operations:

A. Installation of observation holes.
The storage site should have observation holes spaced at intervals of about 200 feet around the storage area. The depth of the holes and amount of casing should vary on alternate holes. The deep holes should penetrate at least 150 feet of the Wellington Shale with open hole below the contact of the Ninnescah Shale to the total depth. The other holes could just penetrate the Ninnescah Shale with the total depth only a few feet into the Wellington Shale. Air samples from these holes should be collected at possibly monthly intervals and analyzed for gas content.

B. Records of products handled.
A complete and exact record should be kept of all products brought in and removed from the storage site.

C. A record of injection pressures should be maintained when storage cavities are filled with product.

D. Setting surface pipe.
The drilled hole for setting surface pipe should be drilled to the seat depth only. If this depth has not been predetermined it should be done by rat-holing ahead to determine the casing point. The practice of cutting the hole to total depth before cementing the surface pipe does not allow optimum conditions for obtaining the best possible cement job on the casing.

E. A high pressure cement squeege should be used to insure the best possible pipe cementing.

F. Centralizers should be used on setting the surface string of pipe.

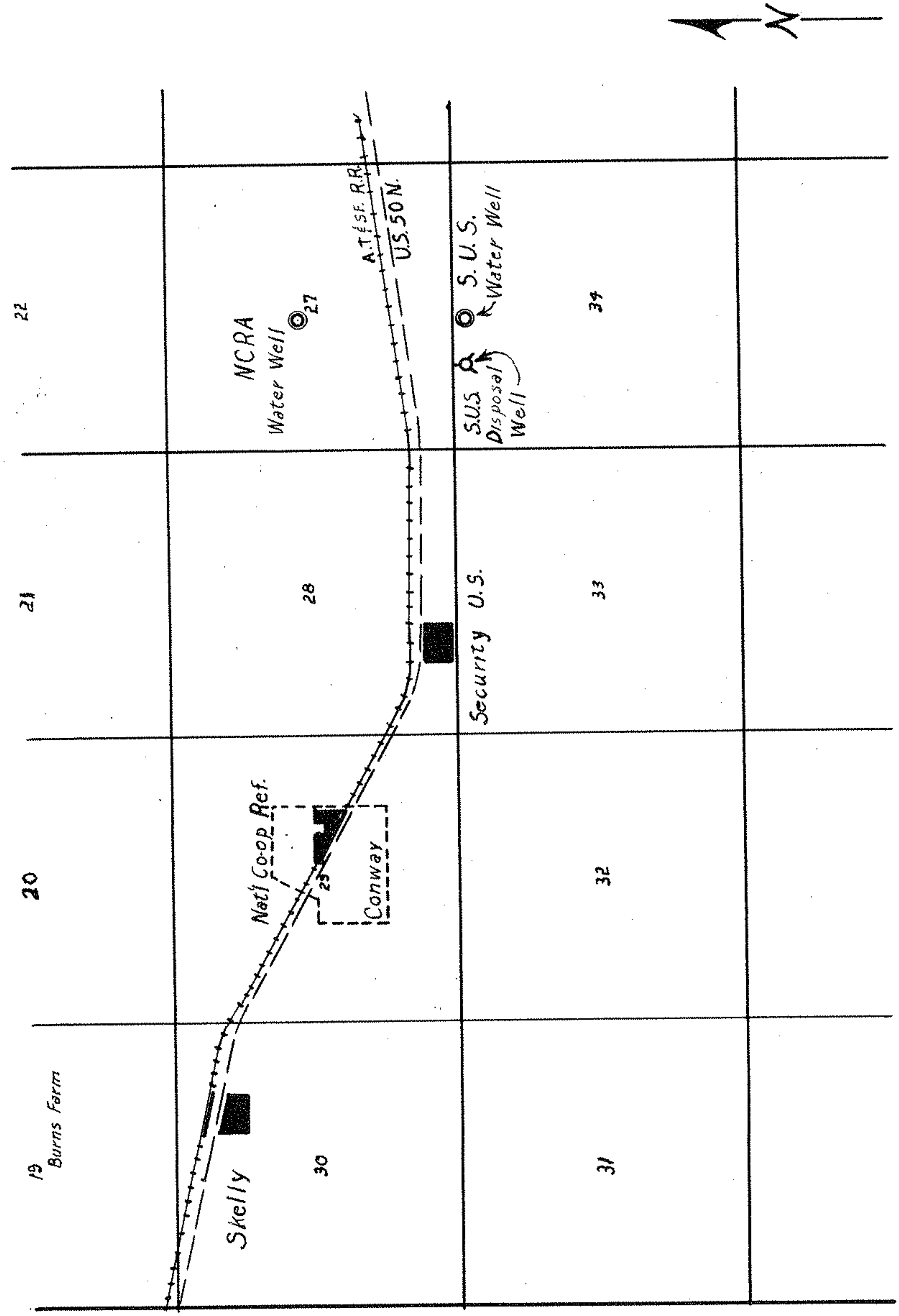
G. Temperature logs should be run on the surface pipe cement job to insure against void areas behind the pipe.

H. The brine disposal wells should have a means of sampling the fresh water aquifer near the point where the casing penetrates the bed-rock formation. The water samples should be obtained from the lower part of the aquifer preferably near the bed-rock contact. A routine sampling program should be maintained and analysis of samples made a permanent record.

I. In case of shallow disposal wells, a means to record static fluid level of the injection horizon should be provided. A continuous recording instrument with permanent type records should be provided.

Plate I

Township 19 S. Range 4 W.
McPherson County



Liquid Petroleum Storage Area
Scale 2 inches = 1 mile

PLATE 2

SKELLY OIL COMPANY

NE/4 Sec. 30; T.19S., R.4W.

Propane Storage Site

Scale 1" = 200 ft.

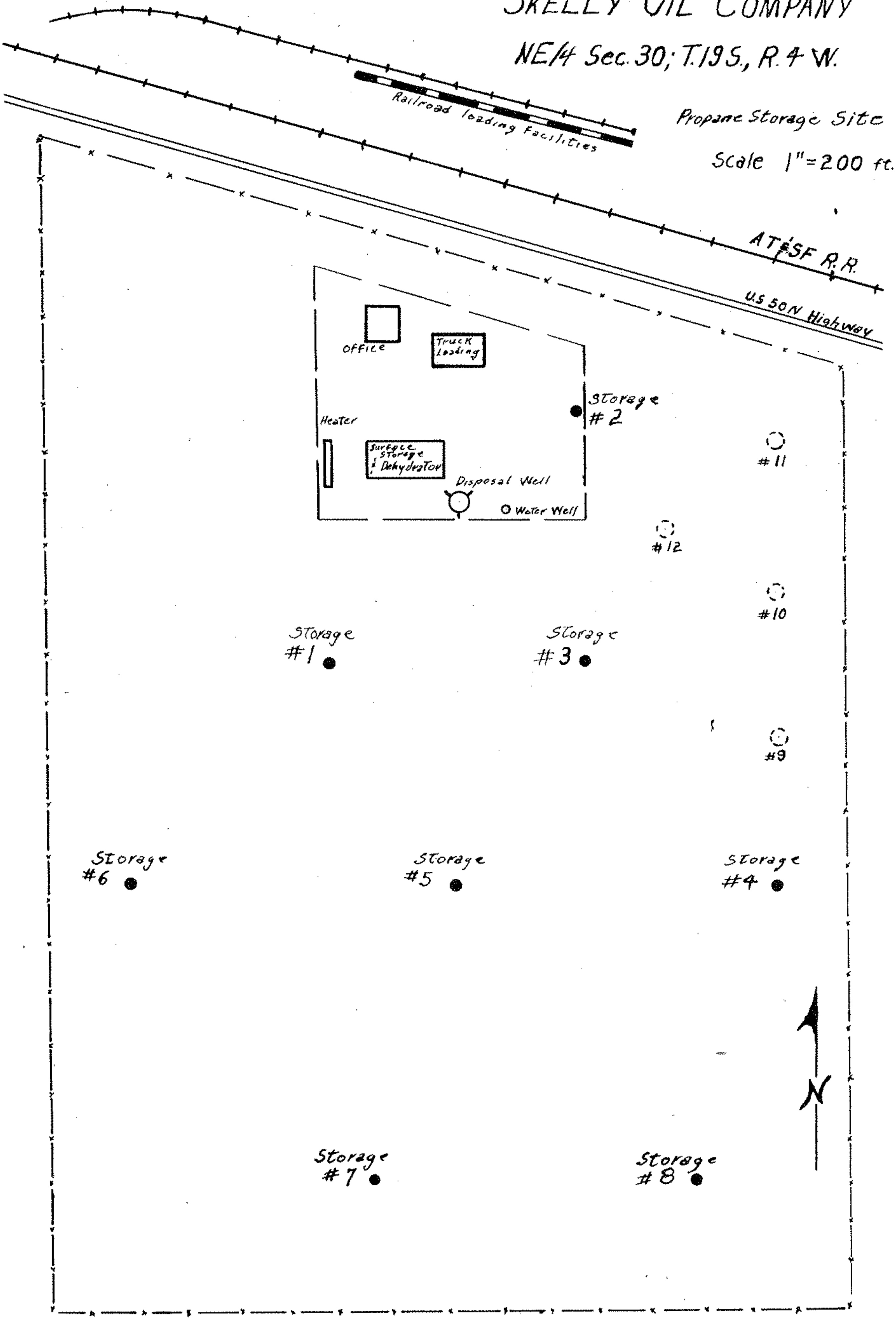


PLATE 3

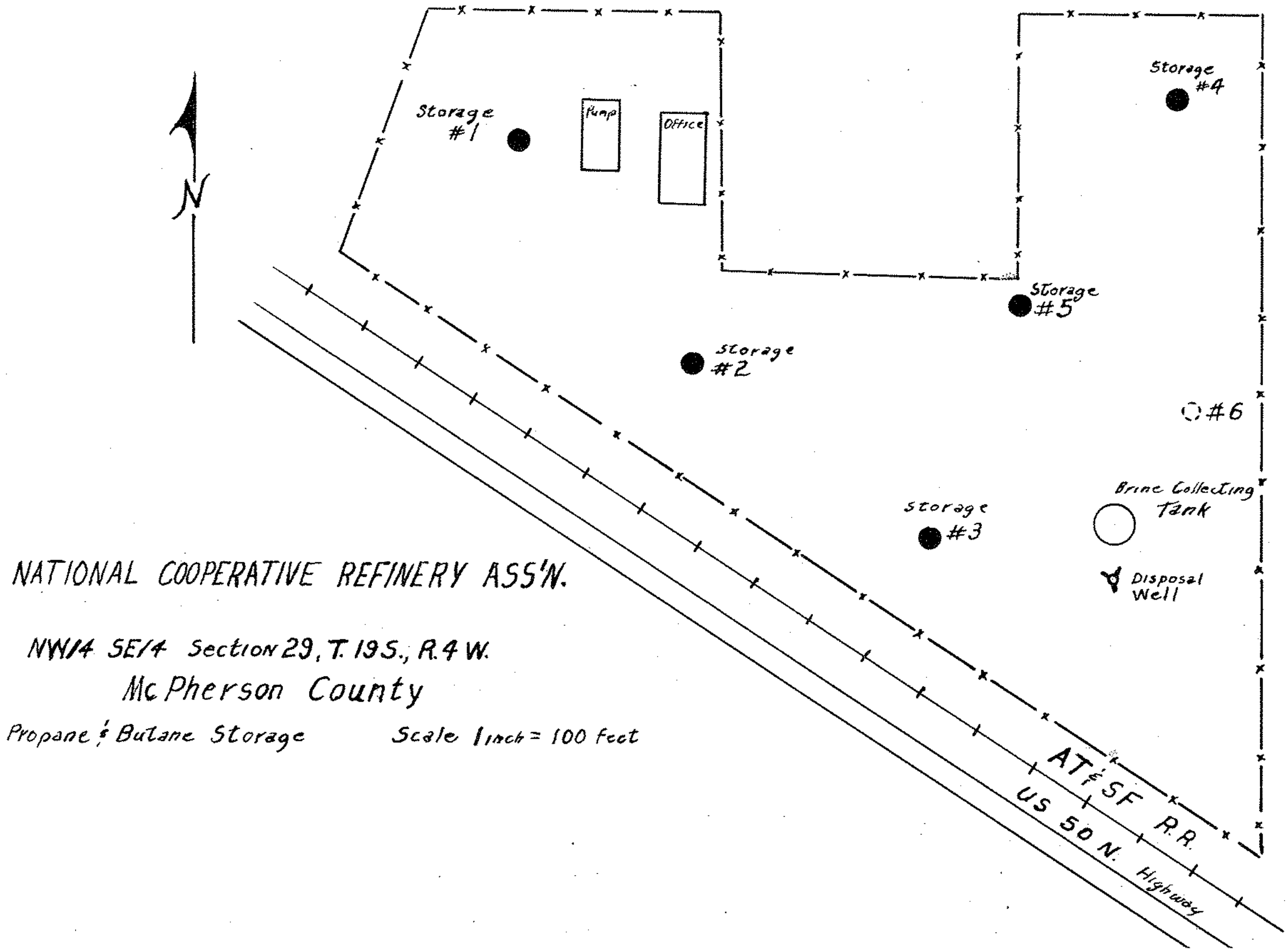
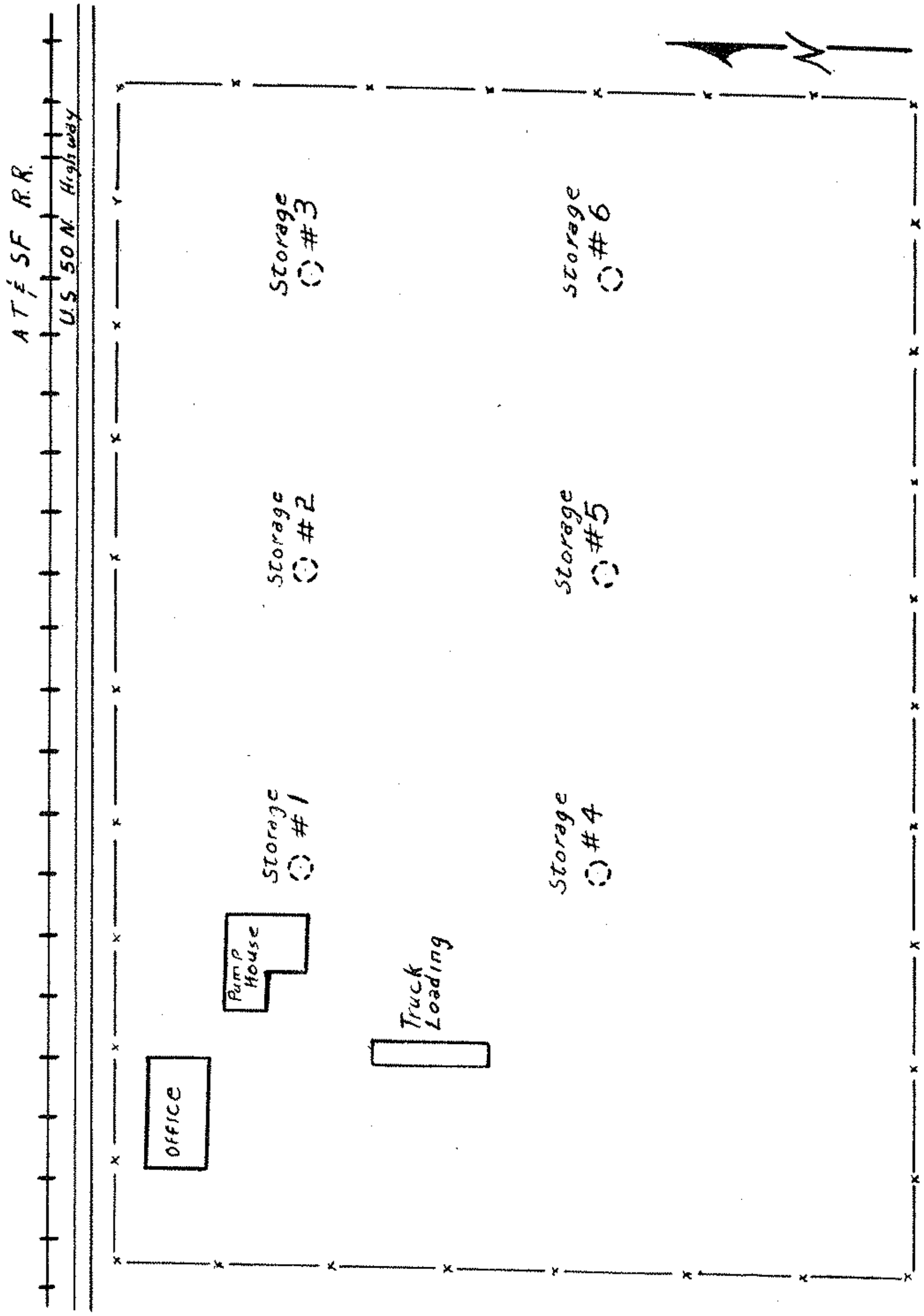

Storage #1
Pump
Office
Storage #4
Storage #5
Storage #2
#6
Brine Collecting Tank
Storage #3
Disposal Well
AT&SF R.R.
US 50 N. Highway
N
NATIONAL COOPERATIVE REFINERY ASS'N.
NW/4 SE/4 Section 29, T. 19S., R. 4 W.
McPherson County
Propane & Butane Storage
Scale 1 inch = 100 feet

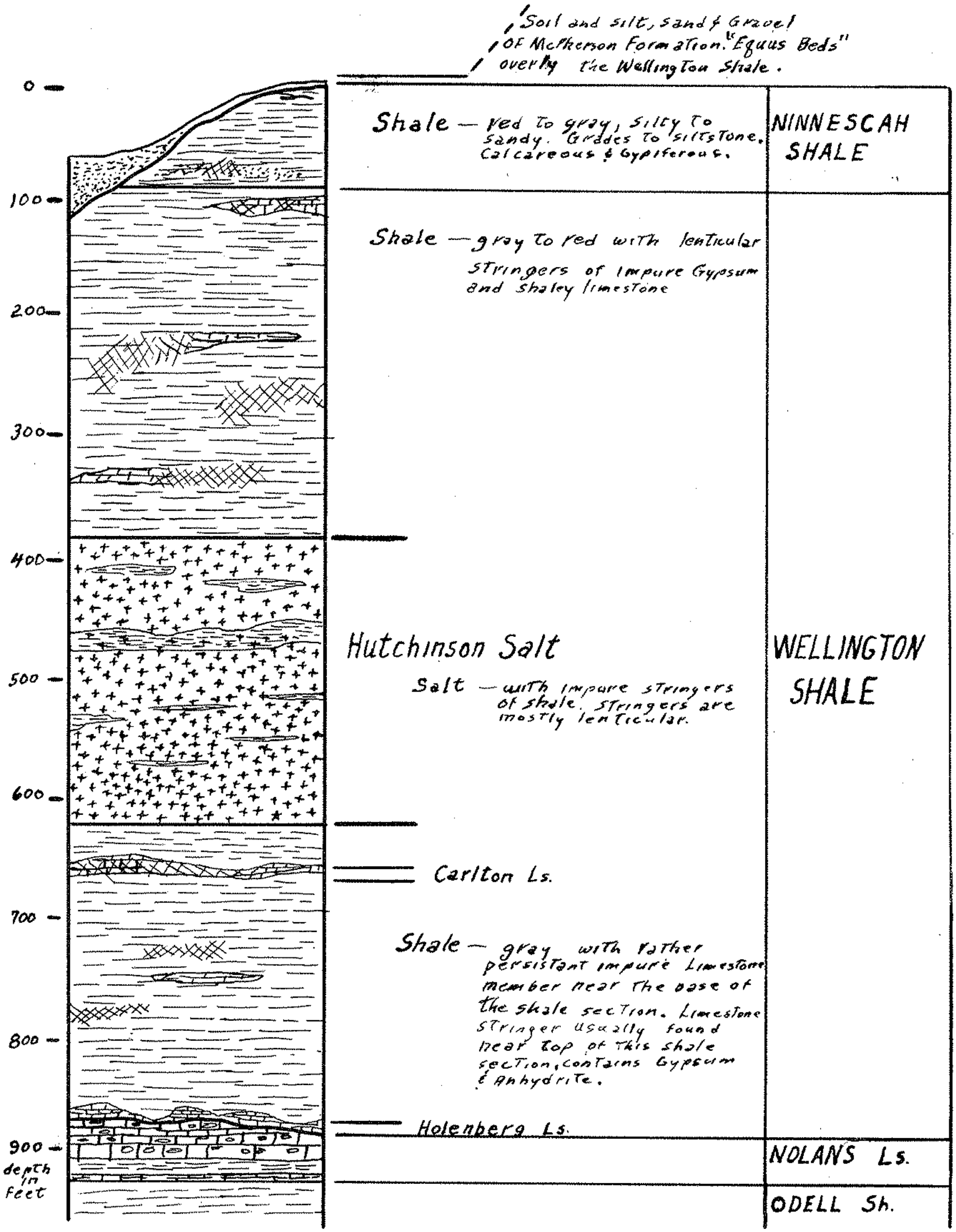
Plate 4



SECURITY UNDERGROUND STORAGE
SE/4 SW/4 Section 28, T.19S, R.4W.
McPherson County

JET FUEL STORAGE SITE   Scale 1 inch = 90 feet

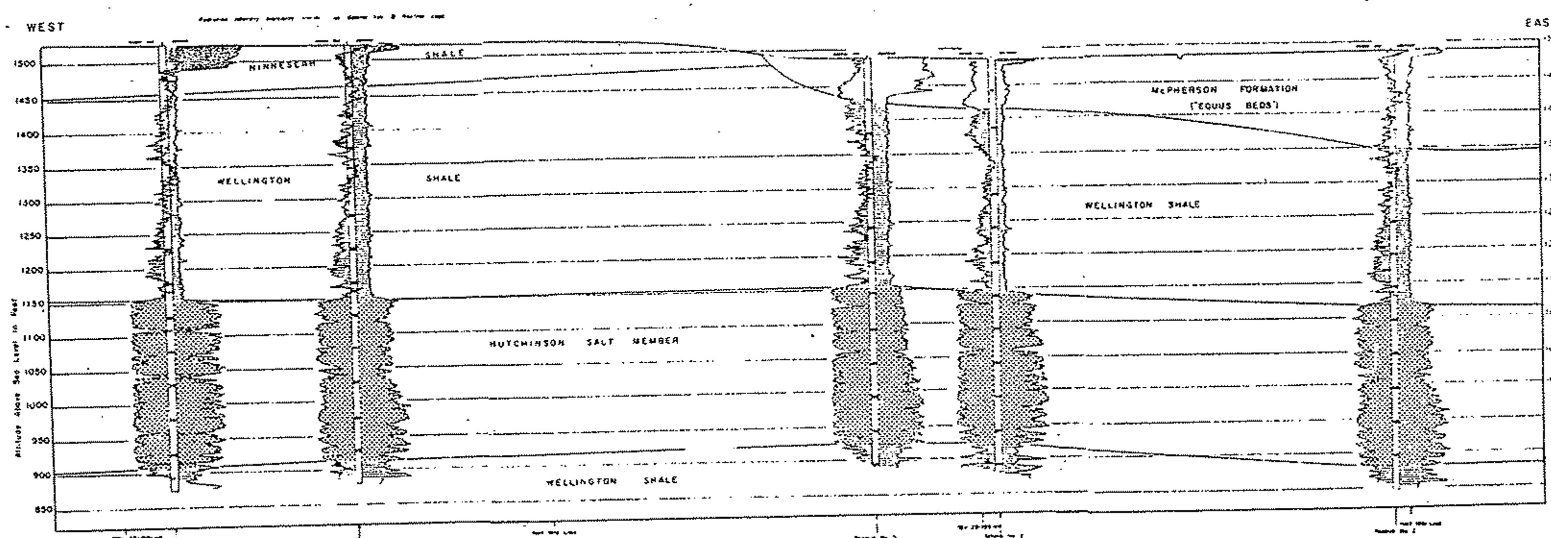
PLATE 5



Generalized Stratigraphic Section
Conway Area McPherson Co.

PLATE 6

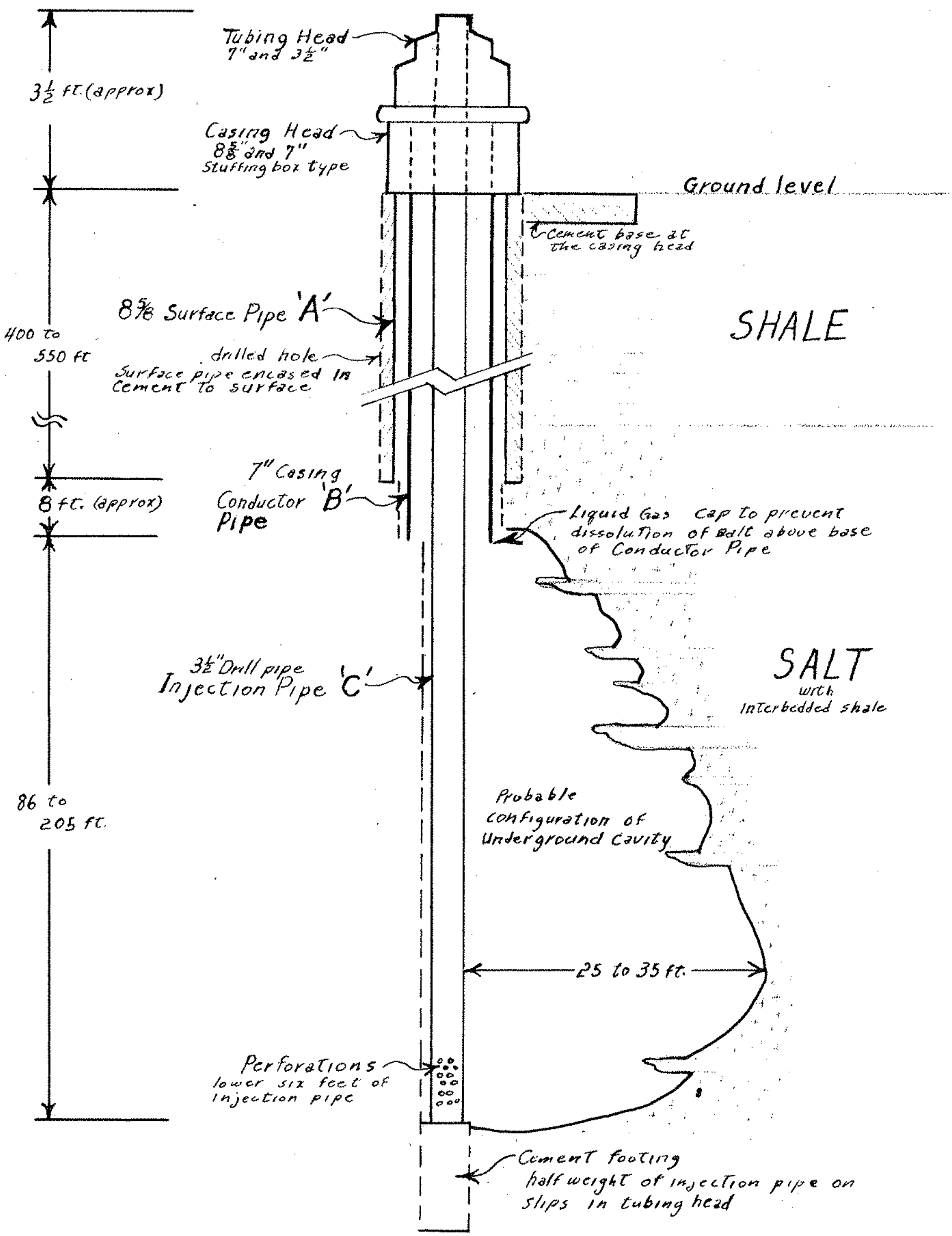
GEOLOGIC PROFILE
of the
CONWAY STORAGE AREA
Near Conway, McPherson County, Kansas
SE..RITY UNDERGROUND STORAGE COMPANY



Vertical Scale: 1 inch = 52.6 feet
Horizontal Scale 24 inches = 1 mile
Vertical Exaggeration 4:1

May 10, 1956

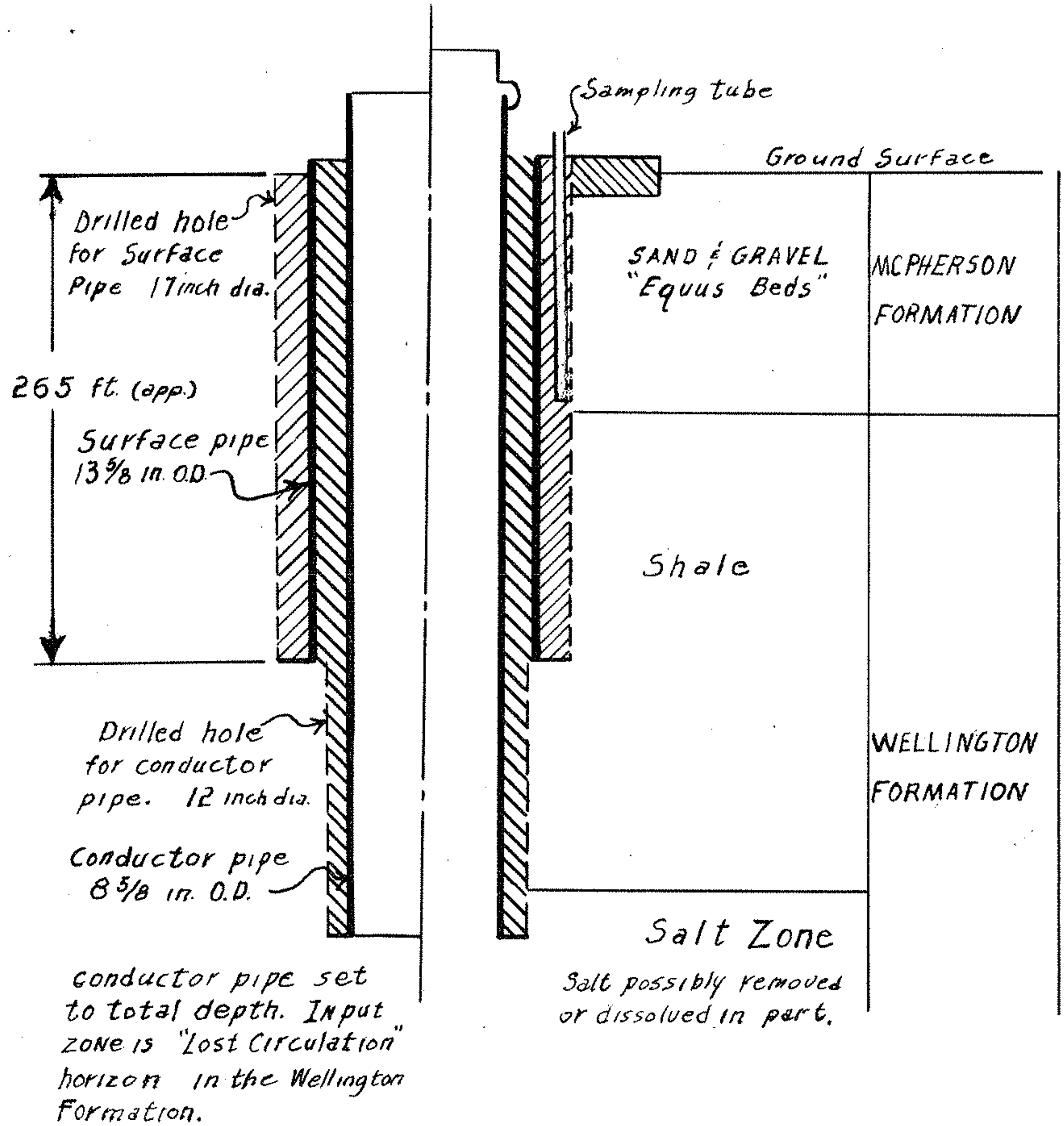
Consulting Geologist



Diagramatic Sketch

Typical Liquid Petroleum Underground storage unit

No Scale intended -- Depths and thickness are approximate



Diagramatic Cross-section
Shallow Disposal Well Installation