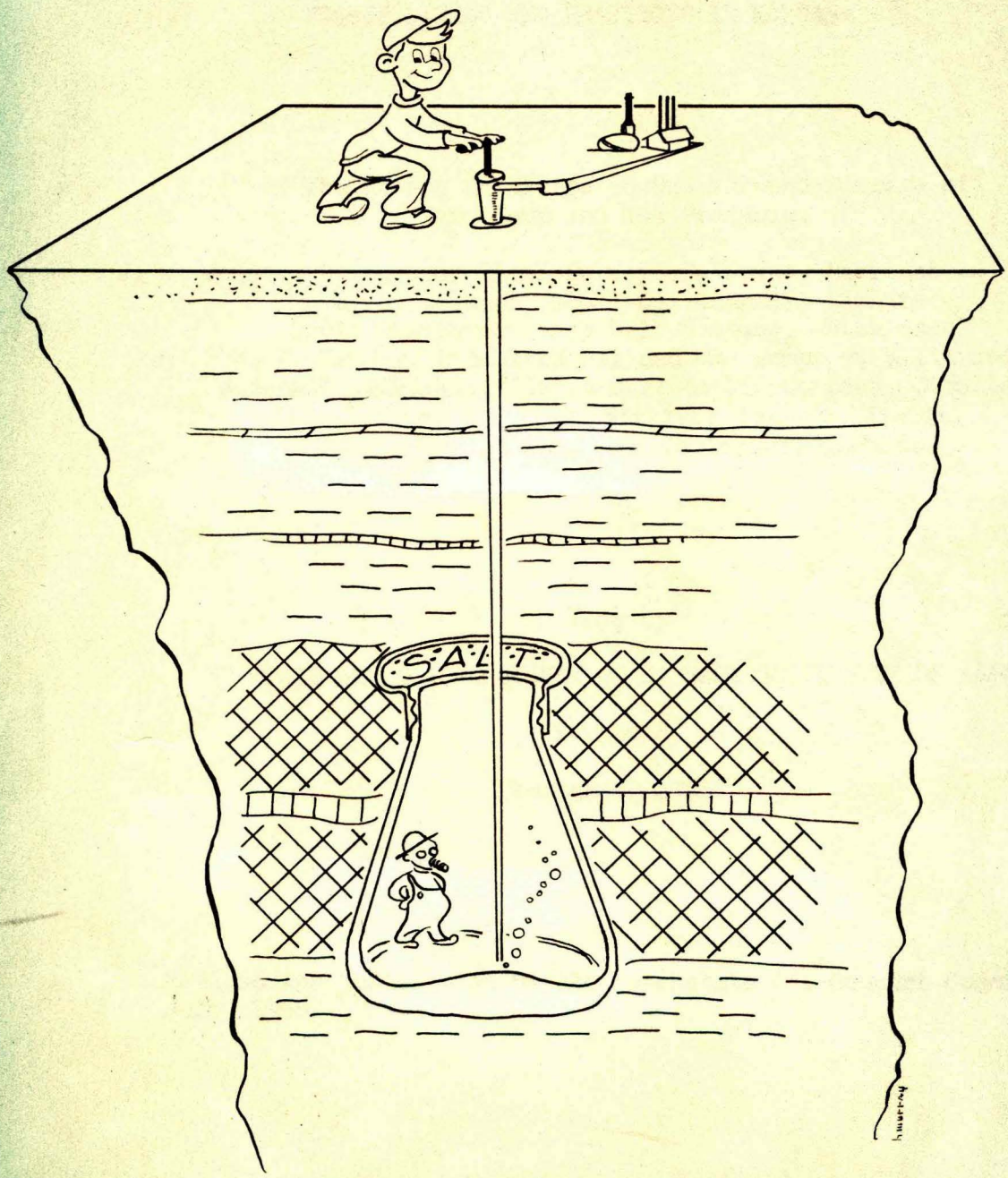
UNDERGROUND STORAGE

of Petroleum & its Products



Possibilities & Practices in Kansas

NOVEMBER, 1954

UNDERGROUND STORAGE OF PETROLEUM AND ITS PRODUCTS --

POSSIBILITIES AND PRACTICES IN KANSAS*

By The Kansas Committee on Underground Storage of Petroleum and Its Products:

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Made by

THE STATE GEOLOGICAL SURVEY OF KANSAS, UNIVERSITY OF KANSAS

Lawrence

November 1954

*Revised for publication by the Interstate Oil Compact Commission
July, 1955

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GENERAL REMARKS

Kansas currently is fifth among the oil and gas producing states. The rate at which pools are being discovered indicates that Kansas will continue to be important as an oil state for a long time. That there is a need for economical storage facilities for petroleum and its products, and especially for L.P.G., is apparent. Underground storage of L.P.G. in artificial caverns in salt, which can be made easily in Kansas, seems to be the most practical method. Five such projects are now in operation in the State.

In the Kansas report a discussion of the five underground storage projects in operation is preceded with a table of statistics regarding the State's oil industry (Table 1) and a summary of the stratigraphy of Kansas in reference to underground storage. Also considered are other storage possibilities.

The cooperation of other officials in the companies represented by the Kansas committee members is appreciated. Thanks also are expressed to officials of the National Cooperative Refinery Association and of the Skelly Oil Company for data that they furnished to the committee. Mr. T. A. Morgan and Mr. D. C. Lilley of the Division of Conservation, State Corporation Commission, attended committee meetings and gave many helpful suggestions. Mr. H. T. Morley of the Stanolind Oil and Gas Company gave permission to use certain salt maps, made by D. F. Moore.

Data on limestone mines were furnished by Mr. J. Lautenschlager of the American Rock Crusher Company, by Mr. Leonard H. Strauss of the Thompson-Strauss Quarries, and by Mr. Geo. Ed. Kerford of the Geo. W. Kerford Quarry Company. Mr. Bob Stroup, Eagle-Picher Company, cooperated with Mr. Allison Hornbaker of the State Geological Survey in furnishing us with data on lead and zinc mines. Mr. D. C. Chade, National Gypsum Company, kindly furnished data on the company's mine.

Dr. Frank C. Foley, Director of the State Geological Survey of Kansas and State Geologist, read and criticized the report. The committee appreciates his interest and help in the study. Mrs. Grace Muilenburg, Journalist, and Mrs. Lila Watkins, Typist, of the Geological Survey, assisted in preparing the report.

PRODUCTION STATISTICS

Table 1. -- Data on production and other phases of the oil industry in Kansas, 1954

Oil produced	118,309,260 barrels
Oil pools discovered	162
Proved crude oil reserves at end of year	978,500,000 barrels
Natural gas produced (14.65 psia)	405,800,000,000 cubic feet
Proved natural gas reserves	15,758,000,000,000 cubic feet
Total natural gasoline produced	2,521,589 barrels
Total L.P.G. (including butane and propane)	2,092,271 barrels
Total natural gas liquids produced	4,613,864 barrels
Oil imported into Kansas	24,966,516 barrels
Oil exported from Kansas	54,968,489 barrels

STRATIGRAPHY OF KANSAS IN REFERENCE TO UNDERGROUND STORAGE

Figure 1 is a sketch map showing distribution of the outcrop areas of rocks of various geologic systems in Kansas. Outcropping and subsurface rocks, with data more or less pertinent to underground storage problems, are listed in Table 2.

Pennsylvanian and Permian rocks provide excellent conditions for mined-out caverns in shale. In almost any part of eastern Kansas suitable shales with strong caprocks are present. Because of the gentle dip of the rocks projects could be located in places in accordance with the requisite amount of overburden. Parts of the Cretaceous section offer the same possibilities.

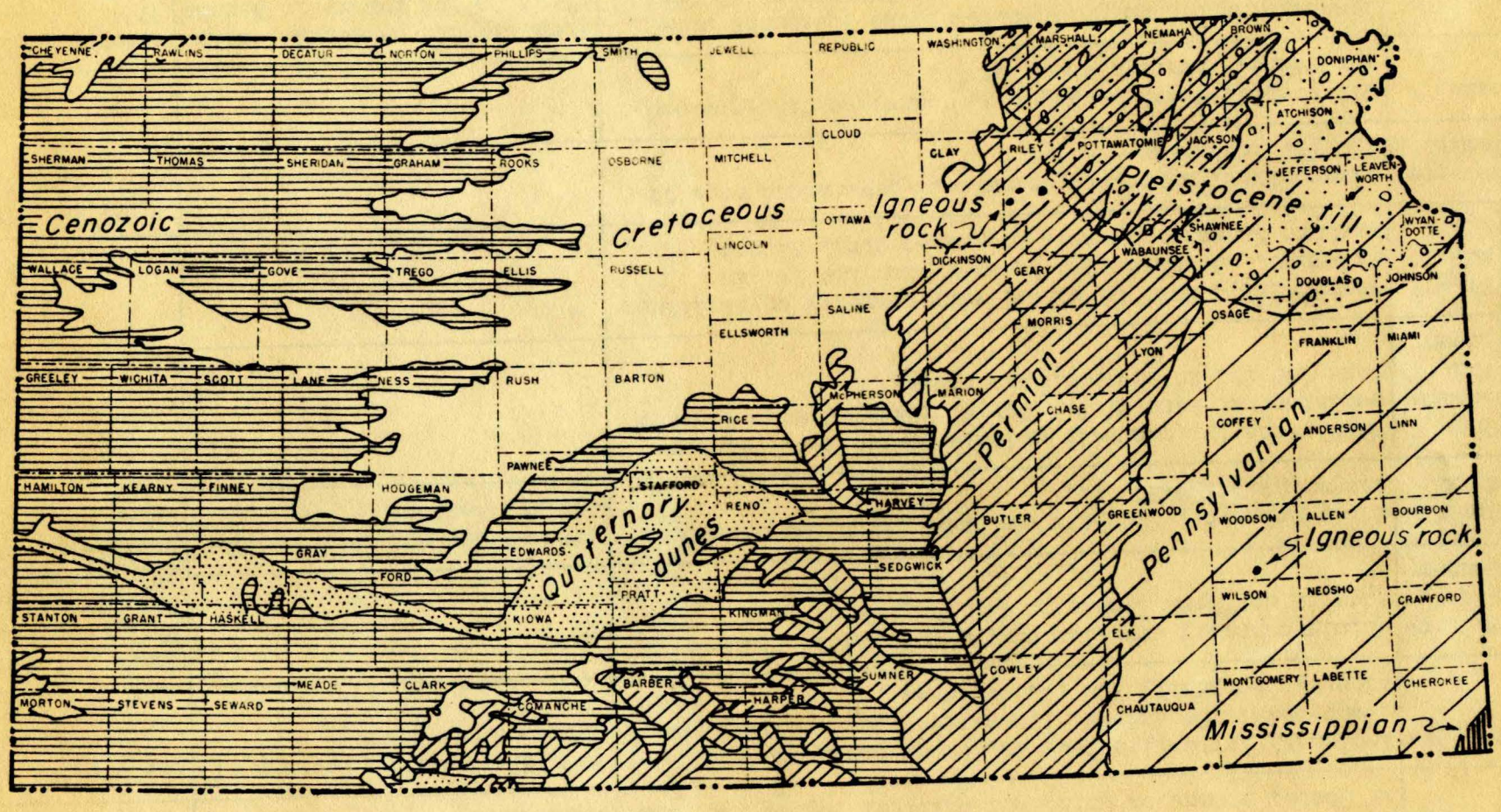


Fig. 1. Generalized geologic map of Kansas

Table 2. -- Stratigraphy of Kansas in reference to storage projects

Systems	Divisions	General data	Remarks, in reference to storage	Special references to literature
Pleistocene (Cenozoic Era)	Recent Wisconsin Sangamonian Illinoian Yarmouthian Kansan Aftonian Nebraskan	Clays, silts, sands, gravels, boulders in surficial deposits, mostly unconsolidated, comprising the soil, valley fillings, stream terraces, wide-spread deposits of loess, and the glacial deposits in northeast Kansas. Thickness 0-300 ft±	Fresh water-bearing beds; adds to overburden (See fig. 1 for surface distribution.)	Moore and others, 1951, pp. 13-17; Frye and Leonard, 1952; several Geological Survey ground-water reports
Tertiary (Cenozoic Era)	Ogallala fm.	Widespread in central and western Kansas, locally in eastern. Mostly stream deposits. Sands, gravels, "mortar beds," most important in High Plains area. Thickness 0-350 ft±	Fresh water-bearing deposits; adds to overburden (See fig. 1)	Moore and others, 1951, pp. 17-20; Frye, 1949; Smith, 1940; several Geological Survey ground-water reports
Cretaceous	Pierre Niobrara Carlile Greenhorn Graneros Dakota Kiowa Cheyenne	Surface outcrops and in subsurface in much of central and western Kansas. Mostly marine, supposed nonmarine deposits in lower part. Clayey and calcareous shale predominant, fine-grained chalky, platy limestone comprising most of lower middle part. Plentiful sandstone in lower part. Total thickness about 2,750 ft.	Clay and shale beds well suited for artificial caverns especially in Dakota fm. (See fig. 1 for surface distribution.)	Moore and others, 1951, pp. 17-28; Plummer and Romary, 1942; Latta, 1946
Jurassic	Morrison fm.	Subsurface in northwestern Kansas. Shales mostly green, pink jasper-like chert and gypsum. Thickness up to 275 ft.		Landes and Keroher, 1938
Triassic	Docum (?) gr.	Nonmarine, red siltstone, buff and white sandstone, some gypsum. Exposed in Morton County; subsurface Morton and Stanton Counties. 40 ft±		McLaughlin, 1942
Permian	Guadalupian series	Silty shale, siltstone, some dolomite, predominantly red or reddish. Outcrop thickness in Meade, Clark, and Kiowa Counties about 290 ft., subsurface in southwestern Kansas about 460 ft.	Probably of no interest except as overburden above salt	Moore and others, 1951, pp. 37-38
	Nippewalla gr.	Contains the Blaine fm. at the top and lies above the Stone Corral dolomite (Cimarron anhydrite of the subsurface). Largely red beds of silty shale, siltstone, and fine-grained sandstone and evaporites. Thick salt sections in the subsurface. Total thickness about 930 ft.	Thick salt beds suited for washed-out caverns (See chapter, this report, on Permian salt beds.)	
	Sumner gr.	Chiefly silty shales. Gray shale predominant, but reds and greens are present, also dolomite, gypsum, anhydrite, and thick salt deposits in the subsurface. This division has Stone Corral dolomite at top, and is next above Nolans ls. Thickness about 1,000 ft.	Thick salt beds suited for washed-out caverns. (See chapter, this report, on Permian salt beds.) Many data are available from well logs.	Moore and others, 1951, pp. 38-52; Moore and others, 1951a; O'Connor, Goebel, and Plummer, 1953; Lee, 1949
	Chase and Council Grove gr.	Chiefly marine shales and limestones. Thicker shales varigated colors. Limestones massive to thin-bedded, several limestones dominantly cherty. Shales mostly lack carbonaceous material. Thickness about 355 ft.	Thicker shales suited for mined-out caverns. Limestones would make strong roofs.	
Pennsylvanian	Wabaunsee Shawnee Douglas Pedee Kansas City Pleasanton Marmaton Cherokee groups	Principally shale, limestone, and sandstone, with numerous coal beds especially in lower part. Thickest formations chiefly shale and range up to 150 or 200 ft. thick. Solid limestone sections generally less than 50 feet; sandstones commonly silty, and carbonaceous and clayey, up to 50 or more feet. Many oil and gas traps. Maximum thickness in eastern Kansas about 2,000 ft.*	Thick shales suited for mined-out caverns with strong limestone roofs. Natural oil traps possibly suited for artificial storage. (See fig. 1 for surface distribution.)	Moore and others, 1951, pp. 53-102; Bass, 1936; Jewett and Abernathy, 1945; Jewett, 1941, 1949, 1954
Mississippian	Meramecian sr. Osagian sr. Kinderhookian sr.	Massive limestone, subsurface only except small area in southeast corner of State. Partly cherty. Lead and zinc ores in southeast Kansas. Many oil traps. Average thickness in eastern Kansas about 350 ft., 500 in northeastern Kansas	Possibly suited for mined-out caverns. Oil traps probably suited for recharge	Lee, 1940; Moore and others, 1951, pp. 107-111
Miss. or Dev.	Boice sh. Chattanooga sh.	Dark to light greenish gray shale, silty to dolomitic, some red; and black and gray shale. Generally not more than 100 ft.	Possibly suited for mined-out caverns, where not at excessive depths	Moore and others, 1951, pp. 111-112
Devonian and Silurian	"Hunton" ls.	Principally dolomites, some limestones. Identified in Kansas only in central and northeast parts. Maximum known thickness 435 ft. in Nemaha County; minimum depth about 2,000 ft., Jefferson County	Probably too deep to be of any interest here, except for oil traps	Moore and others, 1951, pp. 112-117; Lee, Leatherock, and Botinelly, 1948; Lee and others, 1946
Ordovician	Sylvan sh.	Greenish gray, silty, dolomitic shale, restricted principally to area of ancient North Kansas basin. Maximum thickness about 155 ft.	Probably too deep to be of any interest here, except oil traps	Moore and others, 1951, pp. 117-118; Jewett, 1954a
	Viola ls.	Dolomite and limestone. Occurs in subsurface in most of State, absent on principal uplifts. Up to 300+ ft.	Probably too deep to be of interest except for oil traps	
	Simpson gr.	Includes Platteville ls., St. Peter sandstone and lower beds. Dolomites, limestones, thin shales, sandstones. Generally 100 ft. or less.	Possible interest because of numerous oil traps	Leatherock, 1945
	Arbuckle group: Jefferson C. Cotter	Mainly coarsely granular cherty dolomite. Featheredge in northern Kansas to 650 ft., Cowley County		Moore and others, 1951, pp. 118-122; Keroher and Kirby, 1948; Jewett, 1954, pp. 55-56; Jewett, 1954a
	Arbuckle group: Roubidoux	Sandy dolomite, fine-grained sand, with secondary enlargements, 150-200 ft.	Fresh-water source in southeastern Kansas	
	Arbuckle group: Gasconade Van Buren	Mainly cherty, coarsely granular dolomites. Gunter sandstone at base of Van Buren. Beveled edge to more than 200 ft. in southeastern Kansas		
Cambrian	Arbuckle group: Eminence	Very cherty, buff to white, very coarsely crystalline dolomite. Beveled edge to more than 150 ft. in eastern Kansas, 40 to 87 in west-central Kansas		
	Bonneterre dolomite	Glauconitic, noncherty dolomite. Beveledged edge to 150 ft. in basins		Moore and others, 1951, p. 122
	Lamotte ss.	Ill sorted, round to angular, coarse to fine-grained sandstone. Average about 80 ft.		
Pre-Cambrian		Igneous and metamorphic rocks of the "basement complex." Nearest the land surface, less than 600 feet, in Nemaha County**	Possibly can be economically mined in the future in Nemaha County	Jewett, 1954, pp. 56-59

* Pennsylvanian rocks of the Atokan and Morrowan series occur at more than 2,500 feet in southwestern Kansas, but are not listed in this table. "Basal Pennsylvanian" conglomerate, of various ages, contains oil pools in several places.

** "Granite wash" of various ages occurs in several parts of Kansas, and contains oil pools.

PERMIAN SALT BEDS

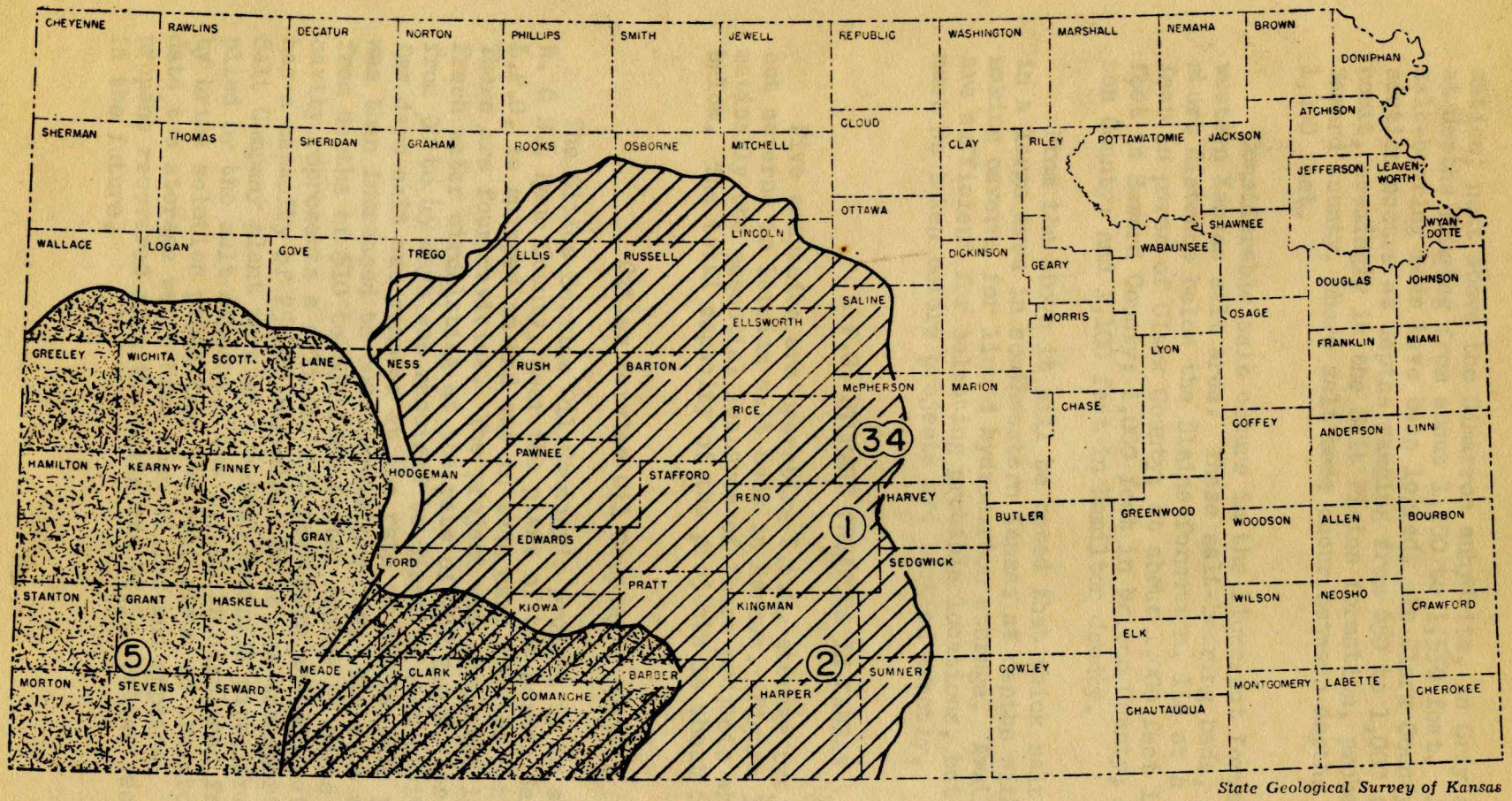
The approximate areas in Kansas underlain by salt beds are shown in Figure 2. An area extending from the Kansas-Oklahoma line from Sumner to Seward County and northward to Rooks, Osborne, and Mitchell Counties, is underlain by thick salt deposits in the Wellington shale. This salt is referred to as the Hutchinson salt member of the Wellington formation, but the top and bottom of sections that are dominantly salt are not along continuous geologic horizons. Near the eastern margin of the area the Hutchinson member is some 250 feet below the top of the Wellington, but farther west, as in Clark and Kiowa Counties, salt extends nearly or entirely to the top of the formation. The salt deposits are generally thicker in the central part of the area. In central Reno County salt beds form a dominant part of a rock section 500 feet thick; but in central Osborne County the salt-bearing section is about 200 feet thick. A well in Pratt County has been drilled through 800 feet of rock which is chiefly salt. Salt in this part of the section in Clark County is about 300 feet thick.

Salt, a soluble substance, does not crop out. Rock layers containing the salt dip gently westward, and because of the westward increase in land elevation, salt is nearest the surface along the eastern margin of the area. It is here that excellent conditions for washed-out storage cavities are found. The part of the salt mined by shaft methods is about 650 feet below the land surface at Hutchinson, Reno County; about 1,000 feet below the surface at Lyons, Rice County; and about 840 feet at Kanopolis, Ellsworth County. At Anthony, Harper County, the same portion of the salt beds is encountered at about 1,800 feet. The top of Wellington salt in Kiowa County lies at a depth of about 1,700 feet and in Clark County at about 2,000 feet. In these two latter places, however, there are shallower salt deposits.

Younger salt deposits occur in Permian rocks in the southwestern Kansas salt area. These are a part of a large assemblage of salt beds extending far to the south and west into Oklahoma, Colorado, Texas, and New Mexico.

Four or more relatively extensive salt deposits occur in the southwestern Kansas salt area. Their stratigraphic positions can best be described in reference to their relationships to the Stone Corral formation (Cimarron anhydrite in oil field terminology) and the Blaine formation, both of which are easily recognized on electric and sample well logs.

Thick salt deposits occur next below the Cimarron anhydrite over a large area. These beds, commonly more than 200 feet thick, are in the upper part of the Ninnescah shale, and in a part of Clark County the entire Ninnescah section seemingly is largely salt. This salt deposit lies at about 1,250 feet below the land surface in Kiowa County; from about 1,000 to 1,500 feet in Clark County; about 1,600 feet in Meade and Gray Counties. Salt occurs in the zone of the Harper for-



State Geological Survey of Kansas

L.P.G. storage projects

1. Cities Service Oil Co.
2. Phillips Petroleum Co.
3. National Cooperative Refinery Assoc.
4. Skelly Oil Co.
5. Stanolind Oil & Gas Co.

Salt beds, Nippewalla group and upper part of Sumner group

Salt in Wellington formation

Fig. 2 Sketch map showing approximate areas in Kansas underlain by Permian salt beds.

mation, next above the Cimarron anhydrite, in Gray and Meade Counties, at depths ranging from about 1,100 to 1,550 feet. About 200 feet of salt-bearing beds have been logged. In Clark County a 300-foot salt section occurs at depths ranging from 650 to 1,000 feet. This deposit, seemingly in the Salt Plains formation, probably extends into Seward County, where salt beds occur between depths of 1,300 and 1,400 feet.

Considerable salt occurs in the Flowerpot formation in the southwestern Kansas salt area. These salt-bearing beds, which occur a short distance below the Blaine formation, lie at a depth of about 450 feet in parts of Clark County; at about 1,000 feet in Gray County; 950 feet in Seward County; 1,000 feet in Morton County; 1,250 feet in Stanton County; and 1,100 feet in Hamilton County.

From the above it will be noted that thick salt deposits occur in a large area in southwestern Kansas at depths within limits of making caverns for liquid hydrocarbon storage. Available well logs are sufficient for selecting probable locations, but of course cores must be taken before projects are located exactly.

L.P.G. STORAGE PROJECTS IN KANSAS

Five companies are operating L.P.G. storage projects in washed-out caverns in Permian salt beds in Kansas. Figure 3 shows diagrammatically the essential features of these projects which are described below. The total capacity of the projects is about 615,500 barrels.

Cities Service Oil Company's Project

The Cities Service Oil Company's project is in sec. 22, T. 33 S., R. 6 W., Reno County, near the plant of the Morton Salt Company. L.P.G. is shipped in and out in tank cars via the Santa Fe Railway. There are four cavities. The project was completed in October, 1953. Fresh water circulating at the rate of 200 g.p.m. for a period ranging from 30 to 45 days was required to dissolve each cavity. For the first few days salt was removed at the rate of 150 barrels per day. The rate was then increased to 600 barrels per day. The salt section extends from depths of 510 to 800 feet (total depths of holes drilled). Each cavity represents a cylinder 200 feet high and 30 feet in diameter, and has a capacity of 25,000 barrels. Brine was transported to the Morton Salt Company plant through a 6-inch Transite pipe; fresh water was supplied by the salt company. The L.P.G. is displaced from the cavities by brine solution piped from the salt plant to the storage project. To date two storage wells have been filled and emptied. Percentage of propane recovered from the wells was 92.5. Better recovery is expected in the future.

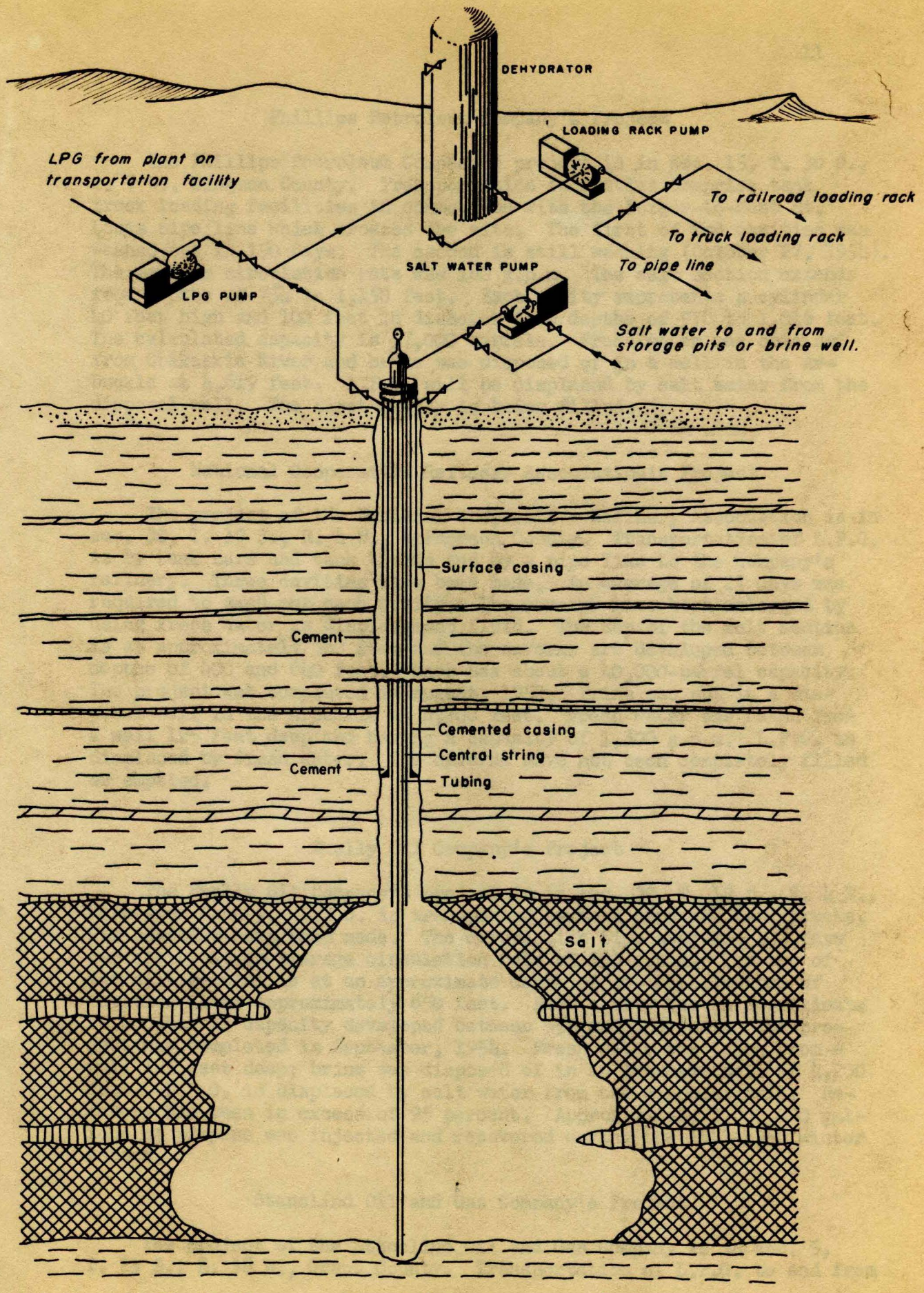


Fig. 3. Diagram of an L.P.G. storage project in an underground cavern.

Phillips Petroleum Company's Project

The Phillips Petroleum Company's project is in sec. 15, T. 30 S., R. 7 W., Kingman County. Transportation facilities comprise tank truck loading facilities in connection with the Borger-to-East St. Louis pipe line which crosses the site. The first of two cavities was washed out in 150 days. The second is still washing (October 27, 1954). The maximum circulation rate was 180 g.p.m. The salt section extends from depths of 754 to 1,150 feet. Each cavity represents a cylinder 40 feet high and 100 feet in diameter from depths of 976 to 1,016 feet. The calculated capacity is 57,000 barrels. Fresh water was obtained from Chikaskia River and brine was disposed of in a well in the Arbuckle at 4,619 feet. L.P.G. will be displaced by salt water from the disposal well. The first cavity is being filled.

National Cooperative Refinery Association's Project

The project of the National Cooperative Refinery Association is in sec. 30, T. 19 S., R. 4 W., McPherson County. Transportation of L.P.G. is by tank cars and tank trucks and by a pipe line to the company's refinery. Three cavities have been made. An average of 27 days was required to wash out each cavity. The caverns have been enlarged by using fresh water as displacement fluid. The top of the salt section is at approximately 380 feet and the caverns are developed between depths of 400 and 640 feet. Each has about a 40,000-barrel capacity. The project was completed in August, 1952. Brine was put in a disposal well in the Arbuckle at 4,200 feet. Fresh water was taken from a well 125 feet deep and having a capacity of 1,300 g.p.m. L.P.G. is displaced by fresh water. The caverns have not been completely filled or emptied.

Skelly Oil Company's Project

The Skelly Oil Company's project is in sec. 30, T. 19 S., R. 4 W., McPherson County. L.P.G. is transported by tank cars and tank trucks. Six cavities have been made. The circulation time averaged 100 days per cavity at an average circulation rate of 130 g.p.m. The top of the salt section is at an approximate depth of 380 feet; bottom of cavities is at approximately 650 feet. Each cavity has an approximate 25,000-barrel capacity developed between 550 and 650 feet. The project was completed in September, 1954. Fresh water was taken from a well 125 feet deep; brine was disposed of in an Arbuckle well at 4,200 feet. L.P.G. is displaced by salt water from the disposal well. Recovery has been in excess of 95 percent. Approximately 3,000,000 gallons of propane was injected and recovered during the 1953-1954 winter season.

Stanolind Oil and Gas Company's Project

The project of the Stanolind Oil and Gas Company is in sec. 5, T. 29 S., R. 38 W., Grant County. Transportation of L.P.G. to and from

the project is by tank cars and trucks. Six caverns have been made. The number of days required to wash out each cavity averaged 117. Circulation rate was 1,783 barrels per day. Some brine was recirculated in two wells. This caused an average increase of 17 days over the time required to make four caverns by fresh water only. The circulation rate for wells in which brine was not recirculated averaged 1,939 barrels per day. The salt section in the six wells ranges in thickness from 60 to 70 feet. The total capacity of the six caverns is 131,531 barrels. The first cavern was completed in April, 1952; the sixth in February, 1954. Brine was disposed of in a deep disposal well and fresh water was taken from a well. The product is displaced by brine or fresh water from the disposal and fresh-water supply wells. To date the six caverns have been filled respectively: 3, 2, 2, 1, 1, and 0 times; they have been completely emptied 1, 2, 2, 1, 1, and 0 times. Average recovery has been 92.86 percent.

OTHER STORAGE POSSIBILITIES

Salt Mines

Kansas salt mines, which have a total capacity of about 375,000,000 cubic feet, constitute vast underground openings available for storage purposes. These mines are in east-central Kansas in Ellsworth, Kingman, Reno, and Rice Counties, and are in the Hutchinson salt member of the Wellington formation of early Permian age. Salt is mined by the room-and-pillar method and even in operating mines there are large amounts of unused space. Depths to mine floor range from 645 to 1,024 feet; ceiling heights range from 9 to 11 feet.

Large amounts of salt are produced by hydraulic mining methods in the same general area of the shaft mines. There are numerous washed-out cavities that now are abandoned and undoubtedly filled with brine. No attempt has been made during the course of this study to assemble data on the operating or abandoned hydraulic mines.

It should be noted that salt mines offer excellent storage possibilities especially for dry or packaged commodities.

Data on eight Kansas salt mines are listed in Table 3.

Table 3. — Data on salt mines in Kansas (Compiled by David Chambers, Carey Salt Company)

Name	Location	Present condition	Capacity, million cu. ft.	Condition of shaft	Remarks
Little River Mine (1 shaft)	Outside NW city limits Little River, T. 19 S., R. 6 W.	Flooded, shaft plugged in 1937 with 6' thick concrete pad at the surface	11.23	Shaft, 7' x 17' Depth to mine bottom, 798' Average ceiling, 11'	Property sold to private individual by Morton Salt Co. Room and pillar
Kingman Mine (1 shaft)	Near Kingman, NE city limits E½ SE¼ sec. 29, T. 27 S., R. 7 W.	Flooded, shaft may be still open	11.00	Shaft, 7' x 16' Depth to mine bottom, ?	Mine closed 1911-12 Surface rights sold later by Independent Salt Co. Room and pillar
Crystal Mine (2 shafts)	Near Kanopolis E. city limit sec. 30, T. 15 S., R. 7 W. sec. 25, T. 15 S., R. 8 W.	Is thought perhaps to be still dry. The Crystal and Royal mines are connected and the estimated total vol. is given in Col. 4	62.44	2 shafts now dirt plugged a. 8' x 8' — escape b. 8' x 16' — operating Depth to mine bottom, 810' Average ceiling, 9'	Property owned by Morton Salt Co. Room and pillar Mine closed June, 1948
Royal Mine (1 shaft)	Near Kanopolis E. city limit	See above	(Included with Crystal mine)	1 shaft, 8' x 16' Salt and dirt plugged Depth to mine bottom, 816' Average ceiling, 9'	See above
Independent Mine (2 shafts)	1 mi. E. and 3/4 mi. N. of Kanopolis, city limits sec. 20, 21, 28, 29, T. 15 S., R. 7 W.	Operating rock salt mine	176.43	2 shafts a. 9' x 16' — escape b. 7' x 16' — operating Depth to mine bottom, 846' Average ceiling, 9'	Operated and owned by Independent Salt Co. Room and pillar
Carey Mine (1 shaft)	Lyons, sec. 34, T. 19 S., R. 8 W.	Dry, in stand-by status	44.88	1 shaft, 7' x 16' Depth to mine bottom, 1,024' Average ceiling, 10'	Owned by Carey Salt Co. Room and pillar Closed October 1948
American Mine (1 shaft)	SE of Lyons sec. 3, 10, T. 20 S., R. 8 W.	Operating rock salt mine	5.30	Shaft, 8' x 16' Average ceiling, 9' Depth to mine bottom, 993'	Owned by American Salt Corp. Room and pillar
Carey Mine (1 shaft)	E. of Hutchinson sec. 15, 16, 22, T. 23 S., R. 5 W.	Operating rock salt mine	63.11	1 shaft, 11½' x 11½' Average ceiling, 9' Depth to mine bottom, 645'	Owned by Carey Salt Co. Room and pillar

Limestone Mines

There are several large underground limestone mines in Kansas. Some of them are being used as storage warehouses.

Thompson-Strauss mine. -- Near Kansas City, at Morris, Kansas, Thompson-Strauss Quarries, Inc., operates a large underground mine from which rock is produced for ballast, rip-rap, concrete aggregate, and agricultural limestone. The Bethany Falls limestone member of the Swope formation, Pennsylvanian, is being mined. Nine acres are being converted into refrigerated warehouse storage; in addition there are approximately 100 acres of worked-out area which could be used for almost any type of storage. Rooms inside the mine are approximately 45 feet square; pillars are about 20 feet square. There is about 175 feet of overburden above the mine, but the floor of the mine is at approximately the same level as the main rails of the Santa Fe railroad; this allows railroad cars to be brought into the mine.

American Rock Crusher mine. -- In August, 1954, the American Rock Crusher Company's mine at Kansas City, Kansas covered an area (exclusive of pillars) of approximately 45 acres. Rooms are approximately 32 feet by 32 feet. Pillars have a diameter of approximately 22 feet, and the ceiling height is approximately 14 feet. The overburden above the mine ranges from about 30 to 110 feet. As of August 14, 1954, the mine was not being used for storage.

Atchison limestone mines. -- The three limestone mines of the Geo. M. Kerford Quarry Company are situated about 2½ miles southeast of Atchison, Kansas, and are between Missouri River and U. S. Highway 75. Mine portals are in the river bluff. Two of the mines are being used for storage. Of these one is being utilized as a Government Ordnance Storage Facility; the other, which has approximately 300,000 square feet walled off to form an underground bonded warehouse for the storage of whiskey and spirits, has unused space totaling more than 700,000 square feet. The third mine has storage space of about 1.5 million square feet gross or 1.1 million square feet net. The pillars in the mines range from about 25 to 35 feet square, or are circular or irregular. Ceiling heights range from 12 to 14 feet. A thickness of solid limestone ranging from 5 to 8 feet remains as ceiling material and a few feet of solid limestone has been left as a floor. Since 1945, when it was recognized that the mines would be useful for storage, mining operations have been conducted with great care to leave smooth and uniform pillars, ceilings, and floors. Temperature, except in refrigerated parts, remains at approximately 56° F. throughout the year. Relative humidity generally is well above 90 percent. Overburden, consisting mostly of shale, ranges from 15 to 100 feet in thickness. The Plattsmouth limestone member of the Oread formation, Pennsylvanian, is being mined.

The mine known as the Ordnance Storage Facility has a gross area of about 621,000 square feet. The ceiling height averages about 12 feet; hence the gross volume of the mine is about 7.5 million cubic

feet. Approximately 170 unmined pillars, 30 to 40 feet apart, support the roof. A concrete floor has been laid on limestone, the ceiling has been treated with Gunite, and some areas have been walled off with Haydite blocks. This mine is refrigerated and equipped according to the needs of the present utilization.

The West Mine is west of the Ordnance Storage Facility and the two are separated by 200 feet of limestone. Its northern and northeastern sections are being mined and further removal of rock in those directions will create several hundred thousand square feet of additional mined-out space. Net space in the mine at present is about 1.1 million cubic feet. All mining operations in this opening have been conducted with great care in order to leave it in the best possible condition for storage utilization.

The East Mine has a gross area of more than 1 million square feet; about 300,000 square feet in the western part has been walled-off and is being used for storing alcohol. Quarrying operations in this mine were halted in 1953. About 600,000 square feet is available for commercial storage facilities.

Other limestone mines. -- There are several other underground limestone mines in eastern Kansas; all of them offer potential storage facilities. A large underground mine on the Union Pacific Railroad about 18 miles west of Kansas City, in Leavenworth County, is being worked and in part is being used for storage of perishable products. The mine is in the Wyandotte limestone, Pennsylvanian. The Peerless Quarries, underground workings in the Bethany Falls limestone, Pennsylvanian, are near the operations of the Thompson-Strauss Company. The Garnett Rock Company has an underground mine in the Plattsburg limestone, in Anderson County. Mr. Francis Reeves operates a mine in Mississippian limestone near Columbus, Cherokee County.

Gypsum Mines

Two gypsum mines are operating in Kansas. The Certain-Teed Products Company has a mine at Blue Rapids, Marshall County, where a gypsum deposit in the Council Grove group, Permian, is worked. The National Gypsum Company has a mine in the Blaine formation, Permian, about 3 miles southwest of Sun City, Barber County. The mined area near Sun City is about 25 acres; approximately 50 percent is available for storage without materially affecting mining operations. Rooms average 10 feet in height and are 40 by 40 feet; that is, 20-foot square pillars are on 60-foot centers.

Coal Mines

It is judged that the underground Kansas coal mines, of which only a few are now being worked, have little or nothing to offer in this study. Most of the present coal mining in Kansas is conducted in open pits. The principal coal-mining district of the State is in

southeastern Kansas where coal occurs in the Cherokee shale, basal Pennsylvanian rocks of that part of the State. There are many old shaft mines in the area. Mining was chiefly by the longwall method, and the workings are not suitable for storing petroleum liquids. Three or more old mines near Leavenworth and one near Atchison are believed to be unsuited for storage purposes. The same is held to be true regarding mines in the Osage mining district, Osage County, and in the Mulberry mining district, Linn County.

Metal Mines

The Kansas part of the Tri-State lead and zinc mining district is in the southeast corner of the State, in Cherokee County. Mines are in Mississippian limestone at depths ranging from 200 to 400 feet. Some of the mines have been worked at several levels.

The Geological Survey has data on 53 mines in the area. As of August, 1954, 22 of the mines were working. Several idle mines are partly or completely filled with water; some are caved badly. Any estimate of total underground space that could be made is judged as probably inaccurate. However, it is estimated that one of the larger mines has total underground space of approximately 37.5 million cubic feet.

It is our opinion that Kansas metal mines are not suited for underground storage of petroleum or its products. In addition to probable engineering difficulties and possible danger of contamination of the products that might be stored, there is the very likely hazard of contamination of the fresh water supply of the area by liquid hydrocarbons.

Natural Petroleum Reservoirs

Kansas now has some abandoned oil fields and numerous barren structures that are judged to have the physical requirements of oil traps. For many years natural gas has been stored in depleted structures; that it may become practical to return petroleum and its liquid products into natural oil traps is a possibility.

Oil or gas, mostly both, have been produced in 80 of the 105 Kansas counties. Production is from rocks of all geologic systems of the Paleozoic Era; oil and gas are also taken from Pre-Cambrian rocks and some gas has been produced from Cretaceous rocks. Depths to oil and gas pools range from approximately 100 feet in some eastern counties to more than 6,500 feet in southwestern Kansas. About 50 producing zones in the stratigraphic column are known.

The occurrence of oil and gas in the various fields in Kansas is associated first with conditions of requisite porosity in the buried strata, and next with the structural and in some cases stratigraphic relations of the porous beds. A majority of the producing oil and gas

reservoirs are of the limestone or dolomite type. In these porosity of irregular distribution, introduced by solution or weathering prior to accumulation of the oil and gas fluids and perhaps in part by processes of dolomitization, control occurrence of hydrocarbons. Most favorable conditions are provided where highly porous rocks occur in the upper parts of anticlinal folds. However, many pools are in clastic reservoirs, and these, like the limestone type, are in part controlled by structure and in part by stratigraphic conditions. The numerous eastern Kansas "shoestring sand" pools and others are included here.

In all probability, should there be a demand for natural oil reservoirs for liquid storage, traps in formations of high permeability and provided with water drive will be sought. In many parts of Kansas there are pools in traps of this kind. Formations of special importance in this respect include the "granite wash," "basal Pennsylvanian conglomerate," "Wilcox" or Simpson sandstone, "Misener sand," "Sooy," and "Mississippian chat" (Ver Wiebe and others, 1955; table 56).

For detailed data on oil and gas reservoirs in Kansas reference is made to numerous publications of the State Geological Survey, and especially to Moore and Jewett (1942), Jewett and Smith (1949), Ver Wiebe and others (1955), and Jewett (1954).

Regarding geologic structures, which are of importance in respect to any type of underground storage, reference is made to Kansas Geological Survey Bulletin 90 part 6.

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(For other sources of geologic information see the State Geological Survey's list of publications.)