PERMIAN SALT DEPOSITS OF THE SOUTH-CENTRAL UNITED STATES.

By N. H. Darton.

INTRODUCTION.

During the last few years extensive drilling for oil, gas, and water has revealed a vast deposit of salt constituting part of the Permian succession in eastern New Mexico and northwestern Texas and Oklahoma. The northern extension of the deposit in the Hutchinson-Lyons area, central Kansas, has been known for many years. The limits of this deposit, especially to the northwest and south, have not been ascertained, but in general the area of thick salt extends fully 650 miles from north to south and 150 to 250 miles from east to west. The thickness and succession of beds are variable, but 700 feet is reported in one hole, and in many places the aggregate is more than 300 feet. These facts indicate that it is the largest known salt deposit in the world. (See Pl. XXI.)

In this report will be given a brief statement of the principal data so far obtained, especially with the purpose of stimulating the collection of further information regarding the succession of salt beds, the nature of the associated strata, and the limits of the several deposits. To this end it is important that those who are drilling in the general region should keep careful records of the strata and collect samples of salts and brines for testing. The United States Geological Survey, in cooperation with the Texas Bureau of Economic Geology and Technology, maintains a field laboratory near Amarillo, where D. D. Christmer, chemist in charge, provides for the collection and general testing of samples without charge.

In most processes of deep drilling there is considerable difficulty in recognizing salt because of its solubility in water, and for that reason many records fail to give reliable information regarding the presence and thickness of salt beds. Some records of borings passing through salt beds either fail to refer to them at all or group them with the insoluble sediments as "shale, salty," "sand and salt," "brine and red sand." Owing to these reasons many of the data given in the following pages are not as reliable as might be wished.

Some borings in whose logs no salt is recorded are in areas that are known almost certainly to be underlain by salt.

In connection with the endeavor to find potassium salts in the United States it is believed that the place in which such deposits are most likely to occur is in this great basin of saline accumulation, where the mother liquors of the sodium chloride might at some time have become so desiccated that their potash content was laid down in small local basins. Many tests have been made of salt and brines from borings in the area treated in this report, and invariably the potassium content has been far too low to have any commercial significance. However, the districts not yet explored by borings are very extensive, and there is a possibility that commercial deposits of potassium salts will yet be found. Such a discovery is not likely to be made, however, unless there is careful collection and testing of samples of salts and brines.

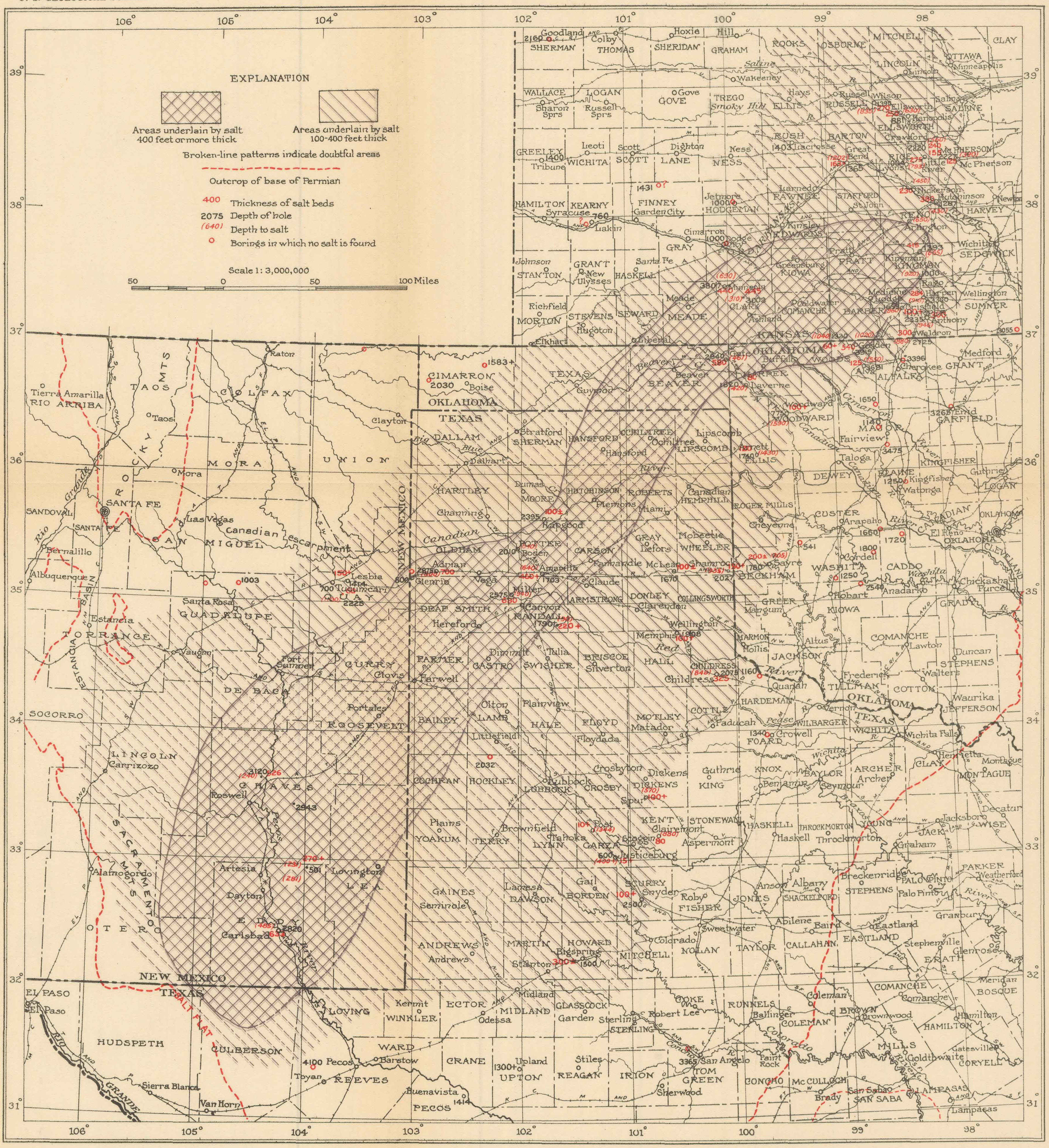
AGE.

The great salt succession occurs undoubtedly in the Permian series, in beds which belong to the Manzano group in New Mexico and the Marion formation in Kansas. The classification of the beds in Kansas is made by the geologists of that State. The section of the rocks of central Kansas (Pl. XXII) shows the stratigraphic relations. From the evidence in New Mexico it is certain that the salt is in the underground extension of the Manzano deposits, which underlie the Triassic in the eastern part of the State. The cross section in figure 38 (p. 220) shows the broader relations to the structure and stratigraphy.

STRATIGRAPHIC RELATIONS.

The salt beds occur in a succession of red shales and sandstones and are associated with more or less gypsum, anhydrite, dolomite, and limestone. The salt is in bodies that vary in thickness and are doubtless lenticular. The records are not comparable in detail, although no doubt part of the diversity is due to the imperfections in the records themselves. In some areas apparently there is an upper and a lower series of salt measures, and some of the holes probably did not reach the lower series.

The records given in this report illustrate the principal features of the stratigraphic relations of the salt measures, especially the two detailed sections of shafts at Lyons and Little River, Kans. (p. —). Unfortunately many of the records do not state the true nature of the beds, failing particularly to recognize anhydrite, which in many records is reported as limestone or other rock. In Kansas there



MAP OF SALT BASIN IN NEW MEXICO, KANSAS, OKLAHOMA, AND TEXAS.

appears to be but little anhydrite or gypsum interbedded in the salt measures or closely associated with them, although thick deposits of gypsum are reported from both higher and lower horizons. In Oklahoma, Texas, and New Mexico gypsum and anhydrite occur abundantly in close association with the salt, notably at Carlsbad, where the main body of salt is overlain by 185 feet of anhydrite and underlain by 1,325 feet of it. With the present lack of knowledge as to the true nature of the materials penetrated in most of the borings it is not possible to recognize any definite order of the strata in the salt succession.

STRUCTURE.

In general, the great Permian salt deposit lies in a wide, flat, shallow syncline, and the thickest salt beds occupy approximately the bottom of the basin. There are also local structural features of various kinds, most of which have not been determined, especially in the wide area of the Staked Plains, where the strata are deeply buried beneath sands of Tertiary age. It may be that the basin structure has persisted from Permian time and influenced the location of the sea from which the salt was deposited. This question, as affecting the western Texas area, has been discussed by Udden.[1]

KANSAS.

Many published data [2] show that a continuous body of thick salt beds underlies an area of at least 7,000 square miles in central Kansas. The salt is worked as a commercial product at several localities, notably near Hutchinson and Lyons, which are the centers of the industry. The sections in Plate XXII show the principal relations of the deposit as determined by borings. The salt measures, which are from 200 to 400 feet thick in the major deposits, are regarded as an upper member of the Marion formation, of Permian age. They are overlain by 200 to 400 feet of the Wellington shale, which separates them from the Permian "Red Beds" (Cimarron group). The salt thins out toward the east and presumably also toward the north, but it may extend to the Nebraska line. Its relations to the northwest and west are not known, for beyond Great Bend the deepest wells have not reached it.

The principal features of the Kansas salt measures are shown in Plates XXII and XXIII and figures 31 to 33. Some of the details are taken from the report by Kirk and Haworth, and others have been obtained from the drillers.

[1] Udden, J. A., Potash in the Texas Permian: Texas Univ. Bull. 17, p. 51, 1915.

[2] Kirk, M. Z., and Haworth, Erasmus, Salt: Kansas Univ. Geol. Survey Mineral Resources, 1898.

At Anthony the salt beds are 415 feet thick (depth, 946 to 1,221 and 1,350 to 1,490 feet); at Kingman, 363 feet thick (depth, 665 to 1,028 feet); at Hutchinson, 380 feet thick (depth, 430 to 810 feet); at Lyons, 275 feet thick (depth, 793 to 1,068 feet); at Kanopolis, 250 feet thick (depth, 630 to 880 feet); and at Wellington, 50 feet thick (depth, 239 to 289 feet). Wells at Arlington, 650 to 1,000 feet deep, were in salt at the bottom, and the record of the 1,365-foot hole at Great Bend reported 125 feet of salt and shale at the bottom. Holes at Rago and Nickerson penetrated the beds for some distance. The thinning of the salt to the east is shown by the records of the Wellington and McPherson wells. Apparently it does not quite reach the surface in central Kansas, although probably the salt springs at Geuda are at or near the outcrop of the salt beds. A record of the McPherson boring is given in figure 31.

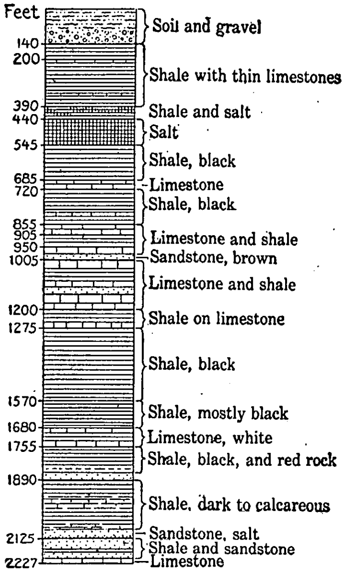
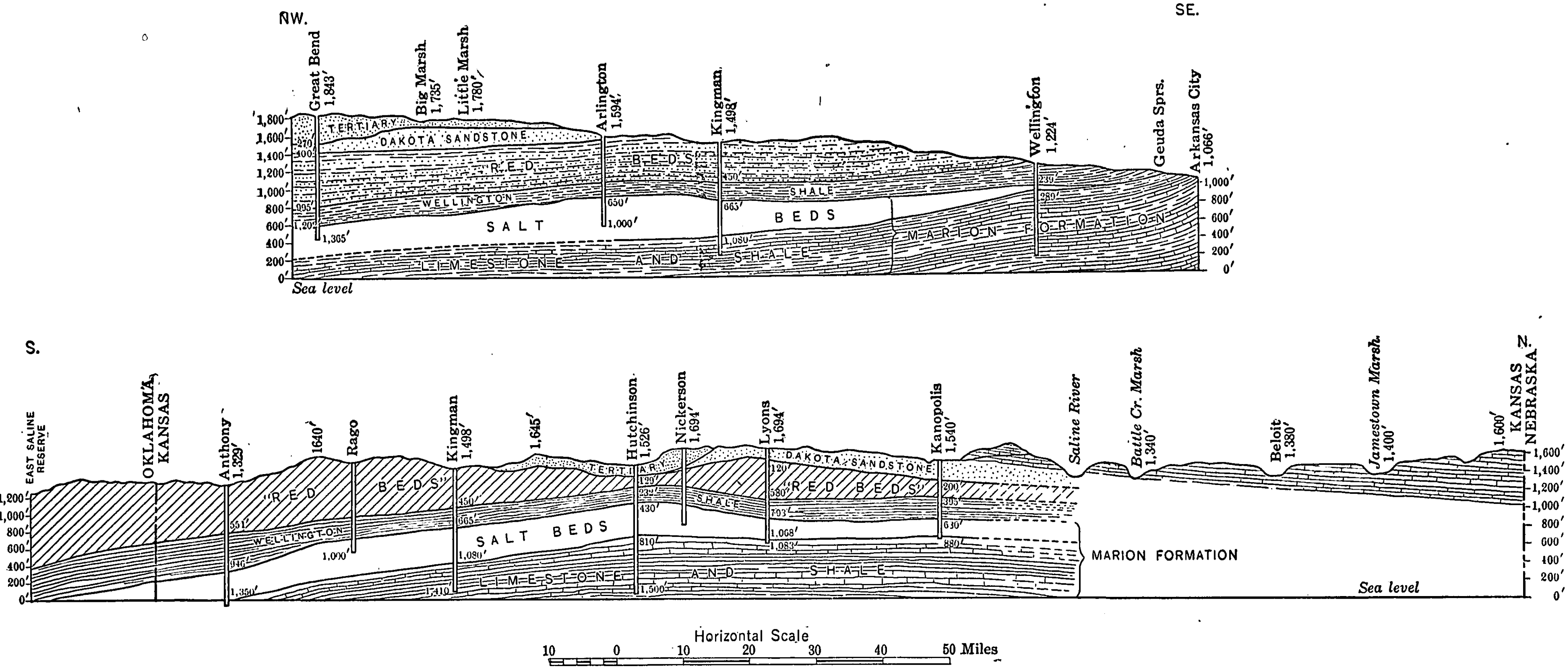


FIGURE 31.—Record of boring at McPherson, Kans.

The following table gives the principal data available as to wells in the south-central part of the State:

Borings in south-central Kansas which penetrated salt beds.

Locality.	Depth (feet).	Principal materials.
Harper, 3 miles southeast of	+3,300	Shale, red, brown, and gray, to 815 feet; salt at 818–824, 946–960, and 970–978 fet.
Ashland, sec. 17, T. 31 S., R. 23 W	3,003	Salt at 310–535, 625–630, 695–700, 1,220–1,235, 1,705–1,712, 1,810–1,855, 1,860–1,880, 1,885–1,895, 1,900–1,920, 1,930–1,960, 2,000–2,025, 2,035–2,055, and 2,170–2,185 feet.
Minneola, SE. ¼ sec. 10, T. 30 S., R. 25 W	3,807	Salt at 690–750, 780–938, 970–1,000, 1,065–1,090, 1,140–1,148, 1,526–1,550, 2,090–2,185, 2,225–2,250, 2,270–2,300, 2,350–2,365, and 3,570–3,577 feet.
Crisfield, sec. 15, T. 33 S., R. 9 W	1,659	Salt at 960–985, 1,010–1,022, 1,205–1,215, and 1,230–1,235 feet.
Anthony	2,335	Salt at 946–1,221 feet; shale, with some salt, at 1,350–1,490 feet.
Kingman	1,393	Salt and shale with three thin limestone beds at 665–1,038 and 1,070–1,080 feet.



SECTIONS ACROSS THE SALT DEPOSITS OF CENTRAL KANSAS.

After Kansas Univ. Geol. Survey Ann. Bull. Mineral Resources, 1898 (Pl. V).

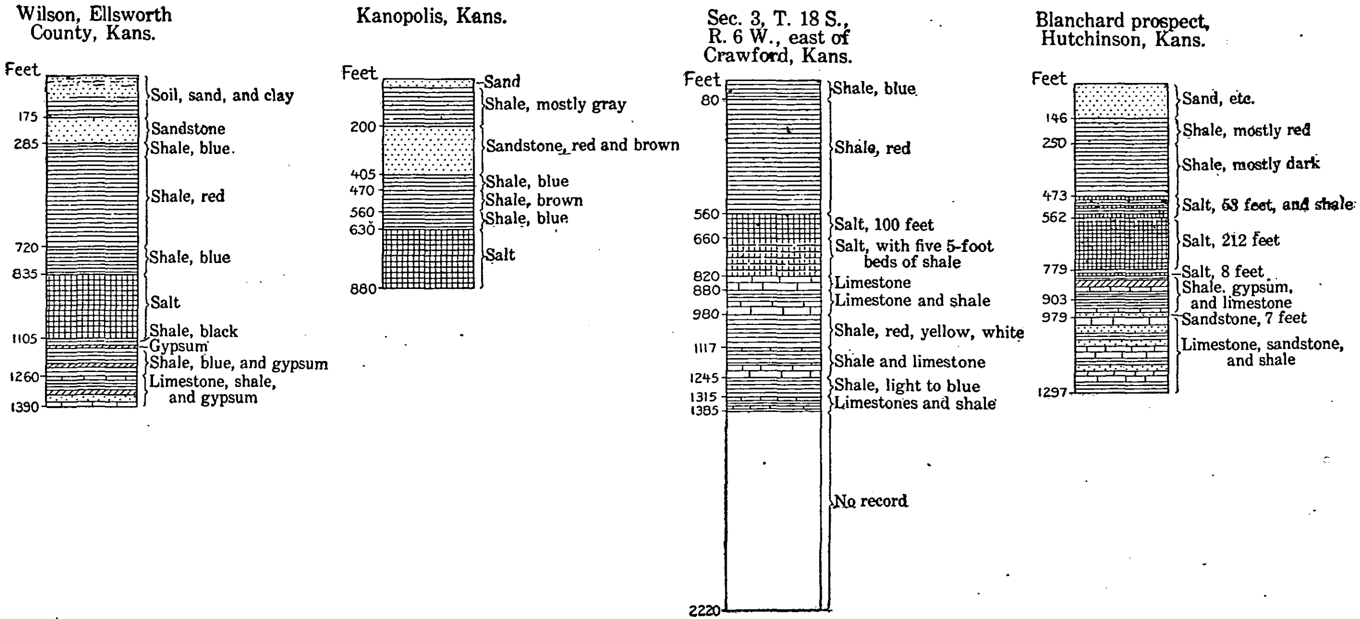


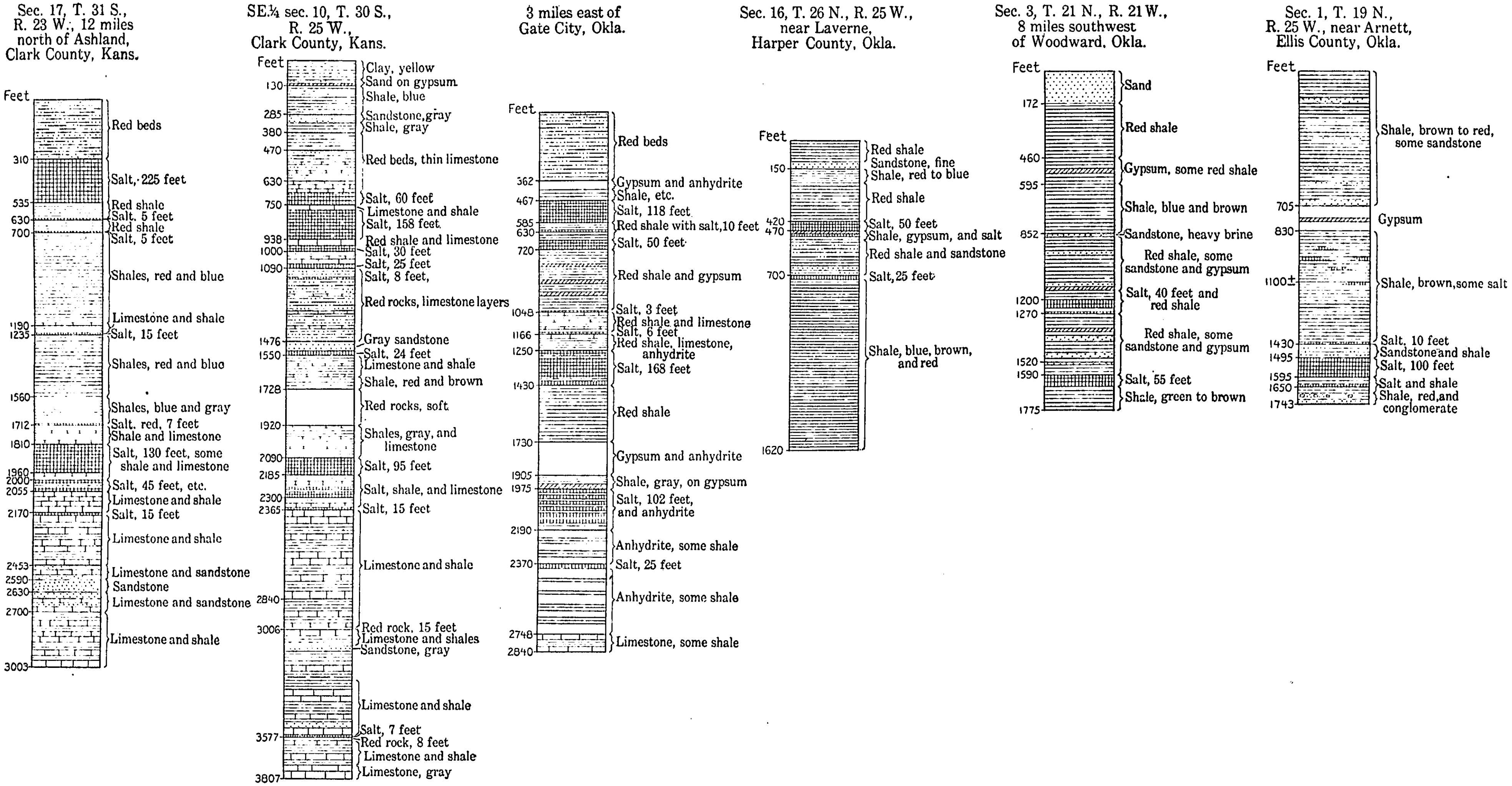
FIGURE 32.—Records of borings in central Kansas.

In the two following records are given the details of the succession of salt and overlying and interbedded strata in the central Kansas region. They are much more accurate than well records.

Record of shaft of Lyons Rock Salt Co., Lyons, Rice County, Kans.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and sandy loam	30	30
Sandy loam	15	45
Sandstone	10	55
Variegated clays	12	67
Blue clay	13	80
Black shale	30	110
Gray sandstone	10	120
Red sandstone	78	198
Red sandy shale	56	254
Red clay	18	272
Soft limestone	3	275
Gypsum and limestone	9	284
Blue shale	4	288
Red and blue shale, mixed with gypsum	292	580
Dark-gray shale	60	640
Reddish-gray shale	30	670
Dark-gray shale	123	793
Light-gray salt rock	2	795
Dark-gray salt and rock	½	795½
Light-gray salt rock	2½	798
Dark-gray salt rock	4	802
Light-gray salt rock	3½	805½
Reddish-gray salt rock	½	806
Gray shale	8	814
Dark-gray salt rock	10½	824½
Gray shale and salt, mixed	3	827½
Gray shale	4	831½
Light-gray salt rocks	9	840½
Rock salt and shale	1½	842
Light-gray salt rock	8½	850½
Gray shale	1½	852
Light-gray salt rock	8½	860½
Shale	1	861½
Light-gray salt rock	6½	868
Shale and salt rock, mixed	2½	870½
Dark salt and shale	8½	879
Crystal salt	4	883
Shale and salt	7	890
Dark salt and shale	18½	908½
Dark-red shale	6	914½
Dark salt and rock	10	924½
Dark salt, with crystals	17	941½
Rock and salt and shale	19	960½
Dark salt and shale	21	981½
Crystal salt	2	983½
Shale	1	984½
Light-gray salt	9½	994
Shale	½	994½
Light-gray salt and a little shale	10	1,004½

[a] Kirk, M. Z., and Haworth, Erasmus, op. cit., p. 93.



RECORDS OF DEEP BORINGS IN SOUTHERN KANSAS AND NORTHWESTERN OKLAHOMA.

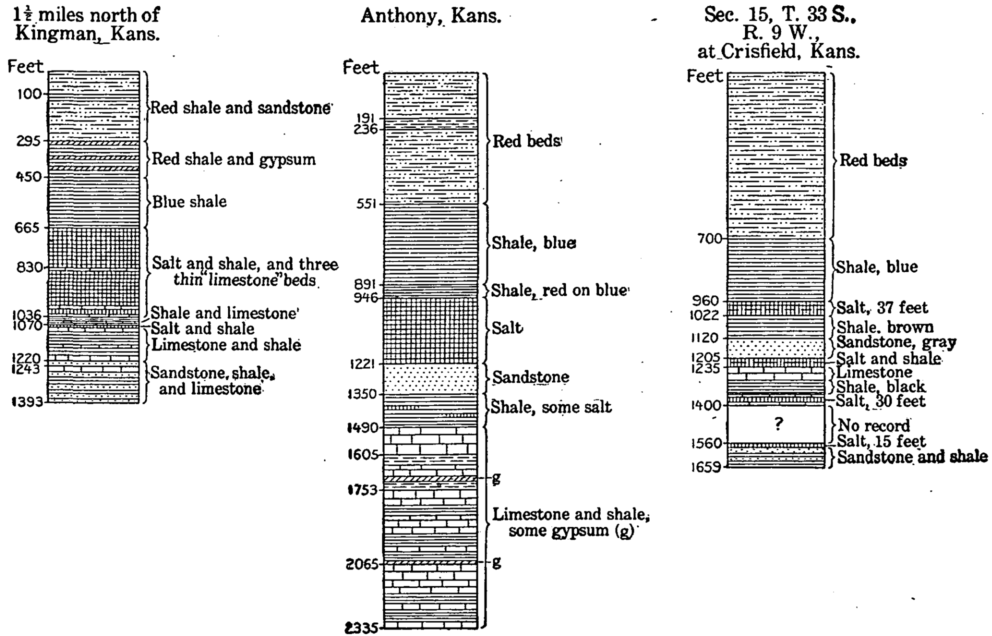


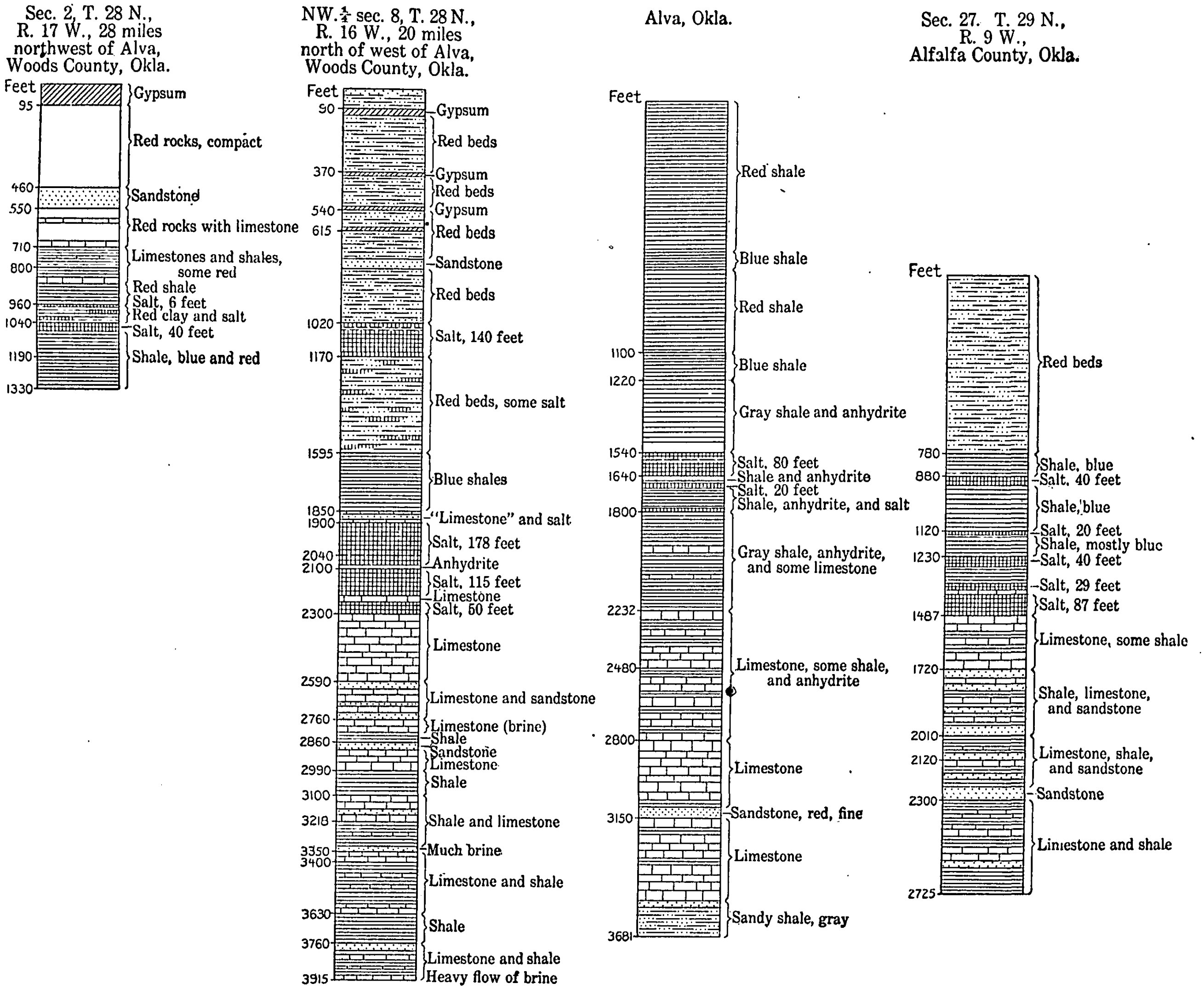
FIGURE 33.—Records of borings in south-central Kansas.

Record of shaft of Standard Salt Co., Little River, Rice County, Kans.[a]

	Thickness.		Depth.	
	Ft.	in.	Ft.	in.
Soil	2		2	
Sandy clay	44		46	
Soft red shale	4		50	
Sand and shale	15		65	
Red and blue shale	284		349	
Blue shale	62		411	
Red and blue shale	10		421	
Red shale	13		434	
Blue shale	6		440	
Red and blue shale	22		462	
Red shale	1		463	
Blue shale	73		536	
Gray shale	3		539	
Blue shale	19		558	
Salt and shale	5		563	
Blue shale	2		565	
Salt and shale	10		575	
Salt	10		585	
Shale	1		586	
Salt	6		592	
Shale	3		595	
Salt	6	7	601	7
Shale	8		609	7
Salt	16		625	7
Blue shale	2		627	7
Salt	3		630	7
Blue shale	1		631	7
Red shale		6	632	1
Blue shale	1	6	633	7
Salt	5		638	7
Blue shale	1		639	7
Clear crystal salt	27		666	7
Shale	5		671	7
Salt	2		673	7
Shale	1		674	7
Crystalline salt	22		696	7
Blue shale	4	6	701	1
Crystalline salt	31		732	1
Blue and red shale	1	2	733	3
Salt	6	6	739	9
Shale	3	6	743	3
Salt and shale		6	743	9
Crystallized salt	15		758	9
Salt and shale		6	759	3
Salt	5		764	3
Salt and shale	3		767	3
Crystallized salt (planning to work this bed)	18		785	3
Salt and shale	1	6	786	9
Salt	9		795	9
Shale	4		799	9
Crystallized salt	7	6	807	3
Shale	9	6	816	9
Salt	3	6	820	3
Shale	17		837	3
Crystallized salt	8		845	3
Shale and gypsum	108		953	3
Sand and shale	6	10	960	1
Sandstone	1	6	961	7
Shale and gypsum	16	6	978	1
Blue and red shale	10		988	1
Shale and gypsum	8		996	1

[a] Kirk, M. Z., and Haworth, Erasmus, op. cit., p. 92.

A boring in progress in sec. 35, T. 21 S., R. 30 W., 25 miles northeast of Garden City, reached a depth of 2,200 feet late in 1919. It passed out of the base of the Dakota sandstone at about 810 feet and finally penetrated several hundred feet of red shale. Strong brines were found at intervals from 1,135 to 1,224 feet, but no beds of salt were reported. Salt beds may exist in this locality, but it is probable that the main salt horizon of the central part of the State was not reached.



RECORDS OF BORINGS IN WOODS AND ALFALFA COUNTIES, OKLA.

A 3,055-foot boring in sec. 11, T. 35 S., R. 2 E., in the southeast corner of Sumner County, apparently was sunk beyond the eastern edge of the salt deposit, but no salt is mentioned in the record.[3] Red materials extend from the surface to 773 feet, and gypsum from 773 to 993 feet, with shale and limestone below.

OKLAHOMA.

The great Permian salt deposit has been penetrated by numerous borings in western Oklahoma, but useful data regarding the salt beds have been given in only a few of the records. R. K. Bailey, of the United States Geological Survey, visited several of the wells in 1917 and 1918 and obtained records and samples for testing. The greatest thicknesses of salt reported were 580 feet at Gate and 540 feet in the Cosden well, northwest of Alva. Smaller amounts were reported in the records of other holes in Harper, Woods, Alfalfa, Woodward, and Ellis counties. Several deep holes, such as those near Enid and Fairview, Okla., and Quanah, Tex., report little or no salt, but this may be due to imperfect observations. For the same reason the reported thickness at Woodward, Arnett, Alva, and Laverne may be too low. The following are the principal data available:

Deep holes in western Oklahoma in the records of which thick beds of salt were reported.

Locality.	Depth (feet).	Materials.
Laverne	1,620	Red beds to 700 feet, with salt at 420–470 feet, gypsum at 480–490 feet, and salt at 490–500 feet; shale (some of it red) at 700–1,620 feet.
Alva, near	3,681	Red beds to 1,100 feet; salt at 1,550–1,640 and 1,680–1,700 feet; shale and salt at 1,780–1,800 feet.
Alva, 20 miles north of west of, NW. ¼ sec. 8, T. 27 N., R. 16 W.	3,915	Salt at 1,020–1,030, 1,035–1,045, 1,050–1,170, 1,900–2,040, 2,062–2,100, 2,115–2,230, and 2,250–2,300 feet; "sand and salt" at 1,860–1,900 feet; brines at 2,010, 2,750, 3,175, 3,250, 3,333, 3,835, and 3,915 feet. (See Pl. XXIV.)
Alva, 28 miles northwest of, NW. ¼ sec. 2, T. 28 N., R. 17 W.	1,330	Salt at 1,040–1,080 feet: clay and salt at 964–970 and 1,010–1,030 feet. (See log, Pl. XXIV.)
Alfalfa County, sec. 27, T. 29 N., R. 9 W.	2,725	Red beds to 780 feet; shales and limestones below. Salt at 880–920, 1,100–1,120, 1,230–1,250, 1,260–1,280, 1,301–1,330, and 1,340–1,427 feet. (See log, Pl. XXIV.)
Gate, three-fourths mile east of, sec. 3, T. 5 N., R. 28 E.	2,840	Salt at 467–567, 572–585, 620–630, 670–720, 1,045–1,048, 1,160–1,166, 1,252–1,288, 1,290–1,395, 1,405–1,430, 1,990–1,997, 2,010–2,020, 2,035–2,040, 2,050–2,063, 2,072–2,087, and 2,107–2,190 feet: anhydrite at 2,370–2,395 feet. (See log, Pl. XXIII.)
Woodward, 8 miles southwest of, sec. 3, T. 21 N., R. 21 E.	[a] 1,775	Salt at 1,590–1,645 feet, under red beds.
Arnett, sec. 1, T. 19 N., R. 25 E.	1,740	Salt at 1,430–1,440, 1,495–1,595, and 1,635–1,650 feet. (See log, Pl. XXIII.)
Cimarron County, sec. 22, T. 4 N., R. 1 E.	2,030	No salt mentioned in record, but outside reports refer to salt.
Magnolia County, 3 miles north of Sayre, Beckham County.	[a] 1,780	Salt samples at 1,345–1,350, 1,395–1,416, and 1,500–1,510 feet.

[a] In progress.

[3] Kansas Univ. Geol. Survey Bull. 3, p. 345, 1917.

Deep borings in western Oklahoma in the records of which little or no salt was reported.

Locality.	Depth (feet).	Materials.
Enid	3,365	Red beds at 48–1,000 feet, alternating limestone and shale at 1,000–3,365 feet, with few red sandstones at intervals between 2,165 and 2,660 feet.
Canute, near, sec. 18, T. 11 N., R. 19 W.	541	Shale and sandstone, red and gray.
Alfalfa County, SW. ¼ sec. 13, T. 28 N., R. 11 W.	3,396	Red and brown rocks to 820 feet; limestone, sandstone, and shale below.
Cimarron County, sec. 22, T. 5 N., R. 5 E.	1,583	Red beds, with gypsum.
Cimarron County, sec. 22, T. 4 N., R. 1 E.	2,030	Red beds to 1,940 feet; limestone below.
South Fairview, sec. 33, T. 20 N., R. 12 E.	1,758	Red shale to 1,690 feet; small bed of salt at about 1,590 feet.
Leedy, 4 miles northwest of, SE. ¼ sec. 27, T. 17 N., R. 21 W.	2,010	Poor record.
Clinton, Custer County	2,507	Red beds, with some blue shale.
Ellis County, sec. 1, T. 19 N., R. 25 W.	721	Red beds.
Gage, sec. 2, T. 21 N., R. 24 W	516	Do.
Major County, sec. 33, T. 20 N., R. 12 W.	3,475	Red beds to 1,690 feet; limestone and shale below.
Custer, Custer County	2,015	Red beds.
Greer County, SW. ¼ sec. 24, T. 7 N., R. 21 W.	2,135	Red and brown beds.
El Renó, Canadian County	3,315	Do.

TEXAS.

Data from borings.—The presence of salt under the greater part of western Texas is known from many deep borings, most of which have been described by Udden.[4] The record of the hole bored by the United States Geological Survey south of Amarillo and data from other holes since bored add to the evidence. However, in this area, as elsewhere, doubtless the salt has been penetrated by some holes whose drillers have failed to report salt or have not noted the thickness of the several beds. The greatest thickness reported is at Adrian, where the aggregate is 700 feet; other notable records are 680 feet in the Miller hole, 545 feet in the Boden well, and 460 feet or more in the United States Geological Survey well. The following are the principal data available regarding salt deposits in wells in western Texas (see also fig. 34):

Deep borings in western Texas in the records of which salt beds were reported.

Locality.	Depth (feet).	Principal materials.
Adrian, Oldham County, 2 miles southwest of.	2,825	Salt at 1,185–1,370 and 2,240–2,440 feet; salt and gypsum at 750–1,185 and 1,370–1,517 feet. (See log.)
Boden field, Potter County	2,000	Salt at 640–645, 650–665, 701–710, 720–730, 875–925, 930–950, 1,005–1,230, 1,290–1,460, and 1,690–1,720 feet; salt and silt at 730–745 feet, a few thin layers at 1,720–2,010 feet.
Miller ranch, Palo Duro Canyon, 7 miles above Canyon, Randall County.	2,575	Salt and red shale at 940–1,170 feet; salt at 1,390–1,430, 1,435–1,500, 1,508–1,530, 1,570–1,610, 1,635–1,680, 1,710–1,720, 1,830–1,950, 2,025–2,205, 2,212–2,315, and 2,440–2,480 feet.
United States Geological Survey boring, Cliffside, 6 miles northwest of Amarillo, Potter County.	1,703	Salt and shale at 665–860 feet; salt at 972–1,058, 1,116–1,322, and 1,392–1,440 feet; salt and sandstone at 1,475–1,538 feet; anhydrite, shale, and salt at 1,581–1,703 feet.
McLean, Gray County, half a mile south of.	1,670	Red beds to 1,650 feet at least; considerable salt to 1,670 feet.

[4] Udden, J. A., Potash in the Texas Permian: Texas Univ. Bull. 17, 59 pp., 1915.

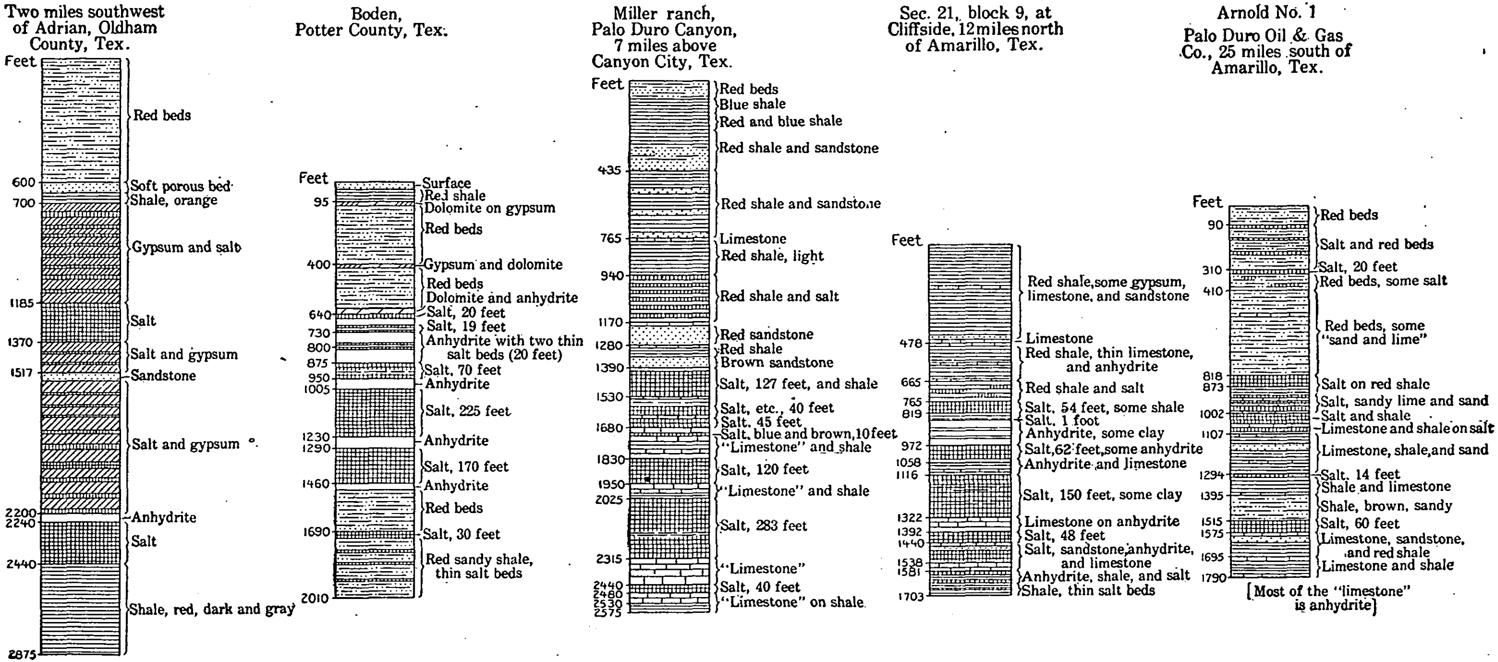


FIGURE 34.—Records of deep borings in northwestern Texas.

Deep borings in western Texas in the records of which salt beds were reported—Continued.

Locality.	Depth (feet).	Principal materials.
Childress, Childress County	1,263	Salt at 848–1,098, 1,118–1,138, 1,178–1,203, and 1,218–1,238 feet. (See log, fig. 35.)
Justiceburg, Garza County	800	Salt at 585–600 and 770–785 feet and below.
Spur, Dickens County	4,489	Salt at 570–580, 633–638, and 732–741 feet; much salt with shales at 900–1,250 feet.
Post, Garza County	1,674	Salt at 1,656–1,674 feet.
Snyder, Scurry County	2,500	Salt rock at 655–705, 720–765, 770–775, 785–800, 870–1,020, 1,570–1,600, and 1,660–1,805 feet.
Upland, Upton County	1,300	Probably in salt at 1,300 feet.
Buena Vista, Pecos County	1,114	Some rock salt at 962 and 975 feet.
Scoggin, Kent County	961	Salt at intervals from 880 to 961 feet.
Shamrock, Wheeler County	2,027	"Shale and salt rock" at 935–1,090 feet and near 1,360 feet. (See log, fig. 36.)
Hapgood well, 28 miles north of Amarillo, Potter County.	2,395	Salt in shale at 840–1,300 feet. (See log, fig. 37.)
Masterson well No. 2, 28 miles north of Amarillo, Potter County.	2,125	No salt reported.
Masterson well No. 3, 28 miles north of Amarillo, Potter County.	2,195	Salt at 1,325–1,415 feet; "lime salt" at 1,415–1,585 feet.
Bivins well, 28 miles north of Amarillo, Potter County.	3,010	Salt 200 feet or more at intervals from 700 to 2,680 feet. Red beds at 2,835 to 3,010 feet.
Ranch well No. 1, 28 miles north of Amarillo, Potter County.	1,900	Salt at 885–920, 1,370–1,382, 1,505–1,550, and 1,590–1,670 feet.
Pullman, Potter County	1,276	Rock salt at 1,143–1,160 feet.
Memphis, Hall County, 5 miles south of.	1,908	Salt rock, etc., at 550–770 and 1,150–1,290 feet; hard red and blue shale and salt at 1,290–1,580 feet.
Hollowfield No. 1 well, Hall County	2,395	Salt at 730–735, 1,080–1,320, and 1,470–1,580 feet.
Oil Issues No. 1 well, Oldham County	1,185	Salt 80 feet at intervals from 660 to 1,140 feet.
Holbrook No. 1 well, Potter County	[a] 2,020	Salt 160 feet at intervals from 955 to 1,630 feet.
W. & P. Masterson well, Potter County	[a] 2,980	Salt at 1,480–1,510, 1,670–1,700, 2,510–2,515, and 2,655–2,755 feet.
Tuck-Trigg well, Potter County	3,920	Salt 200 feet at intervals from 665 to 2,460 feet.
Palo Duro well, Randall County	2,635	Salt 140 feet at intervals from 310 to 2,630 feet.

[a] In 1920 still drilling in soft red rocks, but granite is reported in borings near by.

Deep borings in western Texas in the records of which little or no salt was reported.

Locality.	Depth (feet).	Materials.
Glenrio, Deaf Smith County	800	Red beds, sandstone, dolomite, and anhydrite.
San Angelo, Tom Green County, 4 miles west of.	3,967	No red beds below 183 feet; gray limestone and shale.
Littlefield, Hockley County, midway on north line of league 730.	2,032	Red beds; some lime and sand.
Toyah, Reeves County	4,100	Red beds, gypsum, limestone, sandstone, and shale.
Quanah, Hardeman County	1,160	Red beds to 1,105 feet, possibly lower; no salt.

Spur.—According to Udden,[5] the 4,489-foot hole bored at Spur in 1909 to 1913 revealed three beds of salt at 570 to 580, 633 to 638, and 732 to 741 feet. The lower sands of the red beds, from 900 to 1,250 feet, contained from 15 to 67 per cent of salt, the average being 36 per cent, equivalent to about 105 feet of solid salt. All the salt is in red beds consisting of layers of red sandy shale containing 18 beds of anhydrite and gypsum. A bed of anhydrite extends from 330 to 403 feet, and other thick beds occur at 540 to 570, 603 to 628, and 1,175 to 1,200 feet. Gypsum beds 1 to 15 feet thick occur in the upper 285 feet of the boring. The combined thickness of gypsum and anhydrite is stated by Udden to be at least 250 feet. Below 1,250 feet the hole is in

[5] Udden, J. A., The deep boring at Spur: Texas Univ. Bull. 363, sci. ser. 28, 1914.

dolomite interrupted by minor amounts of sandstone, shale, and anhydrite.

McLean.—Udden[6] gives a detailed driller's record of the 1,670-foot boring of the Panhandle Oil & Gas Co. half a mile south of McLean, but it contains meager data as to salt. Gypsum and salt are recorded at 1,235 to 1,240 feet; salt and white lime rock at 1,290 to 1,300 feet; hard and soft lime, red shale, and salt at 1,300 to 1,350 feet; and red-brown shale and salt at 1,589 to 1,593 feet. It is stated that beds of salt of "considerable thickness were penetrated" ending at 1,260 feet and somewhat above 1,670 feet. Large amounts of gypsum and anhydrite were found.

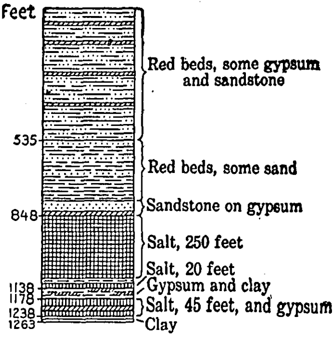


FIGURE 35.—Record of boring at Childress, Tex.

Kent, Scurry, and Garza counties.—Udden[7] gives some data regarding the records of borings at Post, Scoggin, Justiceburg, and Snyder which indicate that the salt bed is present but apparently thinner than in other regions to the north. However, most of the records are not very specific as to the amount of salt penetrated.

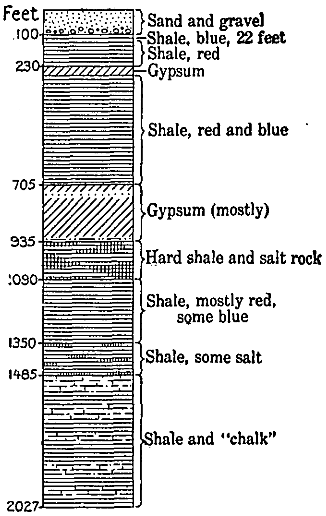


FIGURE 36.—Record of boring near Shamrock, Tex.

The Double U boring, near Post, ended in salt at 1,672 to 1,674 feet, and salt appears to have occurred in small bodies down to 1,344 feet, most of it mixed with sand, clay, and anhydrite.

The 2,500-foot hole at Snyder penetrated several beds of "salt rock" below 655 feet, possibly aggregating 100 feet. Alternating thick beds of salt and red rocks occurred from 690 to 800 feet, clay mixed with salt from 870 to 1,020 feet, and salt and shale from 1,570 to 1,600 feet. The salt rock at 2,130 to 2,160 feet was the lowest salt bed.

The Scoggin boring afforded meager data, but it was reported that salt beds were penetrated at intervals from 880 to 961 feet.

The 600-foot well of the Atchison, Topeka & Santa Fe Railway at Justiceburg was in Permian red shale with "sheets of rock salt" from 311 to 585 feet and "pure rock salt" from 586 to 600 feet.

[6] Udden, J. A., Potash in the Texas Permian: Texas Univ. Bull. 17, pp. 19–23, 1915.
[7] Idem, pp. 28–37.

Big Spring.—It is reported that the well sunk in the courthouse yard at Big Spring in 1892 found salt water at 500 feet and salt from about 900 feet to about 1,340 feet.

Wells north of Amarillo.—The record of the well bored by the United States Geological Survey 6 miles northwest of Amarillo is given in figure 34. It penetrated 460 feet or more of salt in several beds between 680 and 1,600 feet. One bed of nearly pure salt was 150 feet thick.

The Hapgood well, bored to a depth of 2,395 feet in section 65, block 018, 28 miles north of Amarillo, had the record shown in figure 37. The record shows red shale with some salt from 840 to 1,300 feet, but the total amount is not given. The hole was later deepened to 2,395 feet, but although no more salt was reported the record is too general to be useful. Several other holes were sunk in the same vicinity. Masterton well No. 3 of the Amarillo Oil & Gas Co., in sec. 102, block 018, was completed at 2,195 feet; the only salt reported was at 1,325 to 1,415 feet followed by "lime salt" at 1,415 to 1,585 feet. Masterson well No. 2, in sec. 70 of the same block, was 2,125 feet deep, and its record shows no salt. The record of Bivins well No. 1 of the same company, in sec. 106, block 46, 1,535 feet deep, reports salt and red rock at 692 to 940 feet, salt at 1,145 to 1,188 feet, and salt, gypsum, and slate at 1,200 to 1,330 feet. The record of Ranch Creek well No. 1, 1,900 feet deep, reports salt at 885 to 920, 1,370 to 1,382, 1,505 to 1,550, and 1,590 to 1,670 feet—172 feet in all. The drillers of the Miller well at Pullman, Potter County, which had reached a depth of 1,276 feet November 8, 1919, reported salt at 1,143 to 1,160 feet.

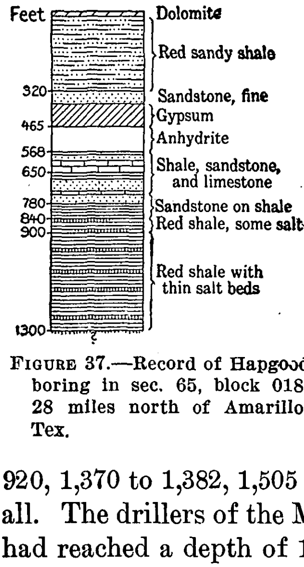


FIGURE 37.—Record of Hapgood boring in sec. 65, block 018, 28 miles north of Amarillo, Tex.

Memphis.—The 1,908-foot boring 5 miles south of Memphis passed through an extensive series of salt-bearing strata, but the record is so general that the thickness of salt can not be ascertained. The amount was probably considerable.

Quanah.—The absence of salt in the record of the 1,160-foot hole at Quanah, in Hardeman County, may indicate either that the salt measures do not extend that far east or that they have been overlooked by the drillers.

San Angelo.—The 3,967-foot hole at San Angelo, in Tom Green County, is apparently in the same category with the Quanah boring.

Buena Vista.—The 1,414-foot hole at Buena Vista, in Pecos County, according to a report given to Udden, penetrated rock salt at 962 and

975 feet, and he states regarding the Permian red beds from 588 feet down: "It is probable that these contain more salt than would appear from the two isolated mentions of rock salt by the driller, who stated that cuttings from some parts of the borings were difficult to obtain and seemed to 'disappear before coming to the surface.'"

Upland.—A boring at Upland, Upton County, reached a depth of 1,300 feet in 1913. According to Udden, the drillers reported salt and brine at 1,100 to 1,120 feet, and at 1,300 feet the cuttings were so scanty that probably a bed of salt or salt-bearing shale was penetrated.

Reeves County.—Apparently no salt has been noted in the holes sunk for oil in Reeves County, although the upper strata penetrated are the red-bed succession of the Pecos Valley region. The 4,100-foot hole northwest of Toyah, described in detail by Udden,[8] began in the Comanche series and apparently penetrated beds of about the same age as those in the 2,820-foot hole at Carlsbad, N. Mex., 80 miles farther north, in which 633 feet of salt was found.

NEW MEXICO.

General features.—Several bore holes indicate that an area of about 20,000 square miles in eastern New Mexico is underlain by the southwestern extension of the great salt bed. Possibly the salt may extend northward under parts of Union, San Miguel, and Mora counties. In the 2,820-foot hole at Carlsbad the salt beds were found to be 633 feet thick, and the record of the hole north of Roswell reported 526 feet of salt. Probably there is not a continuous sheet more than 500 feet thick under all of the eastern or southeastern part of the State, but it seems probable that a large area is underlain by the thick deposit. The limits can only be conjectured within the area underlain by Permian rocks. No outcrops appear, although the salt deposits near Estancia appear to be on the zone in which the horizon of the salt-bearing beds is near the surface. The great salt flat north of Van Horn, Tex., may also mark the proximity of this horizon to the surface. A section across the southeastern part of the State is given in figure 38.

Carlsbad.—In 1913 a large body of salt and anhydrite was found in a 2,820-foot test boring for oil in the NE. ¼ sec. 4, T. 22 S., R. 28 E., near Carlsbad. Samples from this well were tested chemically by E. E. Lyder and W. A. Whitaker, at the University of Kansas. The record in figure 39 and other data were kindly fur-

[8] Udden, J. A., op. cit., p. 39.

nished by the late William H. Andrews. This record is remarkable in showing not only a very thick body of salt but a large amount of anhydrite, features which do not appear in many records of wells in different parts of the lower Pecos Valley in New Mexico.

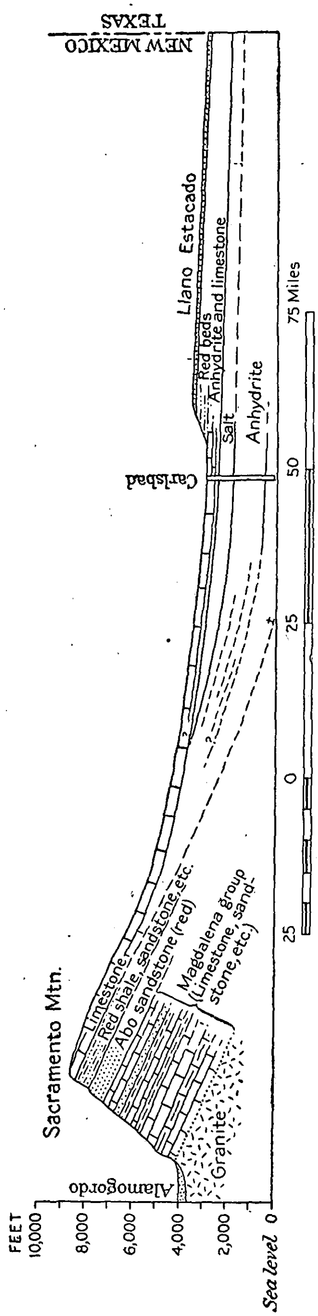


FIGURE 38.—Section across southeastern New Mexico from Sacramento Mountain through Carlsbad.

In 1916–17 a boring 787 feet deep was made in the NW. ¼ sec. 21, T. 22 S., R. 27 E., about 6 miles southwest of the deep hole above described, by the Longyear Co., in a search for potash, some traces of which had been found in the older boring. Samples were carefully collected and tested by R. K. Bailey in the field laboratory of the United States Geological Survey at Amarillo, Tex. Red shales and gypsum extended to 165 feet, gypsum with a few red clay partings from 165 to 428 feet, solid anhydrite from 428 to 629 feet, and alternations of salt and anhydrite from 629 to 787 feet. The thickest body of salt extended from 743 to 775 feet. This record, so far as it goes, confirms the record of the upper part of the 2,820-foot hole as given in figure 39.

Roswell region.—The 3,120-foot hole bored by the Toltec Oil Co. 13 miles north-northeast of Roswell penetrated 526 feet of salt in numerous thick beds interstratified in dolomite and anhydrite, with small amounts of red and gray sandstone. The record in figure 40 is based on the driller's log, with data from a complete set of samples kindly furnished by the company and tested in the laboratory of the United States Geological Survey.

The record of the 2,943-foot hole in sec. 5, T. 11 S., R. 28 E., about 25 miles east of Roswell, does not report any salt, except 2 feet at a depth of 850 feet, but presents the usual reiteration of such terms as "pink and red rock," "limestone," "lime shells," which give scant information.

Undoubtedly the hole passed through the salt and anhydrite succession reported in other holes to the west and east. Much salt water was found, notably at 2,165 and 2,240 feet.

Artesia region.—In a 501-foot hole on one of the Turkey Track ranches, 25 miles east of Artesia, near the northwest corner of T. 16 S., R. 30 E., salt was entered at 231 feet and continued to the bottom. In a well a few miles northeast of another of the Turkey Track ranches, 15½ miles east of Artesia, the salt bed was entered at 281 feet, and 5 miles east of that ranch the salt was entered at 200 feet.

Lesbia.—A 1,414-foot boring at Lesbia is reported to have penetrated salt at 700 feet and from 1,200 to 1,300 feet.[9]

Tucumcari.—The McGee test well for oil, being drilled in the SE. ¼ sec. 27, T. 10 N., R. 31 E., 8½ miles southeast of Tucumcari, penetrated rock salt at 1,100 to 1,135, 1,430 to 1,455, 2,372 to 2,377, and 3,220 to 3,225 feet. The strata below 1,455 feet as reported are 170 feet of red shale, 375 feet of gray limestone, 200 feet of brown shale, 280 feet of dark limestone, 650 feet of brown shale, 620 feet of red shale and limestone, and 194 feet of limestone, mostly dark, to the bottom of the hole at 4,014 feet (September, 1920).

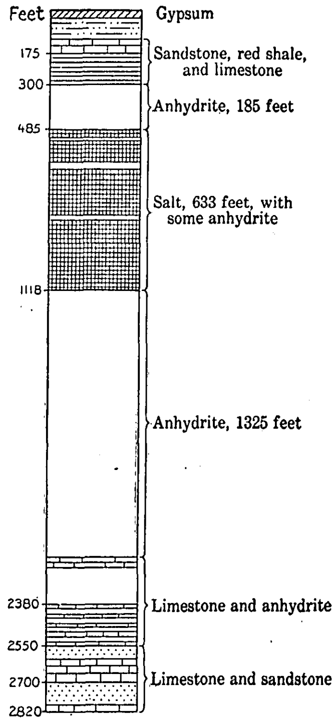


FIGURE 39.—Record of boring in the NE. ¼ sec. 4, T. 22 S., R. 28 E., 8 miles east of Carlsbad, N. Mex.

LIMITS.

The southern limit of the salt deposit in Texas has been discussed in connection with the records at Spur, Buena Vista, Post, etc. (p. 216). The eastern limit is probably about 50 miles west of the outcrop zone of the basal beds of the Permian in western Texas, Oklahoma, and Kansas, and in places it is marked by salt marshes and springs. Apparently the salt thins rapidly toward the outcrop zone, for the records of wells at its eastern margin report small thicknesses. To the north in Kansas the limit is unknown, and the beds may extend to Nebraska. The rate of thinning is gradual, for the salt is more than 200 feet thick at Wilson and Kanopolis. At McPherson it has thinned to 125 feet. Some holes in Kansas north of latitude 39° have failed to report salt, but that is not conclusive evidence of its absence. The

9 Texas Univ. Bull. 17, p. 8, 1915.

western extension of the deposit in Kansas is also problematic, for the salt measures sink deeper in that direction and have not been penetrated. The 1,365-foot hole at Great Bend reached the salt, but holes at La Crosse, Dodge, Jetmore, and northeast of Garden are far too shallow to penetrate it.

The failure to find salt in the two holes 1,583 and 2,030 feet deep in Cimarron County, Okla., may indicate that the salt is absent, was not recorded, or lies deeper than in the region to the east. It is stated by a local observer that some salt was penetrated in the 2,030-foot hole in the western part of the county.

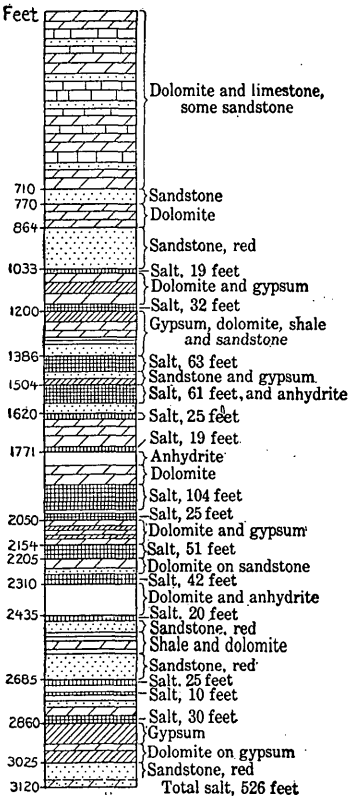


FIGURE 40.—Record of boring in sec. 31, T. 8 S., R. 24 E., 13 miles north-northeast of Roswell, N. Mex.

In New Mexico the salt is so thick at Carlsbad and north of Roswell that its western margin must be some distance west of Pecos River. Apparently no salt exists in the Sacramento Mountains; therefore the western margin may be near longitude 105°, in Otero, Lincoln, and Chaves counties.

AREA AND TONNAGE.

The area known to be underlain by the great Permian salt deposit is not far from 100,000 square miles. If it extends to the southeast corner of Colorado and northward to Nebraska its area is considerably greater.

On the assumption of an average thickness of 200 feet of salt, the gross quantity in the area of 100,000 square miles is about 30,000 billion tons.

ORIGIN.

The salt beds of this great deposit doubtless originated in the evaporation of ocean water occupying a basin or series of basins for a considerable part of Permian time. The irregular distribution of the gypsum and anhydrite in relation to the salt indicates remarkable oscillations in short lines and complexity of local conditions, and the presence of limestone beds at intervals shows that deeper marine submergences occurred from time to time. It is certain that a considerable supply of sea water was necessary for the accumulation of deposits of salt several hundred feet thick over a vast area.

A figure of interest in this connection is the fact that a body of sea water 100 feet deep evaporating to dryness deposits the greater part of its calcium sulphate, amounting to about 2 inches under ordinary conditions, and then deposits about 3 feet of sodium chloride. That the waters were shallow much of the time is shown by the large amount of shale and sandstone present, in part mixed with the salt. Most of these sedimentary materials are red, but some are of gray and other tints.

The studies by J. Usiglio [10] on the deposition of salts from sea water are of interest in this connection. He concentrated water from the Mediterranean Sea, containing 3.77 per cent of total solids, to about one-sixtieth of its volume and obtained the following results:

Salts laid down in concentration of sea water.

[Parts per thousand.]

Specific gravity.	Volume.	Fe_2O_3.	$CaCO_3$.	$CaSO_4.2H_2O$.	NaCl.	$MgSO_4$.	$MgCl_2$.	NaBr.	KCl.
1.0258	1.000								
1.0500	.533	0.0030	0.0642						
1.0836	.316		Trace.						
1.1037	.245		Trace.						
1.1264	.190		.0530	0.5600					
1.1604	.144			.5620					
1.1732	.131			.1840					
1.2015	.112			.1600					
1.2138	.095			.0508	3.2614	0.0040	0.0078		
1.2212	.064			.1476	9.6500	.0130	.0356		
1.2363	.039			.0700	7.8960	.0262	.0434	0.0728	
1.2570	.030			.0144	2.6240	.0174	.0150	.0358	
1.2778	.023				2.2720	.0254	.0240	.0518	
1.3069	.016				1.4040	.5382	.0274	.0620	
Total deposit		.0030	.1172	1.7488	27.1074	.6242	.1532	.2224	
Salts remaining in solution					2.5885	1.8545	3.1640	.3300	0.5339
Sum		.0030	.1172	1.7488	29.6959	2.4787	3.3172	.5524	.5339

[10] Annales chim. et phys., 3d ser., vol. 27, pp. 92–172, 1849.

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