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THE GYPSUM AND SALT OF OKLAHOMA

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ILLUSTRATIONS

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The gypsum companies, with two exceptions, permitted the writer to visit their mills and rendered much assistance in the preparation of the report. One of the two companies whose rules do not allow their mills to be visited gave by correspondence all the information desired concerning their mills and products.

The United States Geological Survey has permitted the reproduction of figures 2, 3, 4, 29, 30, 41, 42, 43, 45, 48, 49, 58, 60, 63, 64, and 65. Half-tones, etchings, drawings, or photographs were furnished by the J. B. Ehrsam & Sons Machinery Company, Enterprise, Kansas, for figures 8, 9, 10, 11, 12, 13, 19, 20, and 21; by the F. D. Cumner & Son Company, Cleveland, Ohio, for figures 14, 15, 16, and 17; by the United States Gypsum Company, Chicago, Illinois, for figures 22, 26, and 28; and by the Oklahoma Gypsum Company, Homestead, Oklahoma, for figure 25.

CHAPTER I.

GENERAL CONSIDERATION OF GYPSUM.

CHEMICAL AND PHYSICAL PROPERTIES.

Composition.—Gypsum is the hydrous calcium sulphate, that is, the sulphate of lime with water of crystallization. Its composition is expressed by the formula $CaSO_4.2H_2O$. It contains when pure 32.6 per cent of lime (CaO), 46.5 per cent of sulphur trioxide (SO_3), and 20.9 per cent of water. The anhydrous sulphate, anhydrite, has the formula $CaSO_4$ and is often associated with gypsum, either in considerable masses or disseminated through the gypsum. Beds of gypsum practically always contain appreciable quantities of other impurities the more common of which are iron and aluminum oxides, calcium and magnesium carbonates, clay, and sodium chloride or common salt.

Hardness and specific gravity.—Gypsum is a very soft mineral, the crystallized form having a hardness of 2 in the Mohs' scale. It is easily scratched with the thumb nail. The specific gravity of pure gypsum is 2.32, but that of the gypsum found in nature varies from 2.30 to 2.40. Its specific gravity in comparison with that of calcined gypsum, limestone, lime mortar, and Portland cement is shown in the following table.[1]

	Specific Gravity
Limestone	2.46 to 2.84
Quicklime	2.30 to 3.18
Lime mortar	1.64 to 1.86
Gypsum	2.30 to 2.40
Calcined gypsum	1.81
Portland cement	2.72 to 3.05

Color.—Gypsum is clear and transparent in the pure crystallized form, selenite, but the presence of impurities gives various shades and tints of pink, red, blue, green, and even black. Beautiful effects are given in some of the Oklahoma

[1]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1901, p. 139.

selenite by the inclusion of cloudy masses of red iron oxide or hydroxide, and of a black substance, probably organic matter, which gives a wavy effect. Green is very common in the selenite lakes and in the clays and sandstones occurring below the main gypsum ledges. This color is probably due to iron, part of which is in the ferrous condition. The fine-grained or rock gypsum is predominantly white but shades of red are of common occurrence. Dark veins or spots may be due to organic matter.

Crystallization.—Gypsum (selenite) crystallizes in the monoclinic system, the common forms of the crystals being plates or prisms with pyramidal terminations. The cleavage is almost perfect, parallel to the 010 face (face b in figure 1) and selenite is readily split in this direction into very thin sheets. This splitting into thin sheets often causes selenite to be mistaken for mica, but the thin flakes of selenite are brittle and not elastic as are the mica flakes. The cleavage is also usually good parallel to the face *n* shown in figure 1. As a result of the two cleavages selenite may often be split into rhombohedrons. Twinning is common on the orthopinacoidal face and the edges of the twinned crystals are sometimes rounded. The common forms of gypsum crystals are shown in figure 1.

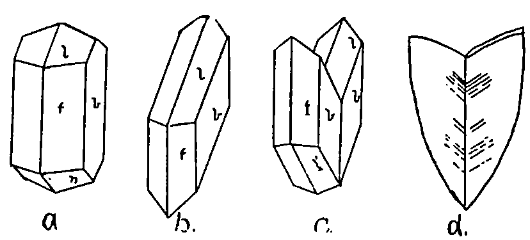

Fig. 1.—Forms of gypsum crystals.

a. Form of gypsum crystal.
b. Common form of gypsum crystal.
c. Twinned gypsum crystal.
d. Twinned gypsum crystal with edges rounded.

Solubility.—Gypsum is only slightly soluble in water as is shown by the following table by Marignac:[2]

[2]Annales de Chimie, Paris, 5th series, vol. 1, pp. 274 to 281. Quoted and verified by G. P. Grimsley, Univ. Geol. Survey of Kans., vol. 5, p. 86.

Solubility of Gypsum, by Marignac.

Temperature	One part of gypsum dissolves in—	One part anhydrous sulphate lime dissolves in—
At 32F. =0C.	415 parts of water	525 parts of water
At 65.5F. =18C.	386 " " "	488 " " "
At 75.2F. =24C.	378 " " "	479 " " "
At 89.6F. =32C.	371 " " "	470 " " "
At 100.4F.=38C.	368 " " "	466 " " "
At 105.8F.=41C.	370 " " "	468 " " "
At 127.4F.=53C.	375 " " "	474 " " "
At 161.6F.=72C.	391 " " "	495 " " "
At 186.8F.=86C.	417 " " "	528 " " "
At 212F =100C.	452 " " "	572 " " "

Although gypsum is so slightly soluble in pure water, the effects of ground water acting upon gypsum deposits through long periods of time are very striking. Caves and sink holes abound in the gypsum region of Oklahoma and ledges are often absent from the outcrops for considerable distances on account of their being dissolved out. The more coarsely crystalline gypsum seems to be more strongly acted upon than the dense fine grained varieties, probably because the cleavage planes and the surfaces between the different crystals permit the water to percolate through the crystalline gypsum more easily than it can through the dense varieties. The effect is to increase greatly the surface of gypsum exposed to the water and to increase correspondingly the solvent action. There is no reason to suppose that the crystalline gypsum is actually more soluble than the amorphous form.

VARIETIES AND OCCURRENCE OF GYPSUM.

Gypsum occurs in nature in several different forms to some of which reference has already been made. The forms usually encountered, are rock or amorphous gypsum, selenite, satin spar, and gypsite or earth gypsum. Anhydrite (calcium sulphate without water of crystallization) is closely related to gypsum and occurs intimately associated with it, so it is considered in this connection.

Rock gypsum.—Both the amorphous or non-crystalline forms and the crystalline form in which the crystals are too small to be observed by the unaided eye are commonly called rock gypsum. The term is sometimes used to include all occurrences of gypsum in heavy ledges, although the ledges may be composed of crystals of selenite of considerable size. In this report the fine-grained form is called rock gypsum while the form in which the individual crystals are large enough to be easily distinguished is called selenite or selenitic gypsum. There is, of course, no sharp line between these types but the distinction is convenient in discussing the deposits in Oklahoma.

Pure rock gypsum is white but, as it occurs in nature, is often colored by the presence of foreign material. Iron is probably the most common coloring agent and produces the pink and red shades and probably the green. Beds of gypsum are often

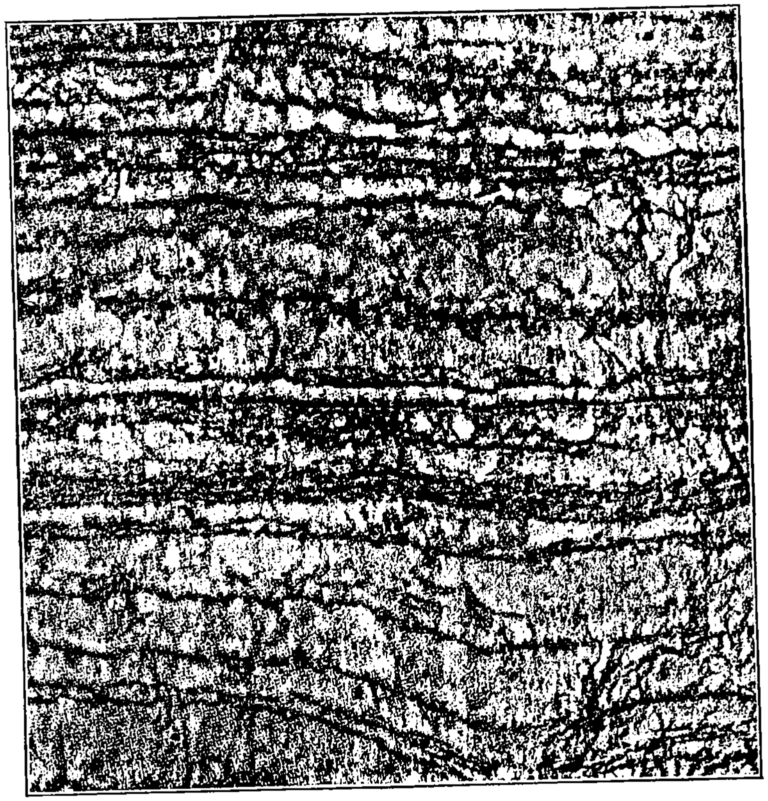

Fig. 2.—Massive gypsum showing banded structure (U. S. Geol. Survey).

irregularly mottled or banded (fig. 2) with darker material, which is probably due to organic matter since the color is usually destroyed by calcining.

Rock gypsum usually occurs in massive beds of considerable areal extent. In Oklahoma beds up to 60 feet in thickness are known and this thickness is exceeded in other regions.

Selenite is the crystalline form of gypsum. The general form of the crystals is shown in figure 1, and where the individual crystals occur separately they usually take on the shapes shown in the figure. A number of such crystals are shown in figure 3. When the crystals grow in masses the relative sizes of the faces vary greatly and the individuals are flat

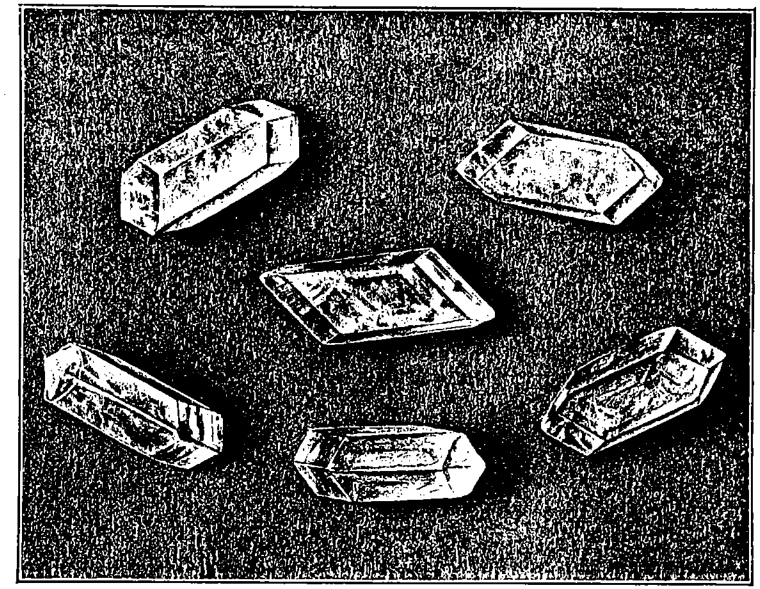

Fig. 3.—Selenite crystals (U. S. Geol. Survey).

or tabular and very thin. This method of crystal growth, with the perfect cleavage, causes a large piece of selenite to split easily into thin sheets. The sheets are slightly flexible but are not elastic. Pure selenite is transparent. The foliation and the transparency often cause selenite to be mistaken for mica.

The sheets of mica, however, are elastic, *i. e.*, when they are bent they will return to their original shape when the pressure is released. The cleavage, slight flexibility, and transparency of selinte are shown in figure 4.

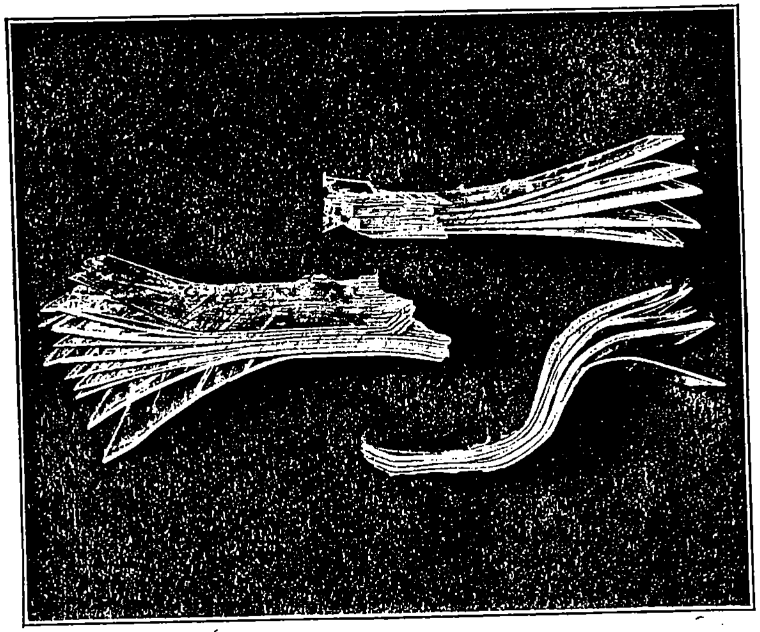

Fig. 4.—Selenite which has been split and bent to show cleavage and slight flexibility (U. S. Geol. Survey).

Selenite usually occurs in bands or veins in the clays below the massive gypsum ledges or, in some regions, unassociated with large gypsum deposits. Locally in Oklahoma crystals of the general shape of those shown in figure 3, are loosely aggregated and the interstices filled with clay. Some of the massive beds are composed of selenite crystals of as much as 3 or 4 inches in their dimensions. The weathered surfaces of such beds give a sort of mosaic effect due to the irregular outlines and different orientations of the crystals. This is rather poorly shown in figure 32 in chapter V. Some very large crystals or crystal masses in which the crystals are similarly oriented have been found in Oklahoma. One found in Dewey County and now on exhibition in the Mineral Building at the Oklahoma

State Fair is about 4 feet long, over 1 foot wide, and 6 inches thick.

Satin spar is crystalline gypsum in which the crystals are needle-like or fibrous. It occurs as veins in shales or other rocks associated with massive gypsum deposits. The veins are seldom over 3 or 4 inches thick. The crystals or fibers extend perpendicular to the length of the vein. In many veins there is a very thin sheet through the middle in which the fibers are parallel to the length of the vein with the fibers of the portions on either side perpendicular to this layer. These veins are deposited by the evaporation or gypsiferous water from the surface of the slopes below the gypsum beds, and usually extend from the surface only a short distance back into the clay. The veins may have any direction in relation to the bedding planes or joints although veins usually occur along both of these when they are well developed.

A typical occurrence of thin bands of satin spar in the clays below the heavy gypsum ledges is shown in figure 5. The fibrous nature of the material is faintly shown in some of the thicker bands. The same phenomena are shown on a larger scale in figure 48 in chapter V. Satin spar does not occur in

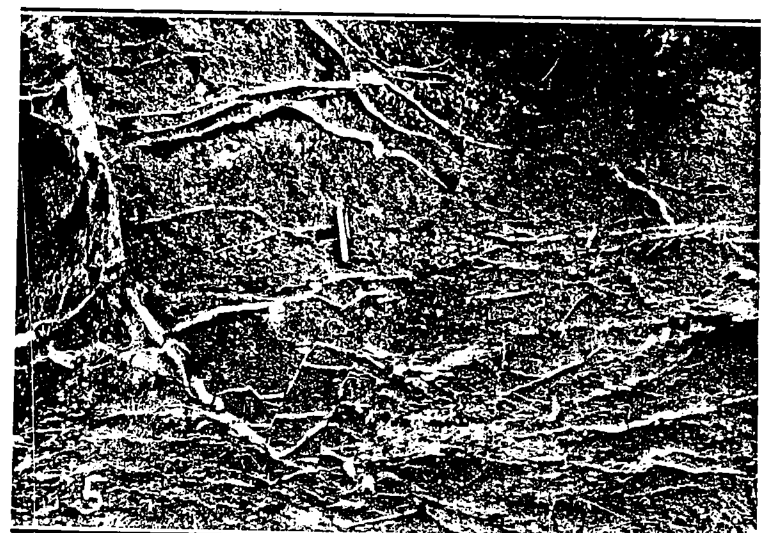

Fig. 5.—Veins of satin spar in clay below heavy gypsum ledge, 1 mile east

sufficient quantities to be commercially valuable by itself, though small quantities of it may be worked with other forms of gypsum.

Gypsite, earth or dirt gypsum, is an impure form of gypsum containing variable quantities of clay and sand. The percentage of calcium sulphate varies from about 50 to about 75 per cent. Clay and fine sand together make up the most of the rest of the material. The clay may carry some iron and more or less organic matter. Gypsite is soft and incoherent and it is easily worked with scrapers or drag scoops. In color gypsite is usually gray, mottled or speckled with white, but where the clay contains much iron the material may be pink or even red. Gypsite occurs generally along the valleys of the small streams or in flats below the level of the gypsum ledges. At some of the deposits in Kansas and in southwestern Oklahoma, the gypsum occurs below rather than above the gypsite deposits. The thickness of the deposits differs greatly even in the same bed. As a general rule they are not over 2 feet thick at the foot of the hills and reach 10 or 12 feet near the stream if the bed is in a valley. The origin of gypsite has been cause of considerable discussion. The statement which applies best to the Oklahoma deposits is that of Grimsley[3] which is given in full.

Origin of the Secondary Gypsum Deposits.

"The deposits of earthy gypsum in the central part of the state were formed at a much later time than the rock deposits we have been describing. They occur in low, swampy ground and strong springs of gypsum water occur in nearly all of them.

"At the same level or 10 to 20 feet below the earth is a stratum of solid gypsum, while near most of these deposits no gypsum is found above. Near the bottom of the Rhodes deposit Dr. S. Z. Sharp found recent shells of general *Planorbis* and *Physa*, and an Indian spear-head was also found. Similar shells were found by the writer, in the Longford earth near the bottom of the deposit. In the earth south of Dillon bones and shell were found.

"Gypsum in a form resembling satin spar and in an earthy form is deposited at the present time in dry weather to the extent of a half inch in a few days by evaporation of running water along channels near these places. Where the gypsum

[3]Grimsley, G. P., Gypsum and Gypsum Cement Plasters: Univ. Geol. Survey of Kans., vol. 5, 1899, pp. 81-83.

water of the springs in these deposits is evaporated there remains a crust of gray earthy gypsum resembling very closely the gypsum earth. Sand, clay and lime in small amounts occur in the deposit mingled with some organic material, as shown in the following analyses of rock and earth gypsum, by Professor E. H. S. Bailey:

	Gypsum Rock in Hope Shaft	Gypsum Earth at Dillon, Agatite Deposit
Silica and insoluble residue	0.34	6.49
Iron and aluminum oxides	0.16	1.04
Calcium sulphate	76.98	65.97
Calcium carbonate	1.68	6.96
Magnesium carbonate	1.30	0.27
Water	19.63	18.56
	100.09	99.29

"In all the analyses made the amounts of silica, alumina and lime carbonate in the earth deposits are higher than in the rock, which would be expected in a secondary deposit in a swamp. The amount of sulphate of lime is lower, so that the earth deposits are not as pure as the rock strata. The impurity of the earth makes it set more slowly, and so makes the material more favorably adapted to wall-plaster manufacture.

"The microscopical crystals of gypsum in this earth are angular and many of them perfect. No masses of gypsum rock are ever found in the earth, and no fragments of other stone or sand in any amount. The material is quite uniform in size and chemical composition through the whole deposit. If the material was washed from gypsum rock of higher levels, as some have maintained, some fragments of gypsum and other rock would certainly be found in some of these deposits.

Spring Theory of Origin.

"The gypsum earth, then, must have been deposited in these places from solution. If from solution in surface streams, considerable sand and silt would be carried in and the chemical composition would vary in different parts of the mass. Further, as in nearly all the areas, no gypsum is over the earth, so that the streams would have to bring the material from long distances. Some sand, clay, lime carbonate, and organic material are shown by chemical analyses and by the microscope, and these may be due to surface agencies. The water circulating through or near the underlying gypsum rock dissolved a portion of the rock and carried it upward in the springs to the surface of the swamp where the mineral was precipitated through evaporation aided by the action of organic matter of decaying vegetation.

"A crust of gypsum would thus be formed and would increase in thickness until all the underlying rock was removed. Now, in some of these deposits borings detect no gypsum below the deposits, but it is found in wells outside at a level below the earth. In such places probably all the gypsum rock adjacent to the gypsum earth area has been removed by solution. Again by building up the swamp floor to a certain height the rise of gypsum water springs may have been so checked as to hinder the earth formation. Whatever the cause, the gypsum earth deposit is not now forming over the entire area in any appreciable amount.

"The uneven thickness of the deposits, some varying from 3 to 8 feet within the main part of the deposit, shows that the conditions were more favorable at certain points than others. Probably these thicker portions were nearer the outlet of stronger springs.

"The deposits were formed in a comparatively short period of time. The presence of modern fresh water shells shows that the deposit is a recent one, formed long after the rock gypsum of the same region."

The discussion applies to the Oklahoma deposits except in a few features. Very few if any of the beds in this state are swampy but all lie on low, level land, or in valleys between the gypsum hills. The deposits of the first line of hills along Cimarron River are below the heavy gypsum ledges and probably contain an admixture of material washed down the slopes. The bulk of the gypsite in these beds, however, is almost certainly formed by crytallization from water solution. In the case of the large gypsite beds in Custer, Harmon, Jackson, and Caddo counties the gypsum is below the gypsite. Shells similar to those mentioned as occurring in some of the Kansas deposits were observed in only one bed in Oklahoma (east of India-

napolis), but careful search might bring them to light in other deposits. Strong springs break out a short distance south of this deposit.

Gypsite is important in the plaster industry of the State. Two mills use gypsite alone and several others use gypsite and rock gypsum together. Gypsite is used for plaster in Kansas, Texas, and Wyoming.

Anhydrite.—Strictly speaking, anhydrite is a distinct mineral and cannot be considered as a form of gypsum. However, it is so closely related to gypsum and is so closely associated with it in nature that it is considered in this connection. Anhydrite is calcium sulphate, $CaSO_4$. It may be considered as gypsum without water of crystallization. It is usually a colorless or white mineral but may be tinted red, blue, or gray by impurities. Its hardness is 3 to 3.5, and its specific gravity, 2.95. It crystallizes in the orthorhombic system and has a cleavage resembling that of gypsum. Gypsum and anhydrite are easily distinguishable in the field by the difference in hardness, since gypsum is easily scratched by the fingernail while anhydrite cannot be.

Anhydrite occurs in Oklahoma in beds associated with gypsum. The most prominent occurrence is in northern Blaine and in Major counties, where the anhydrite occurs as a bed 3 to 5 feet thick in the Medicine Lodge gypsum. (See figures 45 and 46.) Locally the anhydrite is not in a continuous bed but occurs as bowlders or lenses. The lowest ledge of the Greer gypsum in the southwestern part of the State seems to contain considerable anhydrite disseminated through the gypsum.

The weathering of anhydrite is very distinct from that of selenite or of fine-grained gypsum. On slopes gypsum weathers to a soft incoherent powder which covers the fresh gypsum to considerable depth. Anhydrite on the other hand remains hard and white. The weathering of the large blocks which have their surfaces level with the ground usually produces a concave surface with very sharp minor irregularities which are apparently due to washing by rain. This weathering is well shown in figure 6.

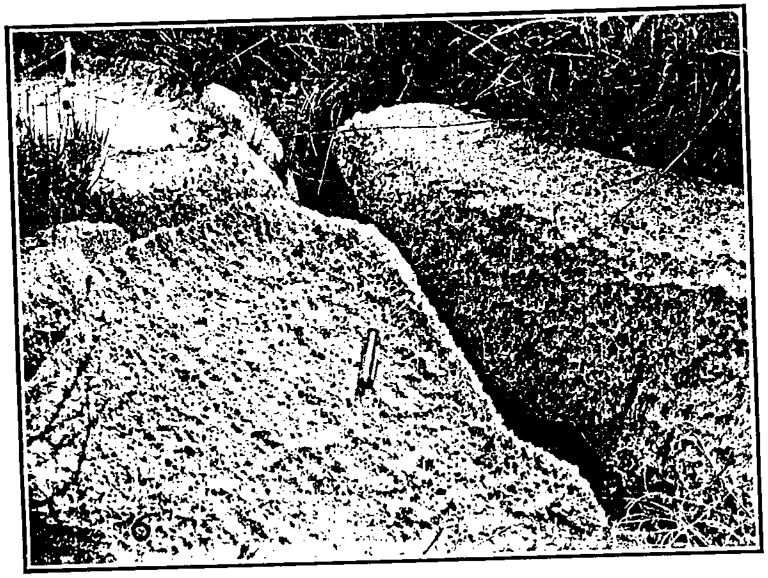

Fig. 6.—Weathered surface of anhydrite blocks near Southard.

THEORIES OF ORIGIN OF GYPSUM.

Several theories have been advanced to account for the origin of gypsum deposits all of which are probably applicable to different deposits. The principal theories will be briefly reviewed here.

Formation of gypsum by the action of sulphuric acid or soluble sulphates on limestone.—If sulphuric acid acts on limestone or any other form of calcium carbonate, gypsum is produced. The reaction stated in its simple form is $H_2SO_4+CaCO_3$ = $CaSO_4+H_2O+CO_2$. The sulphuric acid may be derived from the oxidation of hydrogen sulphide (H_2S) of sulphur springs or volcanic emanations, or by the oxidation of pyrite or iron ide (FeS_2).

Gypsum is formed directly by some thermal springs as in and by the action of sulphurous waters on volcanic tufa. Small gypsum deposits and crystals are found around amaroles of volcanoes. The formation of the gypsum deposits of New

York was attributed by Dana to the alteration of limestone by water from sulphur springs which occur in the gypsum region. Shale layers pass through the gypsum and the gypsum grades into the overlying water lime beds. These deposits are thought by others to have been deposited by evaporation of sea water. The deposits of Nova Scotia and New Brunswick have been attributed to the same source. Concerning these deposits Jennison[4] says:

"Dawson, in discussing the different theories and referring particularly to the deposits of Nova Scotia and New Brunswick, says:

" 'I think it is not improbable that there are instances of all or of most of these modes in the gypsiferous rocks of Nova Scotia. But for the occurrences of the mineral in so thick and extensive beds, interstratified with marl and limestone, there appears to me to be but one satisfactory theory—that of the conversion of submarine beds of calcareous matter into sulphate of lime, by free sulphuric acid poured into the sea by springs or streams, issuing from volcanic rocks. Modern volcanoes frequently give forth water containing sulphurous and sulphuric acids.' Water of this kind would have a greater specific gracity than sea water, and, therefore, flow along the bottom of the sea, and if it came in contact with beds of calcareous matter, the above action would take place and the formation of gypsum would be the result.

"Quite in accordance with this view the gypsum deposits of Nova Scotia and New Brunswick are found, without exception, associated with marine limestone. In some cases they are so closely associated that it is difficult to draw any line of demarcation; one graduating with diminishing or increasing prominence over the other.

"In the gypsum deposits at Tom river, Richmond county, N. S., a vein of limestone about 2 feet wide may be seen in an exposure of gypsum, 20 to 30 feet high. It cuts it transversely and has very distinct walls. * * *

"In the great gypsiferous belt at Cheticamp, Inverness county, N. S., a distinct belt of limestone, having a thickness

[4]Jennison, Wm. F., Gypsum of the Maritime Provinces: Canada Dept. of Mines, Mines Branch, No. 84, 1911, pp. 28-29.

averaging about 100 feet, may be seen, vertical, and separating a bed of snow-white massive gypsum from a bed of the greyish-white, selenitic variety.

"Everywhere, in the gypsiferous field, there is evidence that at one time there existed very extensive deposits of marine limestone. These deposits are often in close contact with what are now our metamorphic hills and mountain ranges. The volcanic action which created these metamorphic hills was not extinct when the marine limestone beds were growing and no doubt afforded the greater supply of sulphuric acid which converted the limestone into gypsum. If this supply was not sufficient, or if the conversion was not complete before the volcanoes became extinct, it is possible that the supply may have been supplemented from other sources, and the action completed.

"The sulphureted hydrogen springs, found in different localities, the iron pyrites, pyrrhotite, chalcopyrite, and arsenopyrite deposits, are all sources of sulphuric acid, and, found in the older rocks in the near vicinity, are quite sufficient to supply the deficiency if it were required. It is, therefore, quite evident that there was, from the many sources, an abundance of sulphur in the field during the Carboniferous age."

Jennison regards the "blow holes" which are of common occurrence in the gypsum and which differ in character from the ordinary sink holes, as vents through which the gases formed by the alteration of limestone to gypsum escaped; and also regards this as additional proof of the origin by alteration of limestone.

Sherwin[5] suggests that the massive deposits in Oklahoma and Kansas were formed by the action of water from sulphur springs on calcium carbonate in solution or on the limestone after it was deposited. He does not, however, account for the presence of sulphur springs sufficient to form such vast deposits.

The decomposition of pyrite gives rise to sulphuric acid and soluble sulphates which may act upon any limestone present and convert it into gypsum. This action undoubtedly accounts for the presence of much of the gypsum disseminated through shales and sandstones and in coal. It is very doubtful, however, if any considerable deposits of gypsum have been formed in this way.

[5]Sherwin, R. S., Notes on the Theories of Origin of Gypsum Deposits: Kans. Acad. Sci., vol. 18, 1903, pp. 85-88.

Formation of gypsum from anhydrite.—Gypsum is formed from anhydrite when the latter takes up water and recrystallizes. The volume of the gypsum formed is 33 per cent larger than that of the anhydrite and the force of the expansion is sufficient to lift considerable thicknesses of overlying strata, and to break crystals of quartz and dolomite in the layers above. Since anhydrite occupies less space than the same amount of calcium sulphate in form of gypsum, great pressures would tend to change gypsum to anhydrite and reduction of pressure would tend to bring about the change from anhydrite to gypsum. Grimsley[6] has noted the fact that samples from deep wells in Michigan show anhydrite rather than gypsum and that in boiler scale the calcium sulphate is present as anhydrite.

In Oklahoma anhydrite occurs in considerable quantities closely associated with the gypsum. A considerable bed occurs in the Medicine Lodge gypsum for 50 miles or more. Gypsum occurs both above and below it and, so far as the writer's observations go, it is impossible to tell whether or not the anhydrite is altering to gypsum. There is no apparent disturbance of the strata above the gypsum as would be expected if the gypsum had been formed from anhydrite, but in so soft rock such slight disturbances might escape notice. As to the alteration of the gypsum to anhydrite, it is very difficult to see how the conditions should bring this about and especially why the alteration should commence in the middle of the bed. The lower beds of the Greer formation are anhydritic but the anhydrite and gypsum seem to be mixed with each other throughout the mass. There is no apparent evidence of the alteration of one to the other and the writer believes that the mixture is the result of original deposition. In any case the formation of gypsum from anhydrite still leaves unsettled the question of the origin of bodies of anhydrite of sufficient size to form gypsum deposits of the magnitude of those in Oklahoma.

[6]Grimsley, G. P., The Gypsum of Michigan: Mich. Geol. Survey, vol. 19, Pt. II, 1904, p. 185.

Deposition of gypsum by evaporation of sea water in enclosed or partially enclosed basins.—There is little doubt that most of the important gypsum deposits of the world have been formed by the evaporation of sea water. Sea water contains 3¼ per cent of mineral matter and the mineral matter is composed principally of the following salts in the percentages given:

Sodium chloride ($NaCl$) common salt	77.758
Magnesium chloride ($MaCl_2$)	10.878
Magnesium sulphate ($MgSO_4$)	4.737
Calcium sulphate ($CaSO_4.2H_2O$) gypsum	3.600
Potassium sulphate (K_2SO_4)	2.465
Calcium carbonate ($CaCO_3$) limestone	0.345
Magnesium bromide ($MgBr$)	.217
Total	100.000

When sea water is evaporated the salts are deposited in the inverse order of their solubilities, that is, the least soluble first. It should be borne in mind, however, that the solubilities of these substances in the presence of each other are quite different from their solubilities in pure water and that in the concentration of sea water many reactions probably take place before the water is all evaporated.

J. Usiglio in 1849 published the results of experiments on the evaporation of water from the Mediterranean Sea. His results are summarized by Clarke[7], who gives the following table showing the deposits at different concentrations. The amounts of the deposits are given in grams for an initial volume of 1 litre.

[7]Clarke, F. W., Data of Geochemistry: Bull. U. S. Geol. Survey, No. 491, 1911, pp. 207-209.

Salts Laid Down in Concentration of Sea Water.

Density	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	.1445	-------	-------	.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	.0302	-------	-------	.0144	2.6240	.0174	.0150	.0358	-------
1.2778	.023	-------	-------	-------	2.2720	.0254	.0240	.0518	-------
1.3069	.0162	-------	-------	-------	1.4040	.5382	.0274	.0620	-------
Total deposit.		.0030	.1172	1.7488	27.1074	.6242	.1532	.2224	-------
Salts in last bittern		-------	-------	-------	2.5885	1.8545	3.1640	.3300	0.5339
Sum		.0030	.1172	1.7488	29.6959	2.4787	3.3172	.5524	.5339

From the table it is seen that the iron in solution is deposited when approximately one-half of the water is evaporated and that over one-half of the calcium carbonate (limestone) is deposited at the same time. The remainder of the carbonate is not thrown down until over 80 per cent of the water is evaporated, and at this concentration the gypsum also begins to come down. The deposition of gypsum continues until about 97 per cent of the water is evaporated. Common sale begins to be deposited when 90 per cent of the water is evaporated. About 83 per cent of the gypsum is deposited before the salt begins to come down and the remaining 17 per cent appears mixed with the vastly larger quantity of salt. The other soluble salts come down with the sodium chloride, but the order in which they are deposited is of no importance in the consideration of gypsum.

If, then, a quantity of sea water were shut off from the ocean in an enclosed basin and evaporated to dryness without the addition of any water from the land or ocean we should expect the salts deposited in the following order: At the bottom, a layer of limestone, the lower part containing some iron; above this a layer of gypsum with the lower part containing some limestone, and the upper part grading rapidly into common salt containing other soluble salts as impurities, and at the top mixture of the most soluble salts. In a case of this kind the would be approximately ten times as much gypsum as limesto and twenty times as much salt as gypsum.

In nature, however, it is very seldom, if ever, that a bo of water of any size could completely evaporate under su simple conditions. Connections would almost certainly be r newed with the ocean from time to time, resulting in freshen of the water and consequent disturbances of the order deposition. Some drainage from the surrounding land wou be sure to enter the basin. If this were not sufficient to cause the basin to overflow it would freshen the water and at the same time would add other mineral matter in solution. Heavy floods might bring down sufficient clay to form a layer of mud over the bottom of the basin and to freshen the water until there would be no deposition from solution for some time. Concentration might then proceed until the limestone or perhaps limestone and gypsum would be deposited when another flood would produce a second layer of mud and prevent the deposition of the more soluble salts. Thus it is evident that the simple sequence of deposition may be interrupted any number of times and that there may be many layers of mud and limestone or of mud, limestone, and gypsum deposited without the concentration proceeding far enough to deposit the more soluble salts.

The mineral matter brought down in solution would add several factors to be considered if evaporation proceeded to dryness. In the formation of the salts from the bittern or mother-liquor the temperature may affect the different combinations formed and the degree of hydration of the different salts. In many cases the connection between the ocean and the enclosed body of water was probably renewed after the deposition of the limestone and gypsum and before the more soluble salts could be deposited. Or, if the soluble salts were deposited, they were probably redissolved and carried away by ground or surface waters, leaving the gypsum and limestone. It is evident that as evaporation proceeded that the area covered by water would continually decrease and that the concentrated water would collect in the deeper parts of the basin. The salt, therefore, would be deposited over a much smaller area than the limestone and gypsum, but it would be many times as thick.

We would expect, therefore, that deposits of limestone formed by evaporation of sea water would be much more wide spread than those of gypsum and that the gypsum would be more wide spread than the salt, but that where the salt was deposited and not removed later that it would be many times as thick as the limestone or gypsum.

The noted Stassfurt deposits[8] give probably the most complete record of deposition by evaporation of a large body of water, but this record is far from being simple. More than 30 saline minerals are found in the deposits; some of them regarded as primary minerals and others as being derived from these by secondary reactions. The majority of the minerals are double salts.

The great difficulty in accounting for the formation of gypsum deposits by the evaporation of sea water is in the immense quantity of water which would be required to furnish the amount of gypsum in the deposits. Sea water probably contains as great a percentage of gypsum at present as it ever did. The thickness of the gypsum layer deposited by evaporation of a body of water 1 foot deep is only .0007 foot. To form a layer of gypsum 10 feet thick would require a depth of over 14,000 feet or 2 2-3 miles of water, if the gypsum were deposited in a basin with vertical sides.

In the case of an enclosed basin with sloping sides the depth might be much less since the area of the body would contract greatly before the gypsum was deposited, and there would also be constant additions of water containing mineral matter from the drainage into the basin. But even when these factors are considered it seems impossible to conceive of enclosed basins of sufficient size and depth to form such deposits as exist in the Permian-Triassic Red Beds of the Great Plains and Rocky Mountain States. Grimsley[9] accepts the deposition in an enclosed basin resembling the Caspian Sea as the origin of the Michigan deposits. He has worked out in some detail the area of the sea and of its drainage basin.

The conditions of deposition in partially enclosed basins have been noticed in some of the preceding paragraphs. The

[8]Clarke, F. W., Op. cit. p. 210-217.
[9]Grimsley, G. P., The Gypsum of Michigan: Mich. Geol. Survey, vol. 9, Pt. II, 1904, pp. 187-191.

discussion of conditions as they exist in such basins at present are given by Wilder[10] as follows:

"Basins which are in some degree connected with the ocean may next be considered. The Bessarabian coast of the Black Sea furnishes an example of salt deposits in bays slightly connected with the ocean and fed from the landward side by rivers. From the Danube to the Dnieper the rivers before emptying into the ocean expand into lakes which are separated from the sea by natural dams. Under ordinary circumstances the water flows into the sea through an opening in the dam, while during storms the water of the sea enters the lakes. Three of these lakes become partially dry every summer and deposit salt which in places amounts to a layer a foot thick. This salt is used for commercial purposes. The calcium sulphate of the river water and of the sea water which is driven in during storms must also be deposited, but the quantity being small, readily escapes notice.

"Many writers on gypsum and salt have called attention to the fact that the Mediterranean Sea furnishes conditions which if but slightly modified would result in deposits of these substances. Although it receives the waters of many rivers, some of them of considerable size, evaporation takes place faster than inflow and if no water entered through the Strait of Gibraltar, or if the supply entering were considerably reduced, much of the mineral matter held in solution would be deposited. A steady current pours in from the ocean, however, and the density necessary for precipitation is not reached. The bottom of the sea rises sharply near the Strait of Gibraltar, cutting off communication between the lower part of the sea and the ocean, but permitting a free interchange of water in the upper level. The depth of the strait is less than 200 fathoms, while the average depth of the Mediterranean is 1,000 fathoms. The accompanying diagram roughly illustrates existing conditions.

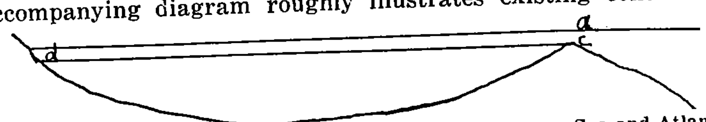

Fig. 7.—Diagram illustrating relations of Mediterranean Sea and Atlantic Ocean (after Wilder).

[10] Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 123-124.

"The amount of salt in the water of the Atlantic is 3.6 per cent, while in the Mediterranean it is 3.9 per cent. The specific gravity of the water of the Atlantic off the Strait of Gibraltar is 1.026, while at the west end of the Mediterranean, near the surface, it is 1.028, increasing in the east end to 1.03. At a depth of 300 fathoms the density is considerably greater than at the surface. A current of water flows in constantly at the surface of the strait (figure 7, *a*). This water is concentrated by evaporation and sinks. The bottom below the line *c d* has been previously filled by this dense water and water is being constantly condensed, sinks and flows out at *c* as a lower current into the ocean. The outlet at the strait is so free that the condensation does not reach the point which results in the deposition of lime, gypsum or salt.

"It is quite conceivable that the opening could be so restricted that the outflow would b egreatly diminished and the density of 1.05 to 1.13 which is necessary for the deposition of limestone be reached. If this were maintained for a long time and the inflow were enough to prevent further concentration a thick layer of limestone without gypsum and salt would be formed. If the opening were still further restricted gypsum would be precipitated and at length salt. In this case, however, the calcium carbonate in the inflowing sea water would be precipitated with the gypsum unless converted into gypsum or a more soluble salt by reaction with other salts or isolated during deposition as is the case today in the Great Salt Lake. The amount of the calcium carbonate (one-tenth as much as the gypsum) if present would be easily recognized. If instead of a small opening the inland sea were shut off from the ocean by a low barrier, over which the sea water passed only in time of great storms, the deposits might be more varied. The water would be diluted at times so that precipitation of the more soluble salts would cease and after a period of evaporation, if the amount of calcium carbonate in the newly added water were considerable, there would be a deposit of limestone succeeded by gypsum. A series of limestone and gypsum beds occurs in the northern peninsula of Michican near St. Ignace."

APPLICATION OF THE THEORIES OF ORIGIN TO THE OKLAHOMA DEPOSITS.

In attempting to apply any of the different theories of origin of gypsum to the Oklahoma deposits several difficulties are encountered. The deposits are continuous on the north with those of Kansas which pass under Tertiary rocks to the northwest, and on the south with those of Texas which probably extend under younger rocks as far as El Paso. To the west the gypsums connect along Canadian River with the deposits of eastern New Mexico which are probably continuous along the eastern flank of the Rocky Mountains with those of Colorado and Wyoming. It is not meant that any individual ledges of gypsum extend over all or even a large part of this area, but that the gypsum occur at the same general horizon and under the same general conditions. Any theory which is applicable to the Oklahoma deposits must apply in large measure to the deposits of the whole area.

The almost total absence of limestone in connection with the gypsum beds in the whole area seems to preclude the possibility of the gypsum having been formed from the alteration of limestone. The entire environment of the beds suggests aqueous deposition, while at the same time all the evidence points to shallow water conditions. The presence of marine fossils, which occur in the thin dolomitic members immediately beneath some of the gypsums, is conclusive proof that there was at least occasional connection with the ocean. The oxidized character of the clays and sandstones and their general fine-grained condition indicates that the material came from rather low lying land on which chemical weathering proceeded unchecked.

The great difficulty in accounting for the deposition of gypsum in such shallow basins as seem indicated is the immense volume of water required to produce such bodies of gypsum. This has already been mentioned briefly in a preceding paragraph. Another difficulty is the almost total absence of limestone or of any carbonate rock. Usually a thin layer of dolomitic sandstone lies immediately beneath the gypsum, but it is usually much less than one-tenth the thickness of the gypsum and it is also far from being a pure carbonate rock.

The absence of limestone may be explained in three ways. In the first place, the sea water of the period may have contained less calcium carbonate in proportion to gypsum at the time of the deposition of the deposits in the Red beds than at present. Chamberlin and Salisbury[11] hypothecate this condition in the Permian Sea as an important factor in the glaciation of the period. However, unless this condition was extreme it does not seem to account for the great apparent discrepancy between the theoretical and observed amounts of limestone. Besides, there was almost certainly considerable drainage into the basins and this drainage must have contained much more carbonates than sulphates unless some unknown source of sulphates existed.

It is entirely possible that the limestone if deposited with the gypsum has been altered to gypsum by the influence of the waters carrying calcium sulphates dissolved from the overlying gypsum. It seems strange, however, that if the theoretical amount of limestone was deposited with the gypsum that it should be everywhere so completely altered. The second explanation, which has been used by Wilder[12] in accounting for the absence of limestone from the Iowa deposits, is that the carbonates entering the basin after the water of the basin had become concentrated would be precipitated very near the mouths of the streams and along the shores. This action is taking place in Great Salt Lake at the present time. The fresh waters entering the lake contain considerable quantities of carbonates but the waters of the lake itself show scarcely a trace. The carbonates are removed immediately and deposited near the mouths of the streams in the form of oolitic sand. While the deposits in Oklahoma were probably not formed in wholly enclosed basins the conditions of deposition were doubtless very similar.

One case in Oklahoma seems to coincide with this conclusion. Southeast of Watonga the uppermost gypsum (Shimer) of the Blaine formation thins and finally disappears, while the dolomitic horizon thickens and prolongs the outcrop for some miles after the disappearance of the gypsums. Here the dolomite or magnesian limestone is about 5 feet thick and relatively pure. This is the only instance of this sort which is known to have been observed in detail, but when it is considered that very little detailed work has been done in the great area occupied by the gypsum and also that much of the probable gypsum bearing area is covered by younger rocks, it is easily seen that

[12] Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, p. 126.

many such cases might occur unnoticed. Sherwin[13] points out that probably the greater part of the drainage into the basins of deposition was from limestone regions and that consequently the stream waters would be high in carbonates. He regards the carbonates as being decomposed by sulphates or sulphuric acid derived from sulphur springs. This reaction might take place, but the presence of a sufficient number of sulphur springs to cause such deposits seems more difficult to explain than the accumulation of sufficient water to form the deposits by evaporation. There are no known areas of Permian volcanic rocks in the region which might provide a source for the sulphur. When all their features are considered, then, it seems probable that the gypsum deposits of Oklahoma were formed by evaporation of water in relatively shallow basins, which, at least temporarily, had more or less connection with the sea.

HISTORY OF GYPSUM.

The use of gypsum and of gypsum plasters has been known since ancient times. The pyramids of Egypt contain plaster work executed 4,000 or more years ago. For their finer work the Egyptians used a calcined gypsum plaster precisely similar to the plaster of Paris of modern times, and the methods of use and the tools used were also similar to the modern ones. The Greeks also used the calcined plaster in making casts, the earliest known use for this purpose.

The white compact variety known as alabaster has been used in Europe for centuries for interior decoration and ornaments, especially in cathedrals and other ecclesiastical buildings. Vases, urns, boxes for different purposes, statues and statuettes, and mural decorations were the more common articles made from alabaster. The name alabaster, however, was applied to marble and onyx as well as to gypsum and it is often difficult to tell which is meant. Selenite in large pieces or flakes was used for windows and also in making boxes or vases to surround lights for the softening effect on the illumination.

The use of gypsum both in the crude and calcined forms has continued up to the present, but the use of the calcined products has shown a rapid increase in the last few decades.

[13]Sherwin, R. S., Notes on the theories of origin of gypsum deposits: Trans. Kans. Acad. Sci., vol. 18, 1903, pp. 85-86.

In the United States the gypsum industry began in New York when the population was principally restricted to the Atlantic seaboard. As the population moved westward the development of the gypsum resources followed. The development of the important Michigan deposits began in a small way about 1840 and that of the Iowa deposits near Fort Dodge in 1872. The first plaster mill in Kansas was built in 1889, and the first mill in Oklahoma a few years later. The development of the deposits in California and along the coast began about 1875. For many years the major portion of the production was ground and sold in the raw form for land plaster. In recent years the consumption of land plaster has shown practically no increase or has decreased, while the use of the calcined products has grown very rapidly, until at present the raw products represent only a small percentage of the value of the gypsum products.

STRATIGRAPHIC DISTRIBUTION OF GYPSUM.

The age of the principal gypsum and salt deposits of the world are given in a table by Wilder[14] which is given herewith.

Foreign	*American*
Pleistocene and Recent	
Caspian Sea and Asiatic Lakes.	Great Salt Lake.
Pliocene	
Transylvania, near Prague (salt).	
Caspian Sea in Karabhogas Bay (salt and gypsum).	
Austria at Wieliczka, Siebenburgen (salt and gypsum).	
Miocene	
None	
Oligocene	
Transylvania and Carpathian Mts. (gypsum and salt).	
Germany, Sperenberg (gypsum).	
France, Montmartue (gypsum).	
Eocene	
None	

[14]Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 114-115.

Cretaceous	
None	
Jurassic	
None	
Triassic	
Germany: Hanover, Austadt. Erfurt, Thuringia. Lothringen (gypsum and salt). England: From Scotland to Devonshire (gypsum and salt)	Black Hills (gypsum).
Permian	
Germany: The Hartz (gypsum). Stassfurt, Sperenberg (gypsum and salt). South Tyrol (gypsum). Russia (gypsum, salt).	Iowa (gypsum) Texas (gypsum). Kansas (salt and gypsum) Oklahoma and Indian Territory. Black Hills (gypsum).
Upper Carboniferous	
None	
Lower Carboniferous	
	Lower Michigan (gypsum). Nova Scotia (gypsum and salt). Virginia (gypsum and salt). Montana (gypsum).
Devonian	
None	
Silurian	
Russia, Baltic provinces, (gypsum).	New York (gypsum and salt). Ohio (gypsum and salt). Pennsylvania (gypsum). Upper Michigan (gypsum).
Ordovician	
None	
Cambrian	
Punjab Salt Range, India.	

In addition to the deposits mentioned in the table the following should be noted: (1) Gypsum and salt in the Pennsylvanian rocks in Kimberly district, Australia[15]; (2) the great deposits of the Rocky Mountain region and the great basin in Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada, probably ranging in age from Pennsylvanian to Jurassic; (3) gypsum in southwestern Germany[16], and in Sussex, England[17], in the upper Jurassic (Purbeckian); and (4) the gypsum and sulphur deposits in the northern Apennines of Italy in the Pliocene.

From the table and notes it will be seen that the more important gypsum deposits are grouped into the Silurian, Permian, and Triassic, in America and Europe, with important deposits in Europe in the Oligocene and Pliocene and in America over restricted areas in the Mississippian. In general it may be said that widespread deposition of gypsum took place in those periods marked by large expanse of land. This is particularly noticeable in the Permian and Triassic in Europe and America, and the Pliocene in Europe. The periods of widespread submergence or of expansion of the water areas. Cambrian (except in northern India), Devonian, Ordovician, Mississippian (except for restricted areas in North America), Cretaceous, Eocene, and Miocene have no important gypsum deposits.

AREAL DISTRIBUTION OF GYPSUM.

The distribution of gypsum deposits outside of the State is of prime importance to the industry in Oklahoma, since this distribution, in large measure, controls the conditions of competition. In the following paragraphs the distribution in foreign countries is noted very briefly and that in the United States somewhat more fully.

Foreign.

Australia.—Gypsum occurs in layers in the Rolling Downs formation (Lower Cretaceous) and Desert sandstone (Cretaceous) in Queensland[18]. The beds are usually thin. Gypsum occurs in the beds of dry lakes and in Carboniferous beds in Western Australia. Large deposits are also reported from New South Wales, but they are too far from transportation to be utilized. Gypsum is produced commercially in Victoria.

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[15] Geikie, O., Text Book of Geol.: 4th Ed., p. 1059.
[16] Op. cit., p. 1153.
[17] Prestwich, Geology: vol. 2, p. 233.
[18] Grimsley, G. P., The Gypsum of Michigan: Mich. Geol. Survey, vol. 9, pt. II, 1904.

India.—Gypsum occurs in immense quantities in Northern India, principally in the Salt Range. Some of the deposits are of Eocene age, but the more important ones are in rocks which are probably Cambrian. Deposits are known in Afghanistan and Baluchistan. The production is small, not exceeding 5,000 tons annually.

Italy.—Gypsum occurs as alabaster in the lower part of the Pliocene of the northern Apennines. The mines at Volterra have been worked for a long period of time.

Australia.—Immense beds of rock salt and gypsum are present in Pliocene strata in the northern flank of the Carpathian Mountains at Wieleczka near Cracow. In the same general region and in Transylvania gypsum and rock salt occur in the Oligocene.

Crete.—Gypsum occurs in beds in the upper Triassic on the island of Crete.

Cyprus.—Gypsum deposits are worked on both the east and west coasts of Cyprus. The rock is calcined and used for building material on the island and is exported to Turkey and Egypt.

France.—The important gypsum deposits of the Paris Basin are in upper Eocene strata. The highest and most important bed is 65 feet thick at Montmarte. It is a fresh water deposit, containing bones of mammals, terrestial shells, and wood, conformable on marine deposits below. Three bands of gypsum occur lower in the Eocene. The product from this area has given the name of plaster of Paris to calcined gypsum the world over. The rock is worked by means of quarries, drifts, and shaft mines. The gypsum is rather impure, carrying as high as 10 to 12 per cent of calcium carbonate, which, however, does not seem to impair the plaster.

Germany.—Gypsum and rock salt beds are intercalated with fresh water limestones in the upper Jurassic (Purbeckian) in Westphalia and in northwestern Germany. The important deposits, however, occur in the upper Triassic in Hanover, Austadt, Erfurt, Thuringia, and Lothringen; and in the upper Permian in the Hartz Mountains, Stassfurt, and Sperenberg.

England.—Gypsum occurs in commercial quantities in Staffordshire, Derbyshire, Nottinghamshire, Cumberland, Westmoreland, and Sussex. The rock occurs as nodules and lenticular beds up to 15 feet in thickness. The principal deposits are of upper Triassic age, but those in Cumberland and Westmoreland are Permian and those of Sussex are upper Jurassic. The deposits have been worked for generations and utilized in various ways. The annual production for several years has been about 200,000 to 225,000 tons.

Canada.—The gypsum deposits of eastern Canada have been described recently by Jennison[10] and his summary is as follows:

"Gypsum deposits of economic importance are found in most of the provinces and territories of the Dominion of Canada. Those having the greatest area, and most accessible, are found in the eastern provinces, where they occur in the lower Carboniferous formation, and are practically inexhaustible.

"In British Columbia large deposits of gypsum occur associated with grey schists and white crystalline limestone. They are found north of the middle crossing of the Salmon river, and have a thickness of over 100 feet. They are also found in the vicinity of Spence's Bridge.

"In Alberta, on the Slave river, 40 miles above Smith's landing, there is an outcrop of limestone, associated with some gypsum and mineral tar. It is also found one mile south of the forks of Salt river. The exposure is 20 feet thick and interbedded, and has underlying it thin layers of red clay.

"In Manitoba, at St. Martin lake, 10 miles west of the outlet of Little Saskatchewan river, gypsum deposits are found of considerable importance. The exposures are worked as open quarries, and the product hauled in the winter season to the shores of Lake Manitoba by team; after manufacturing it is shipped by steamer to Westbourne railway station. The rock is exposed on a number of outcrops, the highest being 60 feet above St. Martin lake. Some anhydrite is seen, and large quantities of selenite. Geologically its position is either that of the lower Devonian or upper Silurian, probably the Salina formation.

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[10] Jennison W. F.. Gypsum deposits of the Martime Provinces: Canada Dept. of Mines, Minech Branch, No. 84, 1911, p. 21.

"In Ontario a small amount of gypsum is mined yearly; it occurs on the Grand river, in the vicinity of Paris, in Brant county. The gypsum formation extends from the Niagara river to Saugeen, a distance of 150 miles. Its occurrence is in veins from 2 to 7 feet thick and separated into several layers.

"In Quebec the principal deposits occur in the lower Carboniferous measures of the Magdalen islands.

Newfoundland[20].—The gypsum deposits of this island occur on the west coast. Geologically they are in the same position and resemble those of Nova Scotia. They occur in extensive beds, with prominent exposures on Romaine brook, at Piccadilly, south side of Port-au-Port bay, and at different points on the south side of St. George bay. The rock is white, and in texture, both compact and granular; very little anhydrite is seen."

United States.

Virginia[21].—The commercial gypsum deposits of Virginia

Watson, T. L. Mineral resources of Virginia: 1907.

occupy a narrow belt about 16 miles long in Smyth and Washington counties in the southwestern part of the state. Intimately associated with the gypsum are considerable salt deposits. Both substances are in shales of Mississippian age which underlie the Greenbrier limestone. The gypsum bearing shales outcrop around a syncline and the dip of the rocks is so steep that mining methods are necessary. The bodies of gypsum are large masses and lenses interbedded with red and gray clays and contain much irregularly distributed anhydrite. The average thickness worked is 30 feet. Commercial development of the deposits began early in the nineteenth century and several companies have operated in the region at different times. In 1910 and 1911 two mills were working at Plasterco and Saltville. The various forms of hard wall plaster are the principal products, but large quantities of the raw gypsum are ground and used as land plaster. Between 1890 and 1906 the annual production ranged from 6,000 to 20,000 tons and between 1890 and 1902 the value ranged from $17,000 to $45,000. Statistics for the past few years are not available on account of there being only two producers.

[20]Op. cit., p. 23.
[21]Eckel, E. C., Bull. U. S. Geol. Survey Nos. 213, 1902 and 223, 1904.

New York[22].—The gypsum deposits of New York are found in the Salina group, the upper part of the Silurian system. The Salina outcrops in an east-ward belt from 10 to 20 miles wide, about the same distance back from the south shore of Ontario. The section in a mine at Lindlen shows 7 beds of gypsum ranging from 4 to 11 feet in thickness separated by shale bands from 1 to 2 feet thick. The beds thin in both directions from Cayuga lake. To the east the beds become impure and are not of commercial importance east of Madison county. Most of the rock is dark colored and too impure to be used for the finer grades of plaster of Paris, but in the western end of the belt some of them are of high grade. For many years practically all of the output was sold crude for land plaster and the manufacture of the calcined plasters was not begun until later than it was in Ohio, Michigan, and Iowa. The gypsum, especially in the western part of the area, has proven suitable for wall plaster and in the past few years the manufacture of wall plaster has increased very rapidly while the production of land plaster has remained almost stationary; so that, at present, the calcined products make up the greater part of the output. Large quantities of the crude and calcined gypsum are used by the Portland cement mills of New York and Pennsylvania. The amount of material in the New York deposits is very great and so far only those deposits advantageously situated in regard to transportation have been developed. Most of the development is by quarries or open cuts but several drifts and shaft mines are used. Thirteen mills were reported as operating in 1910[23] and 12 mills in 1911. The total production in 1910 was 467,399 tons with a value of $1,153,973, and in 1911 was 472,834 tons with a value of $1,199,596. About two-thirds of the crude gypsum is calcined and the value of the plaster in 1912 was four-fifths of the value of the total output.

Ohio[24].—The gypsum deposits of Ohio are confined to small areas near Sandusky bay. The beds occur near the top of the Silurian system in the Rondout formation. On the north shore of the bay, southeast of Port Clinton, 150 to 200 acres of workable gypsum have been shown by core drilling. Another area has been prospected about 2½ miles north of Castalia on the

[22]Eckel, E. C., Bull. U. S. Geol. Survey No. 223, 1904, p. 33-35.
[23]The statistics given for the various states are taken from the Mineral Resources of the United States for 1911, U. S. Geol. Survey.
[24]Peppel, S. V., Gypsum deposits in Ohio: Op. cit., pp. 38-44.

south shore of the bay. Some of the drill holes on the north side of the bay show as many as 8 beds of gypsum varying from 18 inches to 10 feet in thickness separated by limestones from 3 to 10 feet thick. The gypsum where worked is as much as 9 feet thick. It is a rock of a grayish cast due to numerous fine wavy bands of bituminous material. There are occasional thin, shaly partings having irregular courses through the gypsum rock. The material was first worked by open quarries but most of it is now obtained by under ground workings. Water gives considerable trouble. Two plants were operated in 1910 and three in 1911, all on the north shore of Sandusky bay near Port Clinton. On account of the small number of producers the statistics of production are not made public. The combined production of Virginia and Ohio in 1910 was 292,987 tons of crude gypsum with a value of $821,213, and in 1911 was 369,858 tons with a value of $1,056,568. Ohio probably furnished considerably over half the combined production.

Michigan[25].—Gypsum is known to occur in two localities on the Lower Peninsula, at Grand Rapids near the western coast and at Alabaster on the eastern coast. The deposits are found in the lower Grand Rapids series of Mississippian age, which outcrops as a ring around the interior coal basin. The deposits at Grand Rapids consist of an upper ledge 6 feet thick separated by about 1 foot of shale from a lower ledge 12 feet thick. At Grandville there is a ledge 11 feet thick separated by 4 feet of limestone from a lower ledge 14 feet thick. The gypsum is a massive rock gypsum of a high degree of purity. It is worked both by quarries and underground workings. The Alabaster quarry is at Alabaster, three-fourths of a mile back from the shore of Saginaw bay. The bottom of the quarry is about 15 feet above the water level. The face of the quarry is 16 to 22 feet high and more than one-fourth of a mile in length. The cover consists of about 10 to 12 feet of stiff bowlder clay which is removed by a steam shovel. In addition to these deposits on the Lower Peninsula, gypsum is known to occur at St. Ignace in the Upper Peninsula but it is not utilized and little is known concerning its extent or value. It is found in rock of the Monroe group of Saline age. Eight mills were

[25]Grimsley, G. P., Gypsum deposits in Michigan: Bull. U. S. Geol. Survey, No. 223, 1904, pp. 45-47; and The gypsum of Michigan: Mich. Geol. Survey, vol. 9, Pt. II 1904.

operated in Michigan in 1910 and 1911, 7 near Grand Rapids and 1 at Alabaster. In 1910 the total output of crude gypsum was 357,174 tons and the total value of the products was $668,201, and in 1911 the total output was 347,296 tons with a value of $573,926. The value of the calcined products is over four-fifths of the total.

Iowa[26].—The gypsum area of Iowa occupies 60 or 70 square miles near Ft. Dodge, Webster county, near the center of the state. The gypsum occurs as a single bed made up of several layers separated by extremely thin clay partings. It is associated with red clay and is probably of Permian age. The bed is covered, except immediately along the Des Moines river and its tributaries, by a mantle of glacial drift 60 to 80 feet in thickness. The thickness of the gypsum bed is variable on account of the pre-glacial erosion. Where it is fully developed the following divisions are recognized:

Division of Gypsum Bed in Iowa.

		Feet.
5.	Upper rock, suitable for plaster, varying in thickness on account of difference due to loss by pre-glacial erosion	3 to 12
4.	Six-foot ledge, best of the plaster rock	6
3.	Hard ledge, inferior for plaster	4
2.	Eighteen-inch ledge, not good for plaster	1½
1.	Bottom ledge, not good for plaster	5

The material is a dense, fine-grained rock, with alternating green and white bands about one-half inch thick. The microscope shows that it consists of a mass of minute crystals. The development of the Iowa gypsum began in 1872. The mills along the Des Moines river and its tributaries strip the gypsum and operate quarries. Back on the prairie the stripping is too thick for quarrying and the material is reached through shafts. The upper part of the bed is left for a roof. Six plaster mills and one paint mill using gypsum were operated in this field in 1910 and 1911. The output in 1910 was 322,713 tons of crude gypsum and the value of the products was $943,849, and in 1911 the output was 354,204 tons, and the value, $857,287.

[26]Wilder, Frank A., Gypsum deposits in Iowa: Bull. U. S. Geol. Survey No. 223, 1904, pp. 49-52; and Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 99-166.

Practically all the gypsum produced in Iowa and the states to the southwest is calcined. The value of the gypsum sold crude in Iowa, Kansas, Oklahoma, and Texas in 1911 was $66,072. The most of this product went to Portland cement plants. Less than 5,000 tons were sold for land plaster in the four states.

Kansas[27].—The gypsum deposits of Kansas occur in a belt crossing the state from north to south a little east of the middle of the state. The three principal areas are near Blue Rapids in the northern part of the area, near Gypsum City in the central part, and near Medicine Lodge in the southern part. The deposits in the northern portion are in the lowest part of the Permian rocks, those of the central area are higher in the system and those near Medicine Lodge are near the top of the system as exposed in Kansas. The last named beds are the continuation of the main line gypsum hills of Oklahoma. Both rock gypsum and gypsite or earth gypsum are present in almost inexhaustible quantities. The gypsite is most abundant in the central area. Plaster has been manufactured in the state since 1875. Seven mills were operating in 1909 and 1910 and six mills in 1911. During the last few years the value of the annual output has been between $300,000 and $400,000.

Oklahoma.—The gypsum deposits of Oklahoma occur in the Permian Redbeds in the western portion of the State. They consist of rock gypsum and gypsite deposits. The commercial deposits may be divided into three areas: (1) The first line of gypsum hills, along Cimarron river, (2) the second line of hills including parts of Dewey, Custer, Washita, Caddo, and Stephens counties, and (3) the Southwestern Area in the extreme southwestern part of the State. The gypsum of the first line of hills occurs in 3 beds separated by clay shales. The stratification in the second line of hills is very erratic, and the gypsums are not continuous over large areas, but some of them reach a thickness of over 60 feet. There are 5 ledges in the southwestern area, some of them reaching a thickness of 20 feet. Mills are located at Watonga (2), Bickford, Wilson, Alva, Southard, Okeene, Rush Springs, Ferguson, and Eldorado in the gypsum area, and at McAlester in the eastern part of the State. All the gypsum is secured from hillside quarries and

[27]Grimsley G. P., Gypsum and gypsum cement plasters: Univ. Geol. Survey of Kans., vol. 5, 1899, pp. 48-50.

the gypsite is worked with drag scoops or wheeler scrapers. The total gypsum mined in 1910 was 162,788 tons and the value of the products was about $450,000, and in 1911 the gypsum mined was 108,653 tons and the value was $287,591.

Texas[28].—The gypsums of the southwestern area of Oklahoma continue into Texas as far as Colorado river, maintaining the same general characteristics which they possess in Oklahoma. A second area is in the eastern part of El Paso county, east of the Guadalupe mountains. The stratigraphy and the gypsums resemble those of the first area and the deposits were probably formed continuously although the outcrop is interrupted from Colorado river to the Pecos by a covering of younger rocks. A third area is in the Malone mountains, where the gypsum is in Jurassic or Cretaceous rocks. The area is near the Southern Pacific Railway but is distant from any large market and has not been developed. The gypsums of the second line of hills in Oklahoma continue up Canadian river across the Panhandle of Texas and connect with the large deposits in eastern New Mexico. Gypsum is found disseminated through the Cretaceous rocks in the eastern part of the State but not in commercial quantities. Three plants operated in Texas in 1910 and four in 1911. All are in the northern part of the first area in the vicinity of Quanah. The output of crude gypsum in 1910 was 188,559 tons and the value of the products was about $490,000, and in 1911 the output was 179,625 tons with a value of $486,162.

South Dakota[29].—The Spearfish formation, made up of Redbeds of Permian or Triassic age, outcrops in a belt around Black Hills dome in western South Dakota and eastern Wyoming. The outcrop of the gypsum-bearing rock averages about 3 miles in width. The thickness of the gypsum varies greatly, but locally over 30 feet of pure white gypsum occurs. The beds are formed at different horizons; some are continuous for long distances while others are lenticular. Transportation facilities are near the beds at Hot Springs, Rapid City, Spearfish, New-

[28]Blke, W. R., Gypsum beds in southern Arizona: Am. Geol., vol. 18, 1896, No. 223 1904, pp. 68-73; and Gould, Chas. N., Geology and water resources of the Panhandle of Texas; Water-Supply Paper U. S. Geol. Survey Nos. 154 and 191.

[29]Darton, N. H., Gypsum deposits in South Dakota: Bull. U. S. Geol. Survey, No. 223, 1904, pp. 76-78.

castle, and Edgemont. A mill was formerly operated at Hot Springs, but in 1910 only 2 plants, one near Rapid City and one at Spearfish, were operating. In 1911 another plant near Rapid City was added to the list. In the statistics the production of South Dakota is combined with that of several other states and cannot be stated accurately.

Montana[30].—The gypsum beds of Montana occur intercalated with red and green shales and limestones of Mississippian age, which are immediately overlain by Jurassic limestones. The important deposits are in Carbon and Cascade counties on the eastern flanks of the Rocky Mountains. The rocks lie at steep angles near the mountains and nearly level at a short distance away. The beds range from a few feet to as much as 50 feet in thickness. Mills are located at Armington, Bridger, and Riceville, but only at Riceville was there production in 1910. The production is combined with that of several other states in the published statistics and cannot be given.

Wyoming[31].—The deposits of gypsum of economic importance in Wyoming are in the Red Beds of Permian or Triassic age. These rocks are exposed around the base of most of the mountain ranges and in the cores of the smaller folds where there has been sufficient erosion to remove the overlying rocks. The areas where the gypsums are known to occur are as follows: Rawlins uplift, Freezeout Hills, Grand Canyon of the Platte, Black Hills, and the Laramie, Medicine Bow, Shirley, Seminole, Ferris, Rattle Snake, Bighorn, Owl Creek, Absaroka, Prior, Wind River, Gros Ventre, and Salt Creek mountains. In all there are about 1,500 miles of the gypsum-bearing formations exposed, and the gypsums ordinarily vary from 5 to 20 feet in thickness and occasionally reach a thickness of 30 to 50 feet. There are also important gypsite deposits known along the base of the Laramie Mountains. Most of the gypsum deposits are at considerable distance from transportation and the only development so far has been in the vicinity of Laramie. In 1910 and 1911 three mills—two of them at Laramie using gypsum and one at Red Butte, 10 miles south of Laramie, using rock gypsum—were reported. In 1911, 44,687 tons of raw material were used and the products were valued at $116,237.

[30] Weed, W. H., Gypsum deposits in Montana: Op. cit., pp. 74-75.
[31] Knight, Wilbur C., Gypsum deposits in Wyoming: Op. cit. pp. 79-85.

Colorado[32].—The principal gypsum deposits of Colorado are massive beds which outcrop at intervals along the eastern foothills of the Rocky Mountains. They occur in series of red sedimentaries usually referred to as the Jura-Trias. The gypsum reaches a thickness of 30 feet and much of it is of a good quality. The beds have been worked at Loveland, Morrison, Perry Park, Colorado City, and Canyon. The supply is regarded as inexhaustible. Other deposits occur near the station of Gypsum on the Rio Grande Railroad in the western part of the State, also in the San Juan mining region, to the east of the La Sal Mountains, and near Rico in the southwestern part of the State. At the last named locality a bed of gypsum 30 feet in thickness, which has been locally removed by solution, has played an important part in the deposition of the ores of the area[33]. All of these deposits are of Carboniferous age. None of those in the western and southwestern portions of the State have been utilized to any extent.

In 1910 and 1911, 4 mills were operated at Loveland, Canyon City, Ruede, and Portland. The last named mill uses gypsum from Coaldale. The production of crude gypsum in 1910 was 45,280 tons and the value of the products was $118,809; and in 1911 the production was 26,226 tons with a value of $59,936.

New Mexico[34].—The Red Beds of the Permian or Triassic age, which are gypsum bearing over a great territory in the Rocky Mountain and Great Plains regions, occupy great areas in New Mexico. The largest area lies in the eastern part of the State, principally in the valley of the Pecos River. Outcrops along Canadian River connect this field with the vast area of Kansas, Oklahoma, and Texas. The other large areas are in the Rio Grande valley south of the center of the State and the Zuni or Western Region. Very little detailed geologic work has been done on these areas, but gypsum is known to be extremely abundant. A remarkable accumulation of white gypsum sand forming dunes covers an area of about 350 square miles in Otero county. The development of the gypsum of New

[32] Lakes, Arthur, Gypsum deposits in Colorado: Op. cit., pp. 86-88.
[33] Ransome, F. L., Rico folio (No. 130) Geol. Atlas U. S., U. S. Geol. Survey, 1905.
[34] Herrick, H. N., Gypsum deposits in New Mexico: Bull. U. S. Geol. Survey No. 223, 1904, pp. 89-90.

Mexico is greatly hindered by the distance to markets and the excessive freight rates. Several projects have failed on this account. In 1910 only one mill, located at Came, Chaves county, was reported as operating. Small amounts of raw gypsum are quarried at El Rito and the white sands near Alamagordo are used in a small way. The production of New Mexico cannot be given since it is combined with that of several other States in the published statistics.

Arizona[35].—Several localities are known in southern Arizona where gypsum can be obtained in quantity, the principal one being: (1) The Santa Rita Mountains, Pima County, southeast of Tucson, (2) the low hills along the course of san Pedro River in Cochise and Penal Counties, (3) the Sierrita Mountins south of Tucson, (4) the foothills of the Santa Catalina Mountains north of Tucson, and (5) Fort Apache Reservation in Navajo County. In the first named locality the gypsum beds are of considerable thickness and extent and are about 10 miles from the Southern Pacific Railway. The age of the beds is probably Permian or Triassic. The other deposits are apparently small. The deposit north of Tucson has furnished material for plaster used in that town. The deposits on Fort Apache Reservation consists of large selenite crystals. In 1910 gypsum quarried near Winslow, Navajo County, was shipped to plaster mills at Los Angeles, Cal., and a mill at Douglas utilized gypsum quarried near that place.

Utah[36].—The more important gypsum deposits of Utah occur in the central and southern portions of the State, in Juab County, east of Nephi; in Sanpete and Sevier Counties, near Saline; in Millard County, at White Mountain near Fillmore; and in Wayne Couny in South Wash. All are of rock gypsum except the one at Fillmore which consists of granular and crystalline gypsum blown up from the bed of a dry lake. The deposit at Nephi is one of the largest deposits in the United States. It forms the entire mass of prominent spur at the entrance to Salt Creek Valley and outcrops from the level of the creek up the slope in a southwesterly direction in the form of

[35]Blke W. R., Gypsum beds in Southern Arizona: Am. Geol., vol. 18, 1896, p. 394; and Gypsum deposits in Arizona: Bull. U. S. Geol. Survey No. 223, 1904, pp. 100-101.

[36]Boutwell, J. M.. Gypsum deposits in Utah: Bull. U. S. Geol. Survey No. 223, 1904, pp. 102-109.

a vertical bed or lens. The exposed portions of this body are from 275 to 300 feet in thickness, 500 feet in height along the bedding, and at least 200 feet in length along the strike. The entire thickness is of gypsum but the quality of the material varies in different parts of the body. Two beds, one 55 and the other 65 feet thick, are designated as first class gypsum. The age of the Nephi deposit, as well as that of the other rock gypsum bodies, is somewhat in doubt but they have been referred to the Jurassic. The gypsum sands at White Mountain near Fillmore are late Tertiary or Quaternary. In 1910, four mills produced plaster,—one at Nephi, one at Levan, and two at Sigurd. The raw gypsum consumed totaled 46,279 tons and the products were valued at $149,089.

Nevada[37].—The important gypsum deposits of Nevada occur in the northwestern part of the State, in the Humboldt Mountains near Lovelocks and in the Virginia Mountains halfway between Carson and Virginia. The deposits are large and easily accessible to the railway. The rocks are strongly folded and crumpled and the beds of gypsum dip at high angles. Limestone is associated with the gypsums. The age of the deposits is almost certainly Triassic. Other deposits are known in southern Nevada in rocks of probable Jurassic and of Carboniferous age. Considerable beds are known in the Tertiary or later lake beds which are widely distributed over the State. They have not been utilized. Four mills manufactured plaster in 1910,—two at Moundhouse; one at Reno in the northwestern part of the State, and one at Arden, Clark County, in the extreme southeastern portion. Most of the product goes to supply the California markets. The production can not be stated accurately but its value is probably in excess of $250,000.

California[38].—The gypsum deposits of California occur in the southern part of the State. They may be divided into four general types according to their origin—(1) efflorescent deposits, (2) periodic-lake deposits, (3) interbedded deposits, and (4) veins. The efflorescent deposits are of gypsite which has been formed by evaporation of water which has passed through gypsiferous rocks. They are confined to the region of the Coast Range. The deposits are usually shallow and of small

[37]Louderback, George D. Gypsum deposits in Nevada: op. cit. pp. 112-118.

[38]Hess, Frank L., A reconnaissance of the gypsum deposits of California: Bull. U. S. Geol. Survey No. 413, 1910.

extent. The material is often too impure to be used for plaster. Some of the localities where beds are known to occur are Mendota, Coalinga, Dudley, the Lost Hills, M'Kittrick, Sunset, Bakersfield, in San Benito County, east of the Carrizo Plain, and at Carona. The periodic-lake deposits are formed by the evaporation of the water of the intermittent lakes which are abundant in the arid regions of the southern part of the State. These deposits are reported from near Dudley, Kern Lake, Buena Vista Lake, and at Amboy in the Mojave desert where the material is worked for a plaster mill. The interbedded deposits consist principally of thin layers of gypsum, from a fraction of an inch to 3 or 4 inches thick, interstratified with much more impure clayey material. Many of the deposits are too impure to be worked and the only large beds of pure gypsum known are in the Palen Mountains too far from a railroad to be worked with profit. All the interbedded deposits are of Miocene age. The principal deposits are located as follows: on Santa Barbara Creek, French Point, Point Sal, Castaic, Palendale, in the Palen Mountains, in the Maria Mountains, at Necca, and at other places in the Colorado Desert. The vein deposits are unimportant. In 1910 gypsum was ground for land plaster or wall plaster at 9 mills in the State. During that year 45,901 tons of raw material were produced and the products were valued at $242,203. In 1911 the production was 43,855 tons and the value $204,264.

Oregon[39].—The only known commercial deposit of gypsum in Oregon occurs near the middle of the east boundary line on a ridge separating Burnt River and Snake River, 4 miles from Huntington. The gypsum occurs as elongated lenses, 20 to 40 feet thick, in a series of sedimentary rocks with intercalated volcanic tuffs, all probably of early Mesozoic age. The gypsum is in part white and crystalline; in part, however, it contains thin strata and films of a greenish chloritic mineral. Open quarry methods are used in securing the material, which is then carried on an aerial cableway to the railroad on Snake River and hauled 10 miles to Lima where it is burned into plaster. Another deposit, partly gypsite, is reported near Bend Creek in Crook County, but it has not been developed.

[39]Lindgren, Waldemar, The gold belt of Blue Mountains in Oregon: 22d Ann. Rept., U. S. Geol. Survey, Pt. II 1901 pp. 639 and 753; and Gypsum deposits in Oregon: Bull. U. S. Geol. Survey No. 223 1904, p. 111.

Idaho[40].—Gypsum occurs in Washington County in the bluffs overlooking Snake River about 10 miles from Huntington, Oregon. The material consists of lenticular masses of rock gypsum 6 to 20 feet thick, which are apparently of the same series as the deposits near Lime, Oregon. Mining methods must be used to secure the gypsum in large quantities. A railroad passes down the Oregon side of Snake River, sufficiently near for the rock to be carried to it from the bluffs on an aerial cable way. So far the deposit has not been developed beyond the prospecting stage.

Alaska[41].—Gypsum is known to occur in workable quantities in one locality in southeastern Alaska, on the east shore of Chicago Island. The deposit is of very pure gypsum, and is considerably over 50 feet in thickness. The age of the rocks is probably early Mesozoic. The extent of the deposit is not known but it is ample to provide a large supply of material. A railroad one mile in length carries the rock from the mine to a wharf where it is loaded on hulks or barges and shipped to mills on Puget Sound.

[40]Burchard, Ernest F., Mineral Resources of the U. S., U. S. Geol. Survey, 1910.

[41]Wright Chas. W., The building stones and materials of Southeastern Alaska: Bull. U. S. Geol. Survey No. 345, pp. 124-125, 1908.

CHAPTER II.

THE MANUFACTURE OF GYPSUM PRODUCTS.

EFFECT OF HEAT ON GYPSUM.

The greater part of the value of gypsum in the industries depends on the fact that under the influence of a moderate degree of heat three-fourths of the water of crystallization is given off. The gypsum whose formula is $CaSO_4.2H_2O$ becomes $(CaSO_4)2.\ H_2O$. The water begins to come off below 100°C. (212°F.) but is given up very slowly until a temperature of about 130°C. (266°F.) when it is liberated very rapidly. The $(CaSO_4)2.\ H_2O$ thus formed is ordinarily known as plaster of Paris. When it is mixed with water the $(CaSO_4).2H_2O$ takes up water and recrystallizes as gypsum. This "setting" is the property which renders the calcined gypsum of value for plaster in its various forms.

At 163°C. (325°F.) more water is given off and from this temperature to 221°C. (430°F.) little or no change takes place in the material, but above this temperature the plaster takes up water very slowly and sets only after several hours. If heated above 343°C. (430°F.) little or no change takes place in the material, but above this temperature the plaster takes up water very slowly and sets only after several hours. If heated above 343°C. (650°F.) the plaster is completely dehydrated, *i. e.*, it becomes $CaSO_4$ or anhydrite and the crystalline structure is destroyed. It will not set and is said to be "dead burned." At higher temperatures the anhydrite melts, forming a crystalline mass on cooling.

THEORY OF THE SET OF GYPSUM PLASTER.

The principal work in America on this subject has been done by G. P. Grimsley in connection with his work on the gypsums of Kansas and Michigan. His review of the work of earlier investigators and his conclusions are here given in full[42].

"When water is added to plaster of Paris, it sets in a solid mass. This is all that it is necessary for the plasterer to know in order to do his work, but to many of these men the subject of the true nature of the set is an interesting and puzzling problem. Just what is the process of setting of plaster?

"As far as we can learn from the chemical and physical literature, this question was first answered by that famous French chemist, Lavoisier, who in 1765 described the results of his experiments in the following words, translated from the French:

''I took the calcined plaster, as has been described before, and which hardens readily with water. I threw it into a considerable amount of water, in a pan or large dish. Each molecule of plaster, in passing through the liquor, seized its molecule of water of crystallization, and fell to the bottom of the dish in the form of small brilliant needles, visible only with a strong lens. These needles, dried in the free air or with the aid of a very moderate heat, are very soft and silky to the touch. If placed on the stage of a miscroscope, it is perceived that what was taken under the lens for needles are also parallelopipeds, very fine, so they are described as thicker, or many times thinner, and many more elongated. The plaster in this state is not capable of uniting with water, but if it is calcined anew, these small crystals lose their transparency and their water of crystallization, and become again a true plaster, as perfect as before. One may, in this fashion, successfully calcine and recrystallize the plaster even to infinity, and consequently give it at will the property of seizing water.'

"This explanation of the set of plaster through the formation of a crystalline net work was verified a number of times later, and was given by Payen in 1830 as his first principle in the chemistry of plasters.

"The next important contribution to the chemistry of plaster was by Landrin in 1874, who divided the set of plaster into four periods:

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[42]Grimsley, G. P., Mich. Geol. Survey, vol. 9, 1904 pp. 135-139.

"'1. The calcined plaster, on contact with water, unites with this liquid and takes a crystalline form.

"'2. The plaster dissolves partially in water, which becomes saturated with this salt.

"'3. A part of the liquid evaporates, due to the heat set free in the chemical combination. A crystal is formed and determines the crystallization of the entire mass; a phenomenon which is analagous to that which takes place when a piece of sulphate of soda is placed in a saturated solution of this salt.

"'4. The maximum hardness is reached when the plaster gains enough water to correspond exactly with the formula $CaOSO_3$, $2H_2O$; this maximum being to the remainder in proportion to the quantity of water added to the plaster to transform it into mortar.'

"Chatelier in 1887 showed that plaster would set in a vacuum flask, so that evaporation was not a necessary step in the set of plaster, as Landrin maintained in his third principle above.

"According to Le Chatelier, the plaster of Paris compound $(CaSO_4)2.2H_2O$ dissolves in part in the added water, which diminishes the solubility, and the solution becomes supersaturated and $CaSO_4$, $2H_2O$, or gypsum, crystallizes out. In other words, the plaster of Paris dissolves, and becomes hydrated, then crystallizes out as gypsum, and every particle of the plaster goes through these steps.

"My own experiments agree then with those given by Lavoisier, Payen, Landrin, and Chantelier, in that the set of plaster is due to the formulation of crystalline network. The cause of the formation of this network of crystals, or the factor which starts th ecrystallization, is the troublesome part to explain, and this has attracted less attention among investigators along these lines.

"When gypsum is burned it forms, as Landrin showed and as analyses prove, the hydrate $(CaSO_4)2.H_2O$. Marignac called attention to the fact that if water is added in excess, this hydrate in part is dissolved, forming first a clear liquid which then becomes turbid, and crystals of $CaSO_4.2H_2O$, or gypsum are thrown down. How an examination of these formulae shows

that three parts of water have been taken up by the hydrate. $(CaSO_4)2.\ H_2O+3H_2O=2(CaSO_4,2H_2O)$.

"So first the plaster dissolves partially in contact with the water, as Landrin pointed out in his second principle, and as accepted by Chatelier. Next, some changes take place, whereby, according to Marignac's experiment, the liquid becomes turbid and crystallization begins. Landrin thought evaporation took place as a result of the heat formed by chemical combination, and that then a crystal was formed which started the crystallization through the entire mass. Chatelier showed by experiment that evaporation was not necessary and he argued that by taking up of this water the solubility of the hydrate was decreased, and so, on account of the resulting supersaturation, crystallization ensued.

"The solution of the hydrate in these experiments is certainly saturated, and all that is needed is something to start the crystallization. From a study of saturated solutions in the laboratory, it is well known that if crystals are introduced into such solutions crystallization will result and go on until the salt is crystallized out.

"The effect of heat on gypsum in the burning of plaster, as we have shown, is to remove a certain percentage of water and break up the small masses of the rock into finer and finer particles, microscopic and ultra-microscopic in size. If the heat is not carried too far certain particles through the mass may still possess their crystalline form and so they are true crystals though very small. These minute crystals in the saturated solution would start the process of crystallization. Their growth would cause the turbidity of the solution as noted by Marignac, and would result in the percipitation of small gypsum crystals, thus forming the crystal network which constitutes the set of the plaster.

"If the plaster is unburned the gypsum is not reduced to the proper fineness and uniformity, and so would not permit the crystallization to go on in the way it would in the properly burned plaster. But of more importance, the hydrate represented by plaster of Paris would not be formed.

"If the plaster is overburned, the plaster will be so completely comminuted that no minute crystals would be left to start the crystallization. Where the plaster is slightly overburned, the crystals are extremely fine and crystallization goes on very slowly and imperfectly."

PROCESSES OF MANUFACTURE.

The processes and machinery used in the manufacture of calcined gypsum products are in general very simple. The different operations involved in the manufacture in Oklahoma are quarrying, crushing, grinding, calcining, screening or classifying, and mixing.

Quarrying.—In Oklahoma all the rock gypsum is obtained from open hillside quarries. The supply of material near the surface is so great that underground methods will probably not be used for years to come. The material is blasted from the face of the ledge in large blocks and broken by means of hammers or mud shots into pieces easily handled by one man. Dynamite is the explosive used. Hand power augers are used to make the holes for the shots. The augers are of two types. The larger auger is on a heavy tripod like that of a steam drill and is operated by a crank. The other form is a simple auger similar to the carpenter's brace and bit, but 6 to 8 feet long. Pressure from the operator's body is applied to a cross bar at the top of the shaft. The broken rock is loaded into wagons or into dump cars on tracks and hauled to the mill or crushing plant. Gypsite is generally scraped up in drag scoops and loaded into wagons or care through a trap. Where the plant is very near the bed, wheeled scrapers are used and the "dirt" hauled directly to the plant.

Crushing.—Gypsite is ready for the kettles with no further treatment but the rock gypsum must be pulverized to a fine flour before calcining. For the first reduction a powerful jaw crusher (fig. 8) or nipper is used.

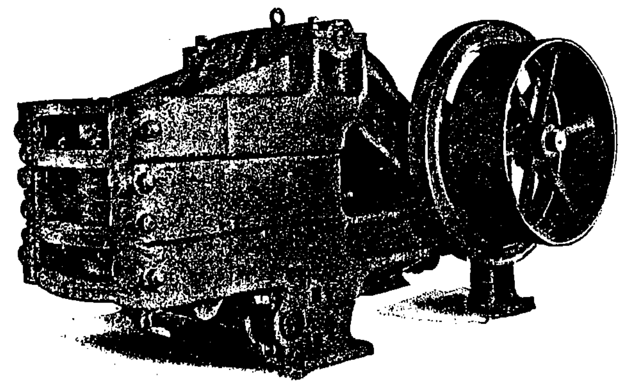


Fig. 8.—Jaw crusher.

The end of the machine opposite the pulley is of chilled iron. Opposite this is a movable chilled plate of the same pattern. The two are set at an angle so as to form a V-shaped box. The movable plate is moved alternately toward and away from the fixed plate by an arm which is driven by an eccentric on the shaft.

The capacity of the crushers and the power required to operate them vary greatly with the condition of the gypsum, since dry rock is crushed much more rapidly and with less power than wet rock. The following table[48] gives data as to size, capacity, etc., of the different sizes of crushers.

Jaw Crusher.

Size jaw opening in inches	Capacity in tons per hr. Jaws set apart 2 in.	Approx. weight, pounds.	Speed rev.	Pulley, inches.	Horse-power, approx.	List price.
15 by 22	12 to 25	10,000	250	36 by 10½	15	$ 550.00
22 by 28	25 to 40	20,000	230	40 by 12	25	900.00
24 by 34	60 to 70	24,000	230	42 by 15	35	1000.00

The 22 by 28 inch crusher is the one generally used in the gypsum mills. This machine will take pieces of about 50 pounds

[48]This table as well as the similar ones in the following paragraphs, is taken from the catalog of the J. B. Ehrsam & Sons Manufacturing Company, Enterprise, Kansas.

weight and reduce them to pieces about the size of a man's hand.

For further reduction a rotary fine crusher or cracker (fig.

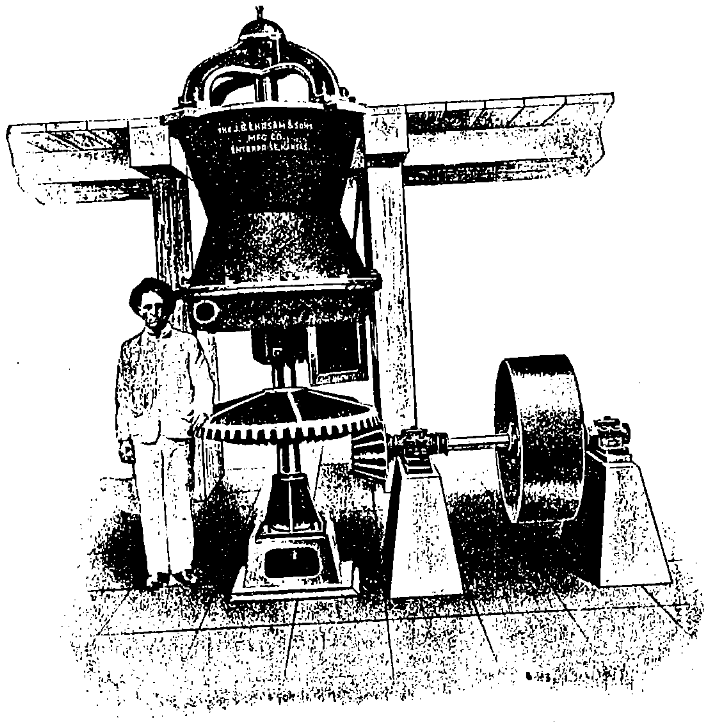


Fig. 9.—Rotary fine crusher or cracker.

9) is used. This machine consists of a conical shell whose inner surface is corrugated. Inside the shell revolves a shaft with a corrugated iron shoe. The crushing action is similar to that of the ordinary coffee mill. The rock is reduced in this mill to pieces a little larger than grains of corn, and in this condition is known as gravel. The crackers are made in different sizes as shown in the following table.

Rotary fine crushers.

No.	Largest size piece will take	Approx. cap., tons per hour	Horse power, approx.	Speed rev.	Pulley, inches.	Approx. weight, pounds.	List price.
1	4 in. Diam.	4 to 8	1 to 3	165	30 by 8	1,600	$150.00
2	6 " "	10 to 20	4 to 6	240	36 by 10	4,200	350.00
3	12 " "	25 to 40	15 to 25	240	36 by 13	10,000	550.00
4	14 " "	30 to 50	20 to 35	240	36 by 15	14,000	700.00

Grinding.—The gravel from the cracker is ground to powder in buhr mills. These mills may be either horizontal (fig. 10)

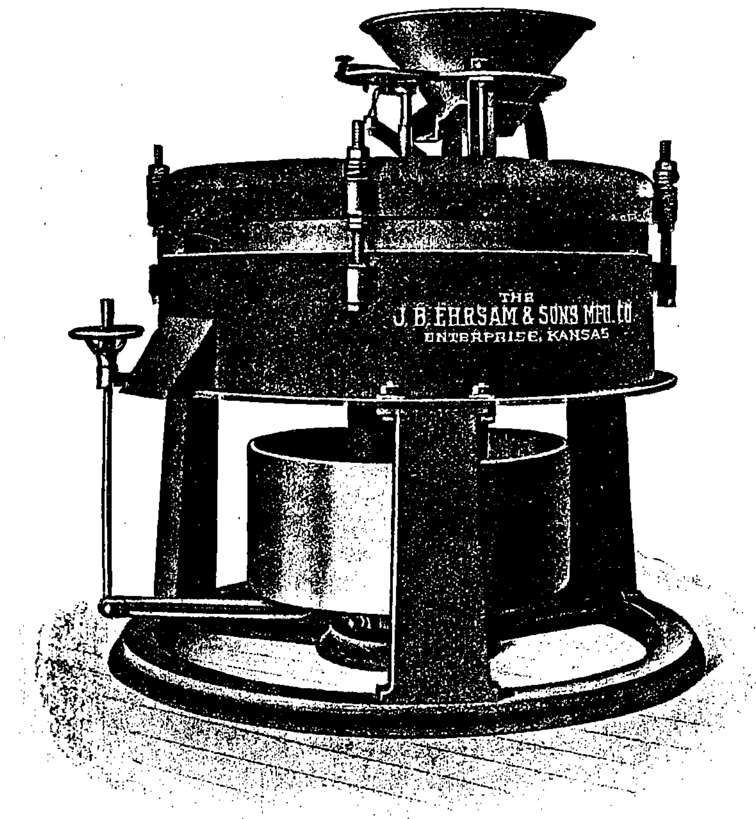


Fig. 10.—Enterprise horizontal buhr mill.

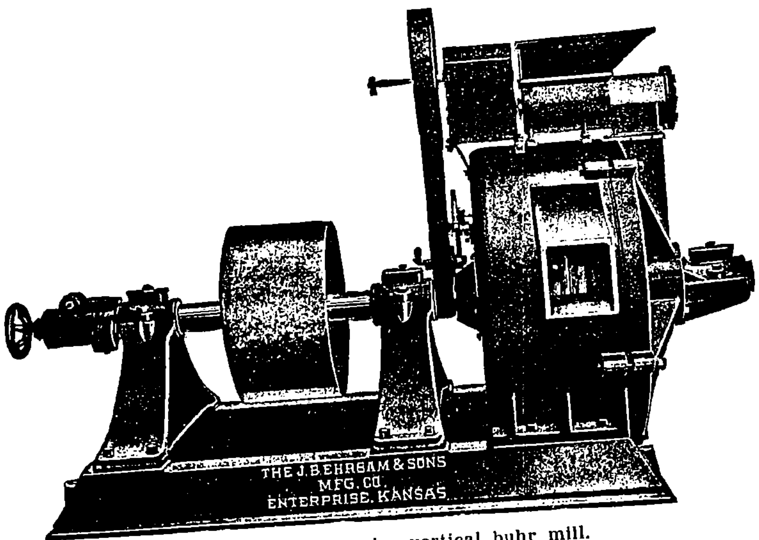


Fig. 11.—Enterprise vertical buhr mill.

or vertical (fig. 11) types. The stones are pebble grit, French buhr stones or rock emery (Sturdevant Mill). The faces of the stones are dressed into radiating furrows and must be re-dressed when they are ground smooth. An additional set of stones is usually kept on hand so as to save delay in operations while the dressing is done. In most of the mills the stones are mounted so that the faces are automatically drawn apart when the mill is not being fed. The capacity of the buhr mill varies greatly with the condition of the gypsum. Wet gypsum grinds much more slowly and requires more power than dry rock. The capacities and dimensions of the different types of buhr mills are given in the following tables:

Horizontal buhr mills.

Size	Height to top of feeder	FLOOR SPACE		Pulley, inches	Speed	HEIGHTS		PRICES			
		Pulley	Geared			Pulley	Geared	Pebble grit	Solid French	Old quarry French	Emery stones
42 in.	5 ft. 11½ in.	5 ft by 5 ft	8 ft. 5 in. by 5 ft.	30 by 14	400	6400	7000	$400.00	$450.00	$500.00	$600.00
36 in.	5 ft. 6 in.	4½ ft by 4½ ft	8 ft. 4 in. by 6 ft.	24 by 10	450	4500	5000	300.00	350.00	400.00	500.00

Vertical buhr mills.

Size	Length	Width	Height	Pulley, inches	Speed	Approx. weight, pounds.	Horse-power, approx.	Cap. tons per hour.	Prices		
									Pebble grit	French buhr	Rock emery
30 in.	6 ft. 0 in.	3 ft. 6 in.	4 ft. 2 in.	20 by 8	650	3600	10 to 20	1 to 4	$350.00	$375.00	$500.00
36 in.	9 ft. 3 in.	4 ft. 2 in.	5 ft. 9 in.	26 by 14	550	6800	20 to 35	3 to 8	550.00	600.00	750.00

Another machine for fine grinding is the lime disintegrator which consists of two cages revolving one within the other and in opposite directions. The cages have short cross-bars. The gypsum gravel is fed into the middle of the cages and by the motion is thrown out between the bars and is pulverized by the impact of the particles against the bars and against each other. The machine does not clog and has a high capacity, that of the 50-inch disintegrator being 60 to 75 tons in 10 hours. This machine saves the expense of dressing the buhr stones. It is used in some of the Michigan mills but has not been introduced into the Kansas and Oklahoma mills.

Calcining.—The calcining kettles are cylindrical and are built of steel three-eighths of an inch thick. The ordinary sizes are 8 to 10 feet in diameter and 8 feet in depth. A vertical rod passing down through the center of the kettle and driven by a cog wheel at the top, is provided with arms which stir the gypsum and keep it from burning on the bottom of the kettle while it is being calcined. Two or four flues about 1 foot in diameter pass through the kettle horizontally to secure a better distribution of the heat. In 4-flue kettles the flues are arranged in sets of two, a lower and an upper set. The kettles are set like a boiler above a grate and surrounded by a wall about two feet thick built of brick—fire brick on the inside and common brick on the outside. A space is left between the kettle and the wall, and partitions in this space cause the gases from the fire to pass into and through the lower flues, then entirely around the kettle and through the upper flues. The 10-inch kettle with 4 flues has a capacity of about 14 tons of plaster. Plans and sections of a 2-flue kettle and setting are shown in figure 12.

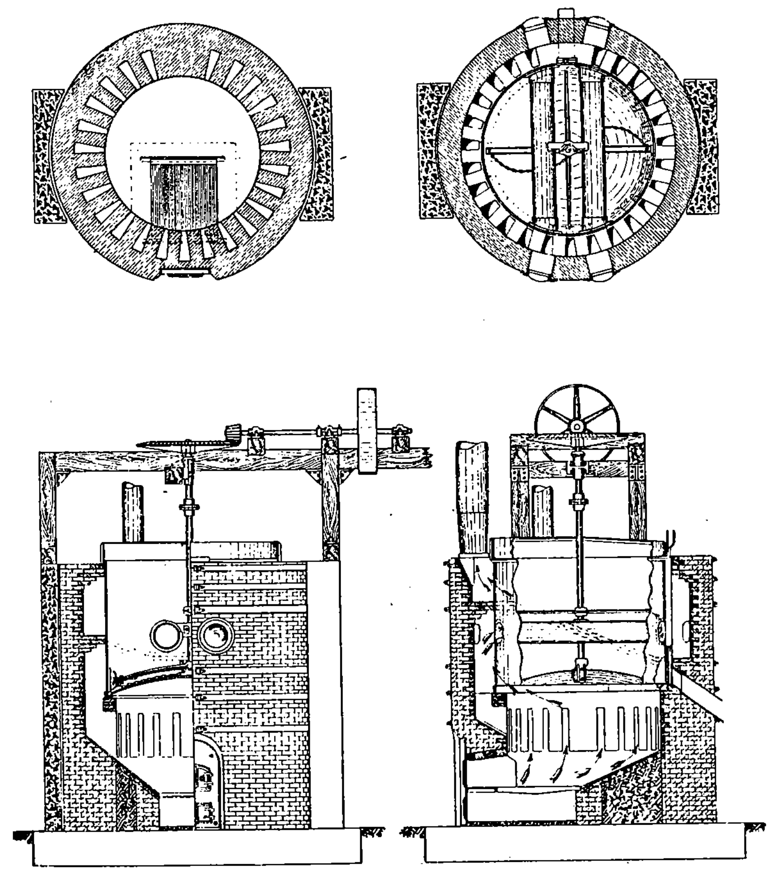


Fig. 12.—Ehrsam's 2-flue calcining kettle, standard setting.

Data concerning dimensions, capacities, and power required for the different sized kettles are given in the following table:

Data for calcining kettles.

Diameter of kettle	6 ft.	8 ft.	8 ft.	10 ft.	12 ft.	14 ft.
Height of kettle	6 ft.	6 ft.	8 ft.	8 ft.	8 ft.	8 ft.
Number of flues	2	2	4	4	4	4
Diameter of flues	12 in.	14 in.	14 in.	16 in.	20 in.	24 in.
Thickness of shell in kettle	¼ in.	¼ in.	¼ in.	⅜ in.	⅜ in.	7-16 in.
Thickness of tubes in kettle	¼ in.	¼ in.	¼ in.	¼ in.	¼ in.	¼ in.
Diameter of smoke stack	14 in.	20 in.	20 in.	24 in.	28 in.	36 in.
Length of smoke stack	40 ft.	48 ft.	48 ft.	48 ft.	48 ft.	48 ft.
Grate surface	2 by 3 ft	3 by 4 ft.	3 by 4 ft.	4 by 5 ft.	4½ by 5ft.	6 by 6 ft.
Diameter of upright shaft	3 3-16 in.	3 15-16in	3 15-16 in.	4 15-16 in.	5 2-16 in.	6⅝ in.
Length of upright shaft, lower section	7 ft. 6 in.	7 ft. 6 in.	9 ft. 10 in.	9 ft. 10 in.	9 ft. 10 in.	9 ft. 10 in.
Length of upright shaft, upper section	3 ft. 6 in.	3 ft. 6 in.	3 ft. 6 in.	4 ft.	4 ft.	4 ft.
Number of kettle bands	3	4	4	6	6	6
Weight of kettle and fixtures	6,000 lbs	12000 lbs	13,000 lbs	20,000 lbs	30,000 lbs	46,000 lbs
Number of common brick above floor	10,000	16,000	17,000	23,000	32,000	48,000
Number of fire brick	2,000	4,000	4,800	7,000	10,000	16,000
Capacity per charge (tons)	2 to 3	5 to 6	6'to 7	12 to 14	15 to 18	20 to 25
Power required on ground gypsum under ordinary conditions	8 h. p.	15 h. p.	15 h. p.	25 h. p.	38 h. p.	50 h. p.
Price	$450.00	$650.00	$750.00	$1000.00	$1400.00	$190.00

The gypsite or ground rock is fed slowly into the kettles, 1 to 2 hours being required to fill a 14-ton kettle, depending on the condition of the material. While being filled the kettle is kept at a temperature of about 212°F.

In about one hour after being filled the kettle reaches a temperature of 230°F. and the mass begins to "boil" owing to the expulsion of the water of crystallization. At about 10° higher the mass settles down solid, but at 270°F. begins to boil violently again. At about 350°F. a gate near the bottom of the kettle is opened and the calcined gypsum flows rapidly into the "hot pit" which is built of fire-proof material.

From this pit the material is elevated and screened through bolting cloth or fine wire screens. The portion passing through the screens is conveyed to bins above the mixers, while the coarse material is reground. In the bins retarder and hair or wood fibre are added, the whole passed down through the mixer which has openings at the bottom, through which the plaster is fed into sacks holding 100 pounds each.

In one mill in the State, at Wilson, the Cummer continuous calcining process is used. In this process a rotary kiln (fig. 14) is used in place of the kettles. The rock is crushed to three-fourths inch ring and stored in a bin over the feed spout of the rotary kiln. A mechanical feeder regularly feeds the crushed rock into the kiln. The calciner is provided with a mechanical stoker and special furnace setting to secure perfect combustion. The heated gases from the combustion are drawn by a fan into a large commingling chamber, which extends the entire length of the cylinder. At the same time sufficient air is admitted through registers in the side walls of the commingling chamber and mixed with the heated gases from the furnace to give the temperature best suited to the material.

The cylinder (which is set at an incline and revolves slowly on steel rollers) has a great many hooded openings so arranged that the heated air and gases from the commingling chamber are drawn by a fan through the hoods into the cylinder, in direct contact with the gypsum gravel which enters the machine at the front end. The rock is constantly being cascaded in the cylinder by means of lifting blades.

In the discharge spout is a recording thermometer which registers accurately the temperature of the rock as it comes out. The dial of this recording thermometer is so located that the operator can watch it and keep the rotary calciner adjusted so as to give a uniformly heated product. It is claimed that the rock as it is discharged will not vary in temperature more than 10° during a whole day's running. The heated air passes through the cylinder in the opposite direction to that in which the gravel is moving. The data for the rotary kilns are given in the following table:

Approximate capacity, fuel, horse-power and labor for Cummer continuous calcining process for gypsum.

No.	Capacity per 24 hours, tons	Horse power	Coal per day for calcining, pounds	Labor per shift. men.
1.	50	6	3,500	1
2.	100	8	7,000	1
3.	150	10	10,500	1
4.	200	12	14,000	1
5.	250	15	17,500	1
6.	300	20	21,000	1
7.	400	28	28,000	2

The general arrangement of a mill using this process is shown in figures 15, 16 and 17.

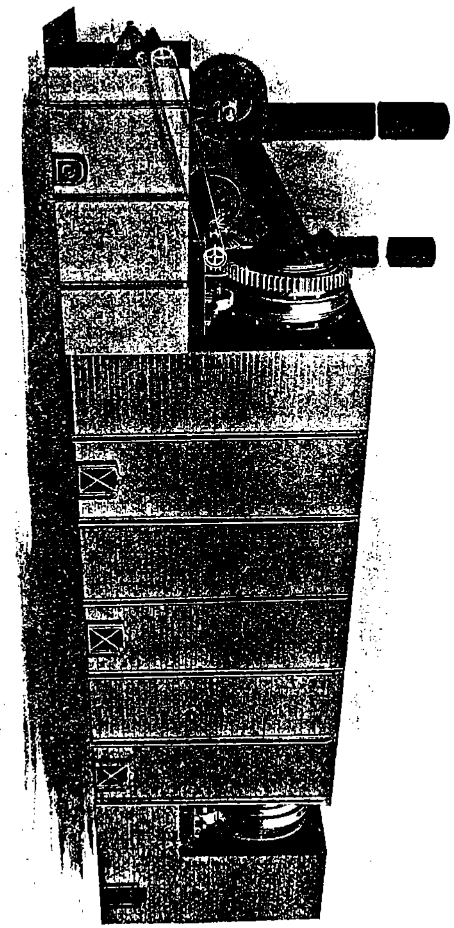
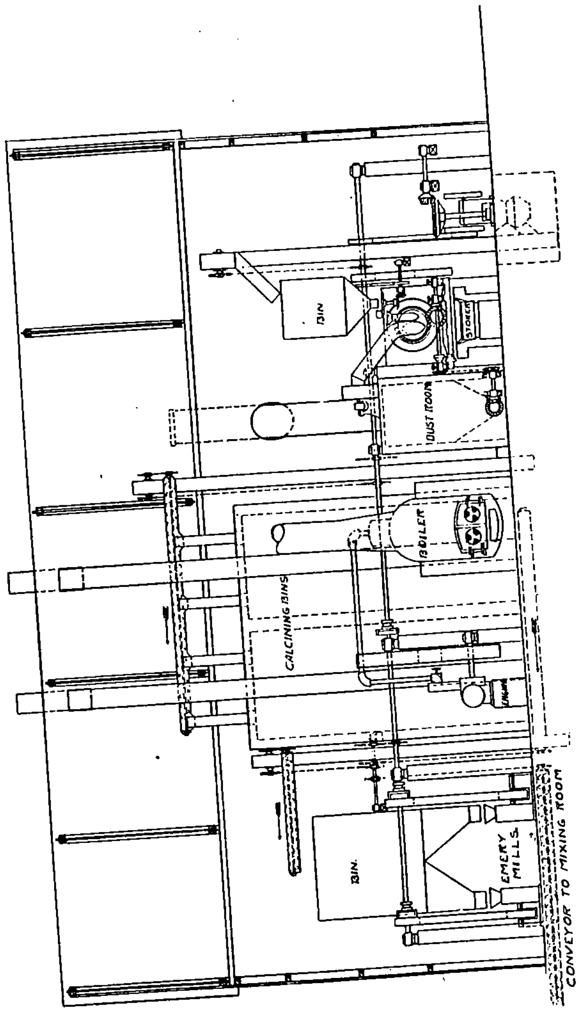
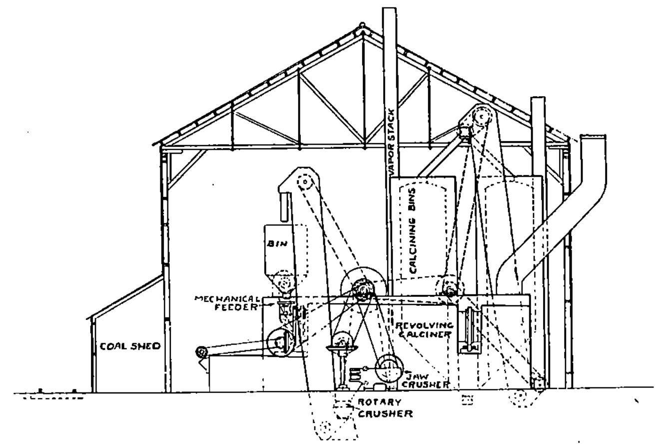


Fig 14.—Cummer rotary calciner.



FRONT ELEVATION.
Fig. 15.—Front elevation of mill using rotary calciner process.



END ELEVATION.
Fig 16.—End elevation of mill using rotary calciner process.

About 10 minutes is required for the material to pass through the kiln and during its passage it reaches a temperature of 400° to 500°F. It is then elevated to large bins built of brick or of wood lined with brick and allowed to remain 36 hours, during which time the excess heat carried over from the calciner is equally distributed through the material, which is thus uniformly calcined. The fine dust is calcined in the cylinder and is carried out by the current of air into a dust room, where it is collected. This dust is used for the finer grades of plaster, such as dental and molding plaster. The calcined gravel is ground in buhr mills, screened and mixed as in the kettle process. The process is based on the fact that heat in excess of that required for calcination when applied in the presence of moisture does not result in "dead burned" plaster. The gravel is steaming during its stay in the kiln and still contains moisture when placed in the bins. The advantages claimed for the process are two, saving of fuel for calcination due to the continuous process, and the saving in power, since the rotary calciner is said to require less power than kettles of equal capacity and much less power is required for grinding the calcined material from the bins than for grinding raw gypsum as it comes from the quarry. It is claimed that 70 pounds of good coal is required to calcine one ton of plaster in the rotary kiln, while 150 to 200 pounds

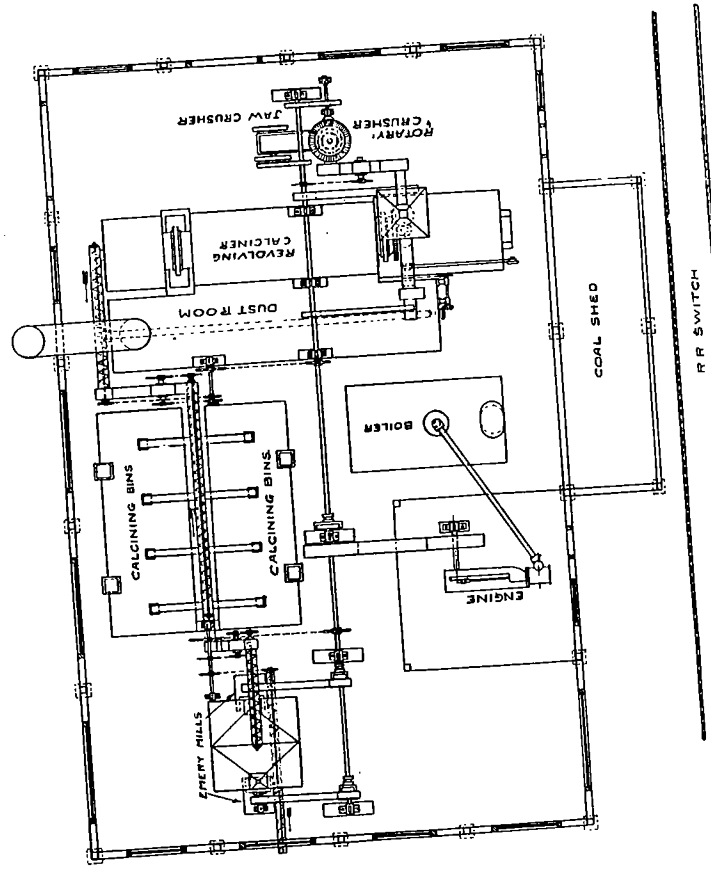


Fig. 17.—Plan of mill using rotary calciner process.

are required per ton in the kettles. The power necessary for a rotary calciner of 200 tons capacity per 24 hours is claimed to be 12 horse power, while 3 8-foot kettles, giving somewhat less capacity, require forty or more horse power at least a portion of the time. The only mill in Oklahoma using this process has been in operation but a short time and the plaster has not yet been thoroughly tried out on the market. However, it is reported to be of good quality, and the plaster made by the process in the east is said to be satisfactory.

In Germany[14] the ordinary wall plaster and plaster of Paris are burned in kettles or in continuous rotary kilns similar to those employed in the United States. The kettles are smaller as a rule and do not have the flues. For the finer plasters, especially for the plaster for molds used in the making of porcelain, continuous kilns are used which are similar to the tunnels used for drying bricks in this country. The walls are of brick and are very thick. The gypsum gravel is loaded on pallets or shelves on rack cars which are moved slowly through the tunnels on tracks. In one type of kiln the heat is not applied directly to the gypsum, but the gases from the combustion chamber are led through flues in the wall. In another type of kiln the gypsum in blocks is loaded on to the cars, which are covered with sheet steel, the cover of each car fitting closely with the cover of the cars to the front and rear. The fuel is burned at the middle of the tunnel, so that the gypsum becomes heated as it approaches the middle, is calcined as it passes the fire, and cools as it approaches the exit.

For the calcining of "estrick" gypsum, a slow-setting hard plaster, burned at about 500°C., kilns resembling the ordinary lime kilns are used. Wilder's description of these kilns is as follows:

"Estrick gypsum is calcined in a kiln resembling the ordinary kiln used for burning lime. When possible, the kiln is located near the quarry or mine, and in a hollow or depression, artificial or natural, so that the trucks carrying the rock from the quarry may be run directly to the top of the kiln and there automatically emptied. The kiln will hold about 200 tons at one time, though all of this amount is not subjected to the full furnace heat. The accompanying diagram will best explain its nature. The sketch is made from the side. The fireplace is represented by D, the ashes falling down into E. The gypsum blocks are thrown in at A, and the whole interior filled. The fireplace on its upper side and rear is grated, and the flames and heat pass directly up through A. The hottest part of the kiln is found at B, where a comparatively small amount of gypsum is brought directly in contact with the grates. From time to time the rock which has been exposed to this great

[14] Wilder, Frank A., The gypsum industry of Germany: Iowa Geol. Survey, vol. 12, 1902, pp. 209-220.

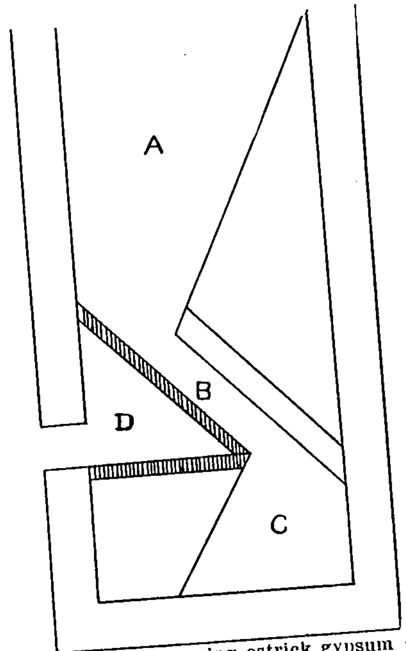


Fig. 18.—Sketch of kiln for burning estrick gypsum (After Wilder).

heat passes on down into C, the cooling chamber. This will take place whenever the rock already calcined and cooled is removed from C and taken to the mill for grinding. The heat in the lower part of A is so intense that nearly complete combustion takes place, and only gases and hot air, without smoke, pass on up through A, and escape at the top. The process is, then, a continuous one, with but slight loss of heat. There is little danger of overheating the gypsum and no attempt to perfectly control the temperature is made."

In France[45] the common type of kiln is similar to the square up-draft brick kilns of the United States. The gypsum is stacked into the kilns with the large blocks in the bottom forming a series of tunnels in which the fuel is burned. Smaller blocks are placed on top, filling the kiln to a depth of about

[45]Grimsley, G. P., The gypsum of Michigan and the plaster industry Mich. Geol. Survey, vol. 9, Pt. II, 1904, pp. 17-20.

13 feet. The kiln is covered by a shed roof. The kiln is fired until the large blocks are glowing. The material next the fire is overburned and that at the top is underburned, but the mixture of the two ground together is said to give a uniform product of good quality. Another type of kiln is circular with the fire pit in the center and with the arches or tunnels of large gypsum blocks radiating from the pit. The top of the kiln is an arch which has flues to control the draft. In other kilns the gypsum is calcined in retorts. Superheated steam has been used for calcining in both Germany and France.

Screening.—From the hot pit the plaster is conveyed by a screw conveyor to a bucket elevator which carries the plaster to the screens. Both the rotary and shaking types are used, the screen being of fine wire mesh about 40 meshes to the inch. The material passing the screens is conveyed into bins on the second story of the mixing room. For plaster of Paris the material is sacked directly from these bins.

Another machine used for classifying the material is the inertia classifier, which is shown in figure 19. This machine is made in sizes of 3 to 8 tons per hour capacity. It requires from 4 to 12 horse power.

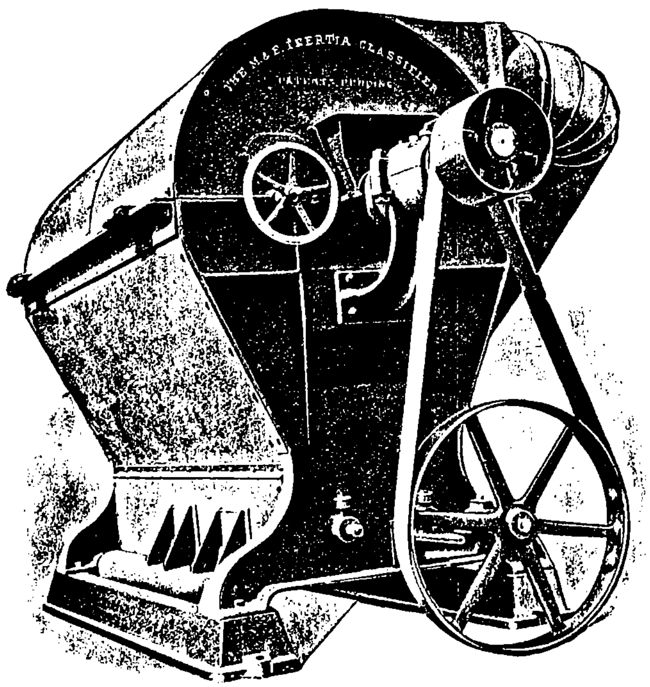


Fig. 19.—Mosher-Ehrsam classifier.

With either method of separation the tailings are conveyed to a regrinding buhr and ground to the requisite fineness.

Mixing.—The mixing machine (fig. 20) consists of a charging hopper, a mixing chamber and a sacking chamber. The charge of plaster is run into the hopper from the bins and the retarder or accelerator and hair or wood fiber, according to the product desired, are added in the proper proportions. By pulling a lever the operator discharges the hopper into the mixing chamber, where it is mixed from 3 to 8 minutes. While this charge is being mixed a second charge is prepared in the hopper so that the operation is continuous. After the charge in the mixing chamber is mixed the operator opens the valves into the sacking chamber by means of the pilot wheel. The mixing chamber has a mixing shaft with two sets of paddles

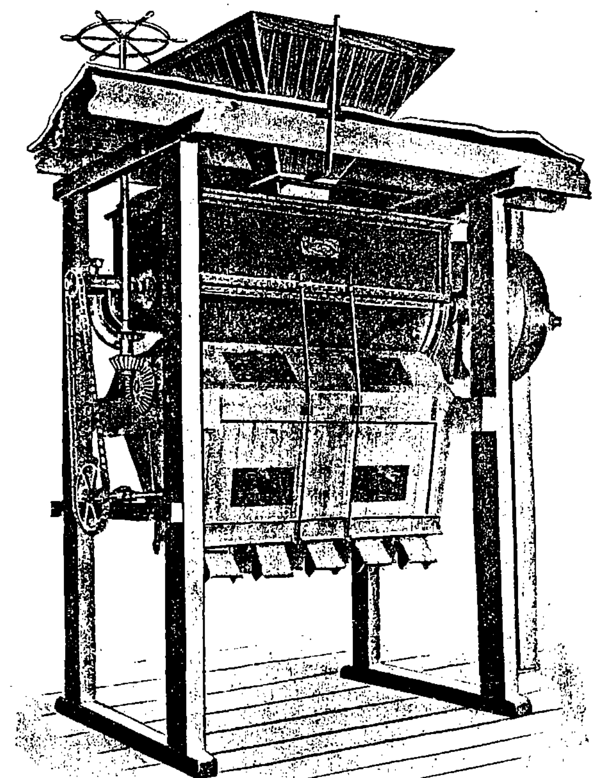


Fig. 20.—Enterprise noiseless mixer.

so arranged that one set throws the material from outside of the mixing chamber toward the center, at the same time causing the material to travel toward one end of the chamber, while the other set of paddles causes this operation to be reversed. Thus there are counter currents of material constantly commingling, causing a perfect mixture. The sacking chamber is made of seasoned lumber, lined with sheet steel and provided with an agitator for keeping the material from clogging. Convenient sacking spouts are provided and the sackers ordinarily have nothing to do with the operation of the mixer, confining their energies entirely to filling, weighing, and sewing. The mixer is made in two sizes. No. 1 has a capacity of from 1,000 to 1,500 pounds to the charge. This machine will mix from 40 to 65 tons of material per day of 10 hours and is provided with five sacking spouts. The mixer should run 165 R. P. M. and is provided with 36-in. by 8-in. tight and loose pulleys. The weight of the mixer is 3,800 pounds. The power required depends entirely on the kind of material mixed and will vary from 5 to 15 H. P. The No. 2 mixer is provided with seven sacking spouts and has a capacity from 1,800 to 2,400 pounds to the charge, and a capacity of 80 to 100 tons per day of 10 hours where a good sacking crew is provided. This mixer should run 165 R. P. M. and is provided with 36-in. by 12-in. tight and loose pulleys. It requires from 15 to 30 H. P., depending on the kind of material mixed. The shipping weight is 4,400 pounds. The list price for the No. 1 mixer is $325.00, and for the No. 2 mixer, $400.00.

SUBSTANCES ADDED TO THE PLASTER.

Plaster of Paris sets in a few minutes and consequently cannot be used alone for ordinary work. In order to delay the set sufficiently to permit the material to be mixed and spread on the walls retarders are added. A great many substances, most of them of an organic nature, are or have been, used as retarders. Glue, blood, sugar, gelatin, flour, saw dust, and many other substances and combinations of these with various inorganic salts have been used. The Oklahoma mills use a retarder which is manufactured by the large packing concerns from slaughter house refuse. The amount of retarder added to the plaster depends on the demands of the trade. Ordinarily a plaster which sets in from 2 to 6 hours is demanded, and to provide such a plaster about 4 to 6 pounds of retarder per ton is used.

In plaster for some special purposes, such as dental plaster, a very quick set is desired and an accelerator is added. Borax and common salt are commonly used for this purpose.

Hair and wood fibre are added to wall plaster. The hair is purchased in large bales by the mills. The compressed material is passed through a small machine which picks it to pieces so that the hairs are evenly distributed through the plaster

in the mixer. The wood fibre is made from cotton-wood, which is fibred by machines, one type of which is shown in figure 21.

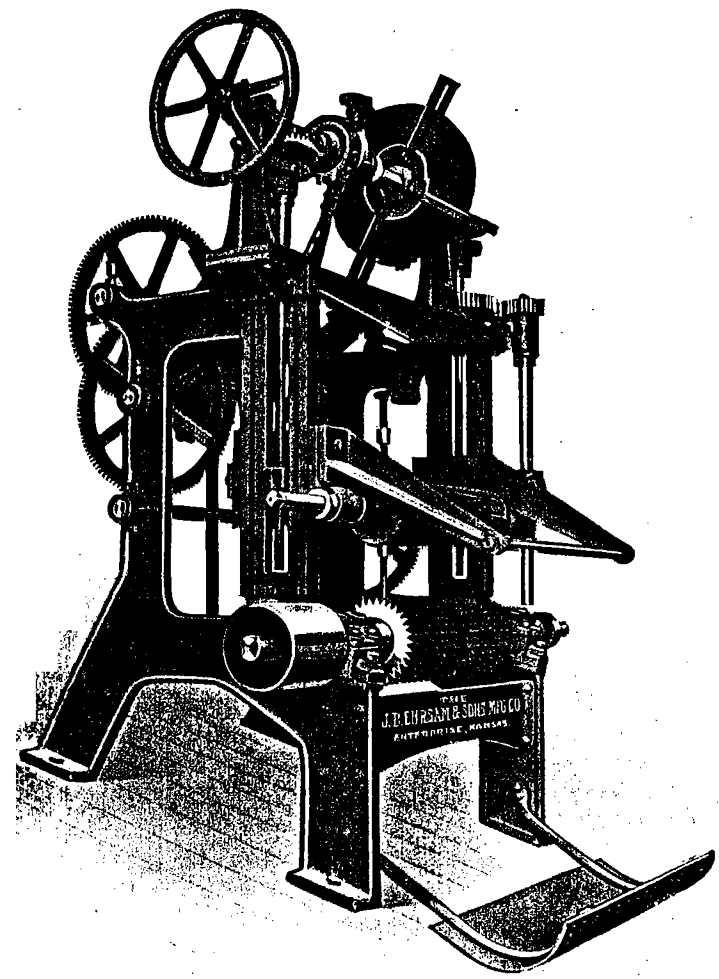


Fig. 21.—Wood-fibre machine.

ARRANGEMENT OF PLASTER MILLS.

While the details of arrangement of the different mills vary considerably the general plans are very similar. In general the crusher is located at one end of the mill and is on the ground, with the cracker in an excavation below it. The rest of the ground floor is occupied by the kettles and hot pit and the sacking and storage rooms. The second floor is occupied by the tops of the kettles and by the buhr mills for grinding and regrinding. The charging hopper for the mixer is also on the second floor. The third story is almost entirely filled with storage bins for the buhrs, kettles, and mixer. In general the crushing and power plants are at one end of the mill, the grinding and calcining departments in the middle part, and the mixing, sacking, and storage rooms at the other end.

The general course of the material is as follows: The crushed gypsum drops from crusher to cracker; the gravel is carried from the cracker by bucket elevator to bins over buhrs, passes through the buhrs and the ground material or flour is carried by bucket elevators to bins over calcining kettles; through these into hot pits, then by screw conveyor and bucket or other elevators to screen or classifiers; the fines from the classifier pass to bin over mixer, and the tailings to regrinding buhrs and then to bin over mixer, all go through mixer into sacks. The arrangement of a 2 10-foot kettle mill adapted for rock gypsum is shown in figure 13.

Mills using gypsite alone have only the regrinding buhrs of the crushing or grinding machines and the material is sent directly from the bed or from drying sheds into the kettles.

COST OF BUILDING AND EQUIPPING PLASTER MILLS.

The cost of building and equipping a plaster mill will vary greatly with the type and capacity of the mill and in less degree with the location with respect to transportation, to availability of building supplies, and to labor conditions. It is, therefore, impossible to give estimates which will fit exactly any particular case. The following estimates, however, are sufficiently accurate under ordinary conditions to give an approximate idea of the cost of different types of kettle mills. The estimates, except for the mill shown in figure 13, are taken

from Jennison's report on the Gypsums of the Maritime Provinces (Canada). The specifications are for the machinery of the J. B. Ehrsam and Sons Mfg. Co. of Enterprise, Kansas, who have equipped most of the mills in Oklahoma and who have furnished estimates for the mill shown in figure 13.

Estimate of cost of plaster mill, having a capacity of 25 tons in 24 hours, wood construction.

Machinery consists of the following:

One 6 by 6 ft. calcining kettle.

One 20 in. Ehrsam vertical green-grinding buhr mill.

One 20 in. Ehrsam vertical regrinding buhr mill.

One 20 in. Ehrsam rotary crusher.

One special Enterprise noiseless mixer.

Necessary elevators, conveyors, power transmission, and kettle-pit feeders for the automatic handling of material from crusher to mixer.

Power required to run plant, 60 H. P.

Cost of special machinery	$1,120
Cost of elevators, conveyors, power transmission and kettle pit feeders	834
Approximate cost of building and bins complete, including masonry and cost of erection	4,000
Approximate cost of power plant, consisting of one simple slide valve engine, one tubular boiler, and connections	800
Approximate cost of plaster mill, complete	$6,754

Estimate of cost of plaster mill having capacity of 100 tons in 24 hours, wood construction.

Machinery consists of the following:

Two 8 by 8 ft. calcining kettles.

Two 36 in. Ehrsam vertical green-grinding buhr mills.

One 36 in. Ehrsam vertical regrinding buhr mill.

One 15 by 22 in. Ehrsam jaw crusher.

One 20 in. Ehrsam rotary crusher.

One No. 2 Enterprise noiseless mixer.

One Ehrsam hair picker.

One 21 in. by 14 ft. vibratory screen.

Necessary elevators, conveyors, etc.

Power required to run plant, 150 H. P.

Cost of special machinery	$ 5,115
Cost of elevators, conveyors, power transmission, bin and kettle-pit feeders	2,385
Approximate cost of bins and building complete, including masonry and cost of erection	14,000
Approximate cost of power plant, consisting of one 16 in. by 36 in. Corliss engine, one 72 in. by 18 ft. high pressure boiler, and connections	3,000
Approximate cost of plaster mill complete	$24,500

Estimate cost of plaster mill having a capacity of 200 tons in 24 hours (see fig. 21). Steel construction and fireproof throughout.

Machinery consists of the following:

Two 8 by 10 ft. calcining kettles.

Five 42 in. horizontal buhr mills.

Three Mosher-Ehrsam classifiers.

One 22 in. by 28 in. Ehrsam jaw crusher.

Three No. 2 Enterprise mixers.

Two vibratory screens, 21 in. by 8 ft.

Elevators, conveyors, power transmission, etc.

Power required to run plant, 300 H. P.

Cost of special machinery	$12,000
Cost of steel building and bins complete	20,000
Cost of concrete foundation and brick work for setting machinery	3,000
Cost of millwright labor, superintendence and setting of machinery	3,000
Approximate cost of power plant, consisting of two 72 in. by 18 in. high pressure boilers, one compound 14 by 28 by 36 in. high speed Corliss engine, pumps, condenser, cooling tower, fixtures, piping and erection	$12,000
Approximate cost of plaster mill complete	$50,000

A similar mill, but with a capacity of 300 tons per 24 hours, requires three 10 by 8 ft. kettles and additional grinding and mixing machinery. The power required is 400 H. P. Such a plant, including the power plant, costs approximately $65,000.

COSTS OF PLASTER MANUFACTURE.

Eckel[46] gives the following table as showing in his opinion the maximum, average, and minimum costs of plaster by the kettle process, in the United States. Fixed charges such as office expenses, interest on investment, deterioration of equipment, and expenses of sales force are not included in these estimates.

	Max.	Min.	Average
Mining or quarrying 2400 pounds gypsum	$0.72	$0.12	$0.30
Power fuel at mill, 75 to 125 pounds coal	0.19	0.05	0.10
Kiln fuel at mill, 225 pounds to 325 pounds coal	0.49	0.15	0.30
Labor at mill	0.50	0.30	0.40
Total cost per ton of plaster at mill	$1.90	$0.62	$1.10

Grimsley[47] estimated the cost of manufacture in the Kansas mills at $1.60 per ton, exclusive of office force and sales agents.

The actual cost in Oklahoma will vary considerably with the local conditions at each mill. The following figures show the cost for three different months at one mill where conditions are probably about an average of those in the State. Owing to the fact that the mill was not running at full capacity these

[46] Eckel, E. C., Cements, limes, and plasters: 1909, p. 32.
[47] Grimsley, G. P., Mineral industry, vol. 7, 1898, p. 392.

costs are rather high, especially for the third month, during which time the mill was run at about half capacity:

	1st mo.	2nd mo.	3rd mo.
Cost of getting raw material to mill	$0.41	$0.40	$0.55
Fuel for power and calcining	0.27	0.31	0.33
Labor in mill	1.02	0.98	1.24
Sundries (repair, retarder, twine, fibre, etc.)	0.28	.21	.23
Total cost per ton plaster at mill	$2.08	$1.90	$2.35

When the items of interest on investment, depreciation of machinery and buildings, and cost of the executive, office, and sales departments are considered, it is apparent that the real value of gypsum products manufactured from rock gypsum by the kettle process is considerably in excess of $2.00 per ton at the mill and, in Oklahoma at least, will be normally nearer $3.00 than $2.00. The products from gypsite can be manufactured for less than this sum because the material can be delivered at the mill much more cheaply than the rock gypsum and does not require crushing or grinding before going to the kettles.

Figures of costs of manufacture by the rotary kiln process are not at hand. Eckel[18] gives the following estimates:

	Max.	Min.
Mining or quarrying 2400 pounds gypsum	$0.72	$0.12
Power fuel at mill, 50 to 89 pounds coal	0.12	0.04
Kiln fuel at mill, 150 to 200 pounds coal	0.31	0.10
Labor at mill	0.30	0.18
Total	$1.45	$0.44

In the writer's opinion these estimates are rather low, especially as no account is taken for retarder, hair, wood fibre, or other sundries.

DESCRIPTION OF OKLAHOMA PLASTER MILLS

At present there are 12 plaster mills in the State, located as follows: 2 at Watonga, and 1 each at Bickford, Okeene, Southard, Wilson, Ferguson, Okarche, Alva, Rush Springs, Eldorado, and McAlester. In the following paragraphs very brief descriptions of these mills, their locations, and equipments are given. The quarries are described under the different counties in Chapter V.

[18]Loc. cit.

The United States Gypsum Company has three mills in the State, one each at Okarche, Southard, and Eldorado. The *Okarche* mill is the oldest in Oklahoma. It is located in northwestern Canadian County, 5 miles south and 2 west of Okarche, at the end of a spur built from the Chicago, Rock Island & Pacific Railway to the east. The mill is a frame building and the equipment consists of a 90 H. P. engine, crusher and cracker, 8 buhr stones, two 8-foot kettles, two mixers, and the usual elevating and conveying machinery. The mill was located

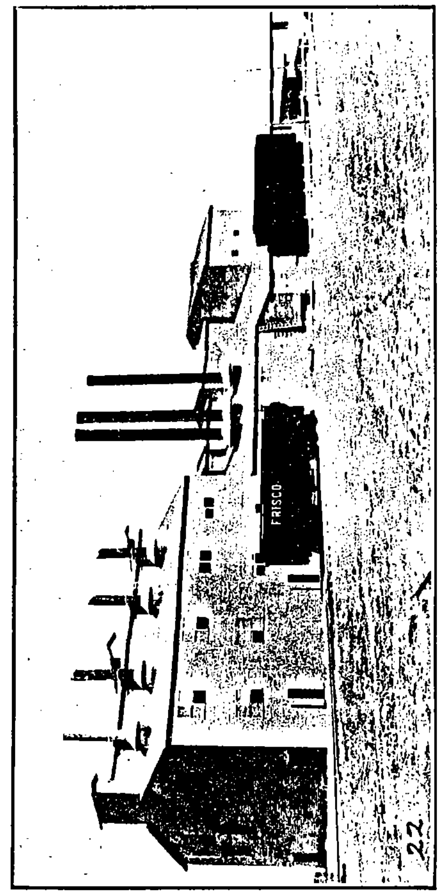


Fig. 22.—United States Gypsum Company's mill at Eldorado.

on account of some gypsite beds but these were exhausted and for some time only rock gypsum from a quarry about one-fourth mile southwest of the mill has been used. The mill was closed down when the company made the purchase at Southard and it will probably not be reopened unless there is a great improvement in business conditions. The *Southard* mill is located southeast of the village of that name in northwestern Blaine County. Transportation is afforded by the Arkansas City and Vernon branch of the St. Louis & San Francisco Railroad. The mill is a large frame building with a large storage room. The equipment consists of a 250 H. P. engine, crusher and cracker, 8 buhr mills, three 10-foot kettles, 2 mixers, elevators and conveyors. All the milling machinery is of Ehrsam make. Both gypsite and rock gypsum are used. This property belonged to the Independence Gypsum Company of Enid, Oklahoma, until the autumn of 1912, when it was sold to the United States Gypsum Company. The products of the Independence Gypsum Company were known under the trade name of "Golden Seal." The *Eldorado* mill is situated just north of the town of Eldorado in Jackson County. This mill is shown in figure 22. The mill has a 150 H. P. engine, four 10-foot kettles, 2 mixers, and the ordinary elevating and conveying machinery.

The *Oriental Plaster Company* of Wichita, Kansas, at present leases two mills in Oklahoma. These are the mill of the Monarch Plaster Company at Watonga, and that of the Southwest Cement Plaster Company at Okeene. The *Monarch* mill is one-half mile north of Watonga on the Chicago, Rock Island & Pacific Railway. The mill covers a very small area in proportion to its capacity. The milling equipment consists of crusher and cracker, 2 French buhr mills, two 10-foot kettles, 1 mixer, elevators, and conveyors. Power is furnished by a 120 H. P. Bates-Corliss engine. The mill has its own lighting system with current furnished by a small dynamo. The rock and gypsite are obtained from the company's land about 7 miles northwest of Watonga. The *Southwest* mill is located at the east side of the town of Okeene, on the Arkansas City and Vernon branch of the St. Louis & San Francisco Railroad. The equipment at the mill consists of buhr mills, two 10-foot kettles, wood fibre machine, and 1 mixer. Power is furnished by a 125 H. P. Fisher-Corliss engine. The crushing plant is located at the company's quarry, which is on the same railroad, 7 miles

west and 2 south of Okeene. Both rock gypsum and gypsite are used.

The *American Cement Plaster Company* of Lawrence, Kansas, operates a mill at Watonga, on the Chicago, Rock Island & Pacific Railway. The materials, rock and gypsite, are obtained from the company's land about 7 miles northwest of Watonga, and are hauled in gondola cars by the railway. The crushing plant is at the quarry and consists of a crusher and

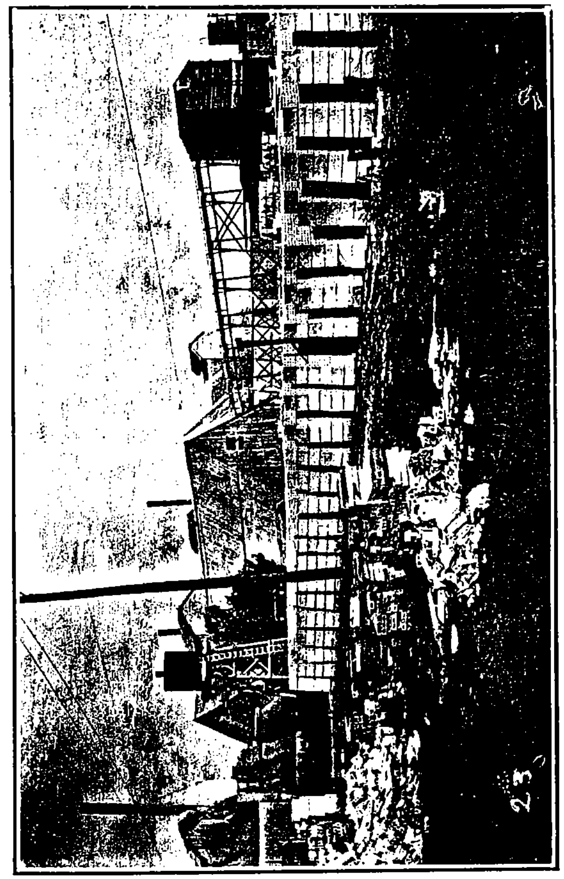


Fig. 23.—Portion of mill and cement tile storage yard of the American Cement Plaster Company at Watonga.

cracker of the ordinary type. Power is furnished by a 40 H. P. Fairbanks-Morse internal combustion engine that uses solar oil as fuel. A portion of the quarry is shown in figure 56. The mill has a large storage house arranged so that the cars of gypsite or crushed rock may be dumped from a trestle. A screw conveyor in a tunnel extends the entire length of the gypsite storage room and the material can be conveyed direct to the kettles. When the plant was visited the "gravel" had to be shoveled into a bin for a bucket elevator, but it was planned to tunnel this room and put in a screw conveyor. The power is furnished by a 150 H. P. Atlas engine. Slack coal is used for fuel in calcining and is burned with a forced draft. The mill is equipped with the usual crushing, grinding, elevating, and conveying machinery. The capacity of the plant is 175 tons per 24 hours, but it can be crowded to 225 tons if conditions are favorable. A part of the plaster is used in the manufacture of partition blocks. A view of a portion of the mill and of the block storage yard is shown in figure 23.

The mill of the *Roman Nose Gypsum Company* is located at Bickford, about 8 miles north of Watonga on the Chicago, Rock Island & Pacific Railway. The mill is at the foot of the line of hills which are capped by the gypsums of the Blaine formation and only a very short haul by wagon is necessary to transport the rock from the hillside quarries to the plant. Gypsite is obtained a short distance to the south. The mill and its surroundings are shown in figure 52 in Chapter V. The power is furnished by a Loomis-Bettibone gas producer and a Weber 250 H. P. producer-gas engine. The crushing and grinding equipment consists of a jaw crusher, rotary fine crusher, and buhrs for fine grinding. Three 8-foot kettles are used for calcining, and 2 Broughton mixers for mixing.

It is planned to use a large share of the product in the manufacture of partition blocks. A large building has been erected for this purpose. The blocks are to be made by a continuous process, for which patents are held by the company. An endless revolving apron, carrying brass frames or moulds with collapsible metal cores, passes under the mixing vats. The plaster is mixed with water and poured into the moulds as the latter pass slowly beneath the discharge end of the vats. The table is sufficiently long to permit the plaster to set in the moulds by the time they reach the end. Here the cores

are removed and are returned to the upper end of the table by a conveyor belt, which carries them through an oil bath so that they are ready for use again. The blocks are hauled from the discharge end of the table on wheelbarrows and stacked in storage yards.

The *Rubey Stucco-Plaster* mill is situated in a canyon in the gypsum hills near the head of Salt Creek about 4 miles west of Ferguson. The mill is at the foot of a steep bluff capped by Medicine Lodge gypsum. The rock was quarried and let down to the mill on cars operated by a gravity system. A double track was used and the loaded car going down pulled the empty one up the inclline. The rope connecting the two cars passed over a wheel at the top of the incline. The speed of the cars was regulated by a brake on the wheel. The mill has two 6-foot kettles with the usual crushing, grinding, and mixing machinery. The location of this plant is very unfortunate, since the coal for fuel must be hauled from Ferguson, a distance of over 4 miles, while the finished plaster must be hauled the same distance. The mill has not been operated for several years and it is difficult to see how it can be operated successfully in view of the keen competition between mills more favorably located in regard to transportation.

The Oklahoma Plaster Company has its mill at Alva, in Woods County, on the Chicago, Rock & Pacific and the Atchison, Topeka & Santa Fe railways. The equipment consists of two

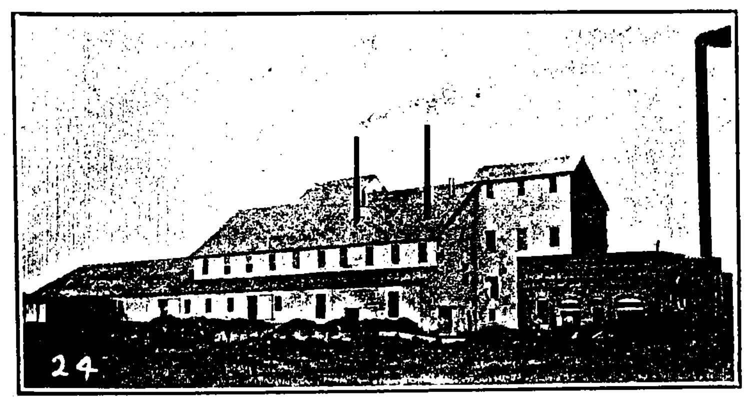


Fig. 24.—Plant of Oklahoma Plaster Company at Alva.

10-foot kettles with the corresponding crushing, grinding, and mixing machinery. The main building is a large frame structure and the power plant is housed in a separate brick building. A view of the plant is shown in figure 24. The raw material is a coarsely selenitic gypsum obtained from a quarry between Quinlan and Belva in Woodward County.

The only mill in Oklahoma using the continuous calciner process is that of the *Oklahoma Gypsum Company*, located at Wilson (postoffice, Homestead) in northwestern Blaine County, on the Arkansas City and Vernon branch of the St. Louis and San Francisco Railroad. The company holds a large acreage of land which is underlain by the Blaine gypsums. The quarry is described in Chapter V. The equipment consists of an Ehrsam jaw crusher and rotary fine crusher, a Cummer rotary calciner with automatic stoker, dust room, and calcining bin, 2 Sturtevant rock emery buhrs, an Enterprise mixer, and the requisite elevating and conveying machinery and storage bins. Power is furnished by a 300 H. P. Webster & Company engine. A view of this mill and a portion of the quarry is shown in

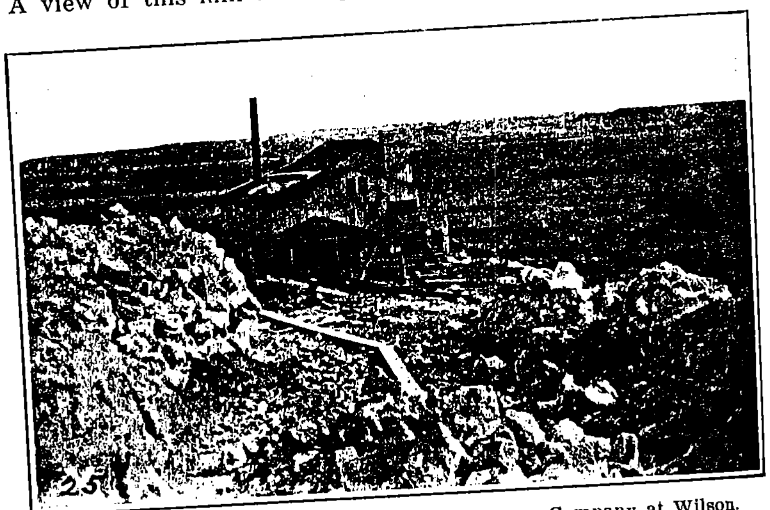


Fig. 25.—Mill and quarry of Oklahoma Gypsum Company at Wilson.

figure 25. The mill is a new one and has been in operation only since early in 1913.

The *Acme Cement Plaster Company* has a new mill located about 4 miles west of Rush Springs in Grady County, at the end of spur track from the Chicago, Rock Island & Pacific Railway. This company does not permit their mills to be visited and no information concerning the mill could be obtained other than that the mill is a fireproof structure of steel and concrete, and that it probably does not differ materially in equipment from the other mills of the State. Gypsite alone is used as a raw material.

The *Elastic Pulp Plaster Company* has a small mill at McAlester in the eastern part of the State. The location was probably chosen on account of the nearness of fuel, since McAlester is in the heart of the coal fields. Rock gypsum is shipped from different quarries in the western part of the State. The mill is a small one, having only one kettle.

CONDITION OF THE GYPSUM INDUSTRY IN OKLAHOMA.

Although the supply of gypsum in Oklahoma is inexhaustible and is easily accessible, the condition of the industry during the past few years has not been satisfactory. This is due to several factors, the principal one being the location of the gypsum area with respect to fuel and market.

The area is at considerable distance from any source of fuel. All the plants in the State, except the one at Eldorado, use coal shipped in from the McAlester field in the southeastern part of Oklahoma or from the Arkansas or the Colorado coal fields. The cost of coal at the mill varies from $2.80 to $4.00 per ton. The cost of coal is much higher than in many other regions at the same distance from productive coal fields. This is due to the geologic conditions under which the Oklahoma coals are found which make mining more expensive than in the eastern and central states. The mining methods in use during the past few years are extremely wasteful and these have also operated to make the cost of coal unduly high. Gas from the northeastern Oklahoma fields has been piped as far as Oklahoma City but has not been brought into the gypsum area and at present it does not appear as if it would be. The newly discovered gas field in southeastern Stephens County may make it possible to use gas for fuel in the extreme southeastern portion of the gypsum area, but the geologic conditions over the greater part of the gypsum area are such as to render the discovery of any oil or gas extremely improbable.

The distance of the Oklahoma mills to the large trade centers and the competition of mills more favorably located also work a hardship on the Oklahoma producers. The far eastern markets can scarcely be entered by the Oklahoma products in competition with those of New York, Ohio, and Virginia; the markets of north central States, including those of Chicago, St. Louis, and Kansas City, are in closer touch with the gypsum supplies of Ohio, Michigan, Iowa, and Kansas than with those of Oklahoma; to the south the Oklahoma products come into direct competition with those of the Texas mills; to the west there are no large markets until the Pacific coast is reached and these are supplied by the mills in Nevada, Utah, and California. To the northwest the mills of Wyoming and Montana are more than able to supply the local markets. Thus, the Oklahoma mills are in a large measure confined to the home markets, or when they enter the larger markets must compete with mills which have a great advantage over them in cost of transportation and, in many cases, a further advantage in the matter of cheaper fuel.

For a few years following 1900 the local markets were very active and the mills established at that time made large production with considerable profit. This encouraged the building of other mills until by 1910 all the mills now in the State, with one exception, had been built. Just about this time the period of great building activity following Statehood suffered a cessation due to a number of causes. As a result of the large number of mills built and the lessened market very few mills have been operated to capacity during the past 3 years and some of them have been idle a greater part of the time. The greater part of the production during this time has been sold at prices so low as to prevent a reasonable profit being made by the manufacturers.

All things considered, it appears to the writer, in spite of the abundant supply of raw material, conditions at present are not favorable for further development of the gypsum industry of the State. Any steps toward the establishment of additional mills should certainly be considered very carefully, especially in regard to available markets for the manufactured

products. The increasing use of the gypsum plasters will tend to better this condition in a few years and the development of new uses for gypsum may produce a marked change for the better at any time.

CHAPTER III.

GYPSUM PRODUCTS AND THEIR USES.

INTRODUCTION.

The products of gypsum may be divided into two general classes, the raw and the calcined products. Of these the calcined are much more important at present, although in times past the amount of gypsum used in the raw state in this country was much greater than that used in the calcined form.

USES OF GYPSUM IN THE RAW STATE.

The principal uses of gypsum in the raw condition are as fertilizer or land plaster, as a retarder for Portland cement, in paints, as an adulterant, and for several minor uses.

Use of gypsum as fertilizer or land plaster.—The use of gypsum as a fertilizer has been known from early times. For this purpose the rock is ground to a fine powder and spread evenly over the land at the rate of about 200 pounds to the acre. The fertilizing action is very pronounced with some soils and some crops, but is absent in other cases. The crops most benefited are clover and other leguminous crops. The continued use of land plaster is known to have a deleterious effect on soils and they finally fail to respond to additional application of the gypsum. This fact has given rise to the old saying that "land plaster makes rich fathers but poor sons."

Many theories have been used to account for the fertilizing action of gypsum. However, it is generally accepted at present that gypsum functions very slightly if at all as a plant food. Its action is believed to be that of decomposing insoluble compounds, such as feldspars and micas in the soil and converting their food elements, especially the potash, into soluble forms so that they can be readily utilized by the plants. This action

would account for the final impoverishment of the soil by repeated applications of land plaster. Gypsum has also a slightly beneficial action in rendering the soil flocculent or granular. Probably the only case where the direct application of gypsum to soil would have any permanently good effect is on soil deficient in soluble plant food but with considerable quantities in the insoluble form. An application of gypsum would probably make it possible to secure a good crop of clover or beans. If all or a part of this crop should be plowed under and the land left fallow and later treated with barn-yard manure, a sufficient supply of food element would be supplied to render the land productive of most of the common farm crops. Such land, however, would require considerable mulching and manuring to keep it in good cropping condition.

The use of gypsum upon manure in the stable or heap is undoubtedly of great benefit. For this purpose the rock is ground to powder and this powder is scattered over the litter or bedding in the stables or pen. Three or four pounds per animal per day are used. The gypsum unites with the nitrogen of the manure to form ammonium sulphate, which is not given off into the air and which is not readily washed from the manure in the heaps by rains, but is still easily available as plant food. The gypsum also seems to cause the potash and phosphates to be retained in the manure. When used in this way, gypsum seems to have no bad effect in the soil as it is probably converted to the lime carbonate in the manure.

Use of gypsum in Portland cement[10].—Pure Portland cement sets in a few minutes and consequently requires the addition of some substance to act as a retarder so that the cement can be manipulated before it sets. Gypsum in some form is almost universally used for this purpose. The gypsum may be used in the raw state or as plaster of Paris. The retarding effect is due to the sulphuric anhydride and consequently a less quantity of plaster of Paris than of raw gypsum is required to produce the same result. However, the cost of the raw gypsum is only about one-half that of the plaster so that the raw material is used in practically all the mills. The raw gypsum is added to the cement clinker before grinding. When plaster of Paris is used, it is added to the ground cement. The

[10] Eckel, E. C., Limes, cements, and plasters: pp. 534-537.

amount of gypsum used varies with the composition of the cement and the retardation desired. Ordinarily 1½ to 2 per cent of gypsum is added. This amount gives the maximum retarding effect with cements of ordinary composition and also the maximum increase of tensile strength. The initial set is usually retarded 1 to 2 hours and the final set 4 to 6 hours. Gypsum in large amounts accelerates the set and weakens the cement. The total quantity of gypsum used in Portland cement is considerable. According to the United States Geological Survey the production of Portland cement in the United States for 1911 was practically 15,000,000 short tons. Taking 2 per cent as the average percentage of gypsum used this would give 300,000 tons as an approximation for the amount used in this way.

Gypsum as a basis for Portland cement.—It has been suggested several times that gypsum could be used as the source of the calcareous element of Portland cement and that the sulphur trioxide driven off could be used for the manufacture of sulphuric acid. Patents have been issued for processes of this sort. However, no commercial attempts to apply the process have been made and there are probably grave difficulties in the way of its application. It is doubtful whether the sulphur trioxide could be completely driven off by any practical method; the value of gypsum for other purposes makes it less available than limestone for use in cement manufacture; and the amount of sulphuric acid produced by a large mill would be so great that it is doubtful whether a market could be found for it under present conditions. The distance of the Oklahoma gypsum deposits from the fuel supply and the absence of clays suitable for Portland cement near the deposits are other factors which seem to render such utilization impossible in this State.

Gypsum as a basis for paints.—Gypsum is used as a basis for paint by a company at Fort Dodge, Iowa, and is reported[60] to give good results. The gypsum is used in the raw form. It is ground much finer than when used for plaster.

Minor uses of raw gypsum.—Rock gypsum in the pure white form known as alabaster has been used for centuries

[60] Wilder, Frank A., Geology of Webster County: Iowa Geol. Survey, vol. 12, 1902, pp. 158-159.

for carved ornaments and interior decorations, especially in churches and cathedrals in Europe. Ground white gypsum under the name of "terra alba" has been used extensively as an adulterant for food stuffs, white lead, and drugs. Gypsum is used in a small way as a drug, in chemical work, as a paper filler, as a brewing salt, and in a number of other ways.

USES OF CALCINED GYPSUM.

Classes of calcined gypsum products.—The following classification by Eckel[61] gives the principal classes of the calcined gypsum products.

Classification of gypsum plasters.

A. Produced by the incomplete dehydration of gypsum, the calcination being carried on at a temperature not exceeding 400°F.

1. Produced by the calcination of pure gypsum, no foreign material being added either during or after calcination—Plaster of Paris.

2. Produced by the calcination of a gypsum containing certain natural impurities, or by the addition to a calcined pure gypsum of certain materials which serve to retard the set of the product.—Cement Plaster.

B. Produced by complete dehydration of gypsum, the calcination being carried on at temperatures exceeding 400°F.

3. Produced by the calcination of a pure gypsum.—Flooring Plaster.

4. Produced by the calcination, at a red heat or over, of gypsum to which certain substances (usually alum or borax) have been added—Hard-finish Plaster.

Besides the names given in this classification a number of others are used in the trade. Plaster of Paris is known as moulding plaster or white finish. Dental plaster is a very white, finely ground plaster of Paris. The name stucco is usually applied to plaster of Paris made from impure gypsum or a mixture of gypsum and gypsite. The cement plasters are distinguished by the addition of hair fiber and retarder. Wood

[61] Eckel, E. C., Cements, limes, and plasters: p. 32.

fiber plaster has wood fiber, usually cottonwood, instead of hair. Keene's cement, Parian cement, and a large number of other special cements belong to the class of hard-finish plasters.

Uses of plaster of Paris.—Plaster of Paris is used quite extensively as a white finish coat for walls. Large quantities are used in the making of moulds for pottery and stoneware. The moulds are usually made in two pieces. These are fastened together and the clay is placed in the mould and pressed into it by hand. When the object is partially dry the mould is removed. Plaster of Paris moulds are especially suited for this purpose on account of the rapidity with which they absorb water from the clay.

Casts of statues and other art objects, and of relief maps and models for various sorts of scientific purposes are made of plaster of Paris. A model of the object desired is made of clay or some other plastic material. A negative of plaster is made by pouring the plaster mixed with water over the object, which is placed in a suitable frame. When the negative has set it is removed from the object and the surface coated with shellac or some other non-absorbent material. Then by pouring plaster on the negative and allowing it to set a copy of the original is obtained. The coating of shellac over the negative prevents the plaster of the cast from sticking to that of the negative. Any number of casts may be made from one negative. Casts of statues and other decorative objects made from flooring plaster ("Estrick" gypsum) are used extensively in building in Germany. When properly treated they are sufficiently resistant for outside use.

The plate glass companies use large quantities of plaster for imbedding plate glass on the polishing tables. A very fine grained plaster free from sand is necessary for this purpose.

Dental plaster is a very pure, extremely fine-grained plaster of Paris. An accelerator, usually common salt, is added to hasten the set. This plaster is used by dentists in taking impressions for artificial teeth.

Hard wall plasters.—By far the most important use of gypsum is in the manufacture of hard wall plasters. As has already been noted these are made in several forms. The gray plasters are those made of gypsite or a mixture of gypsite and

rock, while the white plasters are made of pure rock. A pinkish tinge is sometimes given to the white plasters by mixing with the rock a small amount of red clay which is associated with it. The cement plasters are those which have hair fibre but no sand or wood fibre mixed with the calcined gypsum. The plaster with no fibre or sand is sometimes known as "stucco," but this term is used in several different ways. Prepared plasters are mixed with wood fibre or hair, and sometimes with sand. The wood-fibre plaster can be used without sand, but may be mixed with sand if desired by the trade. Both the hair and wood fibre plasters are mixed with the proper proportion of sand at the mill if desired, but they are usually sold without sand.

In the past few years the use of gypsum plasters has increased very rapidly in spite of their cost being somewhat higher than that of lime plaster. The advantages of the gypsum over the lime plaster may be briefly enumerated as follows:

It is much harder and has a much higher tensile strength than the lime plaster. These qualities give much stronger walls and prevent the cracking and loosening from walls or ceilings so common with lime plasters. Its hardness gives it a smooth, hard surface, well adapted for receiving decorative work. Rats and mice cannot penetrate it. It is not injured by water and will not fall from ceilings if wet by leaking of roofs or water pipes. It requires only one-third the water needed for lime plaster and lessens the danger of shrinking or warping of the wood work. It dries out very rapidly and the plasterers can be followed by the carpenters without loss of time. The second and third coats, if these be desired, can be applied much sooner on gypsum than on lime plasters and this effects a great shortening of the time required to plaster the building. It is a much better insulator for heat and sound than lime plaster. In working properties it is fully equal if not superior to lime plaster. The hard wall plaster works equally well on wood lath, metal lath, plaster board or block, brick, or concrete walls.

The methods of applying gypsum are in general the same as for lime plaster, but a few points should be noted. The gypsum plaster begins to set in 2 or 3 hours and the batches mixed should not be larger than can be used in that time. All old plaster should be removed from the mortar bed and from all tools since this old plaster causes the new batch to set more rapidly than it should. The plaster on the wall should be kept moist until it has had time to set. Too rapid drying produces checking and soft spots in the plaster. The soft spots may usually be remedied by moistening them several times with water.

Plaster wall board, studding, and partition block, or gypsum tile.—These materials are simply applications of the hard wall plasters. The Sackett plaster board of the United States Gypsum Company is made in sheets consisting of alternate layers of felt and gypsum plaster, 4 layers of felt and 3 of plaster. The standard size of the sheets is 32 by 36 inches, one-fourth inch thick. This board contains 8 square feet and weighs 12 pounds. A special board three-eights inch thick is also made. The board made by the American Cement Plaster Company is three-eighths inch thick, is reinforced by wood fibre, and has only a surface layer of felt. This board is made in sizes of 32 by 24 inches, 32 by 18 inches, and 24 by 18 inches. The plaster board is nailed directly to the studding, thus taking the place of lath. The horizontal joints are broken on each side of the partition and the vertical joints on opposite sides. Several advantages are claimed for the wall board over wood lath, among them being the greater strength given to the walls, the fire proof and insulating qualities of the board, the rapidity with which it can be plastered, as it does not require wetting before the plaster is applied. It can also be sawed, or penetrated by an ordinary auger.

The fireproof studding "gypsinite" is made by the United States Gypsum Company. It consists of two selected nailing strips imbedded in "gypsinite concrete," a plaster preparation. It can be nailed into and can be sawed as easily as wooden studding. Connections with plates, sills, and bridging are made with galvanized iron clips. Partitions of this studding with plaster board and plaster or with metal lath and plaster are entirely fireproof. The method of applying the plaster board to the studding is shown in figure 26.

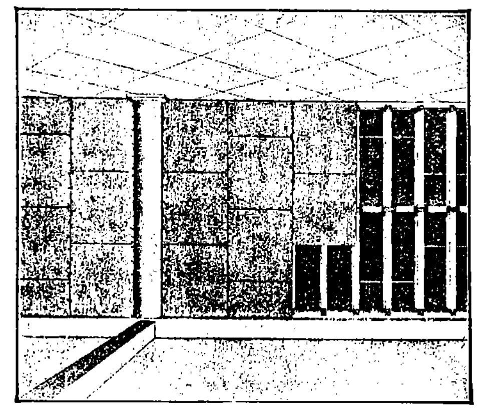


Fig. 26.—Plaster board and "gypsinite" studding.

Cement tile or partition block are made by pouring wood-fibre plaster into moulds of suitable size and shape. A continuous process of manufacture used by the Roman Nose Plaster Company at Bickford is described in the previous chap-

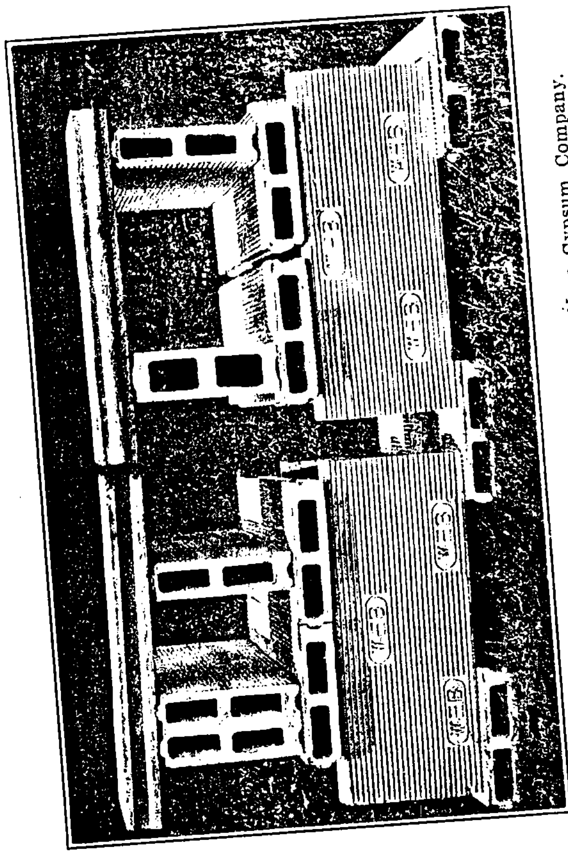


Fig. 27.—Gypsum tile made by Roman Nose Gypsum Company.

ter. The shape of this tile is shown in figure 27. The other companies manufacturing the tile in Oklahoma are the United States Gypsum Company, making the "Pyrobar" tile (fig. 28), and the American Cement Plaster Company, making the

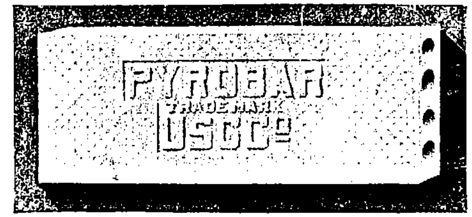


Fig. 28.—Pyrobar gypsum tile.

"American" tile. The advantageous points of the gypsum tile are given by the manufacturers in their literature as follows:

1. Fireproof qualities: practically unaffected by fire; zero co-efficient of expansion; resists action of water under average actual fire conditions, remaining plumb and true and requiring replastering on fire side only for complete restoration; transmits to the opposite side less than 5 per cent of temperature of fire side.

2. Forty per cent lighter than hollow clay tile and affords a corresponding saving of dead weight in building.

3. Is an efficient non-conductor of sound.

4. When laid in gypsum mortar the tile form an essentially monolithic partition of great stiffness.

5. The tile are straight and true and can be sawed into any desired size or shape, thus permitting neater workmanship than clay tile.

6. Give a stain-proof wall .

7. Economical on account of the light weight and large size of individual blocks. Can be laid more rapidly than clay tile.

8. Plastering grounds and trim can be nailed directly to the tile.

9. Electric installation and any alterations to buildings can be made easily and neatly since the tile can be sawed.

10. The tile make excellent column protection and wall furring because of its heat insulating properties.

The size and widths of gypsum tile for various ceiling heights made by one company are as follows:

Sizes and weights of gypsum tile.

Size	Weight per sq. ft., pounds.	For ceiling heights, feet.
2 by 12 by 30 inches, hollow	6	Furring
2 by 12 by 30 inches, solid	8.8	10
3 by 12 by 30 inches, hollow	9	13
3 by 12 by 24 inches, solid	12.4	Book tile
4 by 12 by 30 inches, hollow	11	17
5 by 12 by 30 inches, hollow	13.6	25
6 by 12 by 30 inches, hollow	15.6	28
8 by 12 by 15 inches, hollow	21.6	40

Gypsum plaster as a building material for outside work.—Gypsum plasters are cheap and easily applied so that if the material were resistant to the weather it would be an excellent exterior plaster. However, no process has yet been devised which will render the gypsum plaster weather proof. Some schemes have been devised which are tolerably successful, but the product is too expensive to be used in a large way. Except in arid climates gypsum cannot be considered as a material suited to outside work.

Temporary buildings are often finished with gypsum plaster know as staff. The great expositions have used immense quantities of such plaster and since the buildings are in service only a few months the material is entirely satisfactory. The only case, to the writer's knowledge, in which an attempt has been made to use any of these buildings for a number of years is the building of the Field Columbian Museum at Chicago. This building was used as the Fine Arts building of the Columbian Exposition in 1893 and has been occupied by the Museum ever since. For several years, the exterior walls have been in a half-ruinous condition and constant repairing has been necessary to keep the building habitable.

The Germans use plaster coated with water-proofing substances for relief work and exterior ornaments of buildings.

Wilder[62] describes the methods of making these ornaments as follows

"Figures and reliefs are characteristic of German architecture. When not made out of stone these ornaments consist of cement and gypsum. Gypsum ornaments are hardened, colored and made so weather proof that only close examination reveals the fact that they are not made out of solid material. The gypsum figures and reliefs cost but a small fraction of the sum which would be required to produce the same ornaments in the stone which they so skillfully simulate. The ornaments are cast in moulds of wood, metal, clay, gypsum or lime. If the ornament is simple, the mould may be in a single piece, but if complicated the mould is made of a number of easily detachable pieces. The fact that gypsum expands on hardening, filling all of the interstices of the mould, renders it a most valuable material for making casts.

"Extremely hard figures capable of taking a polish may be made by subjecting the gypsum to steam, then filling the form with the steamed plaster (stuck gypsum) and submitting the form to hydrostatic pressure. * * *

"As protection against the weather the following processes are recommended: warm the gypsum object and rub the surface with a mixture of three parts linseed oil varnish and one part white wax; or, impregnate the surface with sulphur balsam, consisting of fat oil in which sulphur has been dissolved (for instance, linseed oil at 160°C. and 10 per cent of sulphur). Another mixture highly recommended for protecting the surface of gypsum building ornaments is three parts of linseed oil, lead oxide equal to one-sixth the weight of the linseed oil and one part wax. Or the surface may be bronzed and otherwise protected with metal coatings.

"Mixtures containing gypsum which are recommended for ornamental purposes are: One part gypsum plaster and one part lime; four parts gypsum, three parts white chalk or lime, and one part fine sand. For white ornaments, one part fine gypsum plaster, two parts white chalk, with a limited amount of lime water; for gray figures, a mixture of gypsum plaster

[62] Wilder, Frank A., Gypsum industry of Germany: Iowa. Geol. Survey, Vol. 12, 1902, pp. 203-204.

with fine coal dust. The latter mixture gives a considerable degree of hardness, but when objects made from it are exposed to moisture and frost they fall to pieces."

Artificial stones from gypsum.—Various plans for treating gypsum to imitate marble and other materials have been tried and have proven successful in a small way. The German method of making imitation ivory and marble is described by Wilder[53] as follows:

"*Stuck gypsum (calcined plaster) used to produce effect of ivory.*—The fine white gypsum powder is heated and mixed with paraffin which has also been heated to 65° to 70°C. The mass is taken out and any extra paraffin drained off. If the gypsum contains colored impurities they are made all the more conspicuous by the oil. A more vivid color may be given the mass by adding coloring matter to the paraffin.

"*Stuck gypsum (calcined plaster) used in making artificial marble.*—The ingredients are gypsum, finely sieved and burned limestone, and coloring matter. Lime is used in only limited quantities and its function is simply that of a retarder so that the mass may not set within thirty minutes. The mass is worked up in a ball, the coloring matter being worked through in streaks, like the veins in marble. The ball is cut with wire into slabs, which are placed at once upon the wall or over the surface to be covered. When the surface has hardened it is smoothed with pumice and rubbed with a thin solution of gypsum, which closes any pores. It is then rubbed with tripoli and olive oil and finally polished with a woolen cloth. Earth colors are suitable for this purpose, and also any used by the frescoers which are not destroyed by lime. A great many processes for producing marble-like effects with gypsum plaster have been patented in Europe. One of the most recent was issued to Pietro Viotti. In this process 1,500 grams of borax and 150 grams of magnesia are fused together and when cooled mixed with seventy-five kilograms of gypsum."

Gypsum blocks may be hardened by calcining them, allowing them to cool, (usually with the outer air excluded to prevent cracking) and immersing them for a few minutes in a solution of aluminum sulphate and drying them.

[53]loc. cit.

Flooring plaster or estrick gypsum.—This material is extensively used in Germany, but so far has not been manufactured in the United States. It is made by calcining lump gypsum at a temperature of 400°F. or higher. This plaster is completely dehydrated but still retains the crystalline form of the half-hydrate, $CaSO_4 \frac{1}{2}H_2O$, or plaster of Paris. The flooring plaster, although it is what is commonly known as "dead burned" plaster in the United States, takes up water very slowly and sets similarly to the plaster of Paris or stucco gypsum and forms a very hard plaster. If the burning is conducted at a temperature greatly in excess of 400° or 500°F., or if the material remains at this temperature for too long a time, the plaster is truly "dead burned" and will not set on the addition of water[54].

The method of burning the flooring gypsum and the kiln used for this purpose have been described in the previous chapter. As is indicated by its name, estrick or flooring gypsum is principally for floors. The method of using it is described by Wilder[55] as follows:

"The following methods of applying estrick gypsum to floors are recommended by German authors. A bedding of sand 5 centimeters thick is first laid down. If sand is expensive, this may be reduced to 3 centimeters. On this the estrick gypsum mortar is spread to a thickness of 3 centimeters. In preparing the gypsum mortar a box about 1.8 meters long, 1.2 wide and 0.4 high is used. In this box the gypsum is mixed with water till a thick mortar is formed. The water is placed in the box first and into it the gypsum is poured. The gypsum mortar so made is laid on the sand foundation in the following manner: At a distance of three feet from one of the walls a wooden strip in thickness equal to that of the desired estrick layer, is placed parallel to the wall. Between this and the wall the gypsum plaster is poured. After the water in the mortar has in part soaked into the sand and in part evaporated, the mortar is rubbed over with a steel bar and partially smoothed. Perhaps an hour later it is rubbed over again and made still

[54]For complete discussion on the effect of temperature and length of burning on estrick gypsum see translation in Eckel's cements, limes, and plasters, of paper by Van't Hoff and Just.

[55]Wilder, Frank A., Gypsum industry of Germany: Iowa Geol. Survey. vol. 12, 1902, pp. 207-208.

smoother. Then the wooden strip is removed to a distance of three feet and the process repeated. The edge of the part previously prepared is beveled or hollowed so that the new strip may lap over it and become definitely a part of the one already made. At the end of twenty-four hours the floor will be so hard that the foot of an adult makes no dent in it. It is then vigorously tamped till water again appears on the surface. Finally it is smoothed with a steel bar.

"For floors of dwellings a thickness of 3 centimeters for the gypsum covering is regarded as sufficient. For granaries 5 centimeters is recommended. For one square meter of estrick floor, 3 centimeters thick, 100 pounds of gypsum are sufficient. In Germany the cost of a square meter of sand 5 centimeters thick is estimated at three cents, the gypsum for three centimeters coating at twelve cents, and labor at eight cents, making a total cost per square meter of twenty-five cents, or about twenty-two cents per square yard."

Care must be taken to protect the foundation from moisture and to prevent too rapid drying of the mortar. The floors when estrick gypsum has set and dried are hard and durable and are much used in Germany for indoor work. and for covered walks in the place of Portland cement.

Hard-finish plasters.—The following description of the various hard-finish plasters is taken entirely from Wilder's work previously quoted (page 205). A fuller discussion of the composition and properties of Keene's cement is given by Eckel, in Limes, cements and plasters, pages 76 to 78.

"*Other imitation marbles and hard cements in which stuck gypsum (calcined plaster) is used.*—The following cements, in which gypsum is the chief ingredient, are alike in their essential properties. They are usually hard, durable, uniform in structure, set slowly and take a high polish. They may be fastened in thin slabs to nearly any kind of background, do not crack in drying and admit of an admixture of coloring matter without loss of strength. They stand in hardness about one-half way between Portland cement and ordinary stucco.

"1. Keene's cement or English white cement is a slow setting alum gypsum. Gypsum, preferably a white variety, unground, is burned at a red heat, then soaked in an alum

solution, burned a second time at a red heat, and then finely ground, when used it is mixed with an alum solution. If it is used with 20 per cent water, it has a tensile strength of seventy pounds and a crushing strength of 800 pounds per square centimeter.

"2. Parian cement consists of 44 parts stuck gypsum (calcined plaster) and one part calcined borax. The gypsum is saturated with water having the borax in solution and burned at a red heat. It sets slowly and dries in five or six hours. It is used as a covering for both inner and outer walls and may be painted or covered with paper. It should be mixed with as little water as possible, and must not come in contact with fresh lime.

"3. Scagliola is a mixture of finely burned gypsum, ground selenite and lime-water, often made into slabs and used for wall decoration.

"4. German marble cement is like Keene's cement, but possesses greater hardness, having after four weeks a tensile strength of ninety-six pounds and a crushing strength of 850 pounds per square centimeter, when made up with 20 per cent of water. It is used for the most part for outside facades, and must be protected on the weather side against rain by a coating of varnish. It is made by the Walkenruder Gyps Fabrik at Walkenried in the Hartz."

TESTING OF GYPSUM PLASTERS.

No tests on the manufactured products were made in the preparation of this report. The tensile and crushing strength of these plasters has already been shown by tests and by actual experience to be ample for any purpose to which the material is likely to be put. The time of setting is controlled by the amount of retarder added so that test of the setting time of one carload or of one day's output would give no information as to the next carload or next day's output. The time of setting for each carload is usually determined at the mill. In many cases the gypsum used is so uniform that a given amount of a standard retarder will always give the same retardation or so nearly the same as to be depended on for working purposes. The effect of retarder on crushing and tensile strength has been much discussed. Tests seem to show that even small amounts of retarder weaken the strength of the plaster to some degree, but not sufficiently to have any serious effect.

The following notes are compiled from the reports of Grimsley on the gypsum of Michigan and of Wilder on the gypsum of Iowa and from Eckel's Limes, cements and plasters. They serve only to show the general properties of the plasters. There is considerable variation in the results of the tests on different plasters, but none of the plasters tested fall low enough to cause them to be rejected.

The tensile strength of the plasters tested has varied from 107 to 336 pounds per square inch for neat plaster at 1 day; from 128 to 638 pounds per square inch at 1 week; from 168 to 595 pounds per square inch at 1 month, and from 308 to 593 pounds per square inch at 6 months. The addition of sand to plaster in the ratio of 2 parts of sand to 1 part of plaster reduces the tensile strength to approximately one-half to two-thirds the tensile strength of the neat plaster. The difference between the tensile strength of the neat plaster and the plaster mixed with sand is greatest when the plaster is one day old and decreases up to 3 or 6 months. Old plaster if kept dry attains almost the same tensile strength as new plaster in a few weeks. The compressive or crushing strength of neat plaster varies from about 1,300 to 2,000 pounds per square inch. The addition of two parts of sand causes a decrease in the crushing strength. In the Wyoming cement plaster the addition of 2 pounds of retarder, made from dried cactus, per ton of plaster caused a decrease of 20 to 25 per cent in the crushing strength. The addition of 4 pounds per ton decreased the crushing strength about 27 per cent. Some of the manufacturers of Oklahoma conduct tensile strength tests continually and claim that they can determine no appreciable difference between the tensile strength of the neat plasters and that of plasters with 4 to 6 pounds of retarder per ton. The adhesive strength has been made the subject of a few tests but the tests have not been standardized and have given little information of value.

STATISTICS OF PRODUCTION.

In order to give an idea of the importance of the gypsum industry the following statistics are taken from the Mineral

Resources of the United States, for 1911, compiled by the U. S. Geological Survey:

Crude gypsum production in the United States in short tons.

1880	90,000	1906	1,540,585
1885	90,405	1907	1,751,748
1890	182,995	1908	1,721,829
1895	265,503	1909	2,252,785
1900	594,462	1910	2,375,394
1905	1,043,202	1911	2,323,970

Production of gypsum in other countries, 1906-1910, in short tons.

Year	France.		United States		Canada	
	Quantity.	Value.	Quantity	Value	Quantity[1]	Value
1906	1,517,603	$2,423,615	1,540,585	$3,837,975	417,755	$591,828
1907	1,559,685	2,598,828	1,751,748	4,942,264	485,921	646,914
1908	1,553,173	2,559,521	1,721,820	4,075,824	340,964	575,701
1909	1,460,271	2,426,110	2,252,785	5,906,738	473,129	809,632
1910	(2)	(2)	2,370,057	6,523,029	525,246	934,446

Year	United Kingdom		German Empire (Bavaria)		Algeria		Cyprus	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity[3]	Value
1906	252,030	$362,761	55,956	$22,011	30,809	$85,446	23,069	$55,658
1907	263,779	431,313	53,985	17,456	29,101	75,907	27,114	68,146
1908	255,714	431,551	56,563	18,953	28,109	66,537	23,511	57,561
1909	267,676	418,242	56,911	19,254	31,967	75,656	12,230	29,754
1910	286,226	478,095	59,962	22,658	(2)	(2)	(2)	(2)

[1]Quantity sold. [2]Figures not yet available. [3]Exports.

Production of gypsum in the United States in 1910 and 1911, by States and uses, in short tons.

1910.

State	Number of mills reporting	Total mined	Sold without calcining: Ground for land plaster		Sold without calcining: For Portland cement, paint, bedding plate glass and other purposes		Sold as calcined plaster		Total value
			Quantity.	Value	Quantity.	Value	Quantity.	Value.	
Alaska, Arizona, Montana, New Mexico, South Dakota, and Wyoming	11	211,080	280	$1,009	17,653	$38,476	121,898	$611,807	$654,292
California	7	45,901	4,960	14,185	17,318	46,090	31,821	181,928	242,203
Colorado	4	45,820	......	......	(1)	(1)	37,062	118,809	118,809
Iowa	6	322,713	6,159	8,312	30,532	38,683	230,932	896,854	943,849
Kansas	7	135,088	[2]3,751	7,223	41,859	49,971	75,445	320,028	377,222
Michigan	8	357,174	7,097	9,900	57,469	78,478	240,905	579,823	668,201
Nevada and Oregon	5	103,329	4,410	9,322	(1)	(1)	80,123	443,596	452,918
New York	13	467,339	12,494	25,462	160,666	240,118	218,862	888,367	1,153,977
Ohio and Virginia	4	292,987	10,479	21,071	19,292	37,767	226,516	759,375	821,213
Oklahoma	10	162,788	(3)	(3)	10,924	13,896	116,968	442,191	941,256
Texas	3	188,559	(3)	(3)			135,801	485,169	
Utah	4	46,279	4,185	10,841	[4]12,301	15,663	31,333	122,585	149,089
Total	82	2,379,057	53,815	110,325	368,011	559,172	1,583,669	5,853,532	6,523,02[illegible]

1911.

State	Number of mills reporting	Total mined	Ground for land plaster: Quantity	Ground for land plaster: Value	Other purposes: Quantity	Other purposes: Value	Calcined plaster: Quantity	Calcined plaster: Value	Total value
Alaska, Arizona, Georgia,[5] Illinois,[5] Minnesota,[5] Missouri,[5] Montana, New Mexico, South Dakota, Washington,[5] and Wisconsin[5]	8	129,193	382	$1,374	13,537	$13,672	151,376	$781,161	$829,21[illegible]
California	6	43,855	7,399	18,280	15,726	42,103	25,144	143,791	204,26[illegible]
Colorado	4	26,226	......	......	(6)	(6)	10,194	59,926	59,9[illegible]
Iowa	6	351,201	(7)	(7)	(7)	(7)	229,890	857,287	857,2[illegible]
Kansas	6	122,579	[9]4,736	8,702	[8]17,197	47,765	70,795	288,736	345,20[illegible]
Michigan	8	317,296	15,518	15,706	63,502	69,519	206,299	488,671	573,9[illegible]
Nevada and Utah	6	133,960	4,893	9,253	[9]15,562	23,339	98,419	413,403	446,05[illegible]
New York	12	472,8[illegible]4	7,969	17,426	149,722	213,903	268,785	968,267	1,199,5[illegible]
Ohio and Virginia	5	360,858	11,962	26,832	21,160	41,880	283,672	987,856	1,056,56[illegible]
Oklahoma	10	108,653	(7)	(7)	8,194	9,605	75,081	277,986	297,5[illegible]
Texas	4	179,625	(7)	(7)	(7)	(7)	139,023	486,102	486,1[illegible]
Wyoming	3	44,687	......	......	......	......	30,740	116,237	116,2[illegible]
Total	78	2,323,970	52,880	97,573	331,600	491,906	1,598,418	5,872,556	6,[illegible]

[1]Included in Utah.
[2]Includes Oklahoma and Texas.
[3]Included in Kansas.
[4]Includes Colorado, Nevada, and Oregon.
[5]Produces no crude gypsum.
[6]Included in Nevada and Utah.
[7]Included in Kansas.
[8]Includes Iowa, Texas, and Oklahoma.
[9]Includes Iowa and Texas.
[10]Includes Colorado.

CHAPTER IV.

THE GEOLOGY OF THE GYPSUM BEARING AREA OF OKLAHOMA.

INTRODUCTION.

The gypsum deposits of Oklahoma are a part of the Redbeds which form the surface rocks of the greater part of the western half of the State. In order to give the geologic relations of the gypsum members, the geology of the Redbeds as a whole is considered rather briefly in this chapter. The detailed stratigraphy of the gypsum-bearing formations is given as completely as possible in the succeeding chapter.

GEOLOGY OF THE REDBEDS.

DISTRIBUTION.

The Redbeds area of Oklahoma forms a part of the larger area which extends from southwestern Kansas almost to the Pecos River in southwest Texas. The outcrop at the north end is narrow, but widens rapidly to the south and includes most of the western half of Oklahoma. From Red River south the belt narrows until on Colorado River it is about one-half as wide as it is in Oklahoma. The narrowing of the outcrops in both directions from Oklahoma is accounted for in large measure by the covering of the Redbeds by younger formations, and in part by the thinning of the beds. To the west, south, and north the beds disappear under younger formations, —Lower or Upper Cretaceous or Tertiary. They are continuous beneath these younger formations to the west and reappear in a belt along the base of the Rocky Mountains in New Mexico. A narrow strip along Canadian River connects the New Mexico and Oklahoma areas across the Panhandle of Texas. Areas of red rocks in the eastern part of Colorado and Wyoming probably belong to the same great body of Redbeds.

PHYSIOGRAPHY.

Topography.

The western portion of Oklahoma is a plain which slopes southeastward. In the region underlain by the gypsum the streams have cut many canyons, so that while in general the region is a plain, the gypsum area is hilly and is usually considered as a physiographic unit, the "Gypsum Hills Region," which separates the Low Plains to the east from the High Plains which lie to the west of the gypsum area.

Drainage.

Across the gypsum hills, seven rivers run in a general southeast direction. These are from north to south, Salt Fork of Arkansas River, Cimarron, North Canadian, South Canadian, Washita, North Fork of Red River, and Salt Fork of Red River.

Salt Fork of Arkansas River emerges from the gypsum hills just at the Oklahoma-Kansas state line in northern Woods County. Two of its tributaries, Yellowstone and Greenleaf Creeks, have canyons reaching back a few miles into the gypsum hills.

Cimarron River enters the State from Kansas at the northeast corner of Harper County and forms the boundary between Harper, Woodward, and Major Counties on the southwest and Woods County on the northeast. For 8 or 10 miles it flows through a rather narrow valley between the gypsum hills, which form steep bluffs 200 to 300 feet high on either side, and then the valley widens gradually to about 15 miles farther down where the hills on the north side drop back from the Cimarron and swing to the west on the south side of Salt Fork of Arkansas River. On the south side of the Cimarron the hills continue, gradually getting farther from the river, at Fairview the hills are about 8 miles from the Cimarron and from this point southeastward the hills are nearer to the North Canadian than to the Cimarron. On the north side of the Cimarron is a belt of sand hills varying from 1 to 2 miles to 20 miles in width. A large number of tributaries rise on the divide to the southwest of the gypsum hills and flow north and northeast through the canyons in the gypsums into the Cimarron. About 18 miles below the Kansas line, Buffalo Creek joins the Cimarron from the west. It is a long creek which drains a large portion of Harper County. Between Buffalo Creek and the vicinity of Fairview are several creeks flowing north which are not over 10 to 15 miles long and which are spaced 5 or 6 miles apart. From Fairview southeast the tributaries are longer and flow due east to the river.

North Canadian River has an exceptionally narrow valley for so long a stream. It is formed by the confluence of Beaver Creek and Wolf Creek, near Fort Supply, and flows to the southeast very nearly parallel to the Cimarron and from 20 to 25 miles distant from it. The gypsum escarpment discussed in connection with the Cimarron River lies within 5 to 10 miles of the North Canadian from Watonga to El Reno, but faces the Cimarron so that the North Canadian receives very little drainage from the north. A few fairly large tributaries join it from the south from southern Woodward and northern Dewey Counties, but from the southeast corner of Woodward County to the center of Canadian County, where it leaves the gypsum hills, the North Canadian is usually less than 15 miles distant from the South Canadian, so the tributaries are few and short.

Like the Cimarron the North Canadian has a belt of sand hills along its north bank which locally reaches a width of 10 to 12 miles. The gypsum hills along the North Canadian are rounded and there are no steep gypsum capped bluffs as there are on the Cimarron.

South Canadian River enters Oklahoma from Texas a little north of the middle of the north-south line between the two States, and flows in a winding course with a general easterly direction. It forms the boundary between Ellis and Roger Mills Counties and enters the gypsum hills where it bends to the north about 12 miles west of the Roger Mills-Dewey County line and continues through them with a great bend to the north, another to the south and back to the north to Taloga in north-central Dewey County. Here it leaves the gypsum hills and turns abruptly southeast. Through the gypsum hills the sand hills are not so conspicuous along the north side of the river, although they make a broad belt both above and below the gypsum area. The gypsums along the South Canadian do not belong to the same formation as those along the Cimarron and are not so thick nor so regularly stratified. They do not make a continuous escarpment, but cap rather steep sided hills. The tributaries from the north and the south are about equal in number and are all short, the longest being about 15 miles long, and the most of them less than 10 miles.

Washita River differs from the other streams of this region in having steep mud banks. There are no sand hills along its course. It enters the State from Texas only 8 or 10 miles south of the South Canadian, and flows south and east across Roger Mills County, southeast across the southwestern part of Custer County, east and south across the eastern part of Washita County, at the south line of which it turns east and flows in that direction across Caddo County and out of the area under consideration. The Washita enters the gypsum hills near the Roger Mills-Custer County line and continues in them with the exception of a few miles in southeastern Washita and northeastern Kiowa Counties, to Anadarko in southeastern Caddo County. The gypsums are those of the Greer formation and do not form a continuous escarpment as do the gypsums along the Cimarron, but some of the thickest ledges in the entire area are exposed along the Washita in eastern Washita County.

North Fork of Red River enters Oklahoma from Texas about the middle of the west line of Beckham County and flows east and southeast to the corner of that county, then in a meandering course to the south between Greer and Jackson Counties on the west and Kiowa and Tillman Counties on the east. The only exposures of gypsum along this river are in the extreme southeastern portion of Beckham County, where the Wichita Falls & Northwestern Railway crosses the river south of the town of Carter. Here heavy ledges of gypsum extend for several miles along the northeast bank of the river. Along the upper course of Elm Fork, the principal tributary of North Fork, in northern Harmon and western Greer Counties, are four or five ledges of gypsum which form an escarpment resembling the one along Cimarron River.

Salt Fork of Red River parallels Elm Fork about 10 to 12 miles south of the latter through Harmon and western Greer Counties, turns south at Mangum and flows south approximately parallel to North Fork and from 10 to 12 miles west of it. The hills along the Salt Fork in Harmon and Greer Counties are much more rounded than those along Elm Fork a few miles north, and, except at Mangum and for a short distance above, good exposures are not common. After it turns south the course of the river lies outside the gypsum hills.

CHARACTER OF THE ROCKS.

The Redbeds consist entirely of red shales and sandstones. The red color varies greatly in shade in different horizons and from place to place in the same horizon. All graduations from vermillion to maroon or very deep red brown can be observed in short distances where good exposures are common. In general, however, the vermillion and brick reds seem to be more common in the lower formation in which shales predominate and the deeper reds in the upper formations in which sandstones are more abundant. The sandstones are usually composed of very fine, rounded grains, and are cross-bedded and lenticular to a pronounced degree. They often grade into shales in very short distances, but probably more often they pinch out very quickly and are replaced abruptly by shales which contain very little sand. Locally the sandstones are quite coarse and in a few instances are conglomeratic.

The shales are usually very fine-grained, slightly consolidated, and very plastic, with high shrinkage in drying. They usually contain considerable quantities of soluble salts. The color of the clay shales is usually a brighter brick red or vermillion than that of the sandy shales or the sandstones.

The gypsums, although they occur in ledges of up to 60 or more feet in thickness and cover considerable areas, are relatively unimportant when considered as a part of the Redbeds as a whole. Closely associated with the gypsums are white to greenish sandstones and shales, which, on account of their color, are often very striking in fresh exposures. The stratification of these whitish or greenish rocks is very irregular. A greenish band may appear, thicken to 5 or 6 feet, and pinch out in a few rods. The stratification of these light colored bands is probably no more irregular than that of the minor variations in the red rocks, but is much more noticeable on account of the contrast in colors. Two or three ledges of dolomite, usually less than 5 feet in thickness, are the only carbonate rocks.

THICKNESS.

The character of the Redbeds as noted in the preceding paragraphs renders it impossible to make an accurate determination of their thickness by measuring across the outcrop. The stratification is so irregular that a section taken at one place cannot be duplicated even in its larger features at a distance of a mile. In detailed sections great variation is found in the distance of a few rods. The lenticular nature of the sandstones and shales and the crossbedding of the sandstones make it almost impossible to determine the dip of the rocks from observation of short exposures. In the upper portion of the beds some general horizons can be followed and the thickness between them can be rather closely approximated. The only way of obtaining the thickness of the lower portion of the beds is from the logs of the few deep wells which have been drilled in this region.

Williston and Case[54] estimate the Redbeds in Kansas, Oklahoma, Texas, and eastern New Mexico, as "thicker than those of northern New Mexico [1,600 feet], probably reaching 2,000 feet in their totality." This estimate, however, is manifestly too small for the thickness of these beds in central Oklahoma. At Alva, near the Kansas line, a well passed through 1,100 feet of Redbeds. The well started some distance below the lowest gypsum and the mouth was consequently at least 750 feet below the top of the Redbeds as exposed in Oklahoma. To the south of the latitude of Alva the Redbeds thicken downwards rapidly to the middle of the State. At Shawnee a well which was started near the Pennsylvanian-Permian contact shows over 1,000 feet of red rocks. When it is remembered that much of the Permian and all of the Pennsylvanian in the latitude of Alva is non-red and that in the latitude of Shawnee these lower Permina rocks are red and that in addition 1,000 feet or more of the uppermost Pennsylvanian rocks are red, we obtain a total thickness of over 3,000 feet. (750 feet above the mouth of well + 1,100 feet in well at Alva + 500 feet Permian rocks non-red at Alva but red at Shawnee, + 1,000 feet red Pennsylvanian in well at Shawnee = 3,350 feet.) The estimate of 500 feet for the Permian rocks which are non-red at Alva but red at Shawnee is from the thicknesses near the Kansas line. The thickness at Shawnee is probably greater.

[54]Williston, S. W., and Case, E. C., The Permo-Carboniferous of New Mexico: Jour. Geol. vol. 9, 1911, p. 4.

In the deep well recently completed at El Reno the rocks were red and reddish brown to a depth of 2,050 feet. The thickness of the Redbeds formations occurring to the west and lying at a level above the mouth of this well is certainly not less than 900 feet and is probably greater. This well indicates a thickness of 3,000 feet or more for the Redbeds. Gould[55] gives the thickness of each formation of the Permian and the sum of these thicknesses gives a minimum of 2,250 feet for the Permian Redbeds. The maximum is probably 500 feet more. This with 1,000 feet or more of red Pennsylvanian gives between 3,000 and 4,000 feet of Redbeds in the central part of the State. The writer regards 3,000 to 3,500 feet as a very conservative estimate of the thickness of the Redbeds as exposed from the center or east of the center of the State to the west line.

AGE.

The Redbeds of the area under discussion were studied in Kansas and Texas several years before they were in what is now Oklahoma. Before 1893 the Kansas beds had been usually referred to the Jura-Trias or definitely to the Triassic[56], although some of the earliest observers had ascribed them to the Upper Carboniferous and some to the Lower Cretaceous. All these correlations were made on lithologic or stratigraphic grounds.

[55]Gould, Chas. N., Geology water resources of Oklahoma: Water-Supply Paper U. S. Geol. Survey No. 148, 1904.

[56]Hay, Robert, The Triassic rock of Kansas: Trans. Kans. Acad. Sci., vol. 6, 1889, p. 36; and Cragin, F. W., Geological notes on the region south of the great bend of the Arkansas: Bull. Washburn Col. Lab. of Nat. Hist., vol. 2, 1889; and A geological reconnoissance in southwestern Kansas: U. S. Geol. Survey, No. 57, 1890, pp. 20-21; Williston, S. W., Geol. Map of Kansas. 1892.

In 1891, White[57] described the invertebrate fossils from the Texas rocks supposed to be of the same age as the Kansas Redbeds, and Cope[58] had described the vertebrates from the Texas Redbeds some years previously. The age of the Texas beds was decided to be Permian, and although no fossils were found in the Kansas beds they were afterward classed as Permian by Hay[59] and Cragin[60] and by practically all subsequent writers. Recently the Permian age of the lower Redbeds in Texas has been more definitely established, especially on paleobotanic grounds. In the same paper[61] it is shown that the lower Redbeds in north Texas grade into non-red Permian rocks to the south.

In Oklahoma, as is shown later, the lowest part of the Redbeds is Pennsylvanian. The portion which is equivalent to the Permian of Texas has afforded a few fossils, vertebrate, invertebrate, and plant. The vertebrates were found at Nardin and Orlando, the former locality also furnishing invertebrates and plants. The vertebrate from Nardin was identified by S. W. Williston as a species of *Eryops*, a Permian amphibian; the invertebrate was provisionally identified by T. Rupert Jones as *Estheria minuta*, a crustacean usually regarded as Triassic; the leaves were too poorly preserved for identification, but according to Dr. Lester F. Ward appeared to represent Mesozoic forms. The fossils were found in the McCann sandstone quarry 5 miles southeast of Nardin and 12 miles southwest of Blackwell.

The Orlando locality is 2 miles northeast of the village of that name. The vertebrates collected there were identified and reported on by Case[62]. His list of species follows:

"*PISCES.*

"Elasmobranchii.

[57] White, C. A., The Texas Permian and its Mesozic types of fossils: Bull. U. S. Geol. Survey No. 77, 1891.
[58] Cope, E. D., Proc. Amer. Phil. Soc., vols. 17, 19, 20 and 21.
[59] Hay, Robert, Geology and mineral resources of Kansas: Eighth Bien. Rept. Kans. State Board Agri., pt. II, 1893, p. 101.
[60] Cragin, F. W., The Permian System in Kansas: Col. Col. Studies, vol. 6, 1896, pp. 2-3.
[61] Gordon, C. H., Girty, George H., and White, David: The Wichita formation of northern Texas: Jour. Geol., vol. 19, No. 2, 1911, pp. 120-134.
[62] Case, E. C., 2d. Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 62-68.

"Diacranodus (Pluerecanthus) *ampressus (?) Cope.

"Diacranodus is the name applied to this form by Garman in 1885, Bul. Mus. Comp. Zool., vol. 12, and is the name used by Hay in his catalogue of the Extinct Vertebrata of N. A., Bull. 179, of the U. S. G. S., it has been known variously as Diplodus, Didymodus and Pleuracanthus; see the Catalogue by Hay cited above.

"Dipnoi.

Sagenodus (?) sp.

BATRACHIA.

"Diplocaulus magnicornis (?) Cope.

"Diplocaulus limbatus (?) Cope.

"Diplocaulus salamandroides Cope.

"Trimerorhachis sp. Cope.

"Trimerorhachis leptorhynchus sp. nov.

"Cricotus sp. Cope.

"Cricotillus brachydens g. et. sp. nov.

"Eryops megacephalus Cope.

"Crossotelos annulatus g. et. sp. nov.

"REPTILIA.

"Pelycosauria.

"Naosaurus sp. Cope.

"Embolophorus (?) sp. Cope.

"Cotylosauria.

"Pariotichus ordinatus Cope.

"Pariotichus sp. Cope.

"Indet.

"Pleuristion brachycoelous g. et. sp. nov."

Fossil plants from a horizon near that of the vertebrates from Nardin and Orlando were collected near Perry and Red

Rock by David White and Charles N. Gould in the autumn of 1911. The material has not been fully worked up nor described, but the following preliminary statement concerning the plants was furnished the writer by Dr. White[63]: ". . . The flora is very distinctly and conclusively Permian. It contains an abundance of *Callipteris* with *Walchia* and *Gigantopteris*. *Callipteris conferta*, and species of *Walchia*, very likely identical with *Walchia gracilis*, and *Gigantopteris Americana* are among the most characteristic, the latter being nearly everywhere present in the Perry and Red Rock region. . . . There is no shadow of doubt as to the Permian age of the beds near Perry and Red Rock."

These fossils are from the lower part of the Redbeds in the latitude in which they are found. The only fossils found in the upper Redbeds in Oklahoma were found in the Whitehorse sandstone, a member of the Woodward formation, about 600 feet below the top of the Redbeds. The locality is at Whitehorse spring, two miles southeast of the Whitehorse Post Office, and 18 miles due west of Alva. The fossils are all invertebrates and were described and figured by Beede in an advance bulletin of the Second Annual Report of the Oklahoma Department of Geology and Natural History in 1902. Most of the type specimens of the collections were consumed by fire which later destroyed Science Hall at the University of Oklahoma. A new collection was made and the species redescribed and refigured[64] along with a collection from the Quartermaster formation (the topmost formation of the Redbeds) at Dozier, Texas.

Beede's conclusions are as follows:

"The fauna of the Quartermaster beds is different in some respects from that of the Whitehorse sandstone, several new elements having been introduced. * * *

"The faunas are somewhat heterogeneous as to origin. Some of the species seem to be directly derived from the Kansas Permian or Pennsylvanian, while others, as pointed out in the discussion of the species, are derived from the European Per-

[63]Person communication, dated Dec. 9 1912.

[64]Beede, J. A., Invertebrate Paleontology of the upper Permian red beds of Oklahoma and the Panhandle of Texas: Kans. Univ. Sci. Bull., vol. 4, No. 3, 1907.

mian, especially that of Russia. There seems to be comparatively little resemblance to the Indian or Chinese forms. The fossils described as *Dielasma schucherti* Beede seem to have their closest allies in the Productus limestone of India, the only species, perhaps, with pronounced Indian affinities."

The types of the whole Quartermaster fauna were sent to T. W. Stanton, who pronounced them Paleozoic.

In addition to these fossils the dolomitic members immediately under the lower gypsum ledges in northwestern Oklahoma contain poorly preserved specimens of *Pleurophorus* and *Schizodus*. These occur also in a dolomite higher in the section near Eldorado in the extreme southwest part of the State.

Practically all the recent work then has tended to prove that all except the very lowest of the Redbeds are of Permian age. The only exception to this rule is the paper by Williston and Case[65] which has already been quoted. This paper is principally a description of the Redbeds of northern New Mexico, but some references are made to the Oklahoma deposits. In the northern New Mexico beds, as well as in the beds of Wyoming, upper Triassic vertebrates were found below the heavy gypsum ledges and the assumption is made that the gypsums of Oklahoma occupy the same horizon as the gypsums of northern New Mexico and Wyoming, and that therefore they and the sandstones above them are of upper Triassic age. A considerable thickness of the nonfossiliferous rocks below the gypsums is regarded as probably lower Triassic. The lower part of the northern New Mexico beds which contain vertebrates hitherto classed as Upper Pennsylvanian, apparently on the basis of a single cast of *Spirifer* as is indicated in the following quotation from the paper under discussion:

"It has been questioned by us elsewhere whether the vertebrate fossils found in Texas, Oklahoma, southern Kansas, Illinois, and Pennsylvania are really of Permian age. At the south side of the canon, the junior author found a perfect cast of a Spirifer, identified by Professor Schuchert as *S. rockymontanus* Marcou, a form occurring in Colorado in the Pennsylvanian. Though the specimen was found free, so that its exact

[65]Williston, S. W., and Case, E. C., The Phermo-Carboniferous of northern New Mexico: Jour. Geol., vol. 19, No. 1, 1912, pp. 1-12.

horizon could not be determined, its excellent preservation proves conclusively that it had not been carried far from its original bed, and inasmuch as vertebrate fossils are found in the deepest strata of the canon it seems quite certain that the specimen came from an intercalated bed among those yielding so-called Permian vertebrates. No other explanation seems possible. It is the conviction of both the present authors that the lowermost at least of the strata yielding vertebrate fossils are of Pennsylvania age, and this conviction is strengthened by the known position of the vertebrate horizons in Texas, Kansas, Illinois, and Pennsylvania, that of the last-named region definitely known to be Pennsylvanian."

The assumption is thus made that this horizon is the same as that carrying the vertebrates in Oklahoma, Kansas, Texas, Illinois, and Pennsylvania.

In view of the extreme irregularity of the stratification of the Redbeds and the distance which separates the Oklahoma deposits from those of northern New Mexico and Wyoming it seems to the writer that the correlations based on stratigraphy are decidedly open to question. Since there have been no Triassic vertebrates reported[66] from below the gypsums in Oklahoma and since the invertebrates from the Quartermaster considerably above the gypsums have been pronounced by different authorities to be Paleozoic, the age of the upper Redbeds of Oklahoma is regarded as Permian. The evidence of the plants and the invertebrates seems to show conclusively that the Enid formation is of Permian (including Permo-Carboniferous) age, even if it should be decided that the vertebrates should be placed in the Pennsylvanian instead of the Permian to which they have hitherto been ascribed by both the authors of the paper cited.

RELATIONS OF THE REDBEDS.

As has been shown in the preceding paragraphs the greater part of the Redbeds are generally regarded as of Permian age. In Kansas, only the upper portion of the Permian rocks are red, but near the Kansas-Oklahoma line the limestones and

[66] Up to Apr., 1913, Dr. E. C. Case spent a portion of the field season of 1912 studying the Oklahoma beds but results of his work have not been published.

non-red shales of the lower part of the system grade southward into red shales and sandstones so that the line between the red and non-red rocks descends lower in the system and the line between the outcrops swings to the east. As a result there is only a small area of non-red Permian rocks in Oklahoma, most of Kay county and portions of Osage, Noble, and Pawnee counties. The same change takes place in the rocks in the upper part of the Pennsylvanian system, *i. e.*, the limestones in Kansas give way to shales and sandstones in Oklahoma, with most of the sandstone dying out before they reach Arkansas River. To the south of the Arkansas the shales, and further south, the sandstones, take on the red color and become part of the Redbeds. The line between the red and non-red beds passes about midway between Pawnee and Stillwater and southeastward to Stroud, where it swings to the west of south and passes around the west end of the Arbuckle Mountains. The line between the Pennsylvanian and Permian enters the state a few miles east of the northeast corner of Osage County and bears a little to the west of south to the west side of the Arbuckle Mountains. The Pennsylvanian and Permian rock, then, occur in the following areas: (1) a large area of red Permian rocks, (2) a small triangular area of non-red Permian rock in Kay County and adjoining parts of Osage, Noble, and Pawnee Counties, (3) a small area of red Pennsylvanian rocks between the two lines mentioned above, and (4) the non-red Pennsylvanian rock covering most of the eastern half of the State.

The relations of the red and non-red rocks in Texas and in Kansas have been shown[67] to be similar. The Permian in central Texas is white (Albany), but becomes red to the north (Wichita), and limestones give way to sandstones and shales from south to north in the same way that the limestones of Kansas do from north to south.

The upper limit of the Redbeds in Oklahoma is irregular and is always one of unconformity. Limestone of lower Cretaceous (Comanchean) age occurs in small areas in Woods, Woodward, Dewey, Custer and Washita Counties. The patches

[67] Cummins, W. F., The Texas Permian: Tex. Acad. Sci., vol. 2, 1897, pp. 93-98; Adams, Geol. I., Stratigraphic relations of the Red Beds to Carboniferous and Permian in northern Texas: Bull. Geol. Soc. America, vol. 14, 1903, pp. 191-200; Gordon, C. H., Jour. Geol., vol. 19, 1911, pp. 110-125.

seldom exceed a few acres in extent and are on top of the hills or broad divides between the streams. The limestone is seldom over 3 or 4 feet thick and usually seems to have been let down from above as the shales and soft sandstones worked out from beneath it. In the rest of the area in Oklahoma the Redbeds pass under the Tertiary or Quaternary sands. In Texas the Dockum beds, Redbeds of Triassic age, occur unconformably above the Permian[68] Redbeds, but this formation is not present in Oklahoma.

CLASSIFICATION.

The classification of the Redbeds of Oklahoma has been discussed at some length by Gould in two papers, the Second Biennial Report of the Department of Geology and Natural History (Territorial) and Water-Supply Paper No. 148 of the United State Geologisal Survey. These reports are no longer easily obtained by the public, so in this report the classifications are briefly reviewed.

Cragin[69] published a classification of the Permian rocks in which he divided them into two series, the Big Blue or non-red series, and the Cimarron or Redbeds. He revised the classification of the Cimarron series in 1897.[70] Gould in the first of the papers cited above reviewed the previous work on the Redbeds and discussed the classification and stratigraphy of the Oklahoma deposits.

He used Cragin's classification as a basis, but owing to local differences in stratigraphy made important changes. The distinction between the Big Blue and the Cimarron series could not be kept in Oklahoma, since all the Permian rocks are red a short distance south of the Kansas line. The presence of two important gypsum bearing horizons gave a basis for classifying Redbeds into five divisions. These divisions and their subdivisions are as follows:

[68]Gould, C. N., Water-Supply Paper U. S. Geol. Survey No. 154, 1906, pp. 23-24.

[69]Cragin, F. W., The Permian system in Kansas: Colorado Col. Studies, vol. 6, 1896, p. 3.

[70]Observations on the Cimarron series: Am. Geologist, vol. 19, 1897, pp 351-363.

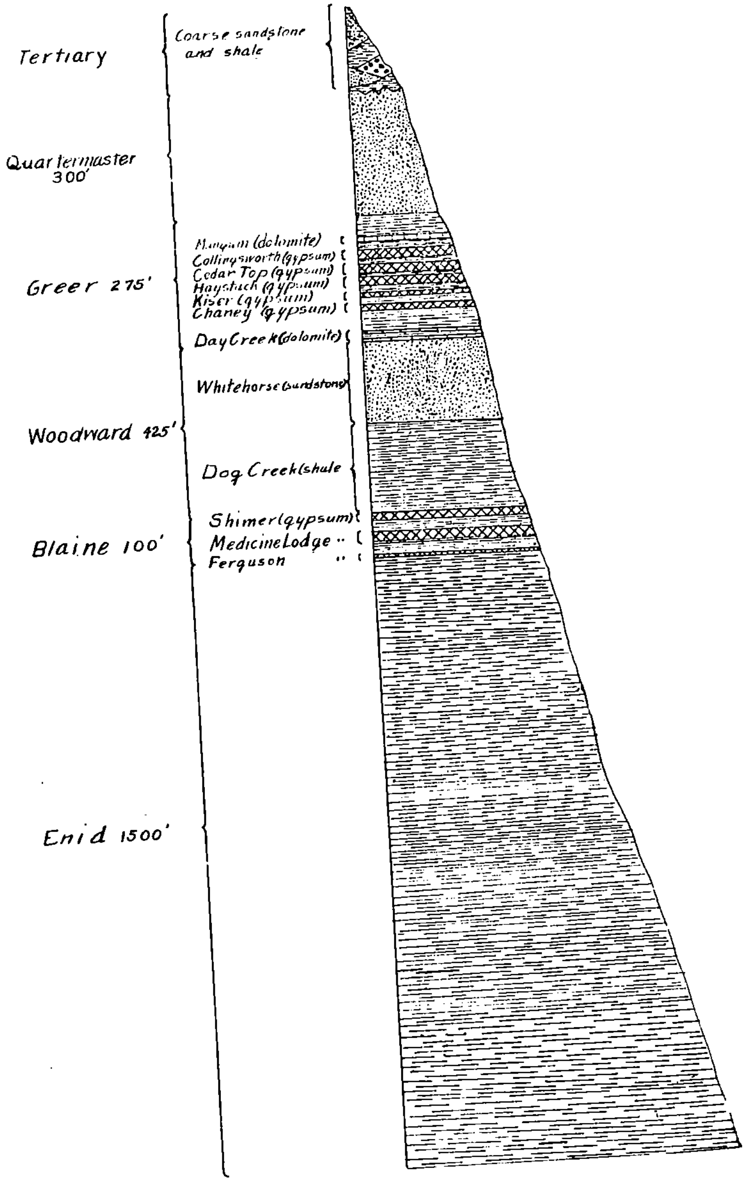
5. Quartermaster division.	
4. Greer division	Delphi dolomite. Collingsworth gypsum. Cedar-top gypsum. Haystack gypsum. Kiser gypsum. Chaney gypsum.
3. Woodward division	Day Creek dolomite. Red Bluff sandstones. Dog Creek shales.
2. Blaine division	Shimer gypsum. Altova dolomite. Medicine Lodge gypsum. Magpie dolomite. Ferguson gypsum
1. Norman division	

The term "division" was used "in a general sense, corresponding with its ordinary English meaning, to designate a larger or smaller sequence of strata which may in one instance correspond to a formation having a simple uniform lithologic character, or in another to a group of such formations."

In 1904 the second paper by Gould[71] appeared, which modified the 1902 classification in some particulars. The term "division" is superseded by the term "formation," which is used in the same sense. The term "Norman division," which included all the Redbeds below the lowest heavy gypsum, is abandoned, and the term "Enid formation" used for the Permian portion of these rocks, and the term "Chandler Beds" for the Pennsylvanian Redbeds. Of the minor divisions the terms Altova and Magpie dolomites are dropped, Mangum dolomite is substituted for Delphi dolomite and Whitehorse sandstone for Red Bluff sandstone. These changes leave the classification as follows:

Quartermaster formation.	
Greer formation	Mangum dolomite member. Collingsworth gypsum member. Cedartop gypsum member. Haystack gypsum member. Kiser gypsum member. Chaney gypsum member.
Woodward formation	Day Creek dolomite member. Whitehorse sandstone member. Dog Creek shales member.

[71]Gould, C. N., Geology and Water Resources of Oklahoma: Water Supply Paper U. S. Geol. Survey, No. 148, 1904



Blaine formation................. { Shimer gypsum member. Medicine Lodge gypsum member. Ferguson gypsum member.

Enid formation.

STRATIGRAPHY.

Under this heading each of the formations is described in turn, commencing with the lowest. The Enid, Woodward, and Quartermaster, which contain no commercial gypsum, are dealt with rather fully and are not discussed elsewhere, and the Blaine and Greer are briefly discussed in order to give their general relationships and the detailed discussion of the stratigraphy and occurrence of the gypsum is taken up separately in the succeeding chapter. The areas of the outcrops of the different formations are shown on the map (fig. 29), and a generalized section is shown on the accompanying diagram (fig. 30)

Enid formation.

The Enid formation includes the rocks from the base of the Permian Redbeds to the lowest heavy gypsum ledge. The Pennsylvanian-Permian contact has been taken as a line crossing the Oklahoma-Kansas State line north of Pawnee, and extending south to that town, then west of south to Purcell, and south to the west end of the Arbuckles. The most recent work[72] has shown that the line should be drawn more nearly south from Pawnee. The upper limit of the formation is the base of the lowest gypsum of the Blaine formation. Owing to the lenticular nature of the gypsum this is not an exact limit, but is still a well defined horizon.

The line between the Enid and Woodward to the south or southeast of El Reno is very indefinite. The Enid formation occupies all or part of the following counties: Grant, Alfalfa, Woods, Major, Garfield, Noble, Payne, Lincoln, Logan, Kingfisher, Blaine, Canadian, Oklahoma, Cleveland, and McClain. The Redbeds in western Garvin and Carter Counties may belong in part to this formation.

The Enid consists almost entirely of red shales with soft, lenticular, red sandstones. The lower portion contains relatively

[72] Dr. J. W. Beede had a party in this region during the field season of 1911. The results of the work have not been published.

more sandstone than the upper, but the shales predominate throughout and comprise practically all of the upper part. Throughout the Enid there are veins of white sandy material. These sometimes occur as lenses having considerable thickness at the center but pinching out rapidly. Lentils as much as 3 feet thick in the center have been observed to pinch out in a very few (10 or 12) rods. Some of the beds of white sand are four feet, or even more, thick and cover areas of several acres. In a few cases of exceptionally good exposures layers of this white sand less than an inch thick can be traced for about one-fourth mile. The grains of the ordinary red sandstones, as well as those of the white layers, are very fine—a large percentage passing a 200-mesh sieve. The shales grade from very sandy to clay shales. The latter are very fine grained, very plastic when wet, and have great drying shrinkage.

The red color of both the sandstone and the shales is due to iron (ferric) oxide, which forms a thin coating over the grains of sand in the sandstones and presumably over the clay particles in the shales. In the uppermost 100 feet some of the shales have a green color. This color is probably due to some form of iron, but since these green shales are largely gypsiferous the color may be due to a compound of iron and calcium. The green color is often mistaken for copper stain.

At about 100 feet below the top of the formation the shales locally are very salty and give rise to salt springs at Ferguson in Blaine County, at the Big and Little Salt Plains on the Cimarron near the Kansas-Oklahoma State line, and at the Salt Plain near Cherokee. It is not to be understood that the salt occurs in these different localities at eactly the same horizon. The water carrying the salt at Cherokee is probably from a horizon considerably lower than that from which the salt water of the Springs at Ferguson come, while the salt horizon at the Salt Plains on the Cimarron is probably somewhat higher.

The shales for 25 to 30 feet below the gypsum ledge are very gypsiferous and the eposures show many veins of satin-spar and selenite. This vein material has almost certainly been derived from the solution of gypsum by water passing through the ledges above and has been deposited near the surface of the exposure by the evaporation of the water. Near the bottom of the strongly gypsiferous layer is a persistent layer 1 to 2 feet thick of greenish selenite, the crystals of which are usually about an inch long, and a single layer of concretions of pure white, fine-grained gypsum. The concretions are in the shape of flattened ellipsoids and all lie with the long axis horizontal. The short or vertical diameter is usually about 2 inches and the long diameter 3 to 6 inches. These concretions lie almost or quite touching each other, forming a layer in the shale. On account of the persistence and uniformity of this double layer it is believed that it is the result of original deposition.

The surface of the territory underlain by the Enid is in general a plain into which the streams have cut shallow valleys. The eastern portion of the outcrop is somewhat hilly on account of the sandstones in the lower part of the formation. This portion is covered by oak trees but the greater part of the area is prairie and only a few cottonwoods and elms occur along the streams. The thickness of the Enid was estimated by Gould[73] at 1,200 to 1,500 feet.

[73]Gould, C. N., Water-Suply Paper U. S. Geol. Survey, No. 148, 1904, p. 44.

Blaine formation.

The Blaine is the great gypsum-bearing formation of the northwestern part of the State and as such its stratigraphy will be discussed in detail in the next chapter. In this connection only a brief notice will be given to the character of the formation and its relations.

The Blaine formation consists typically of three gypsum members separated by shales. The formation always forms a pronounced escarpment, as the soft, easily eroded shales of the Enid are eroded much more rapidly than the gypsums. This escarpment and the outliers have been known since early times as the "Gyp Hills." The outcrop of the formation varies in width from about 1 to 6 or 8 miles. The hills enter the State from Kansas on the south side of the Salt Fork of Arkansas River, follow down that stream a few miles, swing back northwest up the Cimarron, cross the Cimarron just north of ehe Kansas-Oklahoma State line, and follow down the south bank of that river gradually getting farther from it. The formation is well developed as far southeast as Watonga, but from that point on the gypsums become lenticular and the formation plays out about 5 miles north of El Reno. The formation ranges from

75 to 100 feet thick. All discussion of the details of distribution and stratigraphy will be reserved for the succeeding chapter.

Woodward formation.

This formation is well described by Gould and since the field work for this report dealt very little with the formation and determined nothing new concerning it, his description is given in its entirety[74].

"*Dog Creek shales member.*—The Dog Creek member is composed mainly of clays, containing occasional thin ledges of magnesian limestone, which in places grade into a fair quality of dolomite.

"The ledges, however, are usually thin and rarely sufficiently conspicuous to be worthy of more than passing notice. Professor Cragin's original description of this member is as follows:*a*

" 'The Dog Creek * * * consists of some 30 feet, or locally of a less or greater thickness, of dull-red argillaceous shales, with laminae in the basal part and one or two ledges of unevenly lithified dolomite in the upper. The color of these shales resembles that which prevails in most of the divisions below rather than of the terranes above the Dog Creek.'

"In his second paper he modifies his description in this way:

" 'In central Oklahoma it is a great dolomite formation, laminated dolomite occupying a considerable part of the thickness' *b*

"In his second paper he suggests that the name Dog Creek be changed to Stony Hills. The writer agrees that the name Dog Creek is, perhaps, not the best that could be used, but in view of the fact that the dolomites which make up the Stony Hills in eastern Blaine County belong to the Blaine formation

[74]Gould, C. N., Water-Supply Paper, U. S. Geol. Survey No. 148, 1904, pp. 15-59.

*a*Cragin, F. W., the Permian system in Kansas: Colorado Col. Studies, vol. 6, 1896, p. 32.

*b*Cragin, F. W., Observations on the Cimarron series: Am. Geologist, vol. 19, 1897, p. 358.

and do not belong to the Dog Creek, there seems to be no good reason for using the name Stony Hills to designate this member.

"Studies made during the last three years have demonstrated that in many parts of Oklahoma the thickness of the Dog Creek is much greater than that given by Professor Cragin. Near Quinlan, in eastern Woodward County, the aneroid readings indicate 225 feet as the thickness of these beds, measured from the top of the underlying gypsums of the Blaine formation to the sandstones of the next higher formation of this member, the Whitehorse, and in a number of localities 150 and 175 feet were recorded. Exposures are common along the top of the Gypsum Hills from Canadian County to the Kansas line and beyond.

"*Whitehorse sandstone member.*—The Whitehorse sandstone was also described (under the name Red Bluff sandstone) by Professor Cragin in his first paper, as follows:*a*

" 'This formation consists of some 175 or 200 feet of light-red sandstones and shales. * * * Viewed as a whole it is very irregularly stratified, being in some cases considerably inclined, in others curved, and this oblique and irregular bedding, being on a much larger scale than that of the ordinary cross beddings, at first glance gives the impression of dips, anticlines, synclines, etc., that have been produced by lateral pressure, the dips, however, being in various directions. * * * The Red Bluff beds exhibit the most intense coloration of any of the rocks of the series. When the outcrops are wet with recent rains their vividness of color is still greater, and the contrasts of their almost vermillion redness with other colors of the landscape is most striking. Spots and streaks of bluish or greenish gray sometimes occur in these rocks, but not to nearly so great an extent as in the lower beds. The sandstones of the Red Bluffs are generally too friable for building stone, but in some instances selected portions have proved hard enough for such use and are fairly durable.'

"In Oklahoma the Whitehorse member often weathers into conspicuous buttes and mesas. For instance, in eastern Woodward and western Woods Counties a row of these buttes, which

*a*Cragin, F. W., The Permian system in Kansas: Colorado Col. Studies, vol. 6, 1896, p. 40.

rise 100 to 200 feet above the surrounding country, extends from the vicinity of Whitehorse Springs, whence the name, southwest across the Cimarron, to the high divides beyond. To some of these buttes characteristic names have been given, as Lone Butte, Potato Hill, Watersign Hill, Wild Cat Butte, and the like. The noted Red Hill, between Watonga and Geary in southern Blaine County, is composed chiefly of the Whitehorse formation. South of Canadian River this sandstone thickens and on weathering often forms conspicuous bluffs, such as the famous Caddo County Buttes, southwest of Bridgeport. The Whitehorse sandstone is exposed along the Washita from near Chickasha, Ind. T. [Oklahoma], westward, and in the vicinity of Anadarko it forms bold bluffs both north and south of the river, and extends as far west as Mountain View. Ledges which probably belong to the same general horizon outcrop north of the Wichita Mountains in the vicinity of Hobart and Harrison, and it is not impossible that further studies may demonstrate that the same beds extend under the upper gypsums across Greer County. . . .

"'*Day Creek dolomite.*—Resting upon the upper part of the Whitehorse sandstone in Kansas and Oklahoma is a conspicuous ledge of hard, white dolomite, first described by Professor Cragin from exposures in southern Kansas, as follows:[a]

"'Upon the latest of the Red Bluff rests a persistent stratum of dolomite varying in thickness from less than a foot to 5 feet or more. * * * It is true dolomite, containing with the carbonate of lime an equal or even greater percentage of carbonate of magnesia. Though not of great thickness, it is an important member of the upper Permian of southern Kansas and northern Oklahoma, owing to its persistence, which makes it a convenent horizon of reference. * * * The stone is nearly white in fresh fracture, weathering gray, and often has streaked and gnarly grain resembling that of fossil wood. * * * Is cherty hardness and fracture are not due to the presence of silica, as one is tempted to infer, but are characters belonging to it as a dolomite. It is a durable building stone.'

"In his second paper on the Permian rocks, in describing a typical Oklahoma locality, Professor Cragin says:

[a] Op. cit., p. 44.

"'The brow of the Red Hills near Watonga, Okla., is capped with the Day Creek Dolomite, which here presents itself as a compact stratum of gray, somewhat pinkish or reddish tinged cherty-hard rock, little different from the typical ledge that skirts the flanks of Mount Lookout in Clark County, Kans. The stratum here has a thickness of 3 feet.'

"The line of outcrop of the Day Creek in Oklahoma is not continuous; nevertheless, it is found in numerous localities, and on account of its distinctive lithological appearance it is always easily recognized. It is displayed on many of the hills of Woodward County, not only north of the Cimarron, but also between the Cimarron and the North Canadian and south of the latter stream. In Blaine County it forms the caps of a number of the prominent hills, notably the Red Hills between Geary and Watonga. South of Canadian River in Caddo County the dolomite covers the Whitehorse buttes southwest of Bridgeport and outcrops southwestward as far as the headwaters of Cobb Creek and on the west side of that creek past Colony. In the vicinity of Mountain View, in the valley of Washita River, a ledge of dolomite appears at the same general level as that occupied by Day Creek, and another dolomite ledge in the hills north of Harrison may provisionally be referred to this horizon.

The composition of this material in Oklahoma may be understood by reference to the following analysis:

Analysis of dolomite from the summit of the Red Hills 6 miles northwest of Geary, Okla.

	Per cent.
Calcium carbonate	42.47
Magnesium carbonate	52.86
Water	1.82
Oxides of iron and aluminum	1.35
Silica and insoluble residue	1.82
Total	100.32

Greer formation.

The Greer formation outcrops in two areas. The eastern one begins in the southeast corner of Woodward County and extends east of south in a widening belt through the central part of Dewey and Custer Counties and eastern Washita County. In the southeastern part of Washita the belt divides, one branch swinging more to the east through the southwestern parts of Caddo and Grady Counties into northwestern Stephens County. The other swings west along the south line of Washita County and is thought to connect with the western area in Beckham and Greer Counties, although the connection cannot be made out on account of the covering of alluvium and sand in the valley of North Fork of Red River. The western area of the Greer occupies all of Harmon, southern Beckham, western Greer, and western Jackson Counties.

The Greer formation is made up of sandstones, shales, and gypsums, with a ledge of dolomite, having a total thickness of about 150 to 300 feet. The stratification in the eastern area is extremely erratic and no horizon can be traced sufficiently far to be used as a basis for separating the formation into members. The gypsums are lenticular and in the northern part of the area are few in number and not very thick; to the south the gypsum lentils become more numerous and thicker, reaching their maximum in eastern Washita County. Farther southeast the ledges thin out.

In the western area the stratification is more regular and five distinct beds of gypsum and one of dolomite can be traced for considerable distances and are classed as members of the formation.

Quartermaster Formation.

As is the case with the Woodward formation, the Quartermaster contains no important deposits of gypsum in Oklahoma and little attention was paid to it in the field work for this report, and the writer has no facts concerning the formation to add to those already published by Gould[75]. Consequently his description is given in full.

"Above the Greer are 300 feet or more of soft, red sandstones, and arenaceous clays and shales, to which the name Quartermaster has been applied. So far as known this is the highest formation of the Redbeds in Oklahoma.

[75]Gould, C. N., Op. cit., pp. 72-73.

"In the lower part of the formation the rocks are chiefly shales, typically red, but sometimes containing greenish bands and layers. The shales become more arenaceous above, and in places form a strong, consolidated sandstone, which is rather thin bedded and prone to break into small rectangular blocks, and weather queerly into long and narrow buttresses or rounded, conical, or nipple-shaped mounds from 10 to 50 feet or more high. These mounds may be solitary, but in some areas hundreds of them occur in a single quarter-section. The sandstone is further characterized by the marked and very peculiar dip of the rocks in certain directions. The strata often dip at angles of from 20° to 40° to all points of the compass, even in a small area. These dips often produce escarpments that have the appearance of those formed by regularly bedded dipping strata. The most plasible explanation of this phenomenon is that the erratic dipping is caused by the undermining of deep-seated rocks, probably some of the various gypsum members of the Greer.

In this sandstone, particularly in its upper part, there are many springs of soft water, which usually issue as seeps at the head of deep canyons or beneath bluffs of red sandstone. While few of them have large flows, many are large enough to supply farmhouses, or, in some cases, to furnish stock water for ranches. Wells in these sandstones frequently yield good water at moderate depths. In fact, with the exception of the eastern area of the Enid, the Quartermaster is the only Redbeds formation in which any large amount of good water is found.

"Except where covered by younger rocks, the Quartermaster outcrops over practically all of Day and Roger Mills counties [Ellis and Roger Mills], and is also extensively developed in the western part of Dewey, Custer, and Washita counties. To the south and east it is underlain by the Greer, while to the west and north it disappears beneath the sands of the Tertiary. Streams tributary to the South Canadian, Washita, and the North Fork of Red River in the region form canyons in this rock and are fed by springs issuing from it. The name is from Quartermaster Creek, which bows from Day County through the extreme northwestern corner of Roger Mills County and empties into Washita River in Washita County. Along this creek both the lower shales and the sandstones higher up in the formation are well exposed.

The peculiarities of structure and weathering are also well exemplified along this stream. In the present state of our knowledge it is not deemed advisable to attempt to subdivide the Quartermaster formation."

CHAPTER V.

NATURE, OCCURRENCE AND DEVELOPMENT OF THE GYPSUM OF OKLAHOMA.

In the previous chapter it was shown that the commercial gypsum deposits of Oklahoma occur in two distinct formations, the Blaine and the Greer. In this chapter the nature of each of these formations is discussed in as much detail as the present state of our knowledge will permit. The two papers by Gould[76] are used extensively and several of the sections and analyses given in the second report of the Territorial Survey are presented in full in connection with the description of the various localities. The field notes of Frank A. Herald and C. C. Clark, who spent the field season of 1907 in the study of portions of the gypsum deposits, are used wherever possible. The field work of the writer occupied 10 weeks in the autumn of 1912, during which time he was assisted by Jerry B. Newby.

Following Gould the gypsum area is divided into four general areas: (1) the Kay County area, (2) the main line of gypsum hills, *i.e.* the outcrop of the Blaine formation, (3) the second line of gypsum hills or the eastern area of the Greer formation, and (4) the southwestern area. The name Greer County Region was given to the last area when Greer County included what is now Jackson and Harmon counties and a part of Beckham County. The present Greer County contains only a portion of the area so it is thought best to change the name. The areas or regions will be taken up in the order named.

[76]Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 87-120; Geology and water resources of Oklahoma: Water-Suply Paper U S. Geol. Survey No. 148, 1904, pp. 44-52 and 59-72.

KAY COUNTY AREA.

The Kay County area is outside the Redbeds region and the gypsum occurs in non-red Permian rocks at or near the horizon of some of the important gypsum deposits of Kansas. The gypsum is not pure but occurs mixed with clay as gypsite. A mill was operated in this area for awhile some years ago but the known supply of material was exhausted and the mill removed. This locality was not visited in connection with the preparation of the present report and Gould's description[77] is given in full.

"In the central part of Kay County, Oklahoma, in the region between Newkirk and Blackwell, along the various creeks, Duck, Bois d'Arc, Bitter and others that flow south into the Salt Fork, there are a number of local deposits of gypsite or gypsiferous earth. As a usual thing these deposits are not very extensive. However, they are of sufficient importance that one of the four plaster mills in the territory is located there. Its supply of material is obtained along one of the branches of Duck creek.

"The region is slightly rolling. The creeks have carved out broad and shallow valleys in the level prairie. The valley of Duck creek is from one to two miles wide and not over 50 feet deep, sloping gently from the upland to the creek bed. The higher land is prairie and a few trees grow along the creek. The rocks in the country are gray and bluish clays and shales with a few ledges of soft, impure limestone. Few rocks of any kind, however, are exposed, the greater part of the country being practically level prairie with few breaks or washes. It is near the creek bank on a gently sloping surface that the gypsum used in the mill is obtained. The deposit covers several acres, and has been worked out in places to the depth of ten feet or more.

"The Kay County deposits belong to the Marion formation of the Permian. The Marion formation extends from central Kansas south through Marion, Harvey, Butler, Sedgwick, Cowley and Sumner counties. The rocks are soft shale and clays, gray to blue in color, with a few beds of impure gray limestones. Gypsum deposits are not uncommon. Plaster mills have been

[77] Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1904, pp. 87-88.

located in this formation at several points in Kansas, notably at Burns and Mulvane. Other deposits are known to exist in Butler and Sedgwick counties and in the vicinity of Geuda Springs. In general, however, the deposits are local and quite limited in amount. The experience has been that a mill located on this formation will use up its supply of available material in a few years and will be compelled to move.

"Whether or not there are gypsum deposits of any magnitude along the line of this formation further south than Kay County is not known. Occasionally a deposit is reported from this region, but on investigation it has usually proved to be very limited, and for that reason of no particular economic importance. South of Kay County the blue and gray shales of the Marion formation change into typical Red-beds. Now the Red-beds throughout are more or less gypsiferous. But in general the gypsum is so thoroughly disseminated throughout the rock that it can never be utilized. Its presence, however, is demonstrated by the character of the water in these rocks.

"Above the level of the Kay County gypsum there is a thickness of about 1000 feet of red rocks. These rocks, which make up the lower part of the Oklahoma Red-beds, consist chiefly of clays, shales and a few beds of soft sandstones. They occupy the level country in eastern and central Oklahoma between the line of the Santa Fe railroad and the main line of the gypsum hills. There are in this region a few small gypsum deposits. In a number of localities farmers dig gypsum from a bank, burn it and use the product for plaster and mortar. That the rocks of the region are thoroughly permeated with gypsum and other mineral salts is demonstrated by the fact that the water of the part of the region is so strongly impregnated with the various salts as to render it in many instances unfit for drinking."

MAIN LINE OF GYPSUM HILLS.

INTRODUCTION.

The general description of the Blaine formation has been given in the previous chapter. In this connection it is necessary to repeat a few of the principal features. The formation consists of three gypsum members (the Ferguson, Medicine Lodge, and Shimer) separated by red and green shales. The outcrop is a pronounced eastward and northeastward facing scarp above the soft, red shales of the Enid formation. Buttes and peculiar erosional features are very common. The outcrop enters the State from Kansas on the south side of the Salt Fork or Arkansas River and follows down that stream for a few miles, swings back along the north side of the Cimarron, crosses that river near the Kansas line, and extends down the south side, gradually getting farther away from the stream until the gypsums and the hills die out in northern Canadian County.

In the following discussion the description of this range of hills is given in detail by counties, commencing with Woods County at the northwestern limit of the hills in Oklahoma. Before describing the Woods County area the Grimsley's description of the northern extension of the hills in Kansas is given[78].

THE GYPSUM HILLS IN KANSAS.

"The gypsum of the Medicine Lodge area is entirely rock gypsum, is white in color, and in the lower portion of the strata is very compact. This portion is used at the Medicine Lodge mill for the manufacture of *terra alba*. The upper portion has more of the sugary texture and is used in the manufacture of wall plaster. The satin spar which is found throughout the Redbeds below the gypsum is in the form of wavy plates, with perpendicular needles, and variable in character. Some of it is soft, and readily crumbles, while other portions are compact and glassy in appearance.

"*Extent of the area.*—This southern gypsum area is the largest in Kansas, and, with its continuation in Oklahoma and Texas, forms the largest gypsum area in the United States. The rock extends from near the town of Medicine Lodge westward through Barber and into Comanche County, southward into Oklahoma and Texas, and passes under the Tertiary gravels to the north. The trend of the outcroppings of the deposits is the characteristic one of the state, northeast to southwest.

"The gypsum is first seen six miles southwest of Medicine Lodge, in an isolated range of hills three miles long and separated by a narrow valley from a second hill one mile in length.

[78]Grimsley, G. P., Gypsum and gypsum cement plaster: Univ. Geol. Survey of Kans., vol. 5, pp. 70-73.

The valleys of East and West Cedar creeks, two miles wide, separate these hills from the next series, in which the gypsum plateau is continuous to the west. Medicine Lodge river cuts the gypsum in a valley six or seven miles wide. The northern limit of the gypsum cannot be determined, for it is covered with Tertiary deposits. Salt Fork and Sandy creeks cut out broad valleys to the south, and the streams in the eastern portion of Comanche county have removed much of the stratum; but the gypsum is continuous over the greater portion of western Barber and eastern Comanche counties. * * *

"In the eastern part of Comanche county, on Cave creek a second gypsum layer 15 feet thick is found, 15 feet above the Medicine Lodge layer. This upper layer was called the 'Shimer gypsum' by Cragin. It appears to be a local deposit.

"*Geological relations.*—Looking west from the town of Medicine Lodge one can see in the distance a range of hills of erosion with sloping sides and level tops. These hills extend in a north and south direction and are called the Gypsum Hills. The sides are composed of the red clays and shales of the Red Beds, the age of which is still somewhat uncertain, but they probably belong to the Permian. The cap rock is a ledge of solid gypsum, which has protected to a considerable extent the underlying, softer strata.

"At the base of the hills is a massive red sandstone. A second red sandstone is found 125 feet higher, and 100 feet above this comes a ledge of gypsum forming the top of the hills. This gypsum layer varies from 3 to 20 feet in thickness, depending on the amount of erosion. Forty feet below the gypsum is a green gypseous sandstone 2½ feet thick, which stands out as a prominent ledge through the hills. The red clays and shales contain an interlacing network of selenite and satin-spar layers of variable thickness. This material has been dissolved out of the solid stratum and carried downward through the agency of circulating water and redeposited. * * *

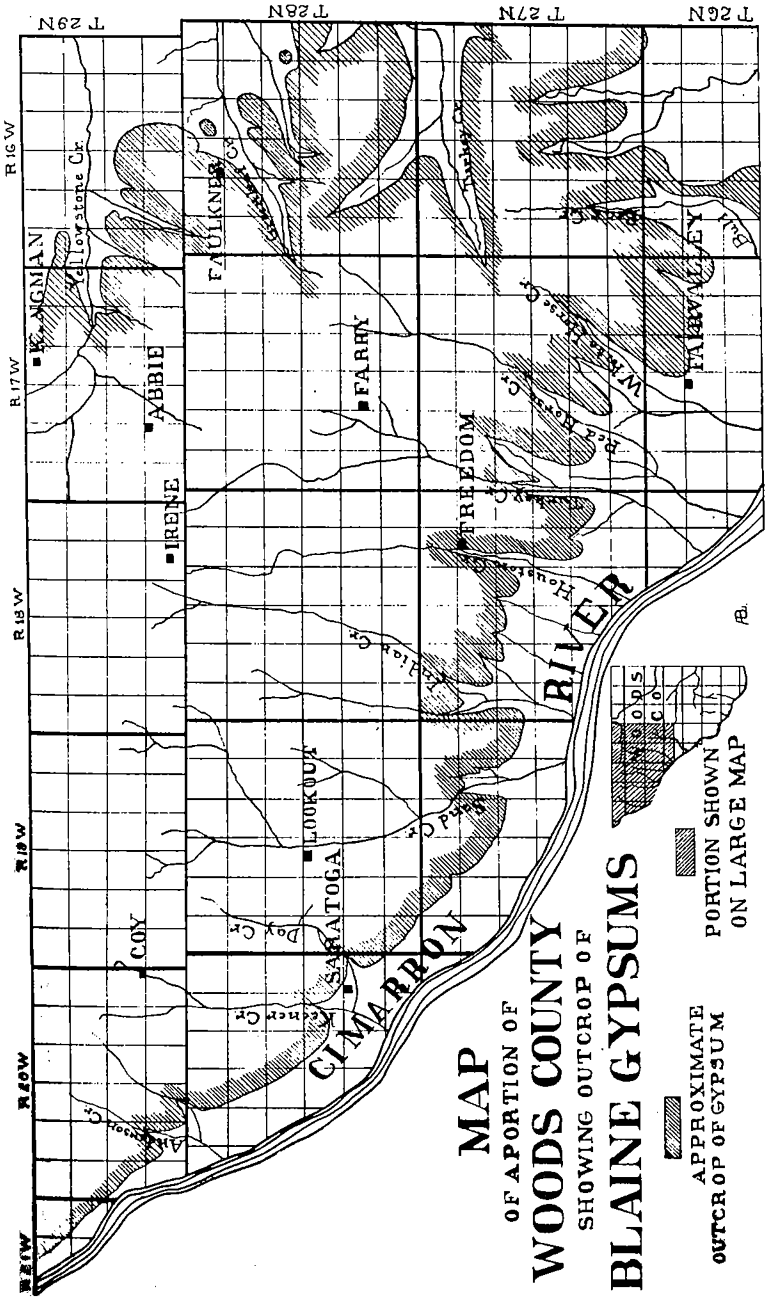
"*Solution effects.*—In the western part of Barber and the eastern part of Comanche counties the solvent effects of water on gypsum are well shown. On Cave creek, four miles west of Evansville, is the Big Gypsum cave in the Medicine Lodge gypsum. A stream of considerable size flows into the west entrance and out of the east one, making the cave, in reality, an underground water course. The length of the cave is at least 100 feet, with a roof at the east entrance 15 feet above the water level, but which soon narrows down to a height of 3 feet. The floor is strewn with large slabs of white gypsum. At the center is an opening through the roof to the sky above. This hole is a few feet in diameter in the cave and 30 feet on the surface and is nearly circular. The western half of the cave is low and the floor is muddy and covered with water so as to be almost impassable. The section near this cave shows 30 feet of the Medicine Lodge gypsum separated by 15 feet of red shale from the Shimer gypsum, which is 15 feet in thickness. This is the typical exposure of the Cave Creek formation of Cragin.

"The natural bridges found here represent remnants of old caves of underground water channels whose roofs have partly fallen in. One of the best of these natural bridges is found on Bear creek south of Sun City. * * *"

WOODS COUNTY.

Area of outcrop.—The Blaine formation makes a crescent shaped outcrop in the Western part of Woods County, and is principally in the portion of the county which belonged before 1907 to Woodward County. The approximate outcrop of the formation is shown on the map (fig. 31). The line of hills crosses the Kansas-Oklahoma line near the east side of R. 17 W. —the old Woods-Woodward county line. The line of the base of the Blaine extends east into R. 16 W. about 1½ miles, then swings south and back west along the north side of Yellowstone Creek as far as Kingman. Here the gypsums cross the creek and follow down the creek on the south side for about five miles, then in a general course to the south until they reach a point about 8 miles west of Avard where they swing back to the northwest on the north side of Cimarron River. The eastward facing escarpment is irregular, the two main indentations being caused by Greenwood (Greenleaf) and Turkey (Moccasin) creeks which have cut canyons back into the gypsums for 5 or 6 miles. There are many minor irregularities and several outliers or buttes, some especially fine ones near where Greenwood Creek leaves its canyon in the vicinity of Faulkner.

Northwest from Fair Valley the bluffs are almost 2 to 3 miles back from the river until within a few miles of the Kansas



line where they come within one-half mile or less of the river. The gypsums cross the river just north of the State line and then swing back on the south side through Harper and Woodward counties. On the Woods County side of the river 8 creeks flow in from the northeast and enter the Cimarron almost at right angles. These are named in order from east to west: White Horse, Red Horse, Turkey, Houston, Indian, Sand, Keener, and Anderson. Each of these, as well as many minor runs, has cut a canyon or gully back into the gypsum upland. The canyons of the streams named are from 2 to 5 miles long and usually less than one-half mile wide at their widest parts. The width of the outcrop varies from a fraction of a mile at the head of the canyons and on some of the very steep slopes, to 2 or 3 miles on some of the long hills between the canyons. Beginning a few miles east of Saratoga and continuing to the Kansas line is a belt in which sand from the valley is blown up over the hills, sometimes covering them to a depth of several feet and obscuring the lines between the Blaine and the formations above and below.

Stratigraphy.—Where the hills cross the Kansas-Oklahoma line 3 gypsum ledges show on the slopes, and these are apparently continuous throughout the outcrop in Woods County. All 3 ledges are entirely selenitic and, as has been mentioned in a previous chapter, the effects of solution by ground water are much more pronounced in the selenitic than in the fine-grained rock gypsum. Sink holes are common and there are several caves, some of them of considerable extent as, for instance, the Bat Cave near Kingman. The slopes of the hills are less abrupt and the crests are more rounded than is the case farther southeast in Blaine County. The fresher exposures show the interlocking network of selenite crystals, but the weathered exposures show a white, powdery mass, sometimes with the outlines of the crystals remaining but often without any trace of them. This white earthy material when mixed with a clay sometimes bears resemblance to gypsite but can be easily distinguished from it by its structure and whiter color.

Often a whole ledge will be dissolved for some distance back into the hill and only 2 or perhaps 1 ledge will show on the side of a hill. In other localities the soft shales seem to "creep" and large blocks of gypsum break from the ledge and slip a few feet down the slope and thus give the appearance of another ledge.

Where one of the lower ledges is absent by solution, the shales and the upper ledges may settle down into the cavity so formed, and this gives rise to an appearance of folding. This is often shown in Woods County, but is not so pronounced as across the Cimarron in Harper County. (See fig. 35.) Some of the effects of solution and also the character of the gypsum in this region is shown in figure 32. This is really a small natural bridge as

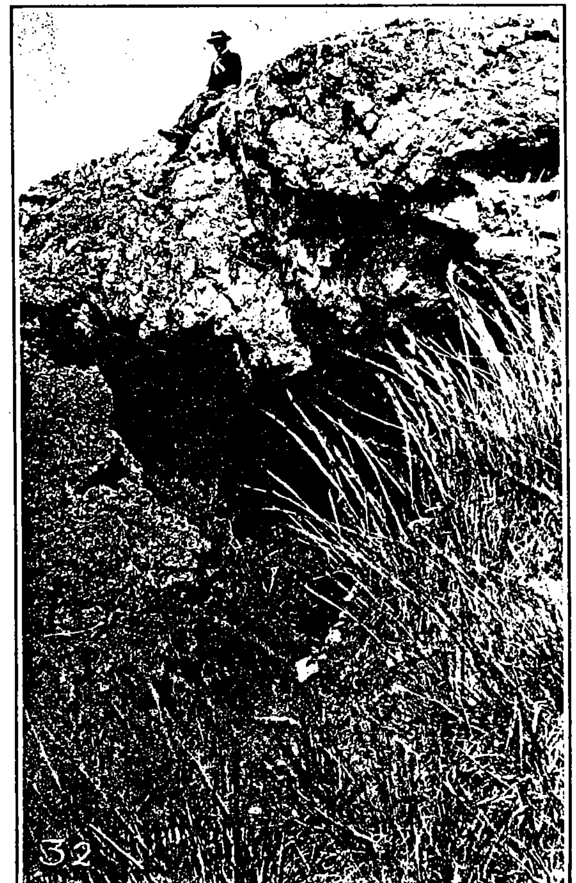


Fig. 32. Outcrop of selenitic gypsum near Kansas line northwest of Winchester.

there is a small sink hole opening just back of where the man is sitting. The outlines of the selenite crystals are fairly well shown about the middle of the ledge.

The absence, by solution, of the ledges in some places and the duplication of ledges by slip in other places make the determination of the stratigraphy difficult. On the clearer exposures, however, there seem always to be 3 ledges of gypsum of which the lowest is much the thickest, while the middle and upper are of approximately equal thickness. The lower and middle are separated by only a few feet of shale and may sometimes coalesce, while the middle and upper are separated by an interval of some 15 feet. The succession is fairly well shown in the following section:

Section on Yellowstone Creek 1½ miles southeast of Kingman in W. ½ sec. 24, T. 29 N., R. 17 W.

		Feet.
6.	Gypsum (Shimer) top eroded	8
5.	Covered, probably green and red shale	12
4.	Gypsum (Medicine Lodge)	8
3.	Covered, probably green and red shale	7

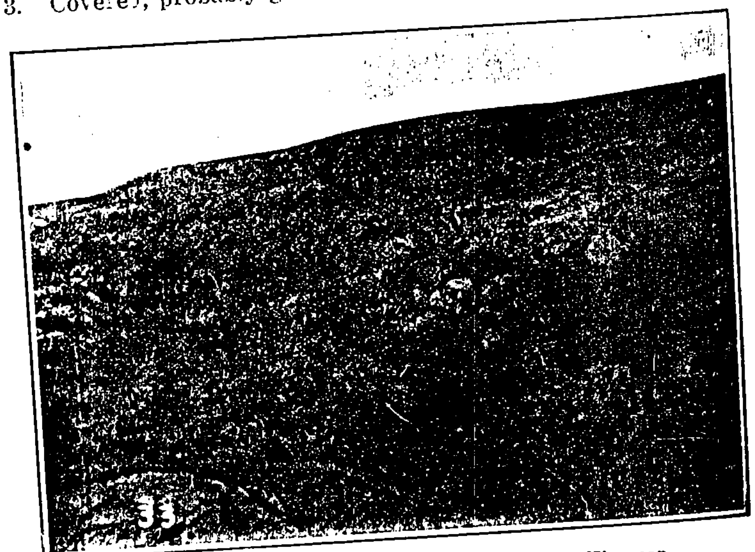


Fig. 33. Canyon of Yellowstone Creek near Kingman.

2.	Gypsum (Ferguson)	18
1.	Covered, probably shale	34

The canyon where this section was taken is shown in figure 33.

While the section is not sufficiently clear to prove absolutely the presence of 3 gypsum members, the abrupt changes of slope between the different members, and the difference in vegetation and in expression leave very little doubt that the three are present.

If the three gypsums are present the names to be applied to them are somewhat in doubt. According to Gould[79] the lowermost gypsum member as exposed in Blaine Couptny (the Ferguson) disappears in the vicinity of Glass Mountains in Major County and he makes no mention of its reappearance. Only the Shimer and Medicine Lodge are mentioned as occurring in Kansas. The evidence is so strongly in favor of the presence of three ledges throughout Woods County, and on the opposite side of the Cimarron, however, that the writer is compelled to believe, (1) either that the Ferguson is present, or (2) that a new ledge has appeared in its place or between the Medicine Lodge and the Shimer.

The question is interesting from a stratigraphic standpoint but is of no importance on the economic side. Therefore in this report the hypothesis that where three ledges are present the lowest represents the Ferguson is accepted merely as a working basis. In other words, where three ledges are present they are called, from the bottom up, the Ferguson, Medicine Lodge, and Shimer, and where two are present, the Medicine Lodge and Shimer. Detailed mapping may prove it necessary to make considerable change in the naming of these gypsums.

Availability and development of the gypsums.—The amount of gypsum present at a reasonable depth in Woods County is very great, ample to supply a large number of mills for an indefinite length of time. At present however, all of it is so far removed from a railroad that it cannot be considered available. Preliminary surveys for the Winnepeg and Gulf Railroad have been run through the gypsum area and if the road should be

Gould, Chas. N., Geology and water resources of Oklahoma: Water-supply paper U. S. Geol. Survey No. 148, 1904, p. 46.

built through this region it will render large deposits accessible. In case this gypsum should become accessible, and an attempt should be made to develop it, the proposed sites for mills should be very carefully prospected, on account of the irregularity of occurrence of the ledges, due to solution. No use is being made of any of the gypsum in Woods County. The mill of the Oklahoma Plaster Company is located at Alva but uses gypsum from near Quinlan in Woodward County. The mill is described in chapter II and the quarry under Woodward County in this chapter.

HARPER COUNTY.

Area of outcrop.—The Blaine formation crosses the Cimarron just north of the Kansas line and then follows down the stream on the southwestern side. For several miles it forms a narrow belt along the southwestern bank, with only a few narrow canyons extending as far as two miles back from the line of bluffs, until Buffalo Creek is reached in the southern part of T. 21 N., R. 20 W. This creek flows in a narrow canyon in the gypsums from about five miles southwest of Charleston, almost due east until it enters the river. The canyon is narrow, not

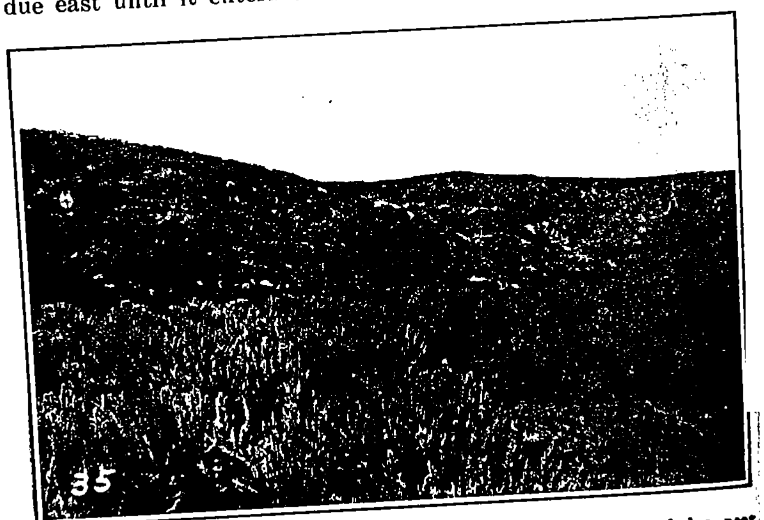


Fig. 35. Folding of gypsum ledge due to solution of underlying ledge, near mouth of Sand Creek, Harper County.

exceeding a mile in width until very near the Cimarron. On the north side of the creek there are only a few minor irregularities in the outcrop, but on the opposite side, Race Horse, Sand, and Sleeping Bear creeks carry the outcrop back to the south a few miles. The width of the outcrop varies from less than a mile to four or five miles. The line of hills leaves the county south of Buffalo Creek in T. 27 N. The approximate area of the outcrop of the formation is shown on the map (fig. 33).

Stratigraphy.—In general the stratigraphy of the Blaine formation in Harper County is the same as in Woods County across the Cimarron. Where clear exposures are had there seem to be three gypsums but on slopes, one or more of these may fail to appear. All of the gypsum is selenitic. The effects of solution are prominent. The solution of the lower ledges often causes the upper ones to appear folded. A synclinal fold of this sort is shown in figure 35.

Duplication of outcrop by slip also appears to be of common occurrence. A rather peculiar structure which is interpreted in this way is shown in the north bank of Buffalo Creek below its junction with Sand Creek (fig. 36).

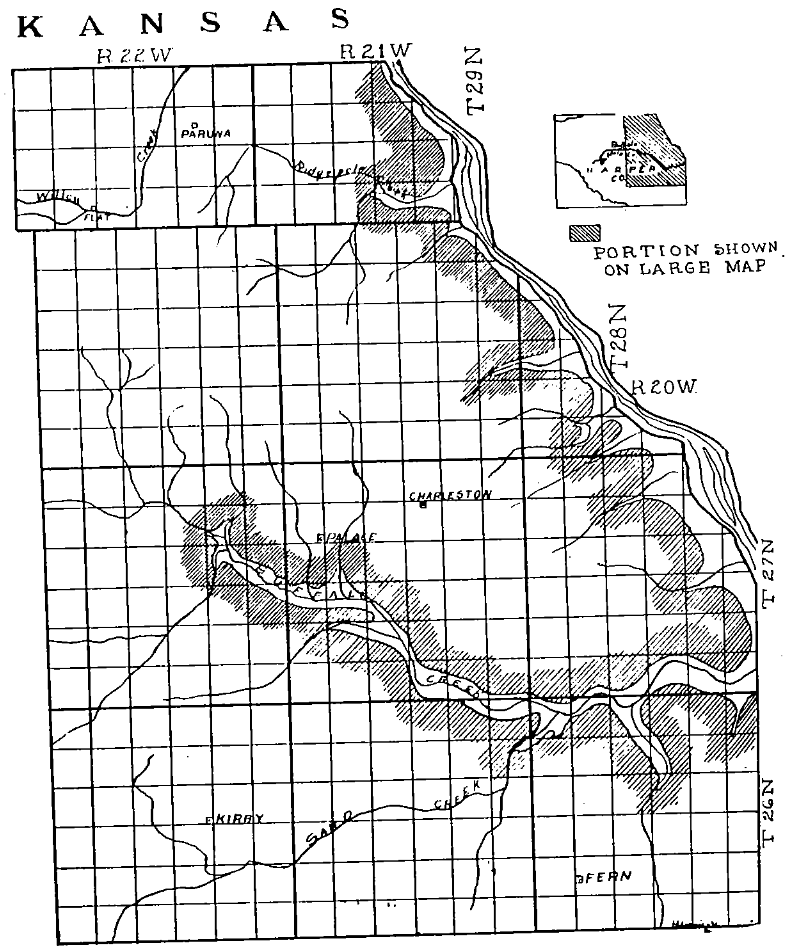
Good sections of the Blaine are very rare in this county. Probably the best exposure is near the Big Salt Plains on the Cimarron where the following section was measured by Gould.[80]

Section at southeastern corner of Big Salt Plain in Harper County.

		Feet.
5.	Red clay to top of bluff	15
4.	Massive white gypsum, the Shimer	15
3.	Red clay	10
2.	Massive white gypsum, the Medicine Lodge	24
1.	Red clay, with bands of selenite and gypsum concretions from the level of the plain	80

The general appearance of the outcrops leads the writer to the conclusion that No. 2, the Medicine Lodge, of Gould's section is usually composed of two members separated by a shale which

[80] This section and those following which are attributed to Gould are from the Second Biennial Report of the Oklahoma Department of Geology and Natural History, unless otherwise specified.



MAP
OF A PORTION OF
HARPER COUNTY
SHOWING OUTCROP OF
BLAINE GYPSUMS

APPROXIMATE OUTCROP OF GYPSUM

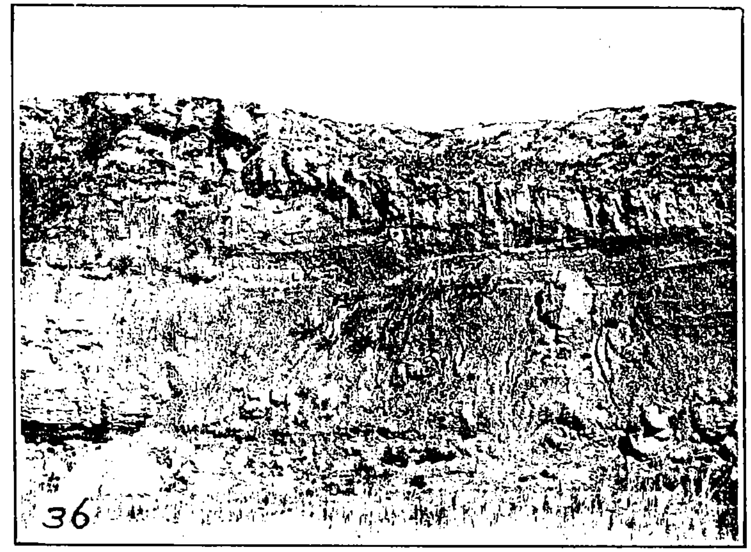


Fig. 36. Duplication of outcrop of gypsum ledge due ot slip. Buffalo Creek below Sand Creek, Harper Couny.

ranges up to seven feet in thickness locally, and that it probably represents both the Ferguson and the Medicine Lodge. The total thickness of gypsum as given in the section seems to hold fairly well for the area in this county.

Availability and development of the gypsums.—The gypsums of Harper County are well exposed for quarrying and the amount which can be obtained is very great, estimated by Gould[81] at 10,000,000,000 tons. Several locations along the Cimarron and along Buffalo Creek and its tributaries furnish good situations for quarries if transportation facilities were at hand. At present, however, the deposits are so far from railroads that there is no possibility of their development in the near future, even if all other conditions were favorable.

WOODWARD COUNTY.

Area of outcrop.—The outcrop of the Blaine formation en-

[81] Gould, Chas. N., Structural materials of Oklahoma: Bull. Okla. Geol. Survey No. 5, 1911, p. 105.

ters Woodward County from Harper in T. 27 N., R. 19 W., continues down the Cimarron in a belt two to five miles in width and passes into Major County on the line between Ranges 16 and 17 W., T. 23 N. Several creeks have cut canyons back into the gypsum indenting the outcrop and carrying it back to the southwest. These creeks are, from west to east, Traders, Girl, Long, Doe, Chimney, and West creeks. The approximate area of the outcrops is shown on the accompanying map (fig. 37).

Stratigraphy.—The stratigraphy of the gypsums in this county is practically identical with that in Woods County on the opposite side of the Cimarron, and in Harper County to the northwest, which have already been discussed. In several places the Ferguson is apparently absent and the Medicine Lodge forms the crest of the hills and buttes. The hills are very rugged and the canyons are deep and steep sided. Many peculiar erosional forms have been developed due to the capping of the very soft sands and clays of the Enid by the relatively resistant gypsum. One of the most striking of these is Chimney Butte, from which Chimney Creek takes its name (fig. 38). The gypsum is entirely removed from this butte but several in the vicinity are capped by gypsum. Mt. Heman and Mt. Zion are large buttes near Heman in the northeastern part of the county.

At this locality the Medicine Lodge seems to be the lowest gypsum and just west of Chimney Butte, (sec. 27, T. 25 N., R. 17 W.) boulders of anhydrite up to five feet in diameter were noticed about the middle of the layer of gypsum. This is the first observed occurrence of a feature which becomes very prominent to the southeast. Lentils 10 to 20 feet long and three feet in thickness occur in the Medicine Lodge near the Woodward-Major County line in sec. 24, T. 23 N., R. 17 W. At this locality all three gypsums are shown. The dolomitic sandstone beneath the Shimer is about three feet thick.

The stratigraphy is shown in the following sections by Gould.

Section made at the high bluff at the southeast corner of the Salt Plain.

		Feet.
5.	Red clay to top of bluff	15
4.	Massive white gypsum, the Shimer	15

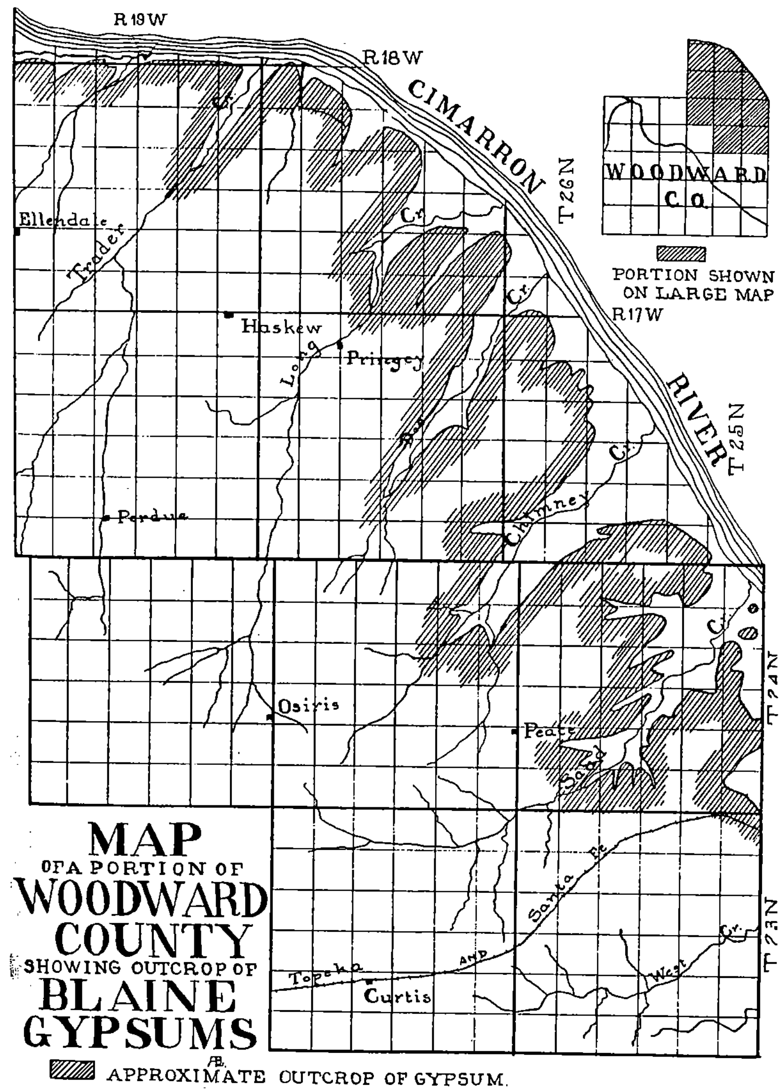


Fig. 38. Chimney Butte.

3.	Red clay	10
2.	Massive white gypsum, the Medicine Lodge	24
1.	Red clay, with bands of selenite and gypsum concretions from the level of the plain	80
		144

Section made on a butte at the mouth of Doe Creek, Woodward County.

		Feet.
4.	Massive, white gypsum, the Shimer	25
3.	Red clay	5
2.	Massive, white gypsum, the Medicine Lodge	30
1.	Red clay and shale slope from the river	200
		260

Section made on Sand Creek five miles northeast of Quinlan.

		Feet.
5.	Red clay with local deposits of gypsum	75
4.	Massive, white gypsum, the Shimer	22
3.	Red clay	7
2.	Massive white gypsum, the Medicine Lodge	30
1.	Red clay from creek bed	120
		254

Availability and development of the gypsums.—The Atchison, Topeka & Santa Fe Railway crosses the line of gypsum hills between Quinlan and Belva in the extreme eastern portion of the county. A great amount of gypsum is available from this line. Up to the present the only development is the quarry of the Oklahoma Plaster Company whose mill is located at Alva. The quarry is located in sec. 10, T. 23 N., R. 17 W., and has been worked out over an area of about one acre. The lowest ledge is quarried. It is about fifteen feet thick and is composed of selenitic gypsum. The bed is cut by vertical funnel-shaped solution channels, varying in size from a few inches to a foot or even more in diameter. The solution channels and joint cracks, which are usually enlarged by weathering, are filled with red clay. The gypsum is shot from the ledge in the ordinary way and the small blocks loaded into dump cars and pushed by hand to a loading trap over the railroad switch.

The amount of gypsum available in this region is sufficient to supply several mills if commercial conditions were such as to justify their construction. The total amount of available gypsum in the county according to Gould's estimate is 8,000,000,000 tons.

MAJOR COUNTY.

Area of outcrop.—Where the line of hills enters Major County from Woodward it is near the Cimarron but it gradually drops back to the south until at Fairview the foot of the main

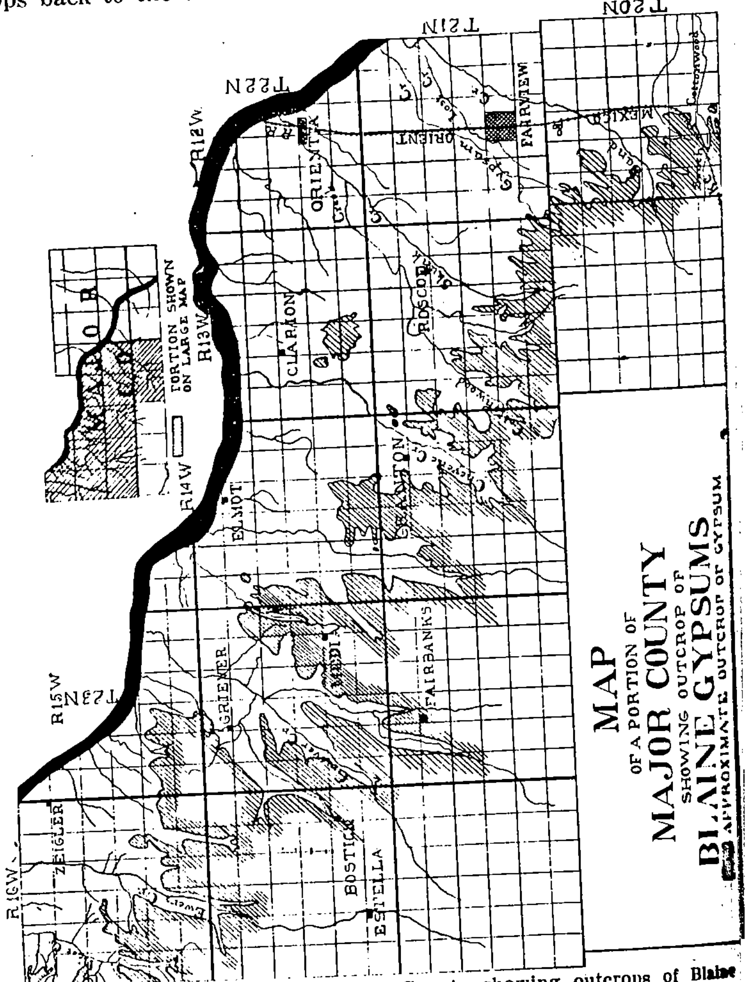


Fig. 39.—Map of a portion of Major County showing outcrops of Blaine Gypsum.

body of the hills is ten miles or more from the river. At Fairview the line of hills leaves the river and turns almost directly south and continues in this direction into Blaine County. The approximate outcrop is shown on the accompanying map (fig. 39).

The outcrop is very irregular and is indented by several creeks. The principal streams from west to east are: West, Main or Ewers, Crooked, West Griever, East Griever, West Barney, Barney, Cheyenne or Skull, Cottonwood, and Gypsum creeks.

Stratigraphy.—In the western part of Major County the three gypsums seem to be present with about the same thickness and separated by approximately the same intervals as to the northwest. These relations are shown by the following sections:

Section at head of Crook Creek Canyon in sec. 14, *T.* 22 *N., R.* 16 *W.*

		Feet.
5.	Shimer gypsum	10
4.	Red and green selenitic shales with some sandstone	15
3.	Medicine Lodge gypsum	15
2.	Red and green selenitic shales with dolomitic sandstone	10
1.	Ferguson gypsum	15

All three gypsums are shown plainly but the contracts are not exposed so that the thicknesses given are approximations. The gypsum is almost completely selenitic.

Section of east side of East Griever Creek Canyon in sec. 28, *T.* 22 *N., R.* 15 *W.*

		Feet.
12.	Medicine Lodge gypsum	16
11.	Greenish sandstone	1
10.	Red and green gypsiferous shale	8
9.	Ferguson gypsum	15
8.	Greenish, shaly sandstone	1
7.	Green shale, very selenitic	1½
6.	Greenish dolomitic sandstone	¼
5.	Red shale with bands of green shale and satin spar	26
4.	Shaly, cross-bedded, selenitic sandstone	7

3.	Red shale, with bands of green shale and satin spar	6
2.	Shaly, cross-bedded, selenitic sandstone	1
1.	Red shale containing many thin bands of green shale and satin spar from East Griever Creek	93

Farther back on the hill and about 20 feet above the Medicine Lodge gypsum is a heavy, honey-combed sandstone that occurs just below the Shimer gypsum throughout this region.

The anhydrite in the Medicine Lodge is present only in thick short lentils. One of the lentils a few feet north of where this section was made is over five feet thick at the middle and about eight feet long. These lentils occur at irregular intervals and at different horizons on the bed. The beds are made up chiefly of selenite crystals.

In sec. 22, T. 22 N., R. 15 W., the Ferguson gypsum shows a thickness of fifteen feet and is underlain by ten inches of greenish dolomitic and selenitic sandstone.

Section on West Barney Creek in sec. 25, T. 22 N., R. 15 W.

		Feet.
13.	Shimer gypsum	8
12.	Honey-combed dolomitic sandstone	2
11.	Covered, probably shale	17
10.	Medicine Lodge gypsum	about 10
9.	Covered, probably shale	13
8.	Ferguson gypsum	11
7.	Greenish dolomitic sandstone	½
6.	Green, sandy shale	3½
5.	Red shale with many thin bands of green shale and satin spar	14
4.	Selenitic sandstone	½
3.	Red and green shales	8
2.	Shale and soft sandstone, red and green, cross-beeded, gypsiferous	8½
1.	Covered, probably shale	41

In this section there are no good exposures of the top of the Ferguson or of either the top or the bottom of the Medicine Lodge. The top of the Shimer is eroded. The thickness of the gypsums as given in the section represent what is actually exposed. The anhydrite in the Medicine Lodge seems to be a continuous body over six inches thick. The upper portions of all three ledges are very selenitic, that of the Shimer especially so. The lower portions of the ledges have taken on the fine-grained condition which is common to all of the gypsum a few miles farther to the southeast.

The gypsums continue around Barney and Cottonwood creeks with little change in their relationships or thickness. All along the line of hills in this county west of Fairview the effects of solution are very prominent. Caves, or underground channels are numerous and range in size from the very small ones to those 50 feet wide and about the same height and of considerable length. Some are reported to be over a mile long. Bat Cave on Main Creek is one of the best known of the caves of Major County.

The origin of the caves is aparently as follows: The gypsum of this region is selenitic and easily attacked and dissolved by ground water. They are cut by two sets of joints almost at right angles to each other. The crossings of these joints locate points where the ground water can effect its greatest solvent action, and funnel-shaped solution holes are formed. After a hole is formed, the water which flows down through the opening begins to work out through the soft sandy layers which lie immediately below the gypsums. At the canyon wall the water working out from this sand softens it and carries it away thus starting a channel under the gypsum ledge. The head of this channel works rapidly back until it comes under the solution hole or sink. Then if there is a second solution hole back farther from the edge of the hill the process will be repeated and so on, until considerable caves are formed if the conditions are favorable.

If the channel beneath the gypsum should become sufficiently wide and deep, the roof may drop in and after the blocks are dissolved and carried away a narrow steep-sided valley may result. Some of the phenomena of solution are shown in figure 40.

The caves, of course, lie partly in the shales below the gypsums and partly in the gypsums themselves. Where two gypsums are separated by only a few feet of shale, the upper gypsums are separated by only a few feet of shale, the upper gypsum may form the roof of the cave or channel while the intervening shale, the lower gypsum, and part of the shales below the

Fig. 40.—Sink, cave, and large joint structure in massive gypsum west of Fairview. (Photo by Beede.)

lower gypsum may be removed by solution and erosion to form the cave. An ideal sectioin of such a cave is shown in figurei 41.

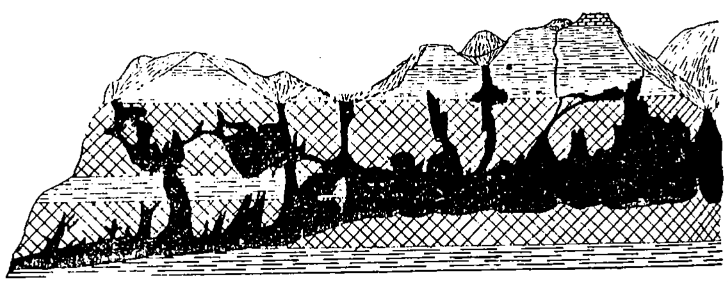


Fig. 41.—Ideal section of gypsum cave. (After Gould, U. S. Geol. Survey.)

Buttes are very common and are often of large size. The best known in this county are those northwest of Fairview called the Glass Mountains. These are a group of outliers or buttes capped by the Ferguson gypsum or by the Medicine Lodge where the Ferguson is absent. One of the most striking of these buttes is shown in figure 42.

The slopes below the gypsum are eroded into a great number of erosion forms, and deeply trenched by running water. The clays below the gypsums are filled with great numbers of

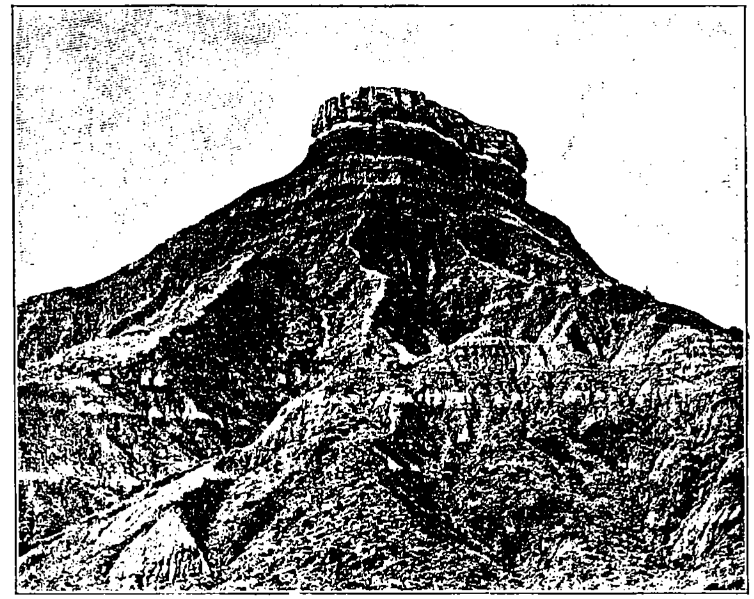


Fig. 42.—Glass Mountains, Major County. (U. S. Geol Survey.)

selenite crystals and thin bands of satin spar. There are also considerable numbers of gypsum concretions. As the slopes are eroded the clay is washed out leaving a layer of selenite and satin spar flakes and gypsum concretions on the surface (fig. 43). These glisten in the sunlight and give rise to the name Glass (or Gloss) Mountains.

The type of weathering and the presence of selenite and satin spar in the red clays are common along this line of the gypsum hills but the effects are especially striking in the neighborhood of the Glass Mountains. To the south of the Glass Mountains the hills become much less rugged than they are to the northwest. The slopes are more gentle and the gypsums are not well exposed as a general rule. These low hills extend south from Fairview across the line into Blaine County. In this region good exposures are rare and complete sections are not easy to obtain.

On the head waters of Cottonwood Creek the Ferguson gyp-

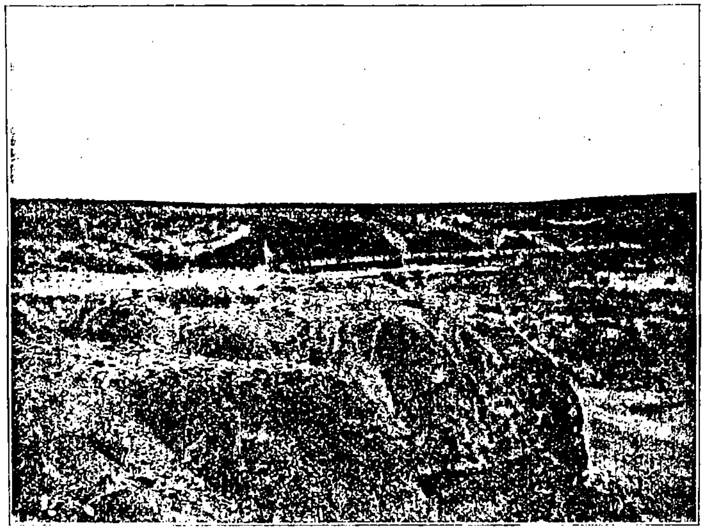


Fig. 43.—Gypsum concretions covering the slopes of red clay, Glass Mountains. (U. S. Geol. Survey.)

sum shows a thickness of six feet six inches at one locality in sec. 30, T. 21 N., R. 13 W., and about one-half mile to the southeast in sec. 30, over 12 feet of the Shimer is exposed. Two miles farther east, in sec. 33, the following section was made. The contacts at the top of the Medicine Lodge and at the base of the Shimer were not exposed and the thicknessess are therefore approximate.

Section on Gypsum Creek, Sec. 33, T. 21 N., R. 13 W.

		Feet
7.	Shimer gypsum—top removed	15
6.	Honey-combed dolomitic sandstone, at least	2
5.	Covered, probably shale	25
4.	Medicine Lodge gypsum, including at least one foot of anhydrite exposed	6
3.	Greenish dolomitic sandstone	1
2.	Covered, probably shale	13
1.	Ferguson gypsum—base not exposed	6

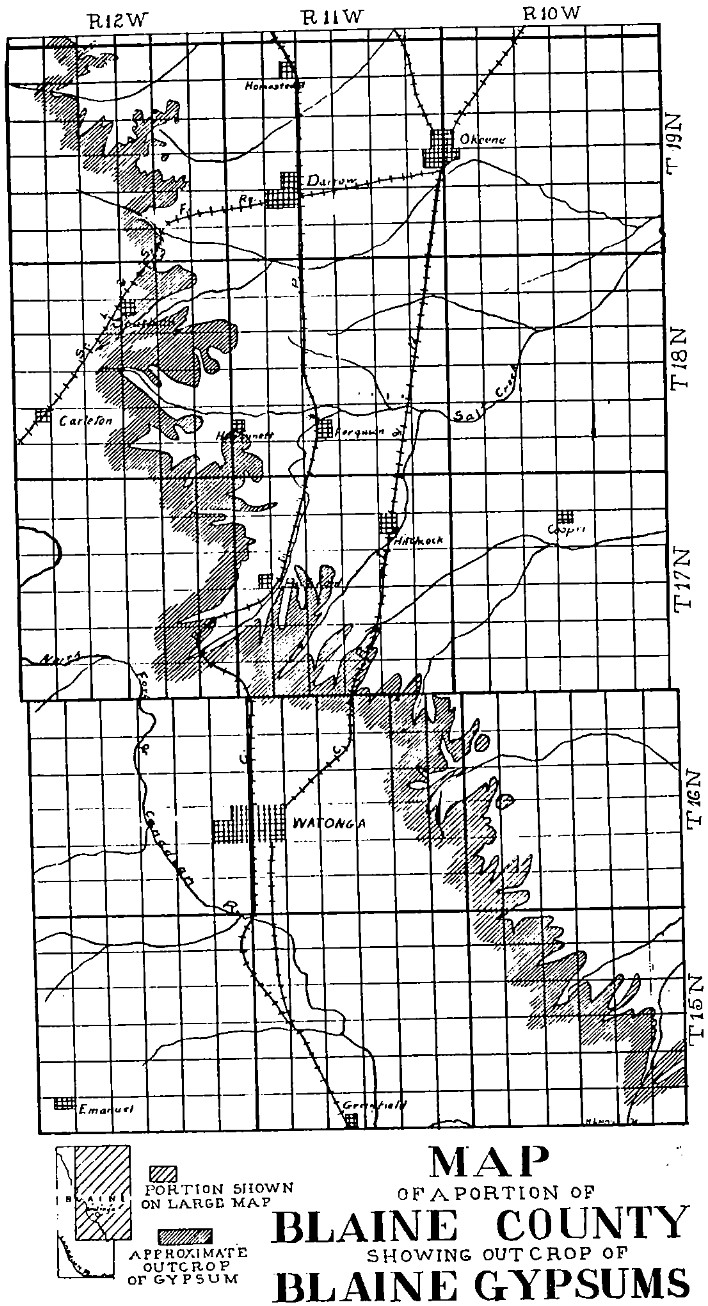
In sec. 6, T. 20 N., R. 12 W., the Ferguson is about six feet thick and the Medicine Lodge is at least 10 feet thick. They are separated by about 17 feet of shale. The Shimer is not shown but the hills are capped by a greeninsh dolomitic sandstone such as occurs under the Shimer. The Shimer probably occurs farther to the southwest. Two miles farther south almost precisely similar conditions are shown. In a cut on the Kansas City, Mexico & Orient Railroad in sec. 29, eight feet of massive white gypsum are shown. It seems to be in the Medicine Lodge but the anhydrite is not shown.

Availability and development of the gypsum.—The gypsum deposits of Major County are at present available only from the line of the Kansas City, Mexico & Orient Railroad south of Fairview. Lines could be run west from this road north of Fairview with comparatively small expense which would render immense quantities of gypsum available, but under present conditions this is not feasible. No use has been made of the gypsum of the county. A mill was projected at Fairview a few years ago but the plans were not carried out. The amount of gypsum present at less than 100 feet deep is estimated by Gould at 12,000,000,000 tons.

BLAINE COUNTY.

Area of outcrop.—The gypsum hills enter Blaine County from the north and extend a little east of south through Tps. 19 and 18 N., R. 12 W. They swing around the head waters of Bitter Creek in T. 17 N., R. 11 W., and then continue southeast across the corners of T. 16 N., R. 11 W., and T. 16 N., R. 10 W., and across T. 15 N., R. 10 W. Throughout most of the county the hills back from the outcrop are covered with sand and the outcrop is usually not over two or three miles wide. The approximate area of outcrop is shown on the accompanying map (fig. 44).

Stratigraphy.—At the Major-Blaine county line the hills are rather inconspicuous and are rounded. To the south they rapidly become more prominent and the canyons are steep sided. Straight west from Darrow the hills show about the same characteristics that they hold throughout the county to the southeast. The exposures in this region are clearer than elsewhere along the line of hills. This is probably due in large



measure to the nature of the gypsums which have changed from the coarsely crystalline selenitic form (which is their principal feature to the northwest) to a fine grained dense form, the typical rock gypsum. This form is apparently much less easily acted upon by water and is not easily dissolved to the extent that the selenitic gypsum is farther to the northwest. Caves and sinks while present are not nearly so well developed as in Major County. The steep sides of many of the canyons are also due in part to the presence of the anhydrite member of the Medicine Lodge gypsum, which reaches its maximum development in the vicinity of the head waters of Salt Creek west and southwest of Ferguson. This is more resistant than the gypsum or the shales and makes a vertical face at the top of many of the bluffs, from which it breaks off in large blocks when undermined. (see figs. 45 and 46).

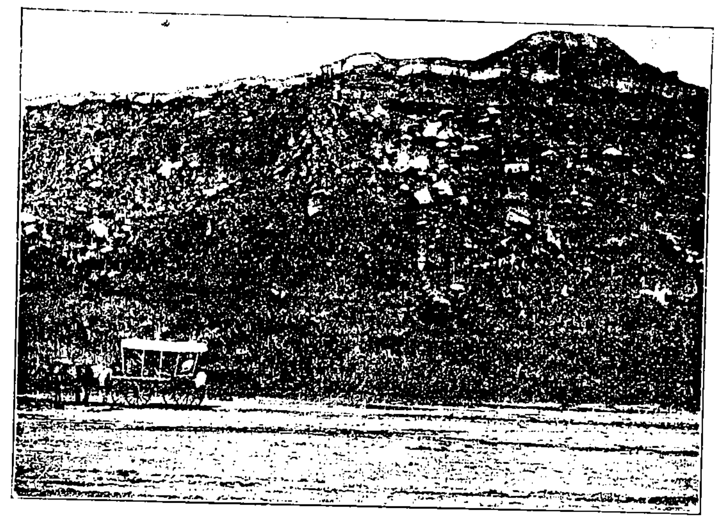


Fig. 45.—Anhydrite member of the Medicine Lodge gypsum, salt plain in foreground. (U. S. Geol. Survey.)

The following notes and sections indicate the character of the gypsums as exposed in different localities:

In sec. 8, T. 19 N., R. 12 W., at the head of a canyon in the northeast part of the section the Ferguson gypsum shows a mile to the southeast in sec. 9, the following section was measured:

Section in SE. ¼ Sec. 9, T. 19 N., R. 12 W.

		Feet
5.	Medicine Lodge	
	Gypsum—top removed	4
	Anhydrite	3
	Gypsum	8½
4.	Greenish sandy shale and dolomitic sandstones	¾
3.	Red and green shale with selenite and satin spar bands	16
2.	Ferguson gypsum	6½
1.	Greenish dolomitic sandstone	½

About one mile farther southeast in sec. 16 the Medicine Lodge is at least 15 feet thick and the anhydrite member three feet thick. The contacts are not well exposed and definite measurements could not be made. The Medicine Lodge and the Shimer are separated by 26 feet of green and red shale, filled with selenite bands. The Shimer is 11 feet thick with the top removed and is immediately underlain by one foot or more of greenish dolomitic sandstone.

In the SE. ¼ sec. 23, in the same township the Ferguson shows a thickness of about eight feet. There is a small cave under the outcrop so that the bottom of the ledge is probably removed and the full thickness not shown.

At the quarry of the Oklahoma Gypsum Company at Wilson in the NE. ¼ sec. 26, T. 19 N., R. 12 W., the Ferguson is 8 to 10 fet thick. The anhydrite member of the Medicine Lodge is about three feet thick and has 10 feet of very pure, fine-grained, white gypsum above it. The Independence Gypthickness of six feet, six inches, with the top removed. One sum Company has quarried the Medicine Lodge and Shimer at Southard in sec. 10 T. 18., R. 12 W. The quarry worked in the fall of 1912 is in the Shimer which is here 17 feet thick, massive and fine-grained. The upper 8 to 10 feet is pure white and the lower seven to nine feet somewhat cloudy. The nature of the rock is shown in figure 50. This property was purchased in the fall of 1912 by the United States Gypsum Company.

The following section was taken 200 paces east of the northwest corner of sec. 11, just south of the section line.

Section in NW. ¼ Sec. 11, T. 18 N., R. 12 W., One Mile East of Southard

		Feet
11.	Anhydrite, at top of hill .... about	4
10.	Gypsum, white, massive	5
9.	Greenish grey sandstone	½
8.	Red shale with green bands	9
7.	Red and green shale with satin spar and green selenite bands	11
6.	Ferguson gypsum, mottled	7
5.	Greenish dolomitic sandstone	½
4.	Red and green shale	8
3.	Green selenite in clay, satin spar	1½
2.	Red shale with thin bands of satin spar	7
1.	Red and green shale with some selinite	30

In this section Nos. 10 and 11 represent the Medicine Lodge. The upper gypsum has been removed by erosion. The Shimer shows about 15 farther back on the hill. The appearance of the weathered surface of the anhydrite, No. 11, is shown in figure six, in chapter one.

Around the head waters of Salt Creek, west of Ferguson, the gypsum hills are higher and more rugged than anywhere else along the outcrop of the Blaine formation. As previously mentioned this is probably due to the ledge of anhydrite which reaches its maximum development here, where it is four to five feet thick. The appearance of the ledge and the manner in which it produces the steep slopes are shown in figure 46.

The following section by Gould was measured at the bluff at the old plaster mill west of Ferguson:

Section Taken on the South Canyon of Salt Creek, at the Rubey-Stucco Plaster Company's Mill

		Feet
7.	Massive, white gypsum, the Shimer	15
6.	Soft, gray dolomitic sandstone	1
5.	Red gypsiferous clay	27

Fig. 46.—Anhydrite blocks from Medicine Lodge gypsum, 4 miles west of Ferguson.

4.	Massive white gypsum, the Medicine Lodge (Contains 3/4 feet anhydrite)	17
3.	Red gypsiferous clay, with green bands of selenite	25
2.	Pinkish, mottled gypsum, the Ferguson	4
1.	Red gypsiferous clay, with thin green and white selenite bands and layers	86

The clay underlying the Ferguson is locally very salt and, in Henquenet's Canyon, near the head of Salt Creek gives rise to many salt springs. These are described in the succeeding chapter of this report.

To the southeast the gypsums show little change in their character and relations for a few miles. In the E. ½ sec. 18, T. 17 N., R. 11 W., across Bitter Creek from the Roman Nose Gypsum Company's mill the following section was measured:

Section Near Bickford i nSE. ¼ Sec. 18, T. 17 N., R. 11 W.

		Feet
6.	Shimer gypsum, top eroded	14
5.	Red and green shale	32
4.	Medicine Lodge gypsums	
	Gypsum	9
	Anhydrite	2
	Gypsum	6
3.	Red and green shales (a 12-14 inch layer of gypsum near the middle)	32
2.	Ferguson gypsum	5 to 6
1.	Red shales	70

The contacts at the bottom of the gypsum ledges are not clearly enough exposed to tell whether or not thin layers of dolomitic sandstone usually present immediately under the gypsums occur in this section. The general character of the outcrops in this region is shown in figure 47. This picture was taken north of the Roman Nose Gypsum Company's mill at

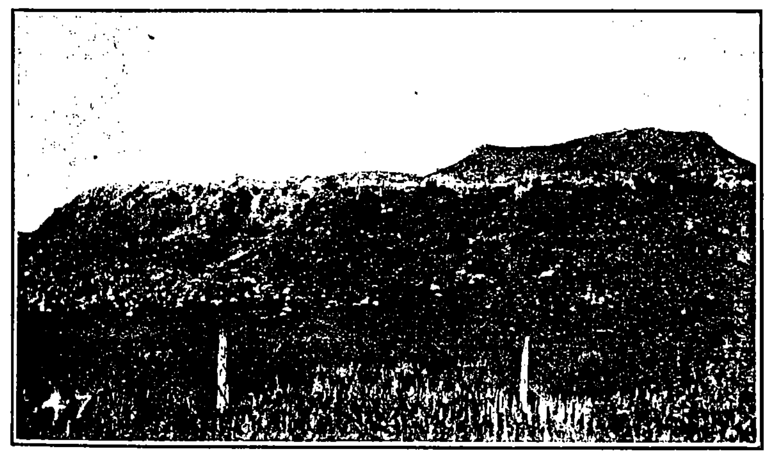


Fig. 47.—Hill near Bickford, showing the three gypsum beds.

Bickford. The Ferguson shows as a bench about one-third of the way up the hill. the Medicine Lodge caps the main hill, while the Shimer caps the outlier at the right of the picture. The white blocks at the foot of the hill and on the slopes are mostly anhydrite from the middle of the Medicine Lodge. The ledge of anhydrite shows about the center of the figure.

Four miles to the southeast of the section just described are the quarries of the Monarch Plaster Company and the American Cement Plaster Company. They are situated in secs. 27 and 34, T. 17 N., R. 11 W. The following section was made by Gould along the Chicago, Rock Island & Pacific Railway at this locality.

Section Along the Chicago, Rock Island & Pacific Railway, Four Miles South of Hitchcock.

		Feet
8.	Massive, white gypsum, the Shimer	8
7.	Gray, dolomitic sandstone	1
6.	Red clay	45
5.	White, massive gypsum, the Medicine Lodge	12
4.	Gray dolomitic sandstone	2
3.	Red clay shales with greenish bands	17
2.	Massive white gypsums, the Ferguson	3
1.	Red clay shales with bands of gypsum	90

The thin gypsum observed between the Ferguson and Medicine Lodge in the section at Bickford is not recorded in this section by Gould. It is exposed; however, in the railroad cut in sec. 27, where it has a thickness of about one foot. Between the Bickford section and the one at the quarries south of Hitchcock the Shimer thins perceptibly and the anhydrite in the Medicine Lodge becomes lenticular and is practically absent in the Monarch and American quarries which utilize the whole thickness of the Medicine Lodge. The satin spar veins in the shales between the gypsums are very abundant in this region and are thicker than usual. (See fig. 48).

Southeast from the Monarch and American quarries, the Shimer continues to become thinner, the Medicine Lodge thins to about seven feet and the Ferguson to three feet while the fourth gypsum, between the Ferguson and the Medicine Lodge, gradually thickens to three feet. This layer is quite selenitic

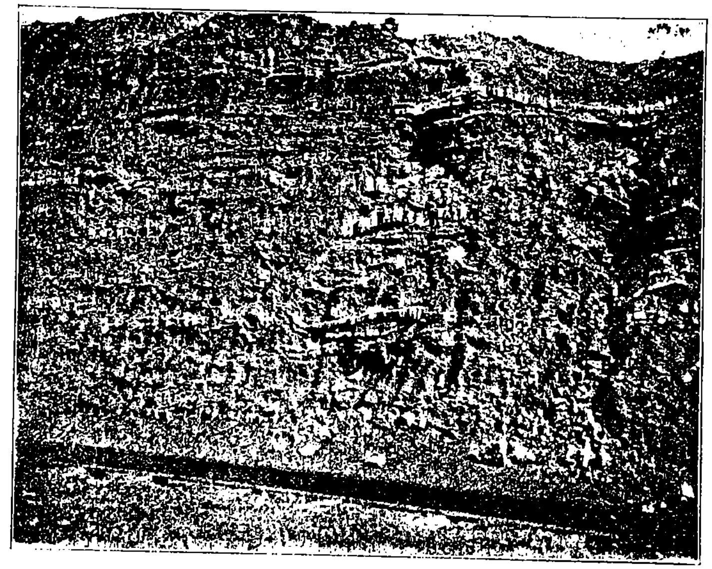


Fig. 48.—Satin spar veins in clay, north of Watonga. (U. S. Geol. Survy.)

while the others are fine-grained. In sec. 19, T. 16 N., R. 10 W., the following section was measured:

Section in SW. ¼ Sec. 19, T. 16 N., R. 10 W.

		Feet
8.	Shimer gypsum	6
7.	Dolomitic	½
6.	Red and green shales with thin dolomitic layers	42
5.	Medicine Lodge gypsum	7
4.	Covered, probably shale	20
3.	Gypsum, selenitic	2
2.	Covered, probably shale	25
1.	Ferguson gypsum	3

The contacts in this section are not sharply exposed and the thicknesses are approximations. The dolomitic layer beneath the Shimer is very fossiliferous, containing large members of pelecypods. The character of the steeper hills in this region is shown in the accompanying view of Cedar Hills (fig 49).

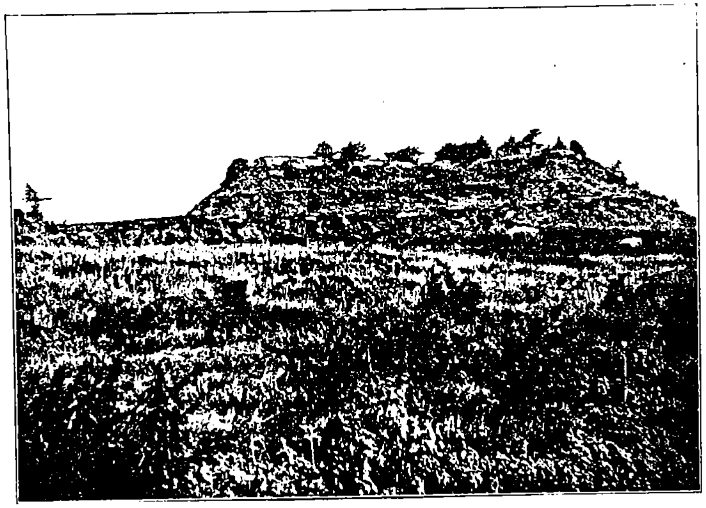


Fig. 49.—Cedar Hill, east of Watonga, showing Ferguson gypsum on the slope and Medicine Lodge gypsum as a cap. (U. S. Geol. Survey.)

Farther to the southeast the Shimer disappears, the dolomitic layer beneath it continues as a thickened, blue to white magnesian limestone, which is locally fossiliferous. In T. 15 N., R. 10 W., the hills grow less and less distinct until at the Blaine-Kingfisher county line they die out to reappear across the line in Kingfisher county.

The following section was measured on a butte two miles west of Altona and one mile west of the line between Blaine and Kingfisher counties.

Section in NE. 1/4 Sec. 14, T. 15 N., R. 10 W., Two Miles West of Altona

		Feet
7.	Medicine Lodge gypsum, top removed by erosion	3
6.	White dolomitic sandstone	2
5.	Red and green shales	16
4.	Gypsum, anhydrite, with satin spar beneath	3
3.	Red and green shale	18
2.	Ferguson gypsum, selenitic	3
1.	Red and green shale	21

Availibility and development of the gypsums.—Blaine County is well supplied with railroads and the gypsums are more accessible than those of any other county along the first line of hills. Three railroads cross the outcrop in the northern part of the county and a fourth is sufficiently near the outcrop to render the gypsums available.

The Kansas City, Mexico & Orient Railroad crosses the outcrop south of Fairview in Major county and remains near the top of the hills for some distance into Blaine County. Spurs two or three miles in length built from this road in the vicinity of Longdale would open up immense deposits. At present there is no development along this road although a mill has been proposed at Longdale.

The Kansas City and Vernon branch of the St. Louis & San Francisco Railroad approaches the outcrop at Wilson east of the center of sec. 26, T. 19. N., R. 12 W., turns south along the foot of a hill which is capped by the Medicine Lodge gypsum. The scarp continues to the southwest on top of the gypsums. In sec. 10, T. 8 N., R. 12 W., a branch of Squaw Creek carries the outcrop back near the railroad and makes a large amount of rock easily available. Two mills with their quarries and the quarry of the third mill, are located on this road.

The new mill and quarry of the Oklahoma Gypsum Company is located at Wilson east of the center of sec. 26, T. 19 N., R. 12 W. The mill is on a short spur from the railroad, at the foot of a hill which is caped by the Medicine Lodge gypsum. The quarry is opened in the Ferguson which is about six feet thick and of a very good quality. From the quarry the rock is hauled to the mill in steel dump cars on a tramway. A large quantity of rock can be obtained from the Ferguson ledge before the stripping becomes prohibitive. It is planned to open a second quarry in the Medicine Lodge above the anhydrite. A thickness of 10 feet of exceptionally pure white gypsum can be obtained with very little stripping.

The present quarry of the Southwest Cement Plaster Company (leased to the Oriental Plaster Company), whose mill is at Okeene, is on the end of a nose in the south part of sec. 26. The material is crushed in a crushing plant located beside the railroad, run into cars on a switch, and hauled to the mill. The quarry opening is small. The old quarry of this company is near the north line of sec. 2, T. 18 N., R. 12 W. The Medicine Lodge gypsum above the anhydrite was quarried. The opening is about 375 by 125 feet in dimensions. The crushing plant was formerly located at this point.

The mill and quarry of the Independence Gypsum Company at Southard was purchased in the fall of 1912 by the United States Gypsum Company. The quarries are located in the NW. 1/4 sec. 10, T. 18 N., R. 12 W. Both the Medicine Lodge and the Shimer have been quarried; about five acres of the Shimer and one acre of the Medicine Lodge have been removed since work began in 1905. In the fall of 1912 a quarry in the Shimer was being worked. The ledge here averages 17 feet in thickness and the greater part is pure white.

The lower five or six feet is somewhat cloudy but burns white. The stripping is usually less than two feet, but many of the joints are opened by solution and considerable work is resuired to remove the clay from the joints. A small portion of the quarry is shown in figure 50. The rock is hauled to the mill, a distance of over one-fourth mile, in wagons and unloaded by hand. Twelve men were working in the quarries and on the wagons at the time the quary was visited, but as high as 25 men have been employed when the mill was running to capacity.

The Geary-Alva branch of the Chicago, Rock Island & Pacific Railway comes near the gypsum hills southeast of Ferguson and follows closely along the foot of the hills through the canyon of Bitter Creek (Roman Nose Canyon) from the lines between secs. 7 and 18 for about three miles to the southwest where it goes up over the gypsums near the head of the canyon. Two mills are located along this road.

The old mill of the Rubey Stucco-Plaster Company is situated about four miles west of the railroad near Ferguson in the South Canyon, near the head of Salt Creek. The quarry is at the top of a hill about 250 feet above the level of the bottom of the canyon. The Medicine Lodge gypsum was quarried. The

Fig. 50.—A portion of the quarry of the United States Gypsum Company in the Shimer gypsum at Southard.

rock was lowered to the mill in cars operated by a gravity system on a double track. Owing to its being located so far from the railroad this mill has not been successful and has not been operated for some years. The tracks from the quarry to the mill have been destroyed. There is no prospect of the mill being operated in the near future.

The Roman Nose Gypsum Company owns the SE. 1/4 and the E. ½ NW. ¼ sec. 18 and the E. ½ SW. ¼ sec. 7, T. 17 N., R. 11 W. The railroad lies parallel to the hills on the west side of the track less than one-eighth mile from the hills on the east. The quarries are in the Medicine Lodge gypsum, above the anhydrite layer. A thickness of five to six feet of good rock can be obtained near the outcrop and eight to nine feet is accessible farther back in the hill. However, the thickness of stripping also increases very rapidly so the quarrying is not carried far from the outcrop until the stripping becomes heavy, and a third quarry has been opened. It is planned to strip the anhydrite from the old quarries and to utilize the gypsum below it, which is about six feet thick and of good quality. The rock is hauled from the quarry to the mill in wagons and unloaded by hand. The location of the quarries and mill is shown in figure 51 and the mill and its surroundings in figure 52.

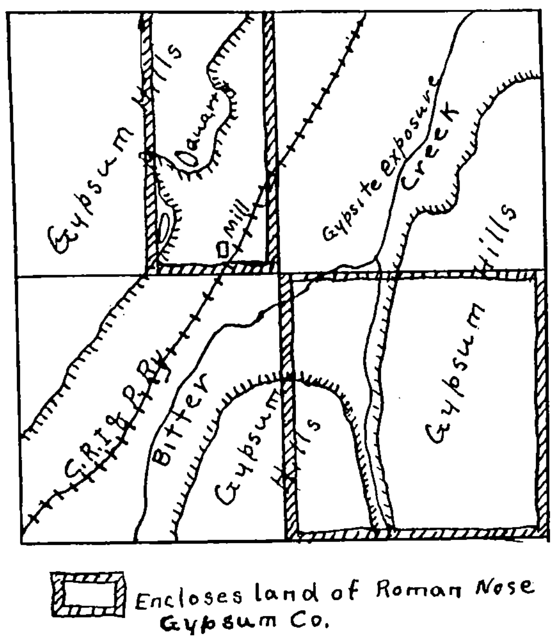


Fig. 51.—Map of sec. 18, T. 17 N., R. 11 W., showing buildings of Roman Nose Company.

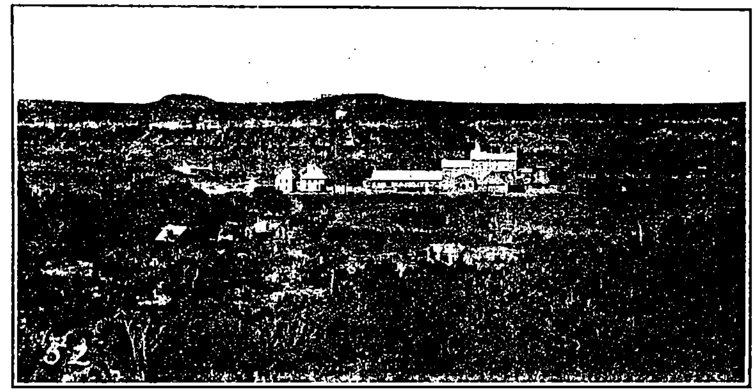


Fig. 52.—Mill of the Roman Nose Gypsum Company at Bickford.

The Enid, Lawton, and Waurika branch of the Chicago, Rock Island & Pacific Railway crosses the gypsum hills about four miles south of Hitchcock. It makes the gypsum deposits of sec. 27 and 34, T. 17 N., R. 16 W., easily accessible. Two quarries, those of the Monarch Plaster Company (leased to the Oriental Plaster Company) and of the American Cement Plaster Company whose mills are at Watonga, are located in these sections. The location of the quarries, gypsite beds and of the hills in these sections and in sec. 35 are shown in figure 53. The small map (fig. 54) shows the location of the holdings of the Roman Nose Gypsum Company, the Monarch Plaster Company, and the American Cement Plaster Company in T. 17 N., R. 11 W.

The quarry of the Monarch Plaster Company is in the NE. ¼ SE. ¼ sec 27. It is opened along the railroad cut and a short spur is laid into the quarry. The entire Medicine Lodge bed is quarried giving a thickness of 12 to 15 feet of gypsum. The stripping is very thin as far back as the face has been worked but increases very rapidly back into the hill. A large quantity of rock can be secured before the stripping becomes very heavy. The conditions of the quarry are shown in figure 55.

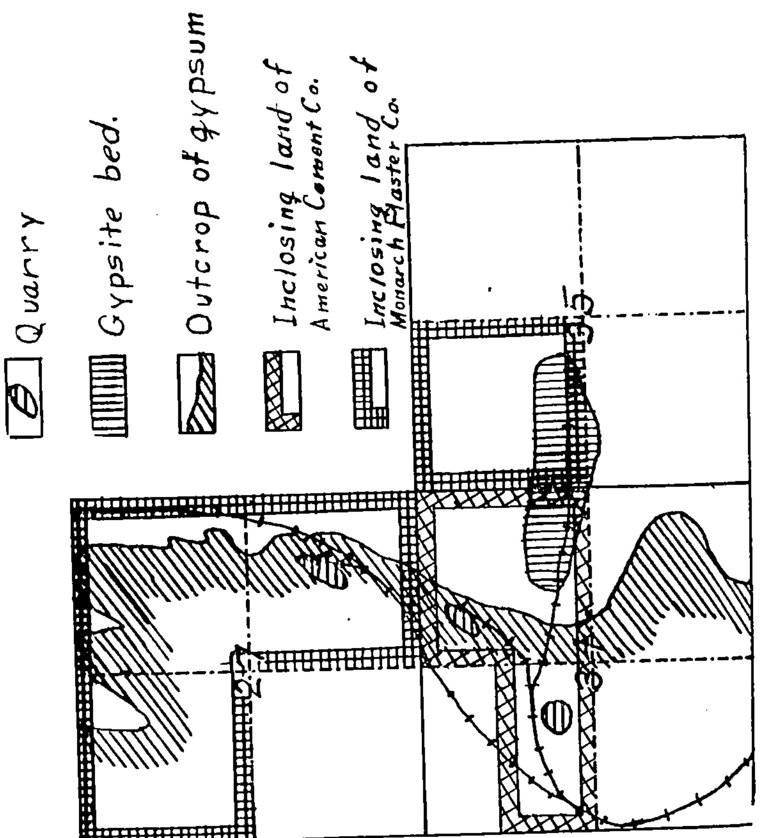


Fig. 53.—Map of sections 27, 34, and 35, T. 17 N., R. 11 W., showing the holdings of the American Cement Plaster Company and the Monarch Plaster Company.

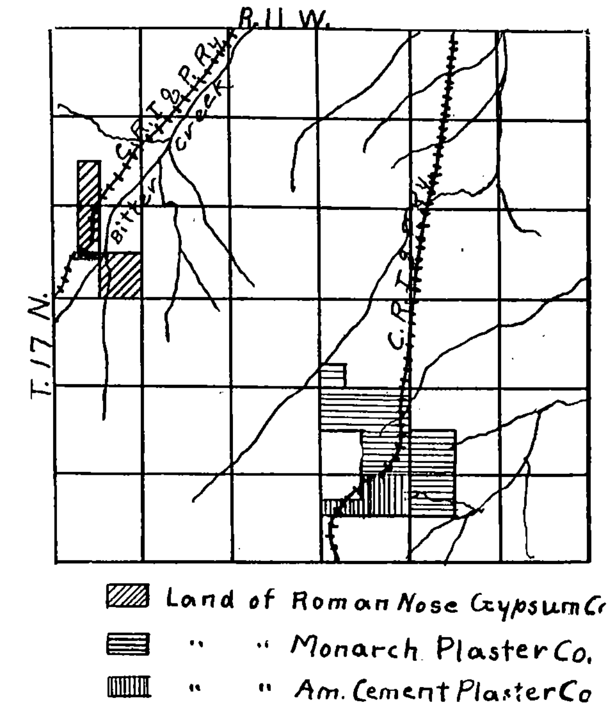


Fig. 54.—Sketch map of T. 17 N., R. 11 W., showing holdings of gypsum companies.

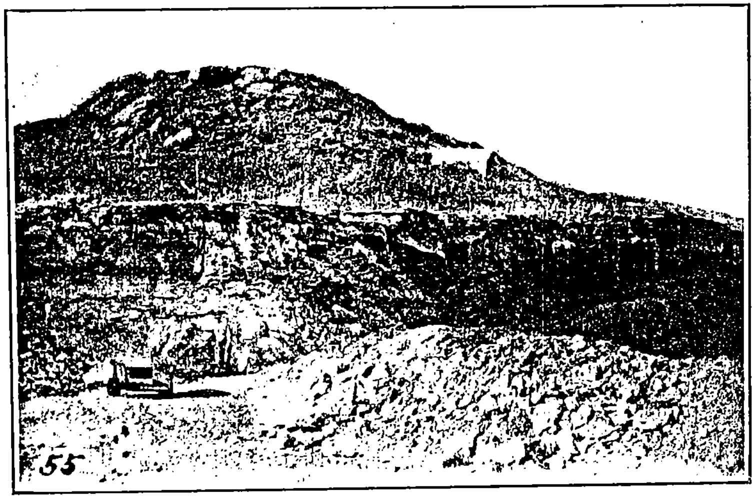


Fig. 55.—Portion of quarry of Monarch Plaster Company.

The quarry of the American Cement Plaster Company is the NE. 1/4 NE. 1/4 sec. 34. T. 17 N., R. 11 W. The quarry worked at present was opened in the summer of 1912, and the opening is still small, less than one-eighth acre having been removed. The nature of the rock and quarrying conditions are identical with those of the Monarch quarry which is only 40 rods distant. The rock is hauled from the quarry face in end dump cars on a track to the crushing plant. The plant has a jaw crusher and cracker of a capacity of 10 tons per hour. The power is furnished by a 40 horse power, Fairbanks-Morse internal combustion engine which uses solar oil as fuel. The gravel from the cracker is elevated and runs directly into cars on the spur track from the railroad. Twelve to fourteen men are employed at the quarry and crusher, at 20 cents per hour. A portion of the quarry is shown in figure 56.

Gypsite beds.—The gypsite beds of Blaine County seem to be more extensive than those of any other county along the first line of hills, but this may be on account of their being better developed. From the nature of the occurrence of gypsite beds it is evident that beds covering considerable areas may be present without being exposed, or may be exposed in such small

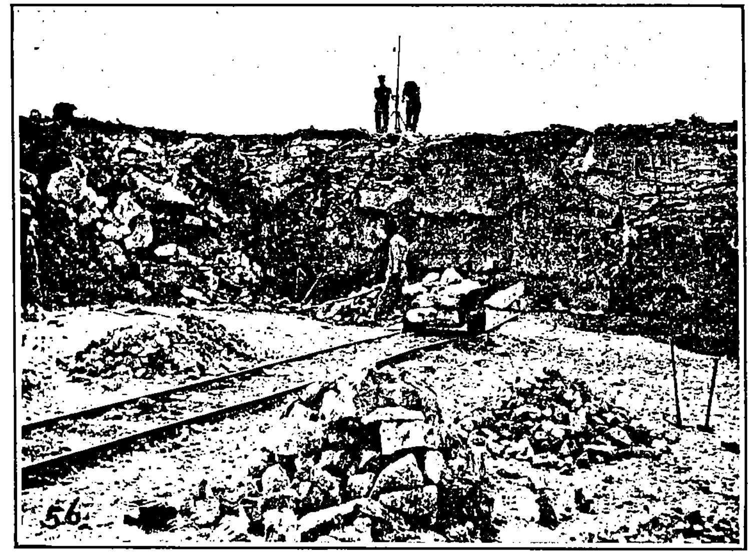


Fig. 56.—Portion of the American Cement Plaster Company's quarry in the Madicine Lodge gypsum northeast of Watonga.

patches as to escape notice unless detailed search is made for them, and little search has been made in counties having no mills.

Three small gypsite beds lie in the draws in E. 1/2 sec. 27, T. 19 N., R. 12 W., about one mile west of the Oklahoma Gypsum Company's mill at Wilson. One bed is about 100 feet by 750 feet and shows a maximum thickness of seven feet of gypsite. At a short distance from this is a second bed about 350 feet square. The full thickness is not shown but the bed is over two feet thick. A similar bed lies to the east. It probably extends down the draw 300 to 400 feet.

The gypsite beds of the Southwest Plaster Company (mill at Okeene) lies in the south-central part of sec. 35., T. 19 N., R. 12 W., and in the adjoining part of sec. 2 in the township to the south. The opening in sec. 2 is about 125 by 375 feet. In thickness the gypsite ranges from about two feet at the foot of the hill to five to eight feet at the creek. The stripping is two feet thick, of the soil near the hill and five feet near the creek. This bed extends east on to the land of the United States Gypsum Company. The quality of the gypsite is better near the creek. The material is hauled to the railroad in wagons and dumped into the railroad cars through a trap. The opening in sec. 35 is about 125 feet square. In thickness and quality the bed is similar to that to the south. The gypsite is hauled to the railroad in wagons whose beds are elevated and dumped into the cars by means of a derrick.

Large deposits of gypsite lie along Bitter Creek at and near Bickford. Exposures are seen at intervals for a distance of about two miles along the creek and in some of its small tributaries. The bed used by the Roman Nose Gypsum Company lies principally on the east side of Bitter Creek in the NW. ¼ sec. 19 and the SW. ¼ sec. 18, T. 17 N., R. 11 W., less than one mile from the mill. In thickness the deposit varies from one foot at the foot of the hill to five feet along the creek and it is covered by soil a few inches to two feet thick. The bed is approximately five-eighths mile long and averages about 75 feet wide. The gypsite is removed by drag scoops and dumped through a trap into wagons. Only about one-tenth of the estimated quantity of the deposit has been used in the five years that the mill has been running.

The mills at Watonga obtain their gypsite from a large bed lying in the SE. ¼ NE. ¼ sec. 34 and the NW. ¼ sec. 35, T. 17 N., R. 11 W. The entire bed covers about 80 acres and the maximum thickness is about eight feet. The material is worked with drag scoops and dumped through a trap into railroad cars on a spur track from the Chicago, Rock Island & Pacific Railway. Judging from a general view of the workings less than one-half of the available material has been removed.

KINGFISHER COUNTY.

Area of outcrop.—The gypsum hills cross the extreme southeastern corner of Kingfisher County. The escarpment lies in secs. 30, 31, 32, and 33, T. 15 N., R. 9 W. The approximate area of outcrop is shown in figure 57.

Stratigraphy.—The gypsum hills die out just about the line between Blaine and Kingfisher counties but reappear in Kingfisher and continue into Canadian County. It is not known

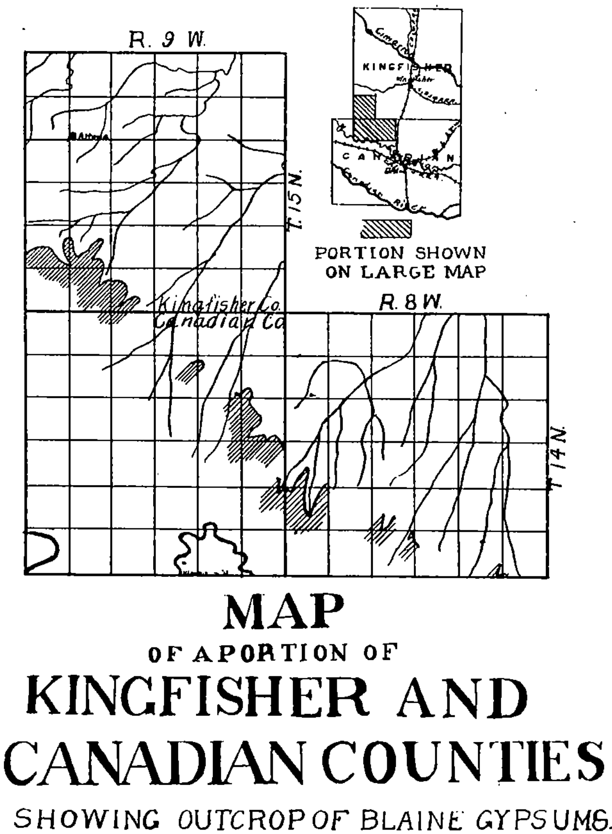


Fig. 57.—Map of a portion of Kingfisher and Canadian counties showing outcrop of Blaine gypsums.

whether the gypsums are absent along the Blaine-Kingfisher county line or whether they are merely covered. In Kingfisher County the section is apparently the same as in the adjoining part of Blaine County. Good exposures are rare. The thickness and relations of the gypsums are shown in the following sections:

Section in NW. ¼ Sec. 29, T. 15 N., R. 9 W.

		Feet
6.	Medicine Lodge gypsum, pink, top eroded	4
5.	Sandy, white dolomite	2
4.	Covered, probably shale	16
3.	Gypsum, with satin spar immediately underneath	2
2.	Covered, probably shale	16
1.	Ferguson gypsum	5

Just north of the Kingfisher-Canadian county line the stratification becomes very erratic and the ledges cannot be traced.

Availability and development of the gypsums.—The gypsums of Kingfisher County are not near enough to a railroad to be considered available at present. No development has been undertaken. Gould estimates the amount of gypsum at 50,000,000 tons.

CANADIAN COUNTY.

Area of outcrop.—The gypsum hills extend into Canadian County from Kingfisher and reach almost to Darlington on the Chicago, Rock Island & Pacific Railway. The hills are not conspicuous and the slopes are gentle.

Stratigraphy.—Just before they cross the south line of Kingfisher County the outcrop of the gypsums becomes discontinuous and the individual ledges cannot be followed. In the north part of T. 14 N., R. 9 W., three gypsums are present which may or may not be the reappearance of the Ferguson, Medicine Lodge, and the unnamed gypsum between them. The upper and lower gypsums are each about three feet thick and the middle one i sabout one foot. All three are usually white but the top parts are sometimes pink and selenitic. The thin middle ledge is occasionally very impure, sometimes clayey and often anhydritic. In T. 14 N., R. 8 W., gypsum occurs in lenticular beds. One of these beds is quarried at the Okarhe mill of the United States Gypsum Company in sec. 34. Southwest of this point the gypsums finally disappear.

Availability and development of the gypsums.—The gypsums of Canadian County approach the Chicago, Rock Island & Pacific Railway north of El Reno. The only development is the quarry mentioned in the preceding paragraph. This property was closed in 1912 and will probably not be reopened.

SECOND LINE OF GYPSUM HILLS.

GENERAL STATEMENT.

The second line of gypsum hills is formed by the eastern portion of the outcrop of the Greer formation. As has been observed, this formation consists of red shales and red sandstones with subordinate amounts of gypsum and dolomite or magnesian limestone. The stratification in the area under consideration is very erratic and the gypsum ledges are not continuous over large areas as is the case in the first line of gypsum hills. Ledges of gypsum several feet in thickness may pinch out or grade laterally into sandstone in the distance of a few rods. As a consequence of this irregularity of stratification the hills in this region differ strikingly from those of the first line. Instead of a single bold escarpment with outlying buttes, the hills are a series of rounded knolls usually covered by grass, or a series of long rounded ridges. Good exposures of any considerable thickness of rock are comparatively rare. The eastern margin of the hills lies from 25 to 50 miles west of the main line of hills. The width of the gypsum outcrops varies from about five to about 30 miles. The areas occupies parts of the following counties: Dewey, Ellis, Roger Mills, Custer, Washita, Kiowa, Caddo, Comanche, and Grady. These counties will be considered in turn commencing at the north. The outcrop of the Greer formation is shown on the general geologic map (fig. 30).

DEWEY COUNTY.

Although the Greer formation outcrops over a considerable portion of Dewey County, the gypsums are thin and relatively unimportant. The high hills north of the Canadian River north and northwest of Taloga are capped by a ledge of rock gypsum four or five feet thick. The gypsum appears to be of good quality but so much of the ledge has been removed by erosion that the areas remaining are comparatively small. No location was observed which seemed suitable for a mill site even if there were transportation facilities at hand. The same ledge continues to the southwest up the river as far as Raymond, and what is probably the same ledge appears at Camargo on the Wichita Falls & Northwestern Railway. Large quantities of gypsum were removed from the railroad cut about one mile north of the town, where the ledge shows a thickness of about four feet. In this locality there seems to be more than one ledge, but the stratification is very erratic, or the gypsums are locally removed by solution and can not be traced along the hillsides for any considerable distance. In at least one case, a bed of gypsums seems to be inclined, that is, to cut across the lines of stratification of the shales and sandstones. No explanation for this phenomenon is offered. The grading of sandstone into gypsum is also well shown here. In tracing a ledge of ordinary redbeds sandstone, a few small white specks or patches of gypsum will be found widely separated in the sand. These increase laterally in number and size very rapidly until, sometimes in the distance of a few rods, the sandstone is entirely replaced by gypsum. The gypsum ledge may continue for a considerable distance, but in many cases grades back into sandstone in a distance of a fraction of a mile. Although the quantity of gypsum at Camargo is large the extreme irregularity of its occurrence, and the amount of stripping which would be necessary to secure a sufficient supply for a mill for any length of time, render its development improbable, at least in the present state of the plaster industry. Six miles northeast of Leedy gypsum ledges show on the hillsides along Stinking Creek and some of its tributaries. In one locality there are apparently four beds, ranging from two to four feet in thickness. These beds can be traced only a short distance and all have considerable cover except at the outcrop. Gypsums show in the bottoms of the canyons and are reported from wells in the vicinity of Putnam and in the southern part of the county but no commercial deposits were observed. The lack of transportation makes deposits in this part of the county unavailable even if they were suitable for development in other respcts.

Gould estimates the amount of gypsum available in Dewey County at about 1,000,000,000 tons. Of this amount, however, it is doubtful if any is practically available at present. The only location where it seems at all possible that a mill could be successfully operated is at Camargo, and this locality should be carefully prospected before any definite steps towards development are taken. No deposits of gypsite are known in the county although it is entirely possible that some beds may be present.

ELLIS AND ROGER MILLS COUNTIES.

The gypsum beds extend up the South Canadian River westward into Ellis and Roger Mills counties, in the area occupied by what was formerly Day County. In Ellis County on the north side of the river, gypsum is exposed along Turkey Creek in the vicinity of Stone. On the south side of the river in Roger Mills County, the gypsum appears near Shirley and extends for some distance up the river. The amount of the available gypsum in the two counties will probably not exceed 500,000,000 tons.

CUSTER COUNTY.

The greater part of Custer County is underlain by the Greer formation and gypsum is of common occurrence except in the extreme northeastern part and in the western row of townships. The gypsum beds increase in thickness and in regularity from northwest to southwest and attain their maximum in this county near Weatherford in the southeastern corner.

In the northwestern part of the county the beds are well exposed in the tributaries of Barnitz Creek in the vicinity of Osceola. Thicknesses of 10 feet of gypsum were observed but all the beds in the immediate vicinity of Osceola outcrop low down on the slopes or in the bottom of ravines so that they can scarcely be considered available even if there were transportation facilities. Farther to the east two ledges, five feet or less in thickness show about three miles north of Independence. These ledges are apparently not continuous over sufficient area to make them of any importance. Three beds show in the draw and ravines about two miles north of Custer City but they are not commercially important. Northwest of Clinton, along the line of the Clinton, Oklahoma & Western Railway, gypsum shows near Stafford. The amount easily available, however, is too small to render the deposit of commercial value. Considerable thicknesses of gypsum show in the vicinity north of Butler but the stratification is so erratic that it is difficult to estimate the amount present. A somewhat hurried examination failed to show any deposits which seemed capable of development.

In a ravine one mile north of Butler a phenomeon was observed which may account in some measure for the seeming irregularity of the stratification of the gypsum in this vicinity. A bed of gypsum lies on the hills back from the ravine. The water which runs over this gypsum and down the small draws into the ravine carries considerable gypsum in solution. Where the supply of water is not sufficient to erode the sides of the ravine rapidly but must run down the sides slowly, there is sufficient evaporation to form an encrustation on the side or wall of the ravine, which may reach a thickness as great as six inches. This encrustation gives the appearance in every respect of a ledge of gypsum of a thickness equal to the height of the wall of the ravine up to the level at which the water leaves the small draws. It seems possible that this secondary deposition caused by gypsiferous water evaporating on fairly steep slopes may account in a small degree for the appearance of thick ledges of gypsum which seem to play out in very short distances. By far the greater portion of these appearances, however, must be due to other causes, such as lateral gradation into sandstone or shale, solution of part of the ledges, lenticular beds, and slip which covers part of the ledge.

The commercially important deposits of gypsum in Custer County lie in the extreme southeastern corner in T. 3 N., R. 15 W., and T. 12 N., Rs. 14 and 15 W., in the vicinity of Weatherford. The hills which extend northwest from Weatherford to the west of Deer Creek and its tributaries, contain ledges of gypsum up to 50 feet in thickness, and equally important beds are found due south and to the southwest of Weatherford. The deposits are available from the Chicago, Rock Island & Pacific Railway. No beds of commercial importance were found immediately on the railway but spurs of one mile or less in length would open up immense beds of gypsum. The gypsum varies in quality, but the prevailing type is a fine-grained, selenitic rock of white, pink, or red color. The following analyses of gypsum near Weatherford are given by Gould: [82]

[82] Gould, Chas. N., Water-supply paper U. S. Geol. Survey No. 148, 1905, p. 63.

Analyses of Gypsum From Near Weatherford.

A. Gypsum from cave five imiles northwest of Weatherford.

B. Gypsum from ledge four miles west of Weatherford.

C. Gypsum from ledge five miles west of Weatherford.

	A	B	C
Calcium sulphate	75.57	77.38	27.25
Calcium carbonate	1.11		46.73
Magnesium sulphate		.83	
Magnesium carbonate	.40		1.42
Water	20.22	20.78	17.36
Oxides or iron and aluminum	.45	.67	8.30
Silica and insoluble residue	1.66	.41	1.22
	99.41	100.07	102.28

The effects of solution on the thick gypsum ledges are very noticeable and caves and sinkholes abound. The entrance to the cave five miles northwest of Weatherford from which sample "A" in the above list was taken is shown in figure 58.

Gypsite beds.—Judging from the conditions in Custer County, there should be considerable deposits of gypsite present. No detailed prospecting has been carried on, however, and at present only one bed of importance is known. This lies in sec. 1, T. 12 N., R. 16 W., and in the adjoining section on the north. The Chicago, Rock Island & Pacific Railway passes through the deposit about one mile east of the station at Indianapolis. The gypsite bed covers between 60 and 70 acres and reaches 18 feet in thickness. The greater part of the material is a fine, light gray gypsite with little sand. The lower portion is a very light reddish brown in color, and somewhat more sandy. The cover consists of from one to eight feet of soil. The extent of this deposit, the character of the material, and its location with respect to the railroad, make it of undoubted commercial importance and its development is probably a matter of a short time.

Summary.—Gypsum occurs over the greater part of Custer County but is of commercial importance only in the extreme southeastern portion. Here, in the vicinity of Weather-

Fig. 58.—Entrance to gypsum cave 5 miles northwest of Weatherford.

ford ledges up to sixty feet thick occur in a short distance of the railroad. The gypsite bed near Indianapolis is apparently of considerable importance. There is no development of the gypsum of the county at present. The amount of gypsum in the county is estimated by Gould, at 6,000,000,000 tons.

WASHITA COUNTY.[83]

The area in Washita County underlain by the Greer formation lies principally in the eastern half of the county. In the southern part the area splits, one part extending west, north off the southern line of the county, and the other to the southeast across the southwestern part of Caddo County.

The gypsum of the eastern part of the county occurs at two general horizons, a lower, which outcrops along Washita River from the Washita-Custer county line south, well into T. 18 N., where it swings away from the river to the east and west and seems to die out; and an upper horizon which caps the high hills along the river. The two groups are usually separated by 100 to 150 feet of shales and sandstones. Both horizons or groups are composed of very thick massive gypsum usually of a pink color. Neither group appears to consist of a continuous ledge although only one is usually present at a given location. From the appearance of the outcrop and the varying thickness of the intervening shales and sandstones, it is thought that each group consists of a series of lenticular beds lying at the same general level.

As has been said above the upper group occurs only on the top of the hills. It is probably present in many places where exposures were not found since many fields are reported as being underlain by gypsum at a depth of a few feet where there are no natural exposures. This gypsum is well developed in T. 11 N., Rs. 15 and 16 W., and probably extends to the south and connects with the large area along the east county line in T. 9 N., R. 14 W. In only a very few cases were exposures of this gypsum observed to cross the line into Caddo County and these exposures persist for only one-fourth to one-

[83]The description of the deposits in Washita County is taken principally from the note book of Jerry B. Newby, who did practically all the field work in this county.

half mile. The gypsum for the most part is fine-grained, massive, and pink. Locally there is considerable white gypsum but uniformly very little selenite. It is reported that a well in sec. 26, T. 11 N., R. 15 W., passed through 70 feet of this gypsum. The exposures on the hill tops in the vicinity show apparent thicknesses that make this well log seem entirely credible. The horizon of this gypsum is probably the same as that of the gypsum at Weatherford. The cover of this gypsum is usually thin or wanting.

The lower horizon of gypsum is much better exposed than the upper. Outcrops are found along the Washita River from the north line of the county extending to within five miles of Mountain View on the south line. In the northern part of the county the ledge is down near the level of the flood plain of the stream. To the south the gypsums are found higher and higher above the stream until they are well up from it and swing away from the river valley. Probably the best exposures are near Cloud Chief, Cowden, on the Washita River due east of Cordell, and on the state road on the south side of sec. 34, T. 10 N., R. 15 W. In sec. 35, of the same township and range, there is a bluff of gypsum which exposes a maximum thickness of about 45 feet. The true thickness is probably in excess of 50 feet since both the top and bottom of the bed are covered. The gypsum is pink on fresh surfaces but weathers locally to a dark red. In one place a lentil of gypsiferous sandstone one to three feet thick, with two large veins of satin spar, is exposed near the middle of the ledge. The length of this bluff is about one-third mile. A smaller bluff showing 20 feet of gypsum and having a length of about 100 yards is four miles due north of the one just described. The cover of the gypsum in both of these bluffs increases very rapidly back into the hill.

In sec. 3, T. 9 N., R. 15 W., along a tributary of the Washita there is a gypsum bluff 50 feet in height. The lower part of this ledge, consisting of a thickness of 10 feet, is a hard pink rock, probably anhydritic. The remaining part consists of a massive gypsum ranging in color from pink to white. Near Cowden in secs. 18 and 19, T. 9 N., R. 15 W., 10 to 20 feet of pink and white gypsum are exposed. There are two ledges, the lower is about eight feet thick and the upper at least 12 feet with the top removed. The two are separated by eight to 10 feet of shale. The under part of the lower ledge is very hard and probably anhydritic.

From the preceding notes, it is seen that wherever the lower part of this thick gypsum is exposed, there is at the base a band, eight to 10 feet in thickness, of harder—probably anhydritic—gypsum, sometimes separated from the main portion of the ledge by shale. The heavy body of gypsum is a more or less continuous ledge, and the outcrop can be followed for several miles in some places. In T. 8 N., R. 15 W., the outcrop swings to the west and disappears in about 10 miles. Only small exposures of thin gypsum are reported to the east.

Besides the two main bodies of gypsum mentioned there are some other beds in the eastern part of the county. The exposures are few and seldom show a thickness of over two or three feet. In the northwestern part of the county the beds are apparently very thin and not widely distributed. Only two outcrops were noted and the thickness exposed in these was not over one foot.

In the western extension of the belt of the Greer formation along the southern line of the county three gypsum ledges appear. In sec. 28, T. 8 N., R. 20 W., the lowest ledge is 16 feet thick. The gypsum is very hard and seems to be largely anhydritic. In these localities the rock breaks from the bed in blocks formed by two sets of joint planes meeting at about right angles and spaced a few feet apart. This gives smooth vertical faces, which are banded with alternating, waving light and dark stripes. The middle ledge is of the same thickness but is composed entirely of selenitic gypsum. No good exposures of the upper ledge were observed, but it appeared thicker than either of the other two. The upper ledges are entirely white. A thickness of 50 feet of gypsum is reported from a well in the section.

Gypsite beds.—So far as has been observed the conditions in Washita County are favorable to the occurrence of large gypsite deposits but at present only a few small beds are known, none of them cover more than three acres. They cannot be considered commercially valuable and there is no necessity for detailed description.

General summary.—Washita County contains immense deposits of rock gypsum, along Washita River in the eastern half of the county. The railroad nearest to the greater part of the deposits is the Arkansas City and Vernon branch of the St. Louis & San Francisco Railroad which lies six to 10 miles west of the region where the gypsums could be well worked. This distance is practically prohibitive under the present conditions of the plaster industry. Small gypsite beds are known but they are not of commercial importance at present. Gould estimates the amount of gypsum in the county at a depth of less than 100 feet as 20,000,000,000 tons, a greater amount than that of any other county in the state.

CADDO COUNTY.

Very little attention was given to the Caddo County deposits in preparation for this report since they have already been rather fully described by Gould.[64] His description is given in full.

"In Caddo County there are deposits of gypsum both north and south of the Washita River. In the region of the Keechi hills in the southeast corner of the county, on the line of the Frisco Railroad between Chickasha and Lawton there are deposits of considerable magnitude. These deposits extend from the Comanche line north to the Keechi hills and beyond. East and west they occupy an extent of some twelve or fifteen miles. In all, the outcrops of gypsum in this locality occupy about two townships. The ledges are not continuous but the gypsum appears as rounded knobs on the prairie or as irregular ledges along the sides of the stream. The gypsum consists of a mixture of hard rock and dirt gypsum. In places the dirt gypsum or gypsite, predominates while in other localities all the material is a rather hard rock. Plenty of localities may be found where a mill could be located for which an abundant supply of dirt gypsums could be optained. The gypsum in this region is usually not pure white but is either pinkish or dark colored. The following section was taken on Little Washita River west of the point where the Frisco Railroad crosses this river. It may be considered a fairly typical section.

[64]Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 110-112.

No.	Description	Feet
5.	Red clay shale	50
4.	Soft rock gypsum, white and pinkish	15
3.	Soft red sandstone	10
2.	Red clay shale	50
1.	Red sandstone along the bed of river	25
		150

"The thickness of many of the ledges in this region is more than that shown in this section. Ledges 50 feet thick are present but it is believed that 15 feet will represent a good average of the Keechi hills locality. Estimating the area at two townships and the thickness at 15 feet the result will be approximately two billion tons for the locality.

"Analysis of gypsum from the vicinity of Cement, Oklahoma, probably a few miles southwest of that town on the Little Washita River.

	Per cent.
Calcium sulphate	74.45
Calcium carbonate	4.25
Magnesium carbonate	.84
Water	18.61
Oxides of iron and aluminum	.61
Silica and insoluble residue	1.02
	99.68

"Analysis of a hard rock from the top of the Keechi hills, Caddo County, Oklahoma.

	Per cent
Calcium carbonate	100.18
Oxides of iron and aluminum	.26
Silica and insoluble residue	.32
	100.76

"West of the Rock Island Railroad on the hills south of the Washita River there are extensive deposits of gypsum in ledges 10 to 20 feet thick. These deposits are first encountered on the hills west of Hog Creek, some eight miles southwest of Anadarko. Along the hills south of the Washita and west of

Hog Creek, between that creek and Fort Cobb, these ledges form the cap rock of the bluff and may be seen for long distances. The cross-bedded, red sandstone below is from 125 to 150 feet thick and the gypsum ledge at the top will average from 15 to 20 feet thick. The extent of these deposits is not definitely known, but gypsums are reported 10 miles south of this line of bluffs. There is certainly an area larger than that of a township. With an average of 15 feet in thickness this will approximate one billion tons for this locality. In appearance this gypsum is white or pinkish and forms ledges of rather soft rock, sometimes partaking of the nature of gypsite. The gypsum in this locality is at the same general level as that in the vicinity of the Keechi hills, or of that across the Washita River to the north.

"The third locality in Caddo County in which gypsum is exposed is along the divide between Cobb Creek and the Washita River northwest of Fort Cobb. The gypsums in this region occur as rounded mounds on the top of the divide. They are in fact but the southeastern extension of the Washita County deposits to the northwest, or perhaps it is more correct to say that they form a connecting link between the Washita County beds and those in Caddo County south of the Washita River. The amount of gypsum in this locality increases as we go up the divide. The most southwestern exposure so far as known is in the northwest quarter of section 13, T. 8 N., R. 13 W. It is a rounded mound occupying perhaps a quarter-section and rising to the height of nearly 100 feet above the surrounding plain, or divide upon which it is situated.

"The amount of material in this part of Caddo County will probably not approximate more than 500 million tons. This will make a total of three and one-half billion tons in the county."

Gypsite beds.—The only gypsite beds of importance in the county are near Cement. One bed of about 30 acres lies principally in the SW. 1/4 sec. 33, T. 6 N., R. 9 W., about one mile north of Cement. The material is a light gray gypsite with little sand. A spur from the Oklahoma City-Quanah branch of the St. Louis & San Francisco Railroad is built to the deposits. Before the burning of the Acme Cement and Plaster Company's mill the material from this bed was used in the

manufacture of plaster. Another bed of 10 acres or more lies about two miles to the north in secs. 21 and 28. Both beds have been largely worked out. The composition of the gypsite bed in sec. 33 is shown in the following analysis:

Analysis of Gypsite From Near Cement.

Calcium sulphate	63.82
Calcium carbonate	4.86
Magnesian carbonate	.14
Iron and aluminum oxides	.69
Water	16.43
Insoluble residue	13.95
	99.89

Development.—No use is being made of the gypsite in Caddo County at present. The mill at Cement which has been mentioned was burned in 1911 and the spur track to the gypsite bed has been partially taken up. Judging from a rather hurried survey, there is not sufficient material remaining to justify rebuilding the mill. The rock gypsum for the mill was secured at Gladys, on a spur from the St. Louis & San Francisco Railroad, about four miles southwest of Cement. This quarry is still operated on a small scale and the rock shipped to Portland cement plants. The analysis given above by Gould is probably of rock from near Gladys.

COMANCHE COUNTY. [85]

"The known outcrops of gypsum in this county are rather unimportant. All the deposits so far as known occupy an area of a few square miles along the north line of the county a few miles northeast of Frisco. The gypsum is exposed in irregular ledges along the slope or on top of rounded hills. The amount of material is not large, perhaps not more than 200 million tons in all. The location of the deposits is such, however, that a number of mills might be profitably located in the vicinity."

[85]Gould, Chas. N., Oklahoma gypsum: Second Bien. Rept. Okla. Dept. Geol. and Nat. Hist., 1902, pp. 110.

GRADY AND STEPHENS COUNTIES.

The outcrop of the Greer formation extends from Caddo and Comanche counties southeast across the southwestern corner of Grady County and into northwestern Stephens County where it disappears. No rock gypsum deposits of commercial importance occur in these counties and the only known deposits of gypsite of importance are in Grady County, four miles west of Rush Springs. One bed of 27 acres lies in the SW. ¼ sec. 23, and another of equal size in the SE. ¼ sec. 22, T. 4 N., R. 8 W. Both beds average about eight feet in thickness. The material was formerly hauled to the mill of the Acme Cement Plaster Company at Marlow. This mill burned a few years ago and a new concrete and steel mill has been erected at the deposits by the same company. A spur track from the main line of the Chicago, Rock Island & Pacific Railway at Rush Springs affords transportation facilities.

SUMMARY OF THE SECOND LINE OF GYPSUM HILLS.

The second line of gypsum occupies parts of Dewey, Ellis, Roger Mills, Custer, Washita, Caddo, Comanche, Grady, and Stephens counties. The gypsums are very thin in the northwestern and southeastern portions of the area and very thick in the central part, in southeastern Custer and eastern Washita counties, where ledges of 60 feet or more in thickness are known. The gypsum varies from white to pink in color and from fine-grained to coarsely selenitic in texture. A part of the lower gypsum is anhydritic in Washita County. The total amount of gypsum in the area is very great but the stratification is so irregular and the transportation facilities are so poor that there has been very little development. Small beds of gypsite occur in practically all the counties, but commercial deposits are known only in Custer, Caddo, and Grady counties. The only mill now operating is at Rush Springs, in Grady County. Mills at Marlow in Stephens County and at Cement in Caddo County have burned during the past few years.

SOUTHWESTERN AREA.

INTRODUCTION.

In the various reports and articles by Gould, this area has been called the Greer County Region and at the time the

first reports were written practically all of the area was included in the County. Since 1907, however, old Greer county has been subdivided and the gypsum area now forms part of Greer, Beckham, Harmon, and Jackson counties. For this reason it is thought best to drop the name Greer County Region and to use instead the term southwestern area, since the area occupies the extreme southwestern corner of the State.

The gypsums of the southwestern area occur in the Greer formation, presumably at the same general level as those of the second line of gypsum hills, and are probably the southwestward extension of those gypsums. The stratigraphy of the gypsums, however, is quite different from that of the second line of hills. Especially in the northern part of the southwestern area, the gypsums occur in well defined ledges which can be traced for considerable distances, and which produce a topography much more similar to that of the first line of hills or outcrop of the Blaine formation, than to that of the second line of hills or eastern part of the outcrop of the Greer formation. In the northern part of the area five ledges of gypsum are well defined and are traceable for many miles. These have been named by Gould as follows, beginning at the bottom: Chaney, Kiser, Haystack, Cedar Top, and Collingsworth.

Gould's description of these gypsum members is given in full.[86]

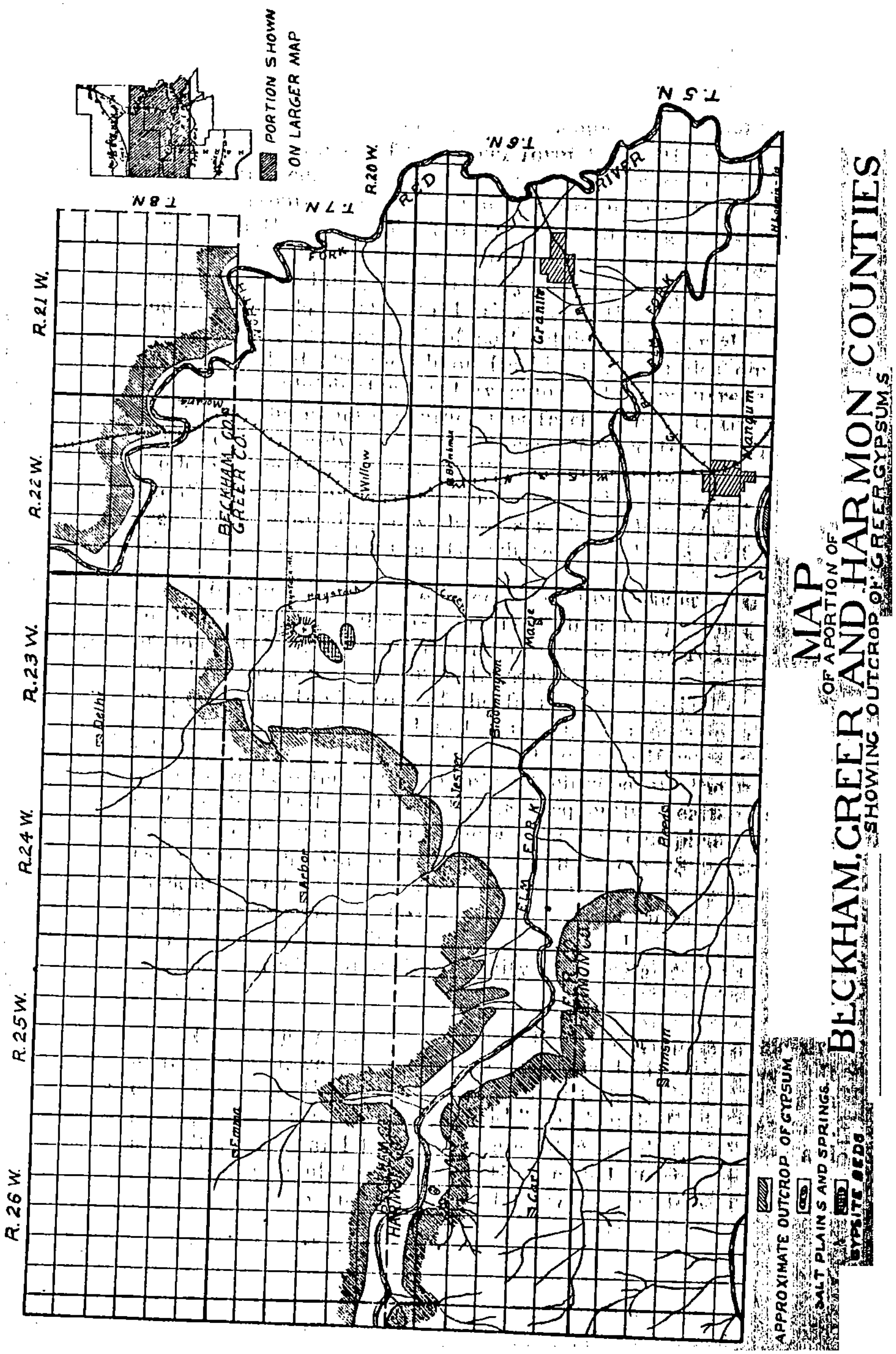
"*Cheney gypsum member.*—This gypsum is well exposed along the south side of Elm Fork from Mangum northeast to the Texas line. It is also seen on Haystack Creek, but on North Fork, in Roger Mills County, (now Beckham), it loses its characteristic structure and becomes simply a gypsiferous band in the red clay. On Elm Fork at the mouth of Hackberry Creek and also at the Kiser and Chaney salt plains near the Texas line, it is a hard massive stratum three to five feet thick, usually white, but sometimes gray or bluish. It is often distinctly stratified or apparently cross-bedded, or it may be that the lines of stratification are wanting. The formation derives its name from the Chaney Salt Plain on Elm Fork of Red River, four miles east of the Texas line.

[86]Gould, Chas. N., Geology and water resources of Oklahoma: Water-supply paper U. S. Geol. Survey No. 148, pp. 66-71.

"*Kiser gypsum member*.—This member is exposed throughout the western area of the Greer formation. It is rarely white and in this regard differs from all other ledges of the Greer. It varies from a decidedly bluish or greenish tint to a drab or gray. On the North Fork it is composed of greenish gypsum and gypsiferous shales becoming hard locally, and on Haystack Creek of bluish and drab gypsum, grading into gypsiferous rock and clay. On Elm Fork, at both the Kiser and Chaney salt plains it is composed of soft, bluish to greenish, selenitic gypsum and at the mouth of Hackberry, 10 miles down Elm Fork, it is a bluish stratified gypsum. These occurrences show that while the general character is fairly constant, the stratum varies considerably in local sections. The softness of the rock renders it particularly susceptible to weathering, and it is frequently inconspicuous. Its thickness varies from one to three feet. The name is from the Kiser Salt Plain on Elm Fork, Greer (now Harmon) County, where the ledge is well exposed.

"*Haystack gypsum member*.—The upper part of the Greer formation consists of three layers of massive gypsum and one of dolomite, interstratified between the beds of red clay shale. The lowermost of the three thicker layers, the third gypsum member from the bottom of the formation, consists of the typically massive gypsum, almost pure white or occasionally grayish in places, with a few thin bands of gypsiferous sandstone. This ledge is often cut by joints which separate the rocks into rectangular blocks. These blocks frequently weather out and roll down the slope and in places render it conspicuously white for miles. The Haystack varies locally from 18 to 25 feet in thickness, and so far as known is the thickest gypsum member in the western area of Greer. It is exposed along all the bluffs on North Fork and Elm Fork and is particularly conspicuous on Haystack Creek and in the vicinity of Haystack Butte, whence the name.

"*Cedartop gypsum member*.—The Cedartop is a massive white gypsum, very similar in appearance to the Haystack. It has a constant thickness of 18 to 20 feet throughout the region of outcrop. It is very conspicuous on North Fork, Haystack, and Elm Fork, and forms the caps of a number of buttes and bluffs throughout the region. It is called "Cedartop" from a prominent butte on the North Fork of Red River, in the ex-



treme southeastern corner of Roger Mills (now Beckham) County. This rock forms the upper ledge of this butte, and may be seen from a great distance up and down the river and even from Headquarters Mountain at Granite, 15 miles away.

"*Collingsworth gypsum member*.—This is the upper gypsum ledge of the Greer formation, and it does not differ materially in lithological appearance from the Haystack or Cedartop. Like them, it is massive and white throughout, and like them, also, it is cut by a series of master joints into rectangular blocks. Where exposed, the thickness varies from 18 to 20 feet, being approximately that of the Cedartop, and not so great as the Haystack. As it is the upper gypsum member it has often been eroded, and for that reason does not always appear in a section. Near the heads of the various creeks, however, it is the prominent ledge, and it is also exposed on a number of conspicuous bluffs, as along North Fork. It is named from Collingsworth County, Texas, just west of Greer (Harmon) County, Okla., where the gypsum is well exposed."

In addition to th's general description of the gypsums it seems best to add a brief discussion of the area by counties, as has been done with the other gypsum areas. The locations of the principal deposits in Beckham, Greer, and Harmon counties are shown on the accompanying map (fig 59).

BECKHAM COUNTY.

The available gypsum deposits of Beckham County are in the extreme southeastern part. From the southeastern corner of the county a bluff 150 to 200 feet high extends for 10 miles or more up the south side of North Fork of Red River. This bluff is made up of red shales with four ledges of massive white gypsums, aggregating about 70 feet in thickness. A view of the bluff is shown in figure 60.

The gypsum in this bluff is available to transportation only where the Wichita Falls & Northwestern Railway crosses North Fork, about three miles south of Carter. Immense deposits of gypsum can be opened up on either side of this railroad by short spurs. The estimated amount of material in the bluff is 1,000,000,000 tons. The stratigraphy and nature of occur-

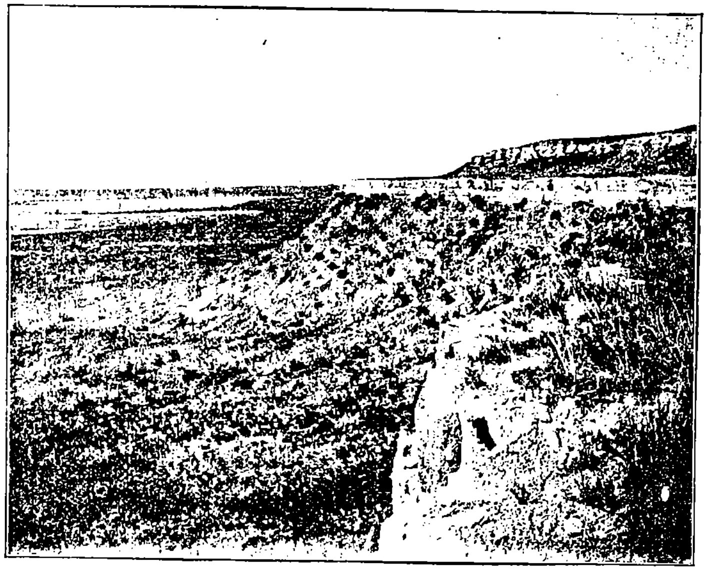


Fig. 60.—Gypsum bluff along North Fork of Red River.

ɪence of the gypsum is shown in the following section by Gould.

Section of Bluff on North Side of North Fork of Red River, Three Miles South of Carter.

		Feet
10.	Rough, weathered, sandy dolomite capping the high hills	3
9.	Red and green gypsiferous shale	24
8.	Massive white gypsum	23
7.	Red and green shale	6
6.	Massive white gypsum	18
5.	Red and green shale	15
4.	Massive white gypsum, occasional thin ledges of sandstone	25
3.	Reddish and green shale	24
2.	Greenish gypsums and gypsiferous shale, becoming hard locally	5

1.	Red and green gypsiferous shale from the base of the hill	30

Just below the lowest heavy gypsum, No. 4 of the above section, the shales are filled with some of the most perfect selenite crystals observed in the state. The crystals are in the main about one inch long, and about one-half as wide and thick. They form a sort of network with the spaces filled with clay. Some selenite bands of about six inches in thickness are present. These are made up for the most part of exceptionally clear selenite, but occasionally contain beautiful cloud-like masses of some red material presumably ferric oxide or hydroxide, or a mixture of the two.

Gypsum probably underlies about six townships in southwestern Beckham County and outcrops near the heads of Fish and Bailey creeks. These deposits although of considerable size are too far removed from transportation to be considered available at present. The stratigraphy of this part of the county and the immediately adjoining portion of Greer County is shown in the following section. [87]

Section Near Beckham County Line Along Haystack Creek, Six Miles South of Delhi.

		Feet
11.	Red clay	50
10.	Hard sandy rock	4
9.	Red and green clay	20
8.	Massive white gypsum	16
7.	Red and green clay	8
6.	Massive white gypsum	18
5.	Red and green clay	20
4.	Bluish and drab gypsum	4
3.	Red clay	15
2.	Gypsum and hard rock	5
1.	Red clay	100

GREER COUNTY.

The gypsums of the southwestern area are well exposed in

[87] Gould, Chas. N., Bull. Okla. Geol. Survey No. 5, 1911, p. 103.

the extreme northwestern part of Greer County along Elm Fork and its tributaries. All five ledges are usually present and they outcrop on bold bluffs which are usually capped by a thick ledge of dolomite. On the north side of Elm Fork the gypsums become noticeable in the vicinity of Haystack Butte in sec. 14, T. 7 N., R. 23 W. This butte is an outlier of a pronounced range of hills to the west. The butte and hills are capped by the Haystack gypsum which is ten to twenty feet thick. The Kiser gypsum outcrops twenty feet lower on the slope and is three to four feet thick. The Chaney gypsum does not appear to be present. From Haystack Butte the bluff extends westward up Elm Fork. All the streams flowing into the river from the north have cut canyons into the gypsums and indent the line of bluffs deeply. At the mouth of Hackberry Creek the following section was measured.

Section on Elm Fork at mouth of Hackberry Creek.

		Feet.
12.	Hard cap rock, dolomite	3
11.	Red clay	20
10.	Massive, white gypsum (Collingsworth)	18
9.	Red and blue clay	8
8.	Massive, white gypsum (Cedar Top)	20
7.	Red and blue clay	5
6.	White gypsum separated into thin beds by sandy dolomite (Haystack)	18
5.	Red and blue clay	12
4.	Bluish, stratified gypsum (Kiser)	4
3.	Red and blue clay	15
2.	White and bluish gypsum (Chaney)	4
1.	Red and blue clay	8

The gypsum bluffs continue up Elm Fork into Collingsworth County, Texas, and back on the south side almost to Mangum.

Along South Fork of Red River there are prominent gypsum bluffs on the south side of the river at Mangum. These extend up and down the river for some distance but are not so pronounced, especially to the west. The stratigraphy is given in the section taken in Jackson County at the junction of Horse Branch and Salt Fork.

Availibility of the Gypsums.—The gypsum deposits at Mangum are about a mile distant from the Wichita Falls & Northwstern and the Chicago, Rock Island and Pacific railways but are on the opposite side of Salt Fork. The expense of bridging the stream would be quite heavy. The amount of stripping increases very rapidly back from the outcrop and quickly reaches a prohibitive thickness. In view of these conditions it does not seem probable that these beds will be developed in the near future.

The deposits along Elm Fork in the neighborhood of Haystack Butte can be reached by four to six miles of spur track from the Wichita Falls & Northwestern Railway near Willow. The greater part of this distance would be over fairly level ground and the expense of building the switch would not be prohibitive under some conditions. In the present state of the plaster industry in Oklahoma, however, and in view of the immense undeveloped deposits with transportation facilities immediately at hand, it seems improbable that such a project should be undertaken. The deposits farther west along Elm Fork are so far from railroads as to render them unavailable at present.

Gypsite beds.—A large gypsite bed has been reported from secs. 26, 27, 34, and 35, T. 7 N., R. 23 W., two miles west of Haystack Butte. The bed covers about 300 acres and is exposed from four to fourteen feet thick. Reports give the maximum thickness as thirty feet. The stripping varies from nothing to six feet. In character the material is light gray in color and is apparently quite sandy. In one locality, about one-fourth mile north of the section corner near the center of the bed, there are indications that the bed is not true gypsite but rather a very fine-grained, soft, gypsiferous, and argillaceous sand such as is often found in lentils in the Redbeds. In the locality mentioned it is overlain by red clay which has all the appearance of Redbeds shale in place. It is reported that the material has been tested and that it makes a good grade of plaster but neither the name of the parties having the tests made nor the reports of the test are available. If the material is suitable for plaster there is a vast amount of it available under favorable conditions, except in regard to transportation. The bed is about four miles from the railroad. A spur built to the gypsum deposits near Haystack Butte could pass through the bed with little or no extra expense.

HARMON COUNTY.

All of Harmon County is underlain by the Greer formation but only in the extreme northern part are there good exposures of the gypsums. These exposures are on the bluffs of Elm Fork in T. 6 N., R. 26 W., and are the continuation of the bluffs in Greer County, which have been described. The following section was taken on the bluffs of Elm Fork in the northern part of sec. 10.

Section of Bluff on Elm Fork in sec. 10, *T.* 6 *N., R.* 26 *W.*

		Feet.
12.	Dolomite	1-3
11.	Red clay	16
10.	Gypsum (Collingsworth)	14
9.	Red and blue clay	6
8.	Gypsum (Cedar Top)	16
7.	Red and blue clay	5
6.	Gypsum (Kiser)	20
5.	Red and blue clay	15
4.	Gypsum (Chaney)	2
3.	Red Clay	12
2.	Gypsum	3
1.	Gypsiferous, red, and blue clay (about)	60

The clays, especially the lower ones, are filled with selenite crystals and satin spar. At the bluff east of the Salt Plain in sec. 11, the thin lower ledges were not observed. The lowest heavy gypsum occurs about 90 feet above the level of the Salt Plain, is about 15 feet thick, and seems to be anhydritic. The second heavy gypsum is 20 feet thick and is separated from the lower by seven feet of red clay shale. A view of this bluff is shown in figure 61, and a view of the canyon and salt plain in figure 67 in the following chapter of this report. These gypsums are too far from a railroad to be available but other conditions for development are favorable.

The greater part of Harmon County is level and there are few good exposures of gypsum south of Elm Fork. The pres-

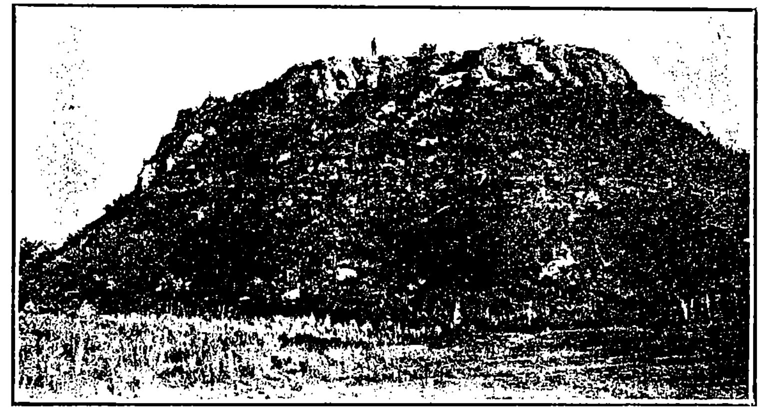


Fig. 61.—Bluff east of salt plain in sec. 11, T 6 N., R. 26 W.

ence of gypsum is shown by sinkholes and by well logs. Practically nothing can be told of the stratigraphy of the gypsums from the meager data at hand. A few small exposures are shown along Salt Fork of Red River, but none were observed which could be said to be of commercial importance. In a large area around Hollis there are practically no exposures. Gypsum is reported from wells. Some bowlders of gypsum were removed from the shallow cuts of the Wichita Falls & Northwestern Railway just east of Hollis, but if they represent a solid ledge most of it has been removed by solution. In some of these cuts the Redbeds appear to be folded into rather sharp folds. This folding is presumably due to the solution of the underlying gypsum beds. At Gould there is an area of bad lands with some channels 20 to 30 feet deep. These show considerable selenite in clay but no available gypsum. Very little can be determined as to the amount of gypsum present in the southern part of the county and practically nothing as to the stratigraphy of the beds. They are presumably at about the same horizon as the well defined ledges in Beckham, Greer, and the northern part of Harmon County. From the stratigraphy along Salt Fork of Red River near Mangum, a region which in a measure connects the northern and southern portions of the area Gould believes that the gypsum of the southern part are at a slightly lower level than those in the northern part.

Availibility of the gypsums.—Gould estimates the amount of available gypsum in Harmon County, *i. e.*, the amount present at less than 100 feet in depth, at 15,000,000,000 tons. However, the gypsum in the northern part of the county is so far removed from transportation that it can not be utilized at present. It is difficult to make any definite statement concerning the deposits of the greater portion of the county, but judging from surface appearances along the only line of railway, the Wichita Falls & Northwestern branch from Altus to Wellington, Texas, the beds are so deeply buried that their utilization seems impossible. There is certainly little promise of development of such deposits while so many large deposits, with more favorable conditions as regards quarrying or mining, and with as good or better location in regard to fuel and transportation, remain undeveloped.

Gypsite beds.—Little search has been made for gypsite in the county and only a few small beds are known. A bed covering 10 to 15 acres and varying in thickness from three to six feet is reported in the NW. ¼, sec. 1 ,T. 2 N., R. 25 W., and adjoining parts of the sections to the north and west. This bed is less than one mile from the railroad. A bed of about 10 acres in area and three to six feet in thickness lies in sec. 6, T. 1 N., R. 24 W.

JACKSON COUNTY.

The Greer formation underlies the western half of Jackson County. The gypsums are more prominent than those in southern Harmon County but much less so than those of northern Greer and Harmon counties. The stratigraphy is usually irregular. The best exposures are on Horse Branch and Boggy Creek.

Gould gives the following sections showing the stratigraphy in the south-central part of the county:

Section of bluff between Salt Fork and Horse Branch near Olustee.

		Feet.
12.	Hard rock, dolomite, forming the cap of the hill	3
11.	Red and blue clay	12
10.	Massive, white gypsum	8
9.	Red clay with ledges of gypsum	24
8.	Massive, white gypsum	12
7.	Red and blue clay	15
6.	Red and blue soft, shaley rock and gypsum	5
5.	Red and blue shaley clay	22
4.	Bluish gypsiferous rock	10
3.	Red and blue clay	8
2.	Massive, white gypsum	3
1.	Red clay slope from Horse Branch	100

Section on Boggy Creek nine miles northeast of Eldorado.

8.	Hard, massive rock, dolomite, forming the cap of the bluffs	5
7.	Red and green shale and clay	30
6.	Massive gypsum	10
5.	Red clay	5
4.	Clay and hard rock	5
3.	Massive white gypsum	15
2.	Red and blue clay	25
1.	Hard, massive gypsum exposed in creek bed	15

In the hill just west of Creta on the St. Louis & San Francisco Railroad, two massive ledges of white gypsum are exposed. The lower is about 15 feet thick and the upper about 12 feet. The upper ledge is covered by about 30 feet of red shale and 6 to 20 feet of dolomite. The slope of the hill is so steep that comparatively little of the gypsum can be obtained without excessive stripping so that mining methods would be necessary. This in itself would not be sufficiently expensive to be prohibitive but, in view of the general conditions of the gypsum industry in Oklahoma, mining methods cannot be considered as feasible at present. Some outcrops of gypsum are known to the west of those described but they are generally small and unimportant.

Availability of the gypsums.—The principal exposures of rock gypsum in Jackson County can be easily reached from the St. Louis & San Francisco Railroad. The main hindrance to their development is the thick cover due to the Mangum dolomite capping the hills and preventing the erosion of the shale from above the gypsum. Mining methods would be necessary to utilize the gypsum, and as has been said, these methods would be too expensive to be feasible at present.

Gypsite beds.—The gypsite beds of Jackson County are

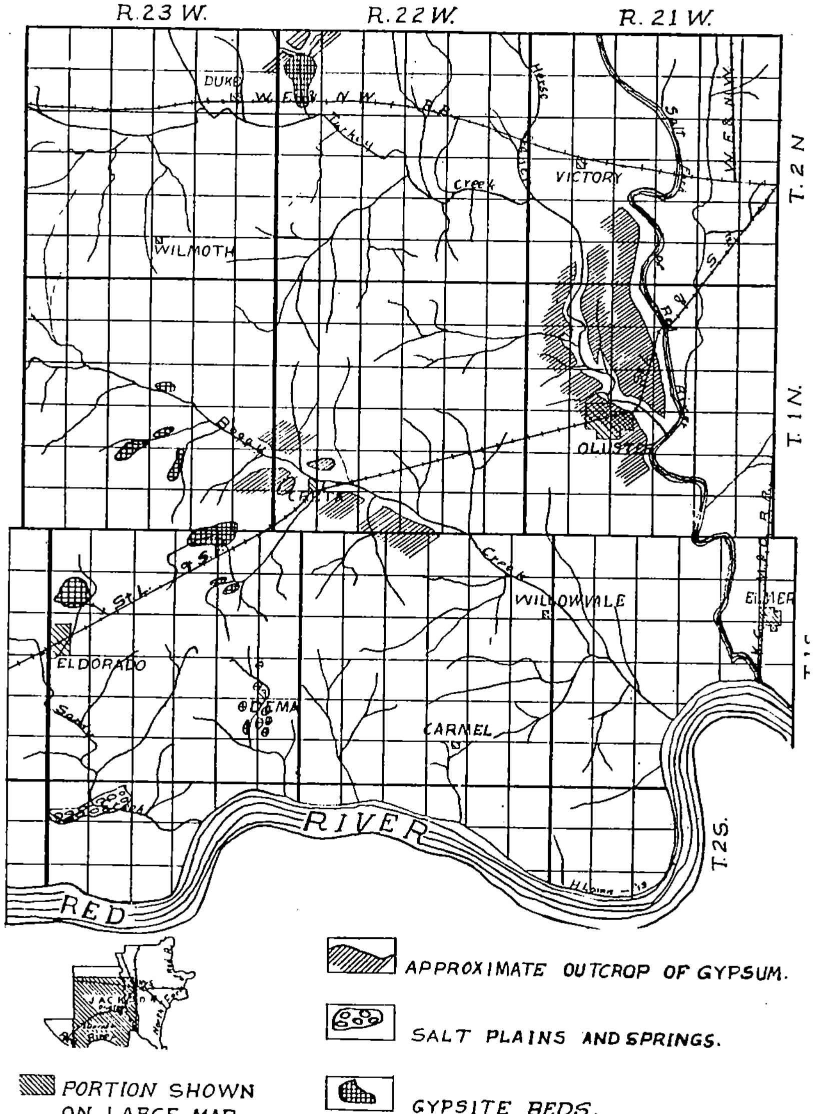


Fig. 62.—Map of portion of Jackson County showing location of gypsite beds and salt plains.

among the most important in the State. They are of large extent and are well situated in regard to transportation. The location of the principal beds is shown on the accompanying map (fig. 62). The largest bed known in the county covers about 400 acres in sec. 7, T. 1 S., R. 23 W., just north of the town of Eldorado. The thickness of the gypsite varies from 8 to 20 feet with little or no stripping. The Eldorado plant of the United States Gypsum Company is situated at the bed and is reached by a spur from the St. Louis & San Francisco Railroad. The company owns this bed and also controls a bed in secs. 2 and 3 of the same township. This bed covers about 140 acres and is 6 to 12 feet thick. The railroad passes near the east end of the bed. Two smaller beds lie in secs. 10 and 11. Together they cover 40 to 50 acres and are 6 to 12 feet thick. Smaller beds lie in secs. 24 and 25.

In the townships to the north there are seven or eight small beds in secs. 21, 22, and 27. The aggregate area is about 40 acres and the depth of the deposits varies from four to eight feet. The beds are between two and three miles from the railroad.

A gypsite bed of approximately 375 acres lies in secs. 6 and 7, T. 2 N., R. 22 W., one mile east of Duke. The Altus and Wellington branch of the Wichita Falls & Northwestern Railway crosses the southern part of the deposit. A creek flows from north to south and through the deposit and exposes rock gypsum of about six feet in thickness along its banks for the greater part of the length of the bed. A lower ledge of gypsum is separated from the one best exposed by a few feet of red shale. The thickness of the lower bed could not be accurately determined. The gypsite is six to eight feet in thickness and has up to two feet cover. Over considerable areas the gypsite lies at the surface. The gypsite is light gray near the surface but grades into pink and reddish-brown in the lower parts of the bed.

CHAPTER VI.

THE SALT PLAINS OF OKLAHOMA.

INTRODUCTION.

Salt is closely associated with gypsum in origin and occurrence and as these points have been rather fully discussed in Chapter I they need not be noticed further here. Salt may be mined from beds of rock salt or may be obtained from brine by evaporation. The processes used in evaporation vary greatly with conditions, but, in view of the present condition of the salt industry of this State, it is not thought worth while to go into a discussion of these features.

Wells and springs of salt water occur in all parts of Oklahoma. Salt water is often encountered by deep borings in different parts of the State. This is especially true in the oil and gas fields. So far however, no investigations have been made as to whether the brines from these deep wells are sufficiently concentrated to be used in the manufacture of salt. In only one place, to the writer's knowledge, has salt been manufactured in the eastern part of the State, viz: at the flowing salt well on Grand River southeast of Choteau in Mayes County.

All that is attempted in this chapter is to give a brief description of the salt plains which occur in the western part of the State in the region of the gypsum hills, and to give brief statements in regard to the conditions of and prospects for development of these plains. The plains described are as follows: a plain east of Cherokee in Alfalfa County, two plains on Cimarron River in Woods, Harper, and Woodward counties, a plain on Salt Creek west of Ferguson in Blaine County, a plain on North Fork of Red River south of Carter in Beckham County, two plains on Elm Fork of Red River in northern Harmon County, and three plains on Sandy Creek south of Eldorado in Jackson County.

ALFALFA COUNTY SALT PLAIN.

The Alfalfa County salt plain lies south of Salt Fork of Arkansas River principally in Tps. 26 and 27 N., R. 10 E., about four miles east of Cherokee. The plain is elliptical in shape with the long axis in a north and south direction. It covers approximately 60 square miles. The surface of the plain is almost perfectly flat, and, except for a few hammocky grassy mounds near the edge, is entirely devoid of vegetation. The surrounding country is somewhat higher than the level of the plain, but the difference in elevation seldom exceeds 20 feet and is usually considerably less than that. The material composing the floor of the plain is silt and a very fine sand. The surface of the entire plain is usually covered with a thin crust of salt crystals which glisten in the sunlight. This crust is dissolved by rain and when the surface of the plain is wet it appears as an ordinary level strip of ground. There are no salt springs on the plain or around its margin and no streams flow across it in ordinary weather. When a hole is dug into the sand and silt, salt water rises until the hole is filled to within about six inches of the top. This brine is quite strong, nearly if not quite saturated. The analysis[88] of the material dissolved in it is as follows:

Analysis of water from salt plain at Cherokee.
In parts per million.

Soda (Na_2O)	150,013
Potash (K_2O)	205
Lime (CaO)	1.524
Magnesia (MgO)	1.739
Chlorine (Cl)	152,100
Sulphates	362
Sodium bicarbonate ($NaHCO_3$)	6,235
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3)	36

This shows a total of 250,779 parts of sodium chloride per million, or approximately 25 per cent of salt as it is probably combined. The amounts of impurities present does not appear great enough to interfere with the recovery of the salt on a commercial scale.

[88]All analyses are by Frank Buttram, Chemist Oklahoma Geological Survey.

Origin of the salt.—The source of the salt of the Alfalfa County plain is not easily seen. It is generally supposed by those living in the vicinity that a bed of rock salt underlies the plain but there is no evidence to support this idea. Saltwater is encountered in wells around the margin of the plain at depths of 20 to 30 feet but to the writer's knowledge no beds of rock salt have been found. It seems probable that the salt water is derived from springs from the Redbeds which have their outlets below the sand and silt of the plain. The flow from the springs and the conditions of drainage into Salt Fork must be such as to raise the level of the salt water to within a few inches of the surface of the plain but not to cause springs to break out through the sand and silt. The water probably obtains its salt from saliferous layers in the Redbeds.

Conditions for development.—No salt has so far been manufactured from this plain. However, the conditions are such as to render its development probable at any time. The western margin of the plain is only four miles from the Kansas City, Mexico & Orient Railroad and the Atchison, Topeka & Santa Fe Railway at Cherokee, and the southern margin is less than that distance from the latter railway west of Jet. The country between the railways and the plain is very level and spurs could be easily constructed. It is impossible to estimate the amount of salt available on the plain. When holes are dug in the plain they fill up very rapidly but no pumping tests have been made to determine whether or not the level of the water can be easily lowered. When the area of the plain is taken into consideration, however, it seems evident that the supply of salt water is sufficient for a very large production of salt even when all adverse conditions are taken into account. The water would have to be obtained from wells sunk in the plain. The soft, caving nature of the sand and silt would make it necessary for these wells to be walled up in some way. The silt remains in suspension in the water for a considerable time and settling basins would probably have to be provided for the water as pumped from the wells. These conditions would probably put some difficulties in the way of the utilization of the brine but they could certainly be easily overcome if development on a large scale should be undertaken.

SALT PLAINS ON CIMARRON.

The two salt plains on the Cimarron in Oklahoma are known

as Little and Big Salt Plains. Little Salt Plain lies just south of the Kansas line between Harper and Woods counties. Big Salt Plain lies 15 to 20 miles farther down the river between Harper and Woodward counties on the southwest and Woods County on the northwest. These plains were visited by the writer in the fall of 1912 but he has nothing to add to the description given by Gould[80] which is:

"Perhaps the most noted of the salt plains, from the standpoint of a historian, is the Big Salt plain of the Cimarron. The first white man to visit this place was probably Coronado, in his journey across the plains in search of the seven cities of Cibola. In regard to this event Mr. J. R. Mead says: 'The route or trail of Coronado, in his famous expedition from the Pueblos of New Mexico across the prairies of Kansas to the populous tribes of the Missouri, will ever remain an open question. The only point we can locate with reasonable certainty is the salt plain of the Cimarron, just within the Kansas line—the only place where rock salt can be obtained on the surface in all the plains country. This salt was known and used by the Indians, and was an article of trade from the Gulf to the British line, and this locality was a well-known geographical point, from which distances were reckoned.' The presence of a dozen or more trails, now nearly obsolete, radiating from the plain like spokes of a wheel, bears testimony to the fact that this place was long used as a source of supply of salt to the various forts and settlements of the surrounding regions. Indeed, it is but a few years since salt from this plain was hauled for hundreds of miles in all directions, and not until the time of discovery of extensive beds in central Kansas did this industry wane.

"The Big Salt plain proper extends for eight miles or more along the Cimarron river. In width it varies from half a mile to two miles. On the south bank the bluffs of red shale and sandstone capped with gypsum rise directly from the edge of the plain to the height of 100 feet or more. North of the plain these bluffs are not so steep, and are at a distance of a half mile or more from the plain. Even here, however, the sinuous white line of gypsum may be traced along the tops of the bluffs as far as the eye can reach. In other words, the plain lies in the broad

[80]Gould, Chas. N., The Oklahoma Salt Plains: Kans. Acad. Sci., vol. 17, 1901, pp. 182-183.

canyon of the Cimarron, enclosed on both sides by gypsum-capped bluffs of red shale.

"The plain is flat and as level as a floor, except for a few meandering channels which, in wet weather, contain a small stream, but are ordinarily dry. After a rain it will sometimes happen that a stream of considerable volume flows over the plain, but during the summer months nearly all the water either evaporates or sinks into the sand. In places where a small stream still runs down the channel the water is often so salty that a thin crust of crystal white salt forms on the surface, resembling nothing so much as a sheet of ice across a small stream in winter. The entire plain is covered with a thin incrustation of snow white crystals. In most places this incrustation is not to exceed an eighth of an inch thick, but it reflects the sunlight and blinds the eye like a snowfield. Especially if the wind is blowing the small particles of salt, a walk across the plain makes the eyes smart and burn in a manner not easily forgotten.

"In a large cove on the south side of the plains proper, there are a number of salt springs which boil up out of the flat surface of the plain. The water is crystal clear, and it sometimes requires more than ocular proof to convince one that it contains nearly fifty per cent of salt. There are scores, perhaps hundreds, of these springs on an area of a few acres in extent. Some of them flow streams as large as a man's arm; others are much weaker. In all cases their presence is marked by a conspicuous white incrustation of salt, which forms around the spring and along the sides of the little stream that flows from it. Particles of grass or weeds blown into these springs or streams soon become covered with white salt crystals. These strings of crystals are often an inch or more in diameter and look like rock candy. In places the incrustation around the springs are so thick that the salt may be scraped up and hauled away. This is the source of the so-called rock salt of the plain.

"The Little Salt Plain is located a few miles further up the Cimarron, just on the border of Kansas. It does not differ materially from the plain just described, except that it is much smaller and the bluffs on either side of the river are neither so high nor precipitous."

Two views of Big Salt Plain are given in figures 63 and 64.

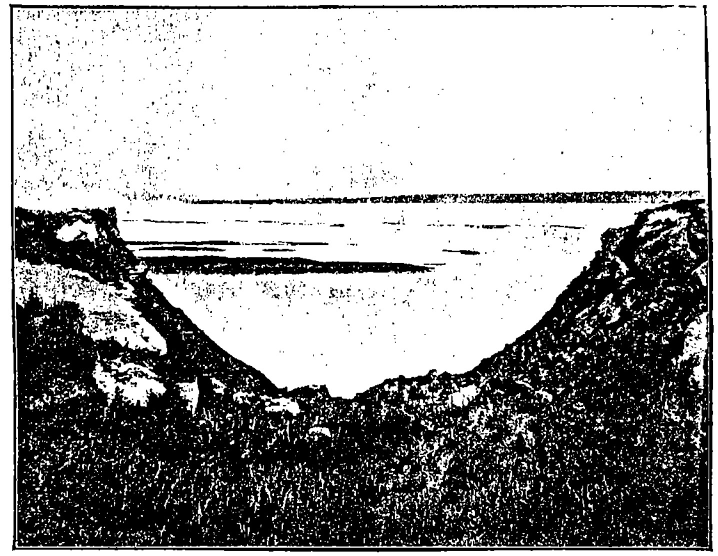


Fig. 63.—View of Big Salt Plain on Cimarron River.

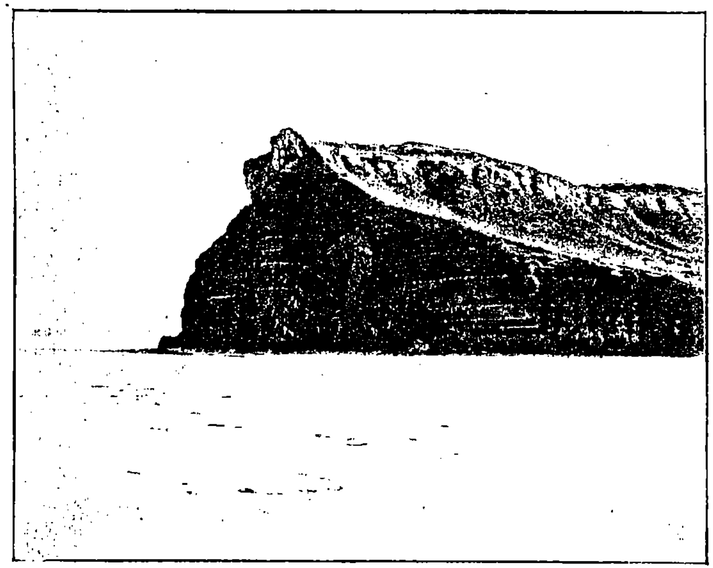


Fig. 64.—Gypsum capped bluff at edge of Big Salt Plain.

The crust of salt near the springs near the southwestern corner of the Big Salt Plain was about six inches thick at the time of the writer's visit and is reported to reach a thickness of one foot during long continued dry spells. A view of a small area where the crust is between one and two inches thick is shown in figure 65.

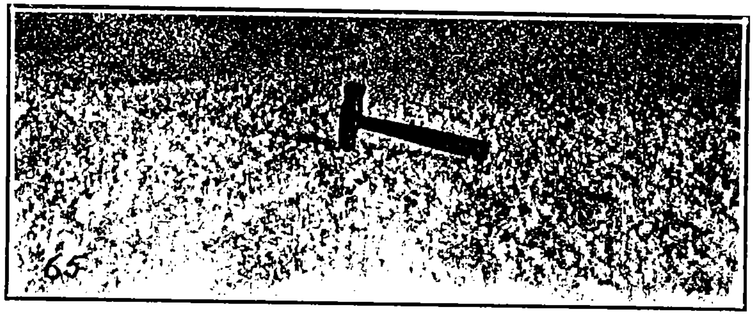


Fig. 65.—Salt crysals on surface of Big Salt Plain.

Prospects for development.—The amount of saturated brine going to waste on these two salt plains is very difficult to estimate but is undoubtedly very large. One of the largest springs on Big Salt Plain forms a stream over a foot broad and three inches deep. There are many other springs and besides a very large amount of water probably works out through the sand. The brine is practically saturated as is shown by the formation of the thick crusts of salt over the streams from the springs, and by the formation of crystals on leaves, weeds, and grass which are blown into pools of water. The crystals formed are cubical and appear to be of pure salt. The water from the larger springs is perfectly clear and would not require settling before evaporation. The conditions at the plains themselves, then, seem to be entirely favorable for the development of a considerable industry but the plains are so far removed from railway transportation that there can be no development on a large scale under present conditions. The nearest railroad is about 25 miles from Big Salt Plain and this distance is prohibitive.

In the early days of Oklahoma Territory salt from this plain supplied the local demand for miles around and there was quite a thriving industry on a small scale. However, when the railroads were built through the territory it became possible to obtain the imported salt in most of the region formerly supplied from the Salt Plains more cheaply than it could be hauled from the plain. The market was thus greatly restricted while the plains were still left so far from the railroads as to render them incapable of development. The amount of salt manufactured at the plains in the past few years has been almost negligible and there is no prospect of improved conditions until a railroad is built near the plains.

BLAINE COUNTY SALT PLAIN.

Blaine County Salt Plain lies near the head of Salt Creek about four miles west of Ferguson. These springs issue from a red and blue mottled cross-bedded sandstone which outcrops about 100 feet below the Ferguson gypsum. The upper or western part of the plain is in two narrow canyons in the gypsum hills. In this part of the plain there is little sand in the beds of the streams and the water flows for the most part on the red and green shales and the sandstones. One canyon extends east and the other joins it from the north. Below the junction of the two branches the stream flows east, in a canyon so narrow that the salt plain is not over 100 yards wide for some distance but gradually widening as it leaves the gypsum hills until the salt plain is one-fourth mile wide. After the canyon begins to widen, the floor is covered with sand to a depth of several feet. About two miles below the springs other streams join the main creek and the water is so diluted that the salt is not formed on the surface of the sand. The crust of salt formed over the plain itself is much thinner than that formed on the Big Salt Plain. It seldom exceeds one-half inch in thickness and is usually much less than that.

Three samples of the salt water were collected, one each from the north and the west canyons and one from the stream below the junction of the two small streams. The three analyses agree prettly closely, as will be seen from the following table:

Analyses of water from Salt Creek four miles west of Ferguson. In parts per million.

A. Water from stream in west canyon.
B. Water from stream in north canyon.
C. Water from below junction of the two streams.

	A	B	C
Soda (Na_2O)	146,273	121,715	140,056
Potash (K_2O)	251	328	297
Lime (CaO)	3,516	3,280	3,588
Magnesia (MgO)	1,532	1,097	1,427
Chlorine (Cl)	150,400	123,600	143,200
Sulphate (SO_4)	3,768	5,043	4,356
Sodium bicarbonate ($NaHCO_3$)	84	101	100
Iron and aluminum oxide (Fe_2O_3 and Al_2O_3)	176	24	28

Prospects for development.—Blaine County Salt Plain furnishes enough brine to make a large amount of salt. From some approximate measurements it is estimated that enough water could be obtained just below the junction of the two canyons to supply a plant having a capacity of eight to ten carloads per 24 hours. These figures do not take account of the water in the sand at the location where the measurements were made. The water could be obtained by leading it from the streams through sluices to tanks or by pumping from wells in the sand. The plant could be located at Ferguson on the Chicago, Rock Island & Pacific, about three miles from the lower part of the plain or a spur could be easily built up Salt Creek to a plant located at the plain.

From the standpoint of economic importance, Blaine County Plain bids fair to exceed all others in the State, as it is nearer both to the coal fields and to market than the others. A number of primitive salt plants have at different times been located along the edge of the plain. The methods employed in securing the salt are extremely simple. A well is dug in the sand of the plain and the water pumped by hand into vats and evaporated by boiling. Fuel, chiefly cedar and oak wood, was formerly obtained from the canyons near by. It is stated that three buckets of brine will make one bucket of salt. The capacity of one of the plants is said to have been from 500 to 2,000 pounds per day. The salt was hauled in wagons to supply local trade, and the demand is said to have exceeded the supply for a number of years.

A few years ago a plant with a capacity of 450 barrels per 24 hours was erected at Ferguson, the nearest railroad point to the plain. The brine was obtained from open and drilled wells and was carried two miles in a 2½-inch wrought iron pipe. Steam was employed to operate the rakes, elevators, conveyors,

etc. The pans were of cement 12 by 50 feet and 20 inches deep. The plant remained in operation but a few months, when it was purchased by one of the large salt companies and shut down. It has since been dismantled.

BECKHAM COUNTY SALT PLAIN.

This plain was not visited by the writer so Gould's[90] brief description is given:

"In the southeast corner of Beckham County, near Carter, on sections 10, 11, 14, 15, Township 8 North, Range 22 West, is a salt plain occupying an area of about 40 acres. This plain, which is about half a mile distant from the North Fork of Red River, is located near the base of the Gypsum Hills. In places, springs of salt water issue directly from beneath gypsum ledges, while in other instances the water boils up in the form of bold springs from the level surface of the plain. There are more than 20 springs, the waters of which unite to form a stream as large as a stove pipe. In view of the fact, however, that a great part of the water sinks into the sand, it is probable that this amount represents but a small part of the actual flow. Salt has been manufactured at this plain at various times."

This plain is now near transportation, as the Wichita Falls & Northwestern Railway passes within less than a mile of the plain about three miles south of Carter. A view of a spring issuing from beneath a gypsum ledge is shown in figure 66.

HARMON COUNTY SALT PLAINS.

Harmon County salt plains are situated on the south side of Elm Fork of Red River in secs. 4 and 11, T. 6 N., R. 26 W. The salt springs boil up from the floor of the plains, a short distance back from the river. On the plain in sec. 4 there are several springs whose waters vary from fresh to saturated brine. The few springs on the plain on sec. 11 have a flow of almost concentrated brine. The area of the plain in sec. 4 is about three acres and that of the plain in sec. 11, about one acre. The plains are in narrow canyons between hills formed by the Greer gypsums. Salt has been manufactured at both of these plains for several years. Formerly the timber which grew in the can-

[90]Gould, Chas. N., Salt: Bull. Okla. Geol. Survey No. 6, 1910, p. 71.

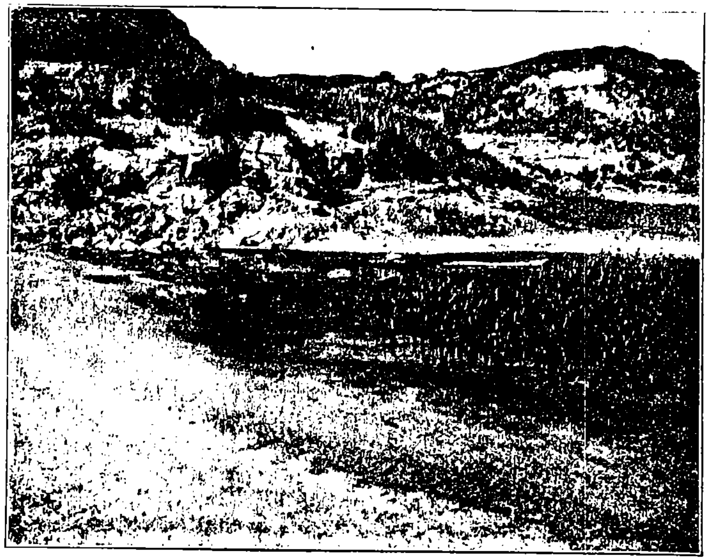


Fig. 66.—Salt Spring issuing from beneath gypsum ledge, Beckham County.

yons was used as fuel but this has been exhausted and solar evaporation has been used for sometime. The water is led from the springs into large tanks or ponds on the floor of the plain. These are built of slabs of rock. The water is fed into the tanks as desired and as it evaporates a crust of salt forms on the surface which settles to the bottom forming a hard crystalline layer of salt. This layer is broken up with picks and the salt shoveled or raked into piles at the edge of the tanks. A view of the plain in sec. 11, showing the tanks and piles of salt is shown in figure 67. A sample of salt taken from the piles analyzed 99.15 per cent sodium chloride. The principal impurities are sodium and calcium sulphates, and iron and aluminum oxides which probably are in the form of dust which is blown onto the piles. Only a very small portion of the available brine is utilized at either plain.

For several years these plains supplied the market for a large territory but the building of railroads has lessened the area in which the salt can compete with the imported product, with-

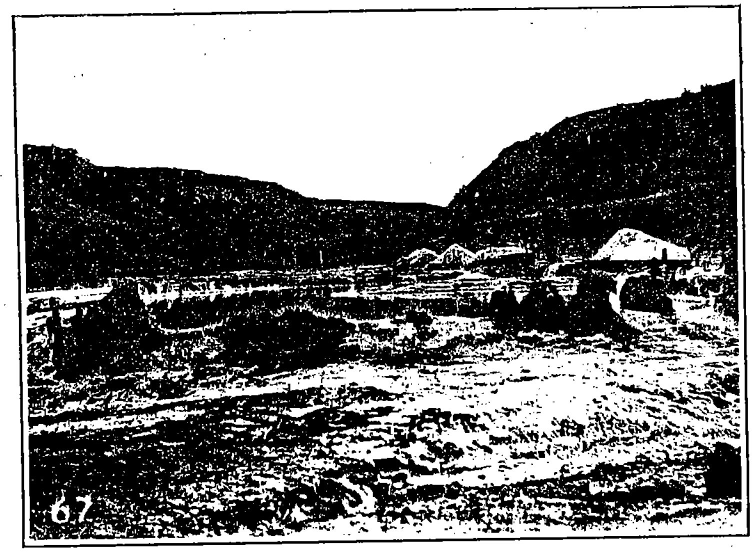


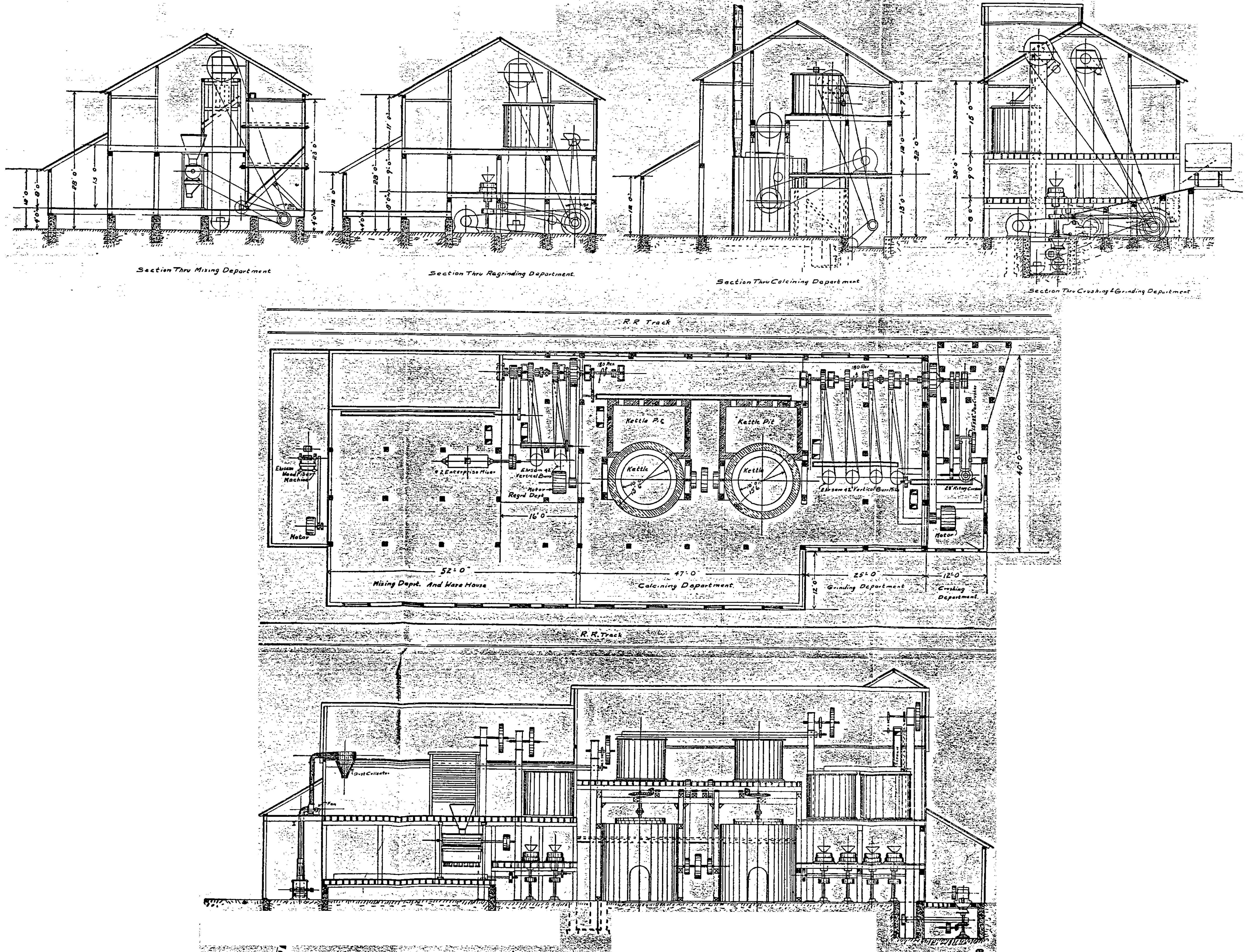
Fig. 67.—View of salt plain in Harmon County.

out making the plains themselves accessible to transportation. In times past the production from the two plains reached as much as 600 tons per year but of recent years the output has been much less. There is no prospect of any marked increase in production unless a railroad should be built near the plains.

JACKSON COUNTY SALT PLAINS.

The salt plains of Jackson County are three in number and they lie close together on the west side of Sandy Creek about three miles from its mouth and about the same distance south of Eldorado. The northern plain lies in the E. ½ sec. 31, T. 2 S., R. 23 W., the middle one in the NE. ¼ sec. 5, T. 3 S., R. 23 W., and the southern plain in the NW. ¼ sec. 5 of the same township and range. All three plains are on small tributaries which flow northeast into Sandy Creek. The northern and southern plains are each about 100 yards wide and 400 yards long, while the middle plain is only 40 yards wide but is about one-fourth mile long. The water comes from numerous springs which boil up from the sand along the streams. The sandy floor of the plains is covered by a thin incrustation of salt. The crust of salt is very thin and the water does not seem to be nearly saturated. Minnows were observed in the small streams swimming up almost to the springs. The water has a very strong taste but is bitter rather than salt.

Some of the incrustation was scooped up with the sand and leached out with water in laboratory. The analysis of the soluble salts show that there is much more sodium sulphate than sodium chloride present and that the potassium sulphate is also high. In the incrustation from the middle plain the proportion of sodium chloride is greater but there is sufficient sodium and potassium sulphates to make the commercial recovery of the common salt questionable. It is possible that the potassium sulphate from the middle plain might be utilized as a by-product. Calcium sulphate is present in greater proportion than it is on any of the other plains investigated.



Section Thru Mixing Department
Section Thru Regrinding Department.
Section Thru Calcining Department
Section Thru Crushing & Grinding Department
R.R. Track
Kettle Pit
Kettle
Motor
Motor Regrd Dept
16'0"
40'0"
52'0"
47'0"
25'0"
12'0"
Mixing Dept. And Ware House
Calcining Department
Grinding Department
Crushing Department
R.R. Track
Dust Collector
Fan

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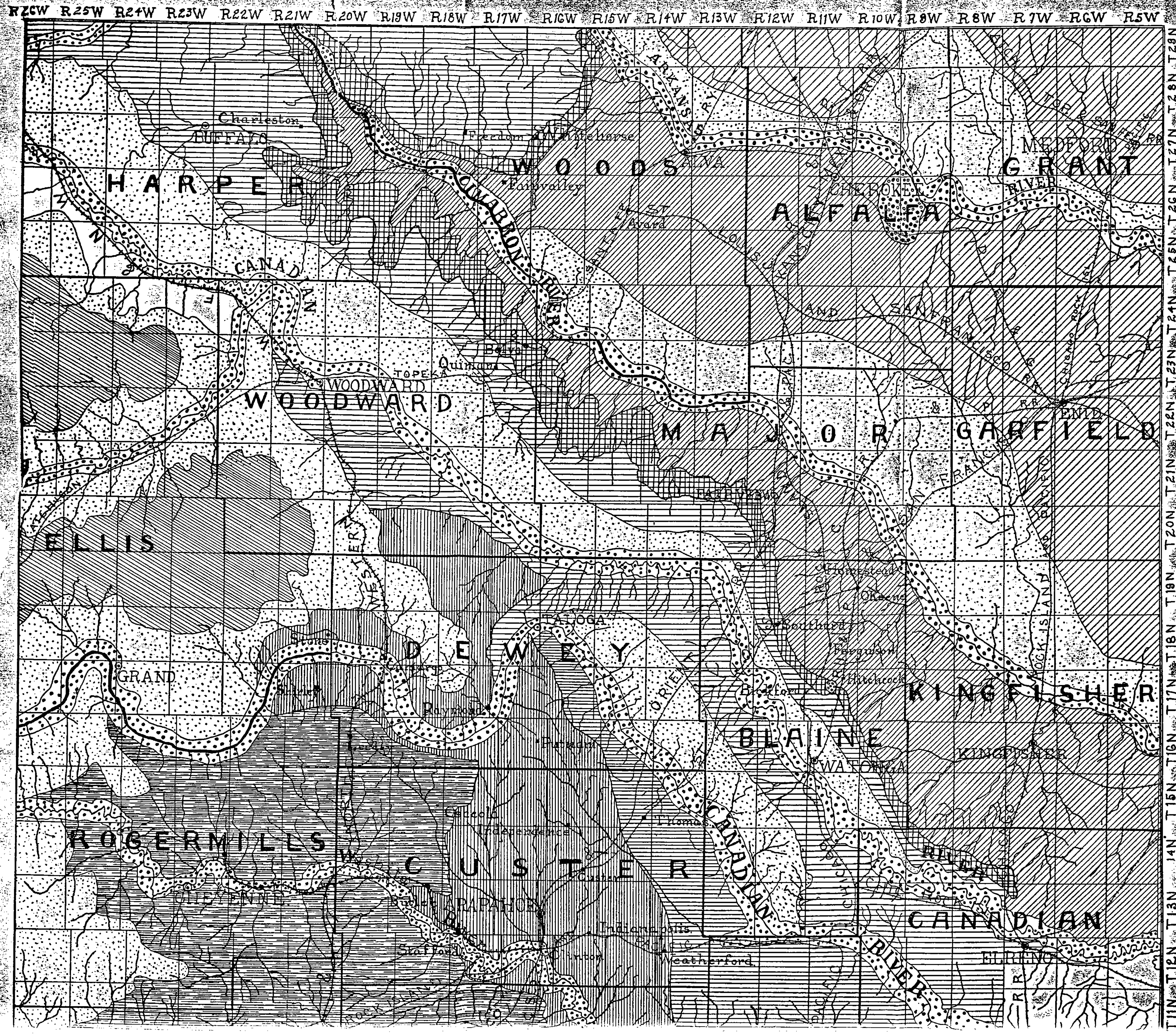
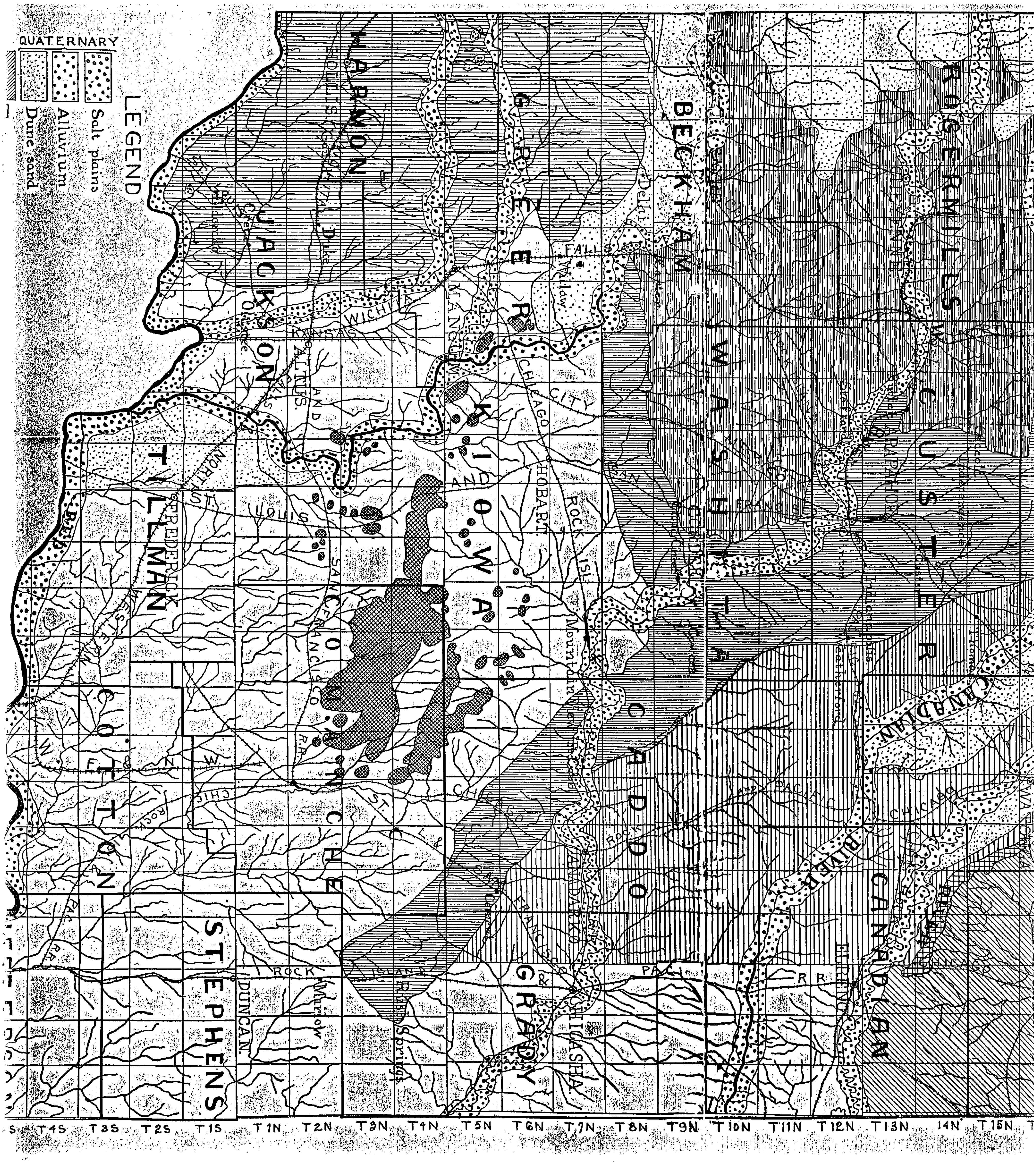


R26W R25W R24W R23W R22W R21W R20W R19W R18W R17W R16W R15W R14W R13W R12W R11W R10W R9W R8W R7W R6W R5W
T28N T27N T26N T25N T24N T23N T22N T21N T20N T19N T18N T17N T16N T15N T14N T13N T12N T11N
HARPER
WOODS
ALFALFA
GRANT
WOODWARD
MAJOR
GARFIELD
ELLIS
DEWEY
BLAINE
KINGFISHER
ROGERMILLS
CUSTER
CANADIAN
Charleston
BUFFALO
Freedom
Whitehorse
Fairvalley
ALVA
CHEROKEE
MEDFORD
Avard
CIMARRON RIVER
CANADIAN
CANADIAN RIVER
RIVER
Quinlan
TOPEKA
WOODWARD
END
GRAND
TALOGA
Homestead
Okeene
Southard
Ferguson
Hitchcock
Bridgeport
WATONGA
KINGFISHER
Thomas
Independence
CHEYENNE
ARAPAHOE
Indianapolis
Weatherford
EL RENO
Stafford



LEGEND
QUATERNARY
Salt plains
Alluvium
Dune sand
HARMON
GREER
BECKHAM
ROGER MILLS
CUSTER
WASHITA
JACKSON
KIOWA
TILLMAN
COMANCHE
CADDO
CANADIAN
COTTON
STEPHENS
GRADY
WICHITA
KANSAS
CITY
FALLS
CHICAGO
ROCK ISL
HOBART
ALTUS
MANGUM
NORTH
FREDERICK
ST. LOUIS
SAN FRANCISCO
PACIFIC
DUNCAN
CHICKASHA
Mountain View
ARAPAHO
Weatherford
CANADIAN
RIVER
RED
ROCK
ISLAND
PAC
RR
T4S
T3S
T2S
T1S
T1N
T2N
T3N
T4N
T5N
T6N
T7N
T8N
T9N
T10N
T11N
T12N
T13N
14N
T15N

A GEOLOGIC MAP
OF THE WESTERN PORTION OF
OKLAHOMA

After Gould, Water-Supply paper U.S.G.S. No 148.
AB.