Gypsum in Kansas

By

ROBERT O. KULSTAD, PAUL FAIRCHILD,
and DUNCAN McGREGOR

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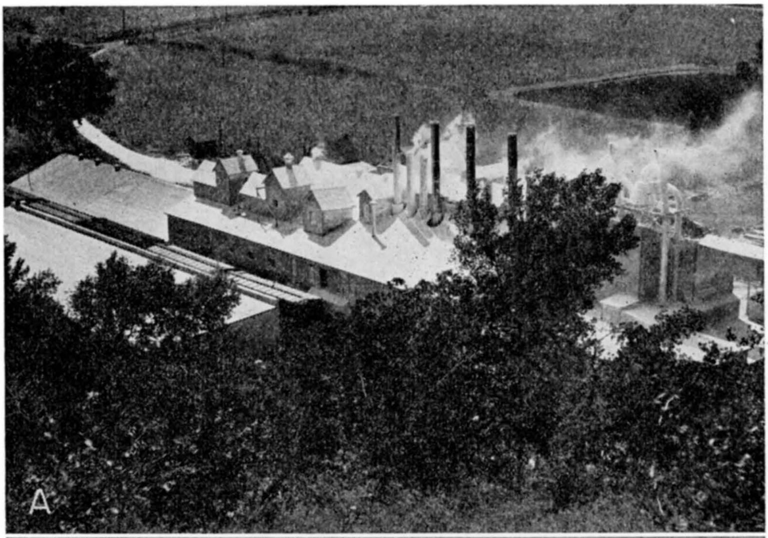

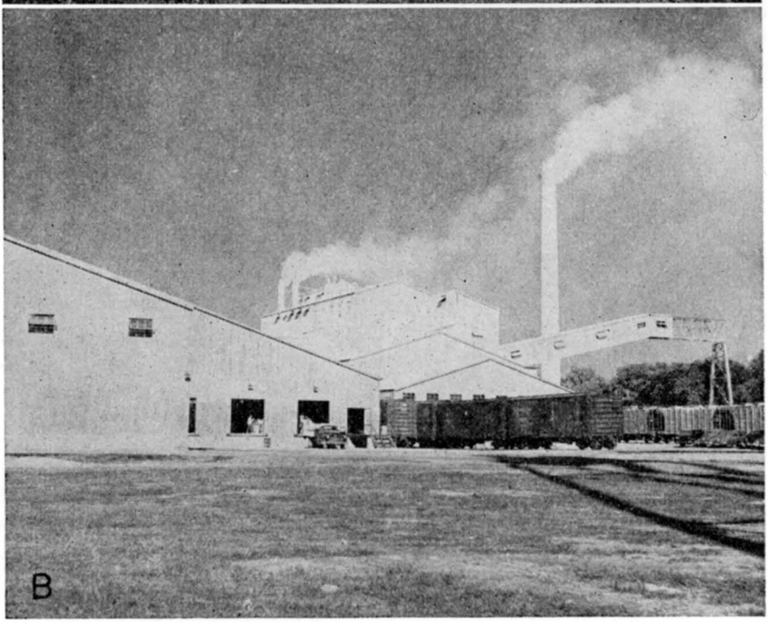

Frontispiece—A. Gypsum processing plant, Certainteed Products Company, Blue Rapids, Kansas. **B.** Gypsum processing plant, National Gypsum Company, Medicine Lodge, Kansas.

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By Robert O. Kulstad, Paul Fairchild,
and Duncan McGregor

ABSTRACT

Calcium sulfate occurs naturally in two forms, gypsum ($CaSO_4 . 2H_2O$) and anhydrite ($CaSO_4$). Additional forms can be obtained by the application of heat to gypsum. The hemihydrate ($CaSO_4 . \frac{1}{2}H_2O$) or "plaster of paris" is the most common of these additional forms. Either gypsum or anhydrite may be deposited from an evaporating body of sea water. Temperature and salinity of water from which the calcium sulfate is depositing are factors that determine which mineral is deposited. Either form may alter to the other, subsequent to deposition.

The known gypsum deposits in Kansas are found in rocks of Permian age. A brief description of Kansas Permian rocks is included in the report.

The gypsum mined near Sun City by the National Gypsum Company is obtained from the Medicine Lodge member, Blaine formation, Nippewalla group, in the upper part of the Kansas Permian section. Gypsum is crushed at the mine and transported by rail 20 miles to the plant at Medicine Lodge for processing. The gypsum beds are found at the surface in much of Barber and Comanche Counties. The Medicine Lodge member consists of gypsum and anhydrite in a single bed, which has a maximum known thickness in Barber County of approximately 30 feet. The anhydrite occurs in lenses in the middle of the bed. Both gypsum and anhydrite are thought to have been formed by original deposition from sea water, although some of the anhydrite has subsequently been hydrated to gypsum.

Gypsum is found in the Wellington formation, which is exposed almost continuously from Nebraska to Oklahoma, but is no longer mined, although several mines operated in the past in the Wellington outcrop area. Wellington gypsum is exposed at few places on the surface, but evidence of gypsum throughout the outcrop area is provided by surface slump structure, old gypsum mines, and subsurface information obtained from oil exploration. The Wellington formation contains a considerable amount of relatively soluble evaporites; consequently its true character is destroyed by weathering. Subsurface information reveals that the Wellington, where undisturbed, contains a salt sequence several hundred feet thick. Directly below the salt is an anhydrite zone 100 to 150 feet thick in the area studied. This anhydrite zone seems to correlate with the gypsum deposits found at or near the surface. Gypsum probably was formed by the hydration of this anhydrite by the action of ground water, although not enough is known about the gypsum deposits to eliminate the possibility that some of them may have been deposited directly as gypsum contemporaneously with the anhydrite.

Gypsum is mined at Blue Rapids by the Certainteed Products Company from the only known deposits of gypsum in the Easly Creek shale, in the Council Grove group of Permian rocks. The company produces gypsum

products in its plant at the mine site. The average thickness of the gypsum bed is between 8 and 9 feet. Petrographic evidence is interpreted as showing that the calcium sulfate was deposited from sea water as gypsum. Some subsequent recrystallization could have resulted from diagenetic processes, some from the action of ground water.

Other gypsum-anhydrite deposits are found in the Day Creek dolomite near the top of the Kansas Permian, in the Stone Corral dolomite of the Sumner group, and in the Oaks shale member of the Hamlin shale of the Admire group.

Most gypsum is calcined for use in the building industry as base coat and finishing plaster or in prefabricated products such as wall board. Calcined gypsum or "plaster of paris" is used also in small amounts as cast plaster, pottery plaster, industrial and molding plaster, dental and orthopedic plaster, and in the manufacturing of plate glass. Raw gypsum is used in the manufacture of portland cement and as fertilizer. Gypsum is also a possible source of sulfur. Gypsum is calcined in kettles or in rotary kilns. Special types of plaster require special handling, and prefabricated gypsum products require special machinery in their manufacture.

INTRODUCTION

Gypsum contributes significantly to our present day economy. Plaster (plaster of paris), one of its processed forms, is used in virtually every modern building to make it more comfortable, more convenient, or more beautiful. Furthermore, some gypsum is contained in most portland cement. Therefore it is a construction material of almost universal use.

In addition to the large quantity of gypsum used for construction material, small amounts are specially processed into orthopedic plaster, pottery molds, statuary, and materials used in such industrial processes as the polishing of plate glass, where a comparatively small amount of gypsum is used but plays an important part in the process.

It would be difficult to do without gypsum. Different substitutes could replace gypsum in several of its uses, but there is no universal substitute and none performs as well nor as economically. On the contrary, the uses of gypsum are increasing, because plaster is easily adapted to prefabrication and is therefore replacing material formerly built in place.

Kansas has large gypsum deposits and well-established gypsum-processing plants. Not only is the quality of the gypsum superior, but the Kansas plants manufacture somewhat specialized products. The growing importance of gypsum consequently makes these deposits and the industry increasingly important.

Previous Work

The one large comprehensive work covering Kansas gypsum deposits exclusively was written by Grimsley and Bailey (1899). It describes in detail the gypsum deposits in Kansas as they were known at that time. Haworth (1902a) wrote a historical report of the gypsum and cement industry in Kansas. Haworth (1898, 1899, 1900, 1902, 1903, and 1904) reported on the annual progress in the gypsum industry and included a description of the industry during the years 1897 to 1903. Much of the geological information that was available at the time that these reports were written is no longer at hand; this report, therefore, draws heavily upon them for some of its information. Haworth (1920) and Moore and Landes (1926) review the report of Grimsley and Bailey (1899).

Scope and Purpose of the Report

The purpose of this investigation is to assemble information that has become available since the previous reports on the Kansas gypsum deposits were published. The industry itself has changed in the intervening years; new methods of investigation have been devised and have yielded new geological information, and study of more gypsum deposits in other areas offers a chance for further comparison with Kansas gypsum deposits.

This report describes all the known gypsum resources of Kansas. The mined deposits receive more attention than the unexploited ones because of the greater amount of information available about them, but an attempt is made to at least mention every known deposit.

The history of the gypsum industry in Kansas is discussed, as well as present-day operation and products. The report includes general descriptions of manufacturing processes, but no detailed description of the Kansas operations. The mineral gypsum, its properties and uses also are discussed.

This report compiles the results of a cooperative project between the State Geological Survey of Kansas and the Department of Geology of the University of Kansas. The early work was done under the supervision of Robert M. Dreyer. The two active mining areas, one at Blue Rapids and one at Sun City, were discussed in theses written for the Department of Geology by Paul Fairchild and Duncan McGregor, respectively. McGregor completed study of the Sun City area in 1947 and prepared the section on Gypsum in the Blaine Formation in this report. Fairchild completed his work on the Blue Rapids area in 1948 and prepared the section on Gypsum in the Easly Creek Shale in this report. Kulstad's work was begun in 1952 and includes study of the Wellington gypsum and mapping of the Blaine formation. Figure 1 shows the location of the areas discussed.

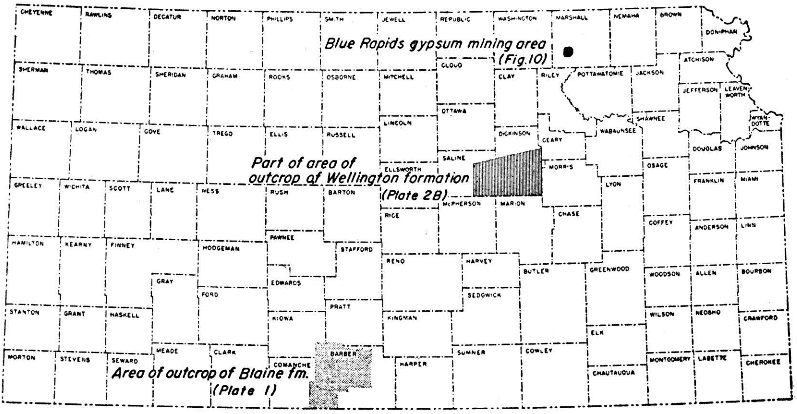


FIG. 1. Index map showing location of areas discussed.

GYPSUM MINING IN THE UNITED STATES

The mineral gypsum is widely distributed in the United States, but the location of mines is influenced by factors other than occurrence of raw material. The areas that consume the most gypsum are the densely populated areas, as gypsum is used chiefly as construction material. Gypsum is mined in Arizona, Arkansas, California, Colorado, Indiana, Iowa, Kansas, Michigan, Montana, Nevada, New York, Ohio, Oklahoma, South Dakota, Texas, Utah, Virginia, and Wyoming. Much gypsum also is imported into the United States, most coming from the Maritime Provinces of Canada.

Table 1 shows the gypsum production in the United States for the year 1952 as reported by North and Jensen (1954). It is presented here to show comparative production figures and prices of the various gypsum products. These figures show that almost 95% of the dollar value of gypsum products comprises prefabricated and cementitious building products. More gypsum was manufactured into wallboard than into any other single product. The average price of wallboard was relatively high, therefore it also accounted for the largest monetary figure for any single item. Base coat plaster, gypsum lath, and portland cement retarder follow wallboard in order of amount produced. Because of difference in prices of the different products, however, their values do not follow in the same order. Portland cement retarder, although

TABLE 1.—*Production of gypsum and gypsum products in United States in 1952*

Use	Short tons	Value: Total	Value: Average
Uncalcined:			
Portland-cement retarder	1,815,489	$6,232,230	$3.43
Agricultural gypsum	866,005	3,072,419	3.55
Other uses [a]	24,233	312,131	12.88
Total uncalcined uses	2,705,727	$9,616,780	$3.55
Industrial:			
Plate-glass and terracotta plasters	48,587	$626,771	$12.90
Pottery plasters	43,991	811,609	18.45
Orthopedic and dental plasters	11,017	390,347	35.43
Other industrial uses [b]	148,621	3,171,052	21.34
Total industrial uses	252,216	$4,999,779	$19.82
Building:			
Cementitious:			
Plasters:			
Base-coat	1,907,871	$26,596,087	$13.94
Sanded	177,679	3,331,533	18.75
To mixing plants	11,703	126,243	10.79
Gaging and molding	176,957	2,943,304	16.63
Prepared finished	16,000	935,670	58.48
Other [c]	220,997	6,082,843	27.52
Keene's cement	52,591	1,158,703	22.03
Total cementitious	2,563,798	$41,174,383	$16.06
Prefabricated:			
Lath	1,757,771	$54,402,346	[d] $23.48
Wallboard and laminated board	2,964,381	108,974,618	[e] 32.88
Sheathing board	123,310	4,281,772	[d] 36.57
Tile	157,451	3,632,397	[f] 78.54
Total prefabricated	5,002,913	$171,291,133	$34.24
Total building uses	....	$212,465,516	....
Grand total value	....	$227,082,075	....

(a) Includes uncalcined gypsum sold for use as filler and rock dust, in brewer's fixe, in color manufacture, and for unspecified uses.
(b) Includes statuary, industrial casting and molding plasters, dead-burned filler, granite polishing, and miscellaneous uses.
(c) Includes insulating and roof-deck, joint filler, patching and painter's plaster, and unclassified building plasters.
(d) Average value per M square feet.
(e) Average value per M square feet of wallboard only.
(f) Average value per M square feet of partition tile only.

the fourth largest product of gypsum in terms of quantity, has the lowest listed price, and so falls far behind other products in total value.

Kansas Gypsum Production

The products made from Kansas gypsum are wallboard, wall plaster, Keene's cement, dental plaster, orthopedic plaster, plate glass stucco, pottery plaster, casting plaster, molding plaster, gaging plaster, and portland cement retarder. This list indicates that many of the Kansas gypsum products are special types that command a higher than average price. These products require not only a careful and special type of handling in their manufacture but also a high-grade gypsum as raw material.

Acknowledgments

The authors are indebted to many persons for information included in this report. The gaps in the historical record could be filled only by persons familiar with the local areas or directly associated with the gypsum companies. It is not possible to mention all who contributed, but their help has made the report more nearly complete.

Special thanks are due to Mr. Kenneth W. Brown, superintendent, and Mr. Fred Williams, mine foreman, of the Certainteed Products Corporation operation at Blue Rapids for their help and cooperation in the studies made in that area.

Mr. Roy Rubin was especially helpful in locating old mine sites in the Hope area. He also provided many photographs having historical interest and much of the historical data concerning gypsum mining in that area.

Special thanks for their cooperation and help are likewise due to Mr. Dudley C. Chads, superintendent, Mr. M. J. Witkowski, quality control engineer, and Mr. Sam Shepler, mine superintendent, of the National Gypsum Company operations at Sun City and Medicine Lodge. Mr. S. E. Woodard of Medicine Lodge helped to obtain data for the structural map of the area near the Pioneer mine.

GEOLOGY AND PROPERTIES OF THE CALCIUM SULFATE MINERALS

Properties of Gypsum

Physical properties.—Gypsum ($CaSO_4 . 2H_2O$) has a specific gravity of 2.32 and hardness of 2. It is commonly colorless, white, or gray. Shades of yellow, red, and brown result from impurities. Crystals, when present, are generally of tabular or prismatic habit and crystallize in the monoclinic system. "Swallowtail" twins, with the orthopinacoid (100) as the twinning plane, are relatively common.

Cleavage is present in two directions: perfect cleavage parallel to the clinopinacoid (010); less perfect parallel to the orthopinacoid (100); there is fibrous fracture to the negative hemipyramid (111).

Varieties of gypsum.—The most common variety of gypsum is massive or rock gypsum. It consists of an intimate intergrowth of small crystals, and ranges from finely granular to coarsely crystalline in texture. It is widely distributed as a sedimentary rock interstratified with limestone and shale. Selenite is a colorless variety of gypsum, occurring as transparent crystals or foliae. Satin spar is a finely fibrous variety filling veins in massive gypsum or other rocks.

Properties of Anhydrite

Anhydrite ($CaSO_4$) has a specific gravity of 2.93 and a hardness of 3 to 3.5. It is commonly white, but a grayish, bluish, or reddish tinge may result from the presence of small amounts of impurities.

The common form is massive; crystals, which are rare, may be lamellar, tabular, or elongate parallel to the "b" crystallographic axis, and crystallize in the orthorhombic system. Cleavage is parallel to the basal pinacoid (001), brachypinacoid (010), and macropinacoid (100). Crystals may be twinned parallel to the macrodome (101).

Relationships of the Calcium Sulfate Minerals

Calcium sulfate occurs naturally as gypsum ($CaSO_4 . 2H_2O$) and anhydrite ($\beta CaSO_4$). Three additional forms are known but are not found in nature. These are the hemihydrate or "plaster of paris" ($CaSO_4 . \frac{1}{2}H_2O$), formed at 128° C., "soluble anhydrite" ($\gamma CaSO_4$), formed at 163° C., and an extremely high temperature (1,200° C.) form, which decomposes rapidly into CaO and SO_3

(Posnjak, 1938; Newman, 1941). These other forms can be produced by heating gypsum, and these transformations must follow a definite succession. All but the last state are obtained at temperatures below 200° C. The order of succession is as follows: gypsum, hemihydrate, "soluble anhydrite", and anhydrite.

The reactions that alter gypsum to the other calcium sulfate minerals are reversible. If water is added to the hemihydrate, gypsum is again formed. The fine needlelike crystals produced by this reaction form an interlocking mass that has cementitious properties. "Soluble anhydrite" is so easily hydrated that if exposed to air it will react with water vapor to form gypsum. Anhydrite reacts with water much more slowly, but laboratory and geological evidence indicates that it too will alter to gypsum.

The development of a multimillion-dollar gypsum industry was made possible by the following factors: (1) Gypsum is an abundant, naturally pure raw material. (2) It can be dehydrated to the hemihydrate at relatively low temperature using relatively simple equipment. (3) The reaction is virtually 100 percent complete, as is the reverse reaction. (4) The product of the reaction (plaster) is stable for a long period of time if stored in a dry place.

Deposition of Gypsum and Anhydrite

The association of calcium sulfate (gypsum-anhydrite) and halite affords evidence that these beds have been deposited by evaporation of sea water within a restricted basin. Table 2 (modified from Clarke, 1924, p. 220), shows the depositional sequence of common evaporite salts precipitated from evaporating sea water. Further evaporation of the sea water precipitates magnesium, potassium, and bromide salts.

Calcium sulfate may be deposited from sea water either as gypsum or as anhydrite, depending on the temperature of deposition and the concentration of other sea salts (mainly sodium chloride) in the water from which the calcium sulfate is deposited. Posnjak (1940) showed that 42° C. is the critical temperature above which anhydrite is deposited and below which gypsum is deposited. Increased concentration of other sea salts in the aqueous solution lowers this temperature and affects the solubility of both gypsum and anhydrite at 30° C., as shown in Figure 2 (from Posnjak, 1940).

TABLE 2.—*Salts laid down in concentration of sea water (in grams)*
(Modified from Clarke, 1924, p. 220)

Density, gram/liter	Volume, liters	Iron oxide	Calcium carbonate	Calcium sulfate	Sodium chloride	Magnesium sulfate	Magnesium chloride	Sodium bromide	Potassium chloride
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	....	....
1.2570	.0302	....	....	.0144	2.6240	.0174	.0150	0.0728	....
1.2778	.023	....	....	....	2.2720	.0254	.0240	.0358	....
1.3069	.0162	....	....	....	1.4040	.5382	.0274	.0518	....
								.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

Thick gypsum beds such as are found in Kansas present further problems. For example, deposition of a 30-foot bed of gypsum in the Blaine formation would require the evaporation of more than 8 miles of sea water, assuming that sea water contained the same amount of calcium sulfate in Blaine time as it does now. So deep a basin of evaporation is incredible; the formation of such thick beds of gypsum required a process more complicated than single-stage evaporation of water in an enclosed arm of the sea.

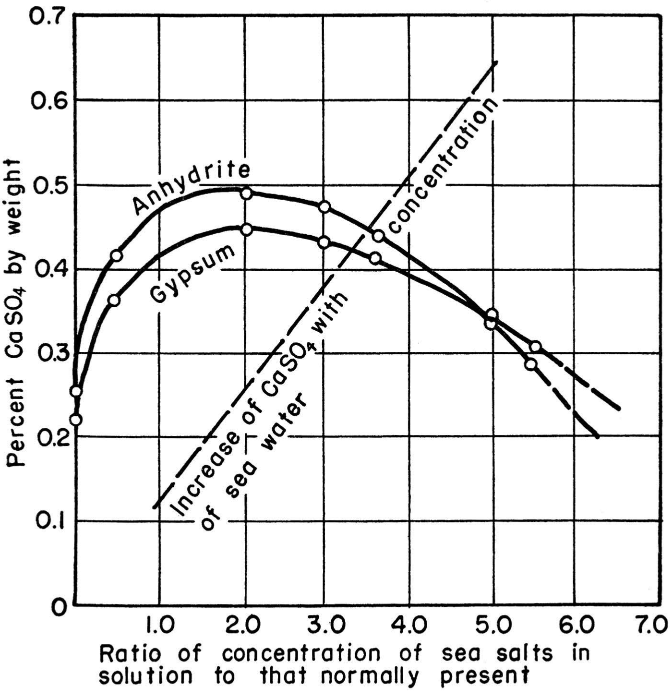


FIG. 2. Graph showing solubility of gypsum and anhydrite in sea water of various concentrations (from Posnjak, 1940).

Several theories have been advanced to account for the origin of various evaporite deposits found in different parts of the world. Ochsenius proposed the now classic theory of evaporation in basins that are partly cut off from the sea by a bar or barrier (Grabau, 1920). As evaporation progressed these basins would periodically receive new supplies of water, as at high tides. Such conditions would result in a more or less continuous "salt pan" so shallow basins would suffice for the acculumation of thick beds of salt or gypsum. Branson (1915) presented a modification of

Ochsenius' theory, assuming the existence of sub-basins separated by low barriers, so that new supplies of concentrated brine from the seaward basins overflow into the landward basins. Under such conditions gypsum would be deposited in the seaward basins and salt in the landward basins. Fulda (1935) suggested that thick evaporites can be formed in basins adjacent to the sea if sea water is added only by seepage through the barrier into the basin. Continued seepage and evaporation would thereby build up the deposit. King (1947) proposed a theory whereby continued restricted access to the open sea is maintained. Under these conditions sea water enters the basin at or near the surface of the water. Upon partial evaporation in the basin it deposits its least soluble constituents. Simultaneously it becomes more dense, sinks below the incoming sea water, and eventually passes to the sea at depth below the incoming current.

Subsequent Alteration of the Calcium Sulfate Minerals

The stability relationships of gypsum and anhydrite through a range of temperature and pressure have been studied by Bowles and Farnsworth (1925). They found that anhydrite was unchanged at a pressure of 19 atmospheres and temperature of 210° C. Gypsum subjected to the same pressure changed to anhydrite at 160° C. Such a temperature can be produced in nature only by extremely deep burial or by intrusion of igneous rock. They proposed that temperature was more effective than pressure in the inversion of gypsum.

McCormak (1926) likewise concluded that temperature was a more important factor than pressure in the dehydration of gypsum. He added, however, that pressure plus time in the geologic sense is an unknown factor and may have more influence on the dehydration of gypsum than any laboratory experiments could indicate.

Newland (1921, p. 141) stated that some economically important gypsum deposits in New York were originally anhydrite. He considers gypsum to be unstable under conditions of permanent load, whereas anhydrite is stable. Evidence for this is the fact that gypsum grades into anhydrite down dip. Muir (1934, p. 1297-1318) stated that the gypsum members of the Blaine formation of Oklahoma were originally beds of sedimentary anhydrite. He based his conclusions on two factors: (1) petrographic evidence shows that gypsum has replaced anhydrite, indicating that anhydrite was the original precipitate; (2) anhydrite is more often encountered than gypsum in drill cores and cuttings at lower depths, that is, down dip away from the outcrop.

Summarizing, either gypsum or anhydrite may be deposited as a result of the evaporation of sea water, depending upon the temperature and salinity of the water. As salinity increases, the temperature above which anhydrite will be deposited and below which gypsum will be deposited is lowered. The Kansas deposits could not have originated from one single body of water because of the tremendous depth of water required; therefore, these beds must have been deposited in a gradually sinking basin of evaporation receiving several influxes of sea water. After deposition either gypsum or anhydrite can alter to the other, under suitable conditions. Temperature, pressure, and the presence of water determine the stability of these minerals.

The foregoing discussion deals in a general way with the deposition from sea water and subsequent alteration of gypsum and anhydrite. Evidence will be presented to show that individual gypsum deposits in Kansas originated in the following manner: (1) The gypsum in the Easly Creek shale was deposited directly from sea water and was later recrystallized, possibly in part during diagenesis, but chiefly by ground water. (2) By far the major portion and probably all of the calcium sulfate in the lower Wellington formation was deposited as anhydrite. The gypsum found in the Wellington was probably formed by the alteration of anhydrite, although the possibility of direct deposition cannot be entirely eliminated. (3) The calcium sulfate deposits in the Medicine Lodge were deposited both as anhydrite and as gypsum, the anhydrite making up the middle portion of the bed. Subsequent alteration has transformed some of the anhydrite to gypsum.

PERMIAN ROCKS IN KANSAS

Virtually all the known gypsum deposits in Kansas are of Permian age. The following general description of the character and surface distribution of rocks belonging to the Permian System in Kansas is given by Moore and others (1951, p. 33).

"Rocks of Permian age which occur in Kansas include evenly stratified predominantly marine deposits in the lower part of the section and irregularly bedded, mainly nonmarine deposits in the upper part. Light ash-gray to cream-colored limestone beds, many of which are distinguished by abundance of flinty chert form persistent benches or escarpments, among which the so-called Flint Hills are most prominent. The Flint Hills extend across Kansas from Nemaha County on the Nebraska border to western Chautauqua

County adjoining the Oklahoma boundary. The escarpments are east-facing because the gentle regional dip of the Permian strata is westward. Between the limestone formations and members of the Lower Permian are gray, green, and red shale units, in part containing marine fossils and in part representing nonmarine sedimentation. Sandstone is virtually absent in this part of the section.

"Middle and upper parts of the Permian succession consist mainly of shale and sandstone, many of them red in color. Thick deposits of salt which occur do not crop out, because the Kansas climate is not arid enough to allow such soluble rock to be exposed at the surface. Gypsum beds, some of minable thickness, may be seen, however, and a few thin but persistent dolomites occur in the redbeds part of the Permian section.

"The outcrops of Permian rocks in Kansas form a belt extending from Washington, Marshall, Nemaha, and Brown Counties on the northern boundary to Meade, Clark, Comanche, Barber, Harper, Sumner, and Cowley Counties on the Kansas-Oklahoma line. . . . The total outcrop thickness is about 3,000 feet."

Permian rocks in the Midcontinent region are divided into four series from oldest to youngest as follows: Wolfcampian, Leonardian, Guadalupian, and Ochoan. Wolfcampian and Leonardian rocks are known in Kansas and Guadalupian may be present; at present the division between Leonardian and Guadalupian rocks in Kansas is not established (Swineford, 1955), because of difficulty in correlating the redbed facies in Kansas with marine rocks of the type section. There are no known Ochoan rocks in Kansas. A graphic column of the Permian rocks in Kansas (Fig. 3) shows the stratigraphic relationship of the different beds.

The very extensive gypsum and anhydrite deposits have been exploited in relatively few places. Economic factors, rather than quality of the deposits, may delay or prohibit actual mining operations. Even the unworked and unworkable deposits are beneficial in other ways, however. Some of these deposits underlie broad areas in the subsurface, and are easily recognized. Stratigraphic correlation and determination of geologic structure are thereby greatly facilitated, contributing significantly to petroleum exploration. Moreover, in certain areas the erosion of the gypsum-anhydrite beds by subsurface solution has allowed weathered rock to accumulate on the surface rather than to be washed away. The deep soil thus produced is well suited to agriculture.

GYPSUM IN THE BLAINE FORMATION

The Blaine formation, chiefly gypsum and anhydrite, comprises the Medicine Lodge, Nescatunga, Shimer, and Haskew members (Fig. 3); all but the last of these crop out extensively in south-central Kansas. The gypsum in the Blaine formation, unlike that in other areas in Kansas, is the rock most resistant to erosion at its outcrop, and it forms the "Gypsum Hills" of Kansas and Oklahoma. Plate 1A shows distribution of outcrops of the Blaine formation in Barber, Comanche, and Kiowa Counties. This map is based on field observations and areal photographs. As the gypsum beds form the cap rock on the hills in much of the area, beds could

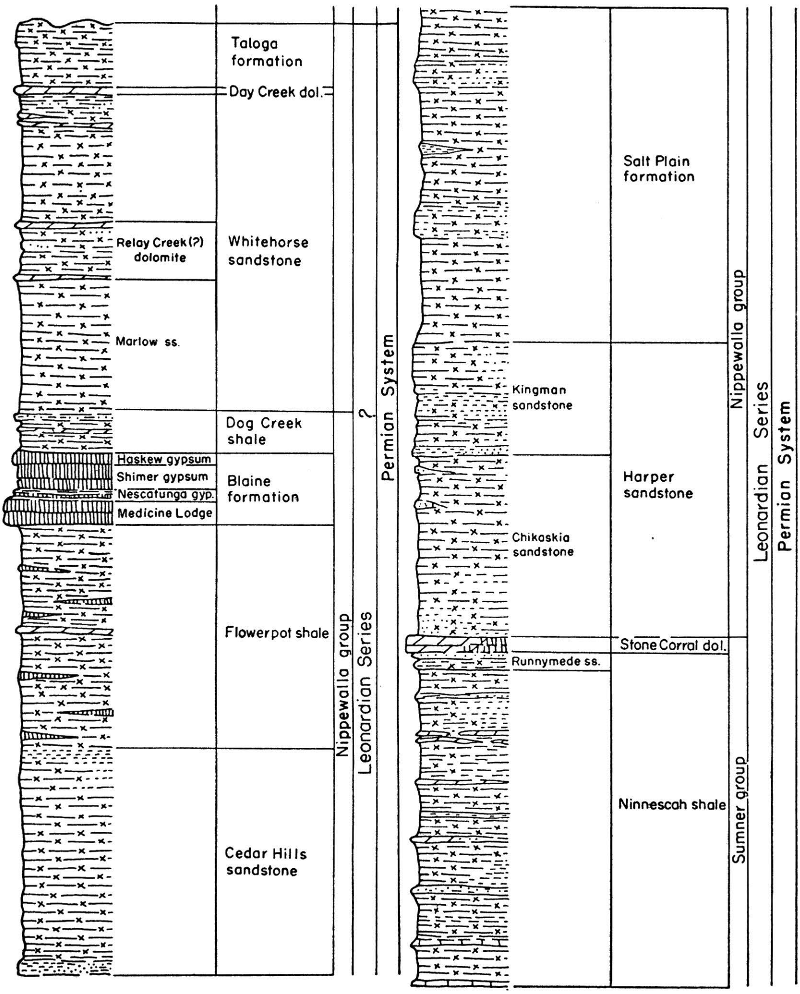
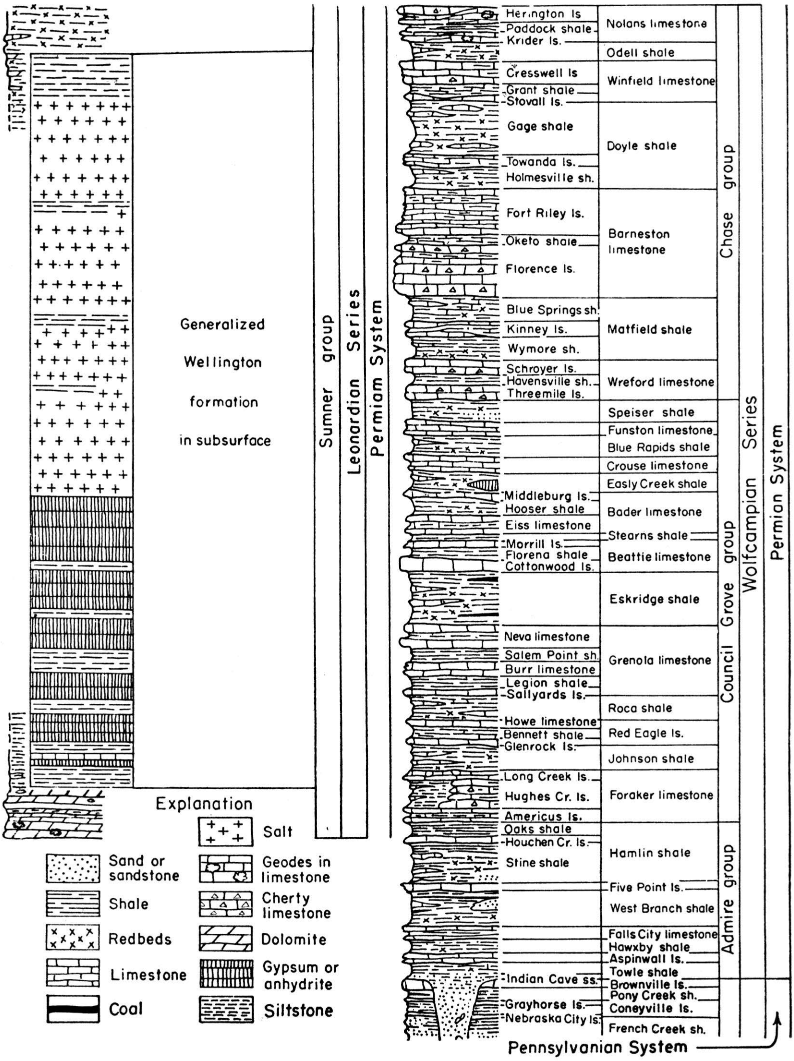


FIG. 3. Generalized stratigraphic section of Permian rocks in Kansas. Note that the Wellington rocks are represented as subsurface rocks.

be traced directly on the photographs with a minimum of ground control. Where the gypsum beds could not be mapped from actual exposures or readily projected between exposures, their position was inferred from the topography. The gypsum beds do not crop out continuously; however, they do form an identifiable ledge if not deeply covered. The gypsum outcrops are more prominent, more numerous, and more nearly continuous on the south wall of valleys than on the north wall. In fact, gypsum is not the most resistant



bed in the sequence in many places on north walls. Gypsum probably lies close to the surface in some areas not indicated on this map, but there is not enough evidence to warrant mapping it.

In the eastern part of the area the only visible gypsum bed of the Blaine formation is the Medicine Lodge gypsum member. Farther west and south the Nescatunga and Shimer gypsum members appear. In Kansas the total thickness of this part of the Blaine ranges on the outcrop from a featheredge to more than 30 feet. Because the outcrop is not continuous, it is impossible to draw an exact line of demarcation between areas of single-bedded gypsum (Medicine Lodge) and multibedded gypsum (Medicine Lodge, Nescatunga, and Shimer), but this dividing line is somewhere near the Barber-Comanche County line. Where the Medicine Lodge and Shimer form separate outcrop patterns the Medicine Lodge was mapped, but at the scale of Plate 1A it would make little difference which bed was mapped.

The quality of the gypsum can not be determined by analyzing samples from the outcrop. Although gypsum is very resistant to erosion in this part of the state, nevertheless it is greatly altered by exposure. Most gypsum outcrops in the area are honeycombed with solution channels and have a superficial crust of secondary gypsum on them. This is due probably to the evaporation of calcium sulfate saturated ground water on the surface of the outcrop. Surface water also has dissolved some gypsum at the outcrop so that the outcrop thickness is not indicative of the true thickness.

Pioneer Mine Near Sun City

Gypsum is mined near Sun City, Kansas, from the Medicine Lodge member of the Blaine formation (Fig. 3). The mine, called the Pioneer mine, is operated by the National Gypsum Company, which also operates a gypsum plant in Medicine Lodge, Kansas. In 1950 Medicine Lodge had a population of 2,288 and Sun City a population of 231. Both cities are in Barber County (Pl. 1A, Fig. 1).

Gypsum is mined on the room-and-pillar system. The pillars are 20 feet across. The distance between pillars is 40 feet (60 feet from the center of one pillar to the center of the next). The height of the face generally is about 20 feet (Fig. 4).

The face is drilled for shooting with a mobile hydraulically operated machine drill that can drill two holes at once and several holes from one position (Pl. 4A). The gypsum is not undercut but is shot off the solid rock. Figure 5 is a diagram of the placement of the holes.

After shooting, the gypsum is loaded into shuttle cars (Pl. 4B) with a mechanical loader (Pl. 4C) and moved to a ramp where it is unloaded from the shuttle car directly into the mine trains.

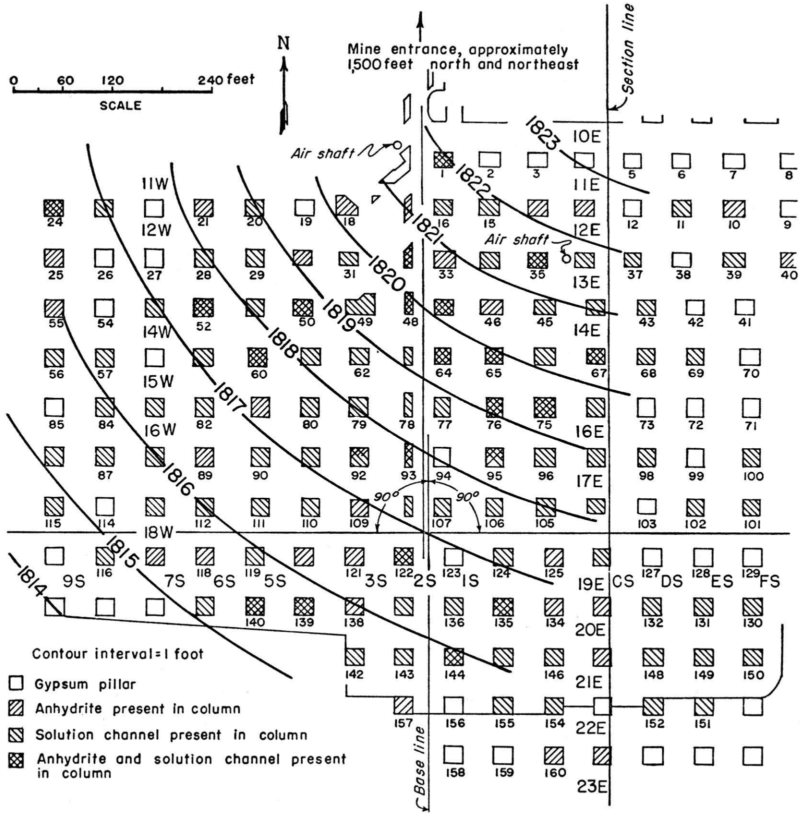


FIG. 4. Map of part of the underground workings of the Pioneer mine, Sun City, Kansas, comprising portions of sections 9, 10, 14, and 15, T. 31 S., R. 15 W. Structural contours on mine floor drawn on surface 18 inches above base of Medicine Lodge gypsum. Contour interval 1 foot.

Each shuttle car, which obtains its electrical power from the cable it drags behind it, carries approximately 12 tons of gypsum. A traxcavator is used to clean up the face.

There are 4 mine trains containing 14 cars each. Each car carries approximately 3 tons of gypsum. Two 55-horsepower diesel locomotives operate separately to haul the trains from the loading point in the mine to the crushing plant outside the mine.

The crushing plant (Pl. 5B) contains a primary and a secondary crusher. The secondary crusher produces pieces of gypsum 1½ inches in size or smaller, which are stored in covered bins for shipment to Medicine Lodge by rail in covered hopper cars.

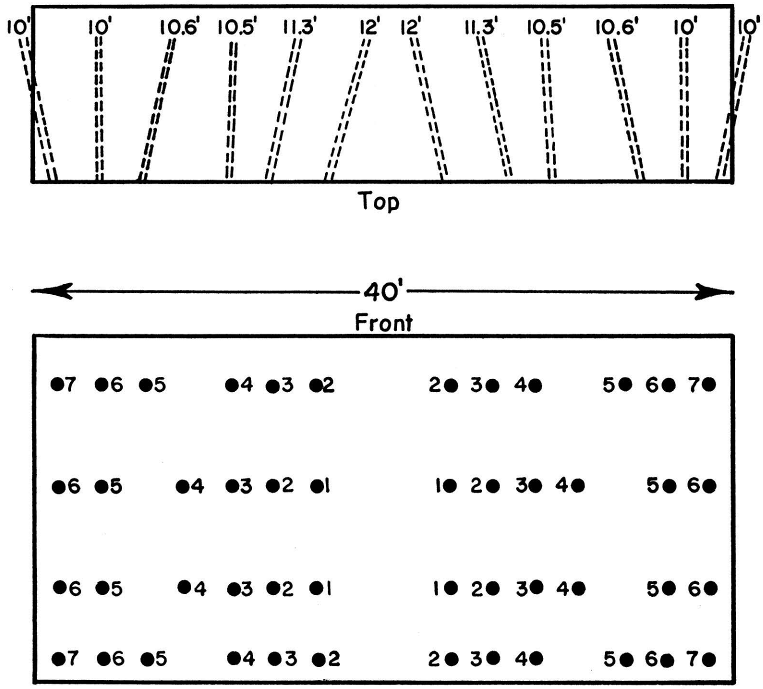


FIG. 5. Diagram showing placement of shot holes, Pioneer Mine, Sun City. Holes marked (1) are instantaneous; (2) 25 millisecond delay; (3) 50 millisecond delay; (4) 75 millisecond delay; (5) 100 millisecond delay; (6) 125 millisecond delay; and (7) 175 millisecond delay.

NATIONAL GYPSUM COMPANY PLANT AT MEDICINE LODGE

The plant at Medicine Lodge (Frontis.) is nationally known for the manufacture of Keene's cement, a gypsum product of high quality. According to Lenhart (1952, p. 152-153), "The chances are most of the decorative work in your local theatre (ornamental figurines, statuettes, etc.) were cast from rock mined in western Kansas." The plant employs both rotary kilns and kettles in the processing of gypsum, and recently expanded its facilities for making wallboard.

The plant's production is primarily Keene's cement and wall-board, but other products produced there include fillers for paper, an ingredient for toothpaste, portland cement retarder, extending agents for paint pigments, industrial plaster, building plaster, gaging and molding plaster, casting plaster, and dental plaster.

The mine near Sun City and the plant at Medicine Lodge are both served by the Atchison, Topeka, and Santa Fe Railway.

History of Gypsum Mining in Barber County

The beginning of gypsum production in Barber County is an interesting story. It was recorded by Haworth (1902a) who wrote:

> "The late Prof. Robert Hay wrote a magazine article for Harper's magazine, which was published in June, 1888, in which he described and illustrated the mansard-like hills of Barber County, and gave a good description of the gypsum rock found there in such great quantities. The magazine chanced to fall into the hands of English capitalists, who at that time manufactured what is known in England as Keene's cement, a variety of cement known throughout England and Europe as being superior to anything else of foreign make for use as a high-grade plaster for costly buildings. A delegate was sent to Barber County to investigate the gypsum described by Professor Hay. He found it as described, or rather as one of the company expressed it to the writer, 'the half was not told'. The final outcome was that a branch factory of the Keene Cement Company was established at Medicine Lodge, which began operations in 1891, and has continued ever since, under the management of Mr. Thomas Best, producing a plaster known as Best's Keene's cement, that is generally recognized throughout eastern United States as being superior to the famous Kiege's Windsor, a brand that is considered by architects of Boston and New York fully equal to any imported cement."

According to an unpublished manuscript by G. L. Knight on file at the State Geological Survey of Kansas, Thomas J. Best and his brother William C. Best began manufacturing Keene's cement at Medicine Lodge in 1889. Gypsum was first obtained from quarries a few miles southwest of Medicine Lodge. Quarrying operations were later moved to a place called Kling in northwestern Barber County. Gypsum was later quarried on the south side of the valley of Medicine Lodge River just west and south of Sun City. As these quarries were cut back into the hills the overburden increased so that in 1930 or 1931 the quarrying operations were abandoned and underground mining was begun. In the 1930's the operation was transferred to the National Gypsum Company, which is operating the mine and plant at present.

Geology of the Medicine Lodge Gypsum Deposits

Stratigraphy

The stratigraphy of the Blaine formation, based on the classification of Norton (1939), is shown in Figure 3. The local stratigraphy in the vicinity of the Pioneer mine is shown in Figure 6.

The Flowerpot shale, which is soft, red, and gypsiferous, is the lowermost formation that crops out in the Sun City area. The shale was named by Cragin (1896, p. 25-26) for Flowerpot Mound, southwest of Medicine Lodge; he described the outcrops of the Flowerpot shale as follows:

"The surface is often strewn with fragments of white, pink, red or water-clear satin-spar flecked with green or red clay, and is sometimes also set off with sparkling crystals of selenite.

". . . in canyon walls . . ., the satin-spar forms a network with irregular rhomboidal meshes, . . . warped plates traversing the clay in all directions, . . . sometimes in spacious sublenzitoid compartments subject to partition in various directions by intersecting veins. The seams vary from mere paper-seams to plates several inches in thickness.

"A noticeable and picturesque feature of the Flowerpot clays is the manner in which their outcrops are carved by the elements. They are, in fact, a theater of rapid erosion, and many weird spectacles present themselves in their relief forms. . . . they are frequently cut into rather steeply sloped faces having that peculiar pattern of sculpture that is best designated as *cone-and-gully erosion*".

The Flowerpot shale ranges in thickness from 170 to 190 feet; only the upper 145 feet is exposed in the vicinity of the Pioneer mine. The shale rests on the Cedar Hills sandstone, which is not exposed in the area.

The Blaine formation overlies the Flowerpot shale. The type locality of the Blaine is Salt Creek Canyon near Southard, Blaine County, Oklahoma (Gould, 1905, p. 44). The Blaine formation at the type locality includes four gypsum members. In the vicinity of the Pioneer mine, however, the Medicine Lodge gypsum is the only member of the Blaine present. Farther west in Comanche County additional members are present. The Medicine Lodge gypsum ranges in thickness from 10 to 30 feet; the maximum thickness is exposed in the mine. It is a massive deposit; the lower and upper parts are soft, porous, and smoke-gray, whereas the middle part is harder, more compact, and white. The color variation is well shown in the quarry exposures (Pl. 6B). At the base of the gypsum there is a bed of impure, hard dolomite 6 to 12 inches thick.

Where the upper gypsum members of the Blaine are missing, as at Sun City, the shale above the Medicine Lodge cannot be dis-

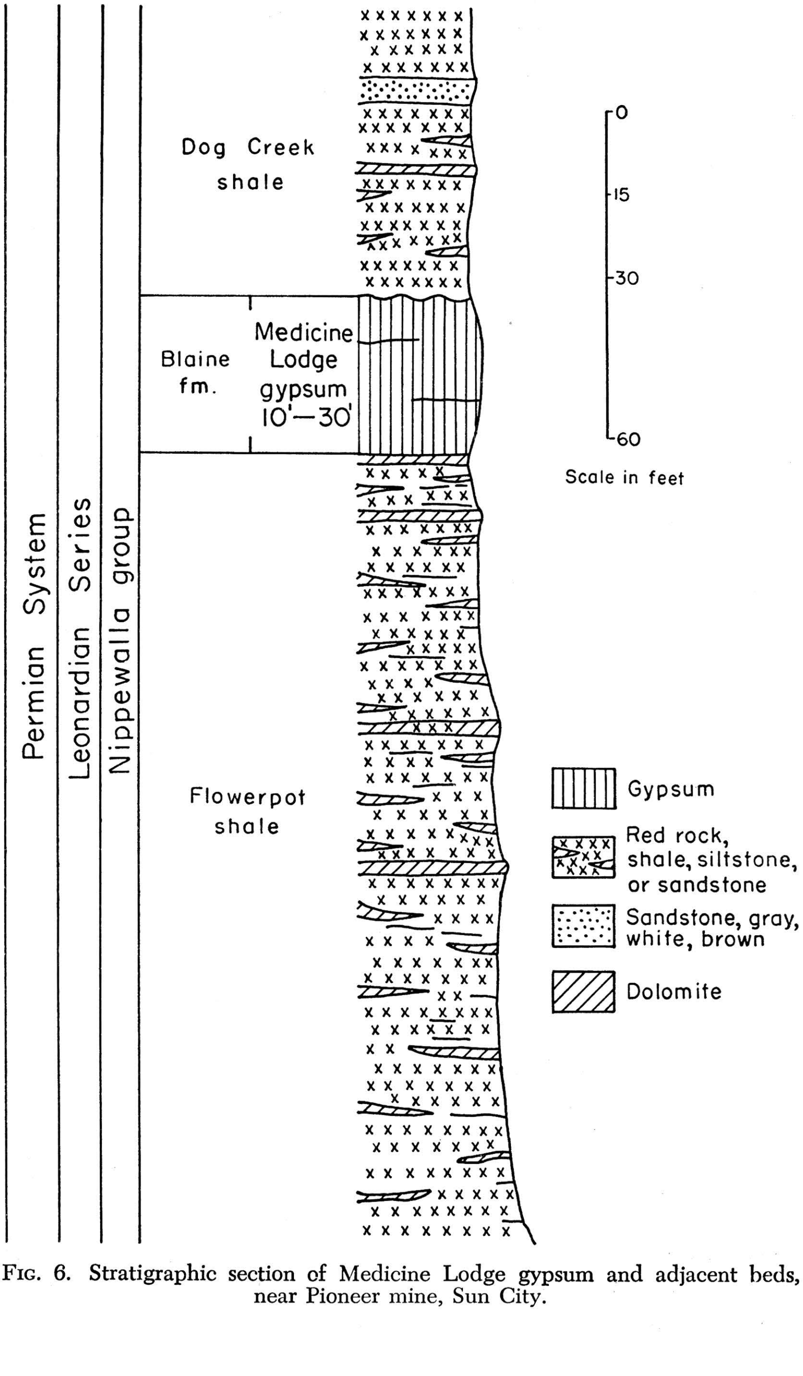


FIG. 6. Stratigraphic section of Medicine Lodge gypsum and adjacent beds, near Pioneer mine, Sun City.

tinguished from the Dog Creek shale, so is included therein (Pl. 6A).

The Dog Creek shale overlies the Medicine Lodge gypsum. The type locality is on Dog Creek south of Lake City, Kansas (Norton, 1939, p. 1799). The shale is soft, red, and gypsiferous and includes layers of dolomite and dolomitic sandstone. The maximum thickness is about 53 feet.

Structure

The redbed strata are relatively flat, the regional dip to the southwest being about 11 feet per mile. Structural contours drawn on the base of the Medicine Lodge gypsum (Pl. 1B) show slight irregular dips in several directions. Structural contours drawn on a surface 18 inches above the base of the gypsum in the Pioneer mine (Fig. 4) show a dip to the southwest of 57 feet per mile. North of the mine the gypsum forms a small anticline. The observed structural irregularities may represent initial dips, slump structure, or both.

Field Relationships of Gypsum and Anhydrite

Anhydrite is not common in the surface outcrop of gypsum in the Sun City area. Near the Natural Bridge, 5 miles south of the Pioneer mine, however, the association of gypsum and anhydrite can be observed along the stream bank. The anhydrite occurs as two lenses separated horizontally by massive gypsum, but occupying the same vertical position about 10 feet above the base of the gypsum. Each lens is about 12 feet in length and 12 inches in maximum thickness.

The relationship between gypsum and anhydrite can best be observed underground in the columns and walls of the Pioneer mine. The anhydrite occurs as lenticular deposits ranging in thickness from a fraction of an inch on the outer edges to a maximum of 2 feet in the middle. Where anhydrite is present, it lies about 10 feet above the base of the gypsum. In some places the anhydrite extends the entire width of a 20-foot pillar, but commonly it is not that extensive. Where anhydrite is absent, solution channels generally are present. The solution channels are zones filled with breccia in which the gypsum is crumbly, porous, and sugary, and shows traces of red clay. In many places there is a large flow of water through these channels. Figure 3 shows the location in the Pioneer mine of gypsum, anhydrite, and solution channels, which may occur in the same column; the distribution of the anhydrite is very spotty; columns having solution channels exceed those in

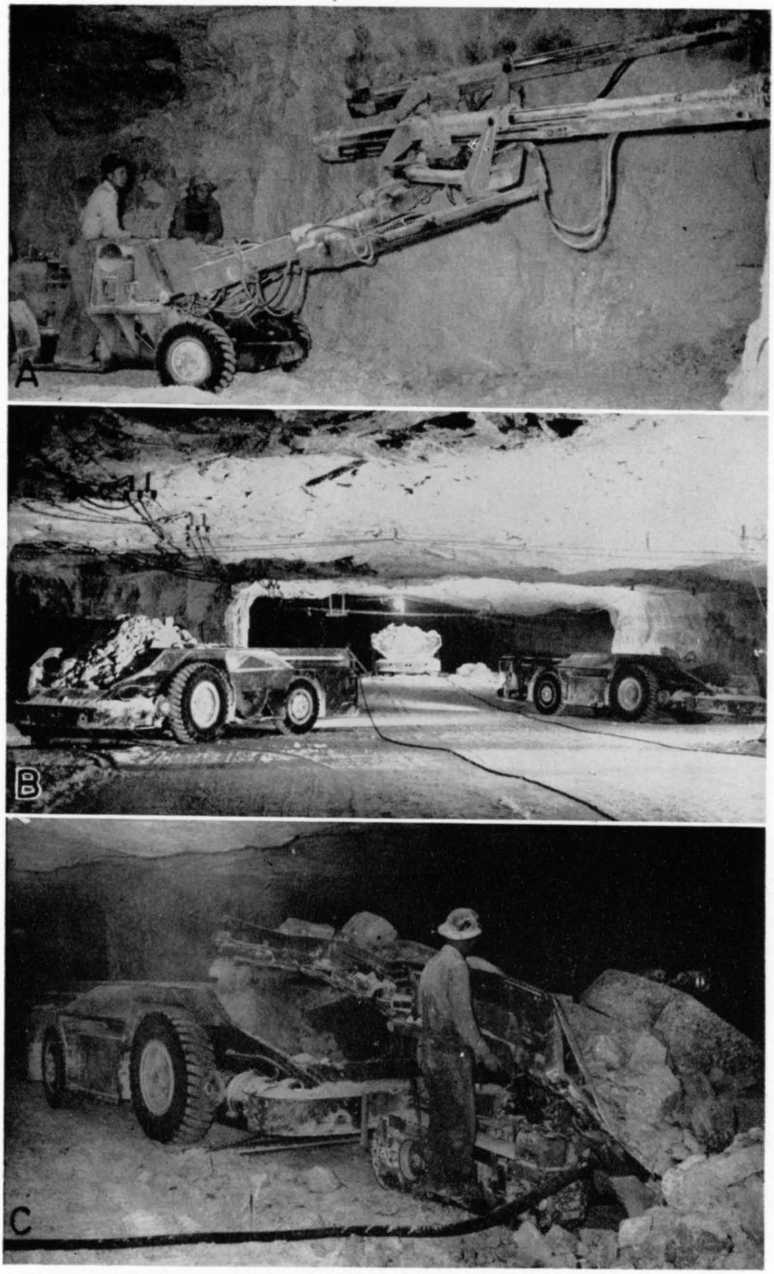


Plate 4. Equipment operating in Pioneer Mine, Sun City. (*Pictures courtesy of Homer Venter, National Gypsum Company*). **A.** Machine drill capable of drilling several holes from one position. **B.** Shuttle cars used to haul gypsum from place of mining to mine trains. **C.** Mechanical loader used to load gypsum into shuttle cars at place of mining.

PLATE 5. Pioneer mine near Sun City. (*Pictures courtesy of Homer Venter, National Gypsum Company*). **A.** Underground workings. Note anhydrite layer above the number 3 painted on pillar in center of picture. **B.** Crushing plant at Pioneer mine, and loaded mine train.

PLATE 6. Aspects of the Medicine Lodge gypsum. **A.** Outcrop of Dog Creek shale and Medicine Lodge gypsum near Sun City. Upper part of gypsum is irregular, owing to solution. The shale has slumped down into the gypsum. **B.** Exposure of Medicine Lodge gypsum in quarry face near Pioneer mine. Note color variations that give layered appearance. **C.** Photomicrograph of anhedral crystals of gypsum from lower part of gypsum bed. (Crossed nicols, × 18).

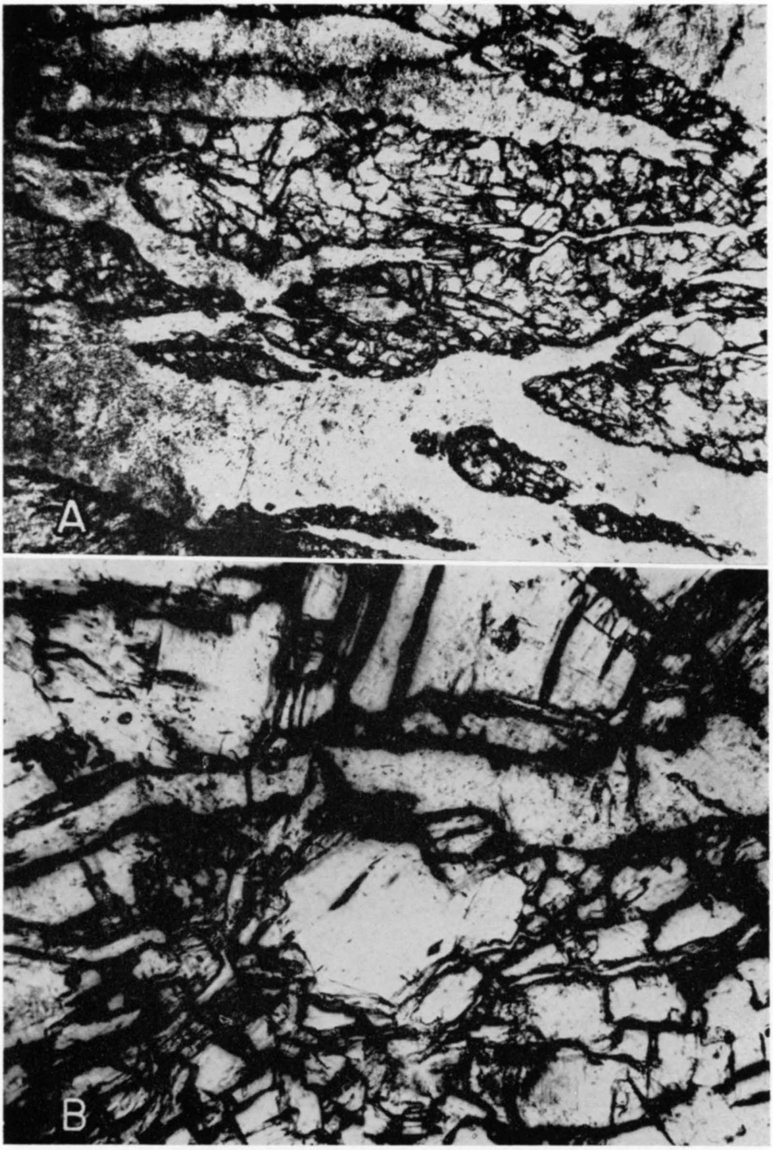


PLATE 7. Photomicrographs of gypsum veinlets penetrating anhydrite. **A.** Sharp-walled irregular veinlets (light) penetrating anhydrite (dark). Note islands of anhydrite within gypsum. (Plane light, × 20). **B.** Sharp-walled veinlet of gypsum penetrating anhydrite along cleavage planes. Note parallel walls. (Plane light, × 85).

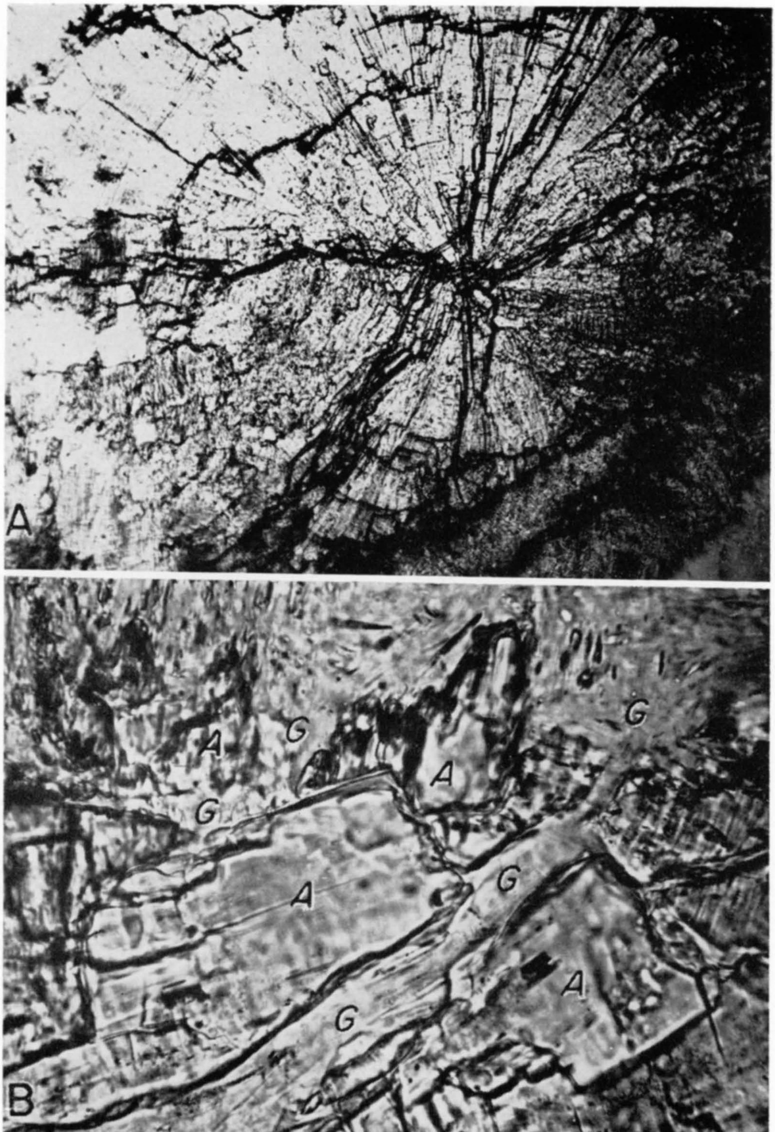


PLATE 8. Photomicrographs of gypsum and anhydrite. **A.** Radial aggregate of anhydrite. Note gypysum-anhydrite contact in lower right corner. (Plane light, × 18). **B.** Gradation of anhydrite *(A) to* gypsum *(G)*. Very irregular contact between anhydrite and gypsum along upper portion of field. Gypsum also penetrates anhydrite as veinlets (Plane light, × 360).

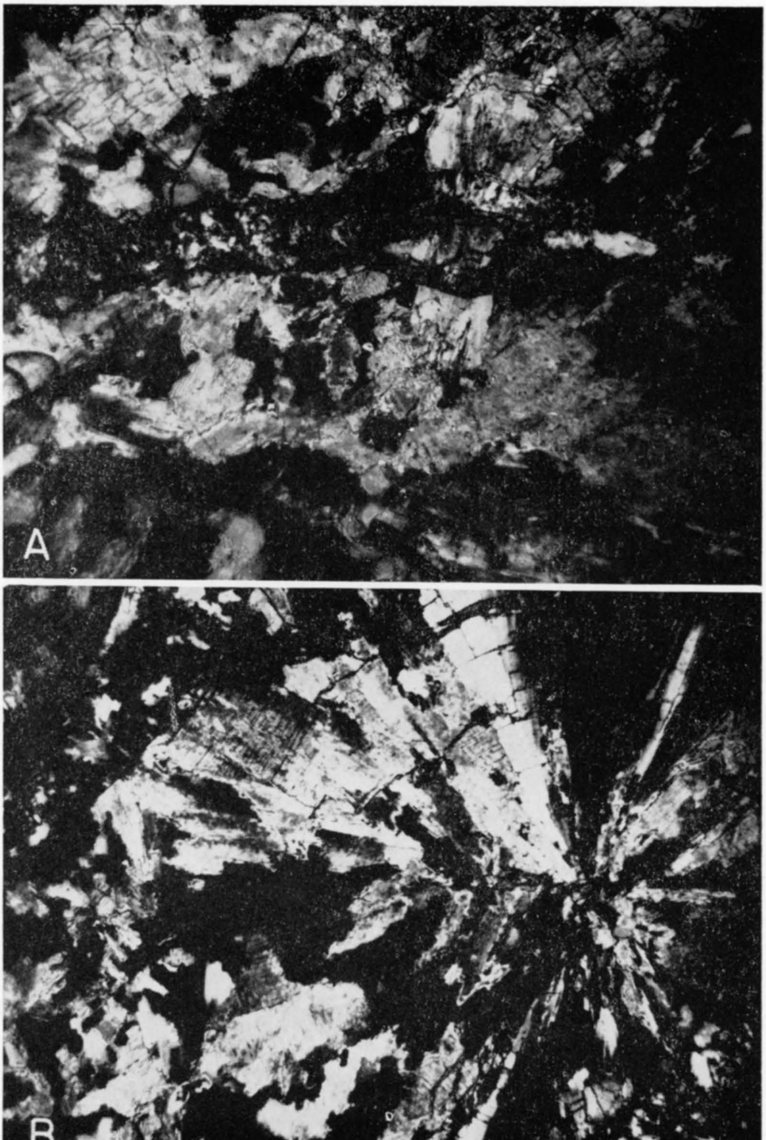


PLATE 9. Photomicrographs of gypsum and anhydrite. **A.** Gypsum veinlet cutting anhydrite crystal (center of field). Veinlet branches to enclose part of anhydrite crystal. Optical continuity is maintained. (Crossed nicols, × 18). **B.** Radial aggregate of anhydrite (Crossed nicols, × 18).

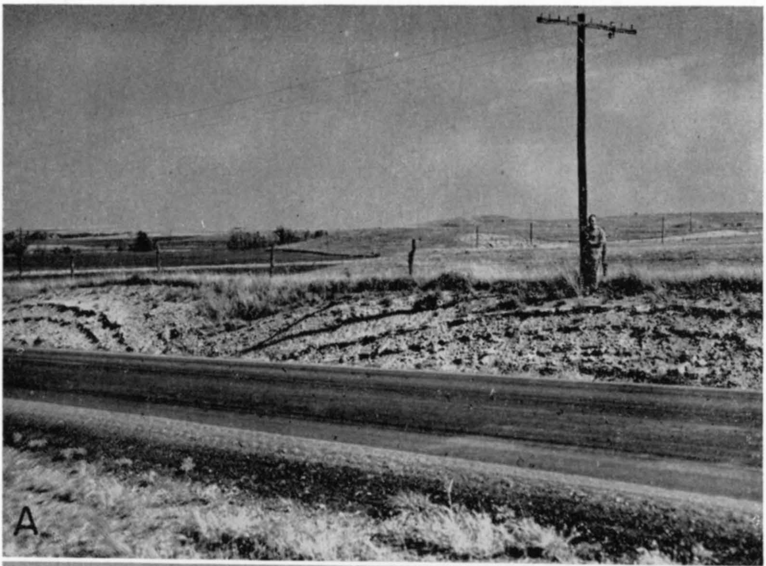


PLATE 10. Limestone beds in Wellington formation. **A.** Slump structure revealed in limestone beds in road cut in sections 34 and 35, T. 15 S., R. 1 W. **B.** Plowed field in Wellington outcrop area in southern Dickinson County. Light spots indicate limestone beds. These are the only indication of outcrops in much of the area.

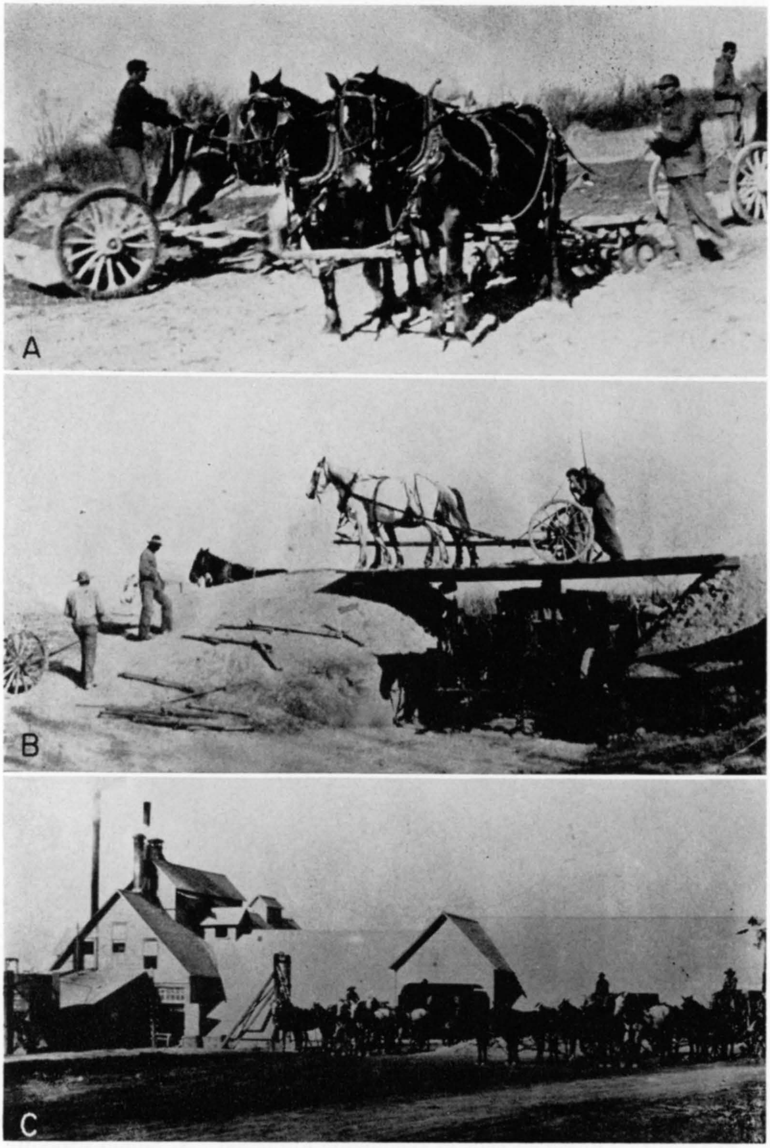


PLATE 11. Longford gypsite pit and plaster mill, which operated from 1895 to 1912. (*Pictures courtesy of A. Greep, Longford, Kansas*). **A.** Scrapers and disk used in mining gypsite. **B.** Scraper loading into wagon. **C.** Plaster mill at Longford.

which anhydrite alone is present; there is no pattern of anhydrite distribution.

The center part of the gypsum has a layered appearance, owing to the color variations of the gypsum and anhydrite. Plate 5A shows the relationship of gypsum and anhydrite and the color variations.

A thin gray shale seam ⅛ to ¼ inch thick is present 22 feet above the base of the gypsum, throughout the mine. The upper limit of mining is controlled by this shale seam, along which the gypsum breaks cleanly.

Gypsum also has been produced commercially 8 miles southwest of Medicine Lodge; also 4 miles west of Sun City at a locality called Kling. The thickness of the gypsum at the above localities averages about 8 feet. Anhydrite is not present.

Petrology of Gypsum and Anhydrite

Gypsum and anhydrite from the Pioneer mine were studied to determine their genetic relationships.

Lower part of the gypsum bed (to 10 feet above base).—Megascopically, the gypsum is soft, gray, and crystalline. Anhydrite is absent. Microscopically, the gypsum rock has the following characteristics: 1. The crystals, which are anhedral, range from 0.04 to 5 mm in size (Pl. 6C). 2. A few small anhedral crystals of dolomite and scattered patches of iron oxide are present. 3. Anhydrite is completely absent. 4. The underlying dolomite grades into the gypsum.

Middle part of the gypsum bed (10 to 22 feet above base).—Megascopically, both gypsum and anhydrite are present. Where anhydrite is present, the gypsum is compact; where anhydrite is absent, the gypsum commonly is porous and sugary. Brecciated zones containing red clay are present. The anhydrite occurs in lenses averaging about 12 feet in length and 1 foot in thickness. The contact between gypsum and anhydrite shows veinlets of gypsum penetrating into the anhydrite. The veinlets commonly surround portions of the anhydrite and most are sub-parallel to the bedding planes of the anhydrite (Fig. 7).

Microscopically, the gypsum and anhydrite have the following characteristics: 1. The gypsum is composed of anhedral crystals ranging from 0.05 to 5 mm in size. 2. Veinlets filled with gypsum extend into the anhydrite. Some of these veinlets are sharp walled, and many have parallel matching walls (Pl. 7A, B). 3. Radial aggregates of anhydrite crystals are common (Pl. 8A, 9B). 4. Anhydrite crystals cut by gypsum maintain optical continuity (Pl. 9A). 5. The gypsum-anhydrite contact seems gradational at many places (Pl. 8B). 6. Evidence of distortion in the gypsum and anhydrite is lacking.

Upper part of the gypsum bed (22 to 30 feet above base).—Megascopically, the gypsum is soft, gray, and crystalline. A shale seam, ⅛ to ¼ inch thick, occurs in the mine about 22 feet above the base. The upper surface of the gypsum is irregular.

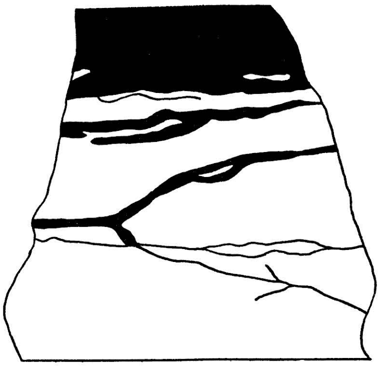


FIG. 7. Sketch showing gypsum veinlets penetrating anhydrite within Medicine Lodge gypsum at contact of gypsum and anhydrite. The gypsum (black) penetrates into the anhydrite (light) as small irregular veinlets, roughly parallel to the contact (× ⅔).

Microscopically, the gypsum rock exhibits much the same characteristics as that in the lower part. Iron oxide is present, but dolomite and anhydrite are absent.

Petrologic Interpretations

Evidence for the hydration of anhydrite to gypsum.—Megascopically, solution channels occur at about the same height above the base of the gypsum as the lens-shaped masses of the anhydrite. Hydration of anhydrite to gypsum and subsequent solution of the resulting gypsum may account for solution channels at approximately the same horizon as the anhydrite. The gypsum along the solution channels is brecciated, soft, porous, and sugary in contrast to the compact gypsum found elsewhere. In the solution channels, a thin coating of red clay is present on some of the gypsum fragments. The lenticular shape of the anhydrite likewise may be an indication of hydration.

Microscopically, the gypsum surrounds aggregates of anhydrite in many thin sections. Many of the aggregates show gradation of anhydrite to gypsum. Thus it seems that in places gypsum is later in origin. The gypsum-anhydrite contact is gradational in many places.

Evidence against hydration of anhydrite to gypsum.—Megascopically, the thickness of the bed is the same whether anhydrite is present or not. Theoretically, hydration of anhydrite to gypsum should cause an increase of about 63 percent in volume, and presumably any such increase in volume would cause some local distortion of the bed. No evidence of distortion attributable to expansion was observed in the field, however. The lateral discontinuity of the anhydrite may be the result of lenticular deposition due to local variation in temperature and salinity.

Microscopically, anhydrite is completely absent in the lower and upper parts of the gypsum. It would seem logical that some relics of anhydrite would be present if all the gypsum had formed by hydration. The irregular, sharp, parallel matched walls of numerous gypsum veinlets in the anhydrite denote fracture filling.

Relationship of the gypsum and anhydrite.—In view of the above megascopic and microscopic evidence, the following sequence of events may account for the observed relationship between gypsum and anhydrite.

The Medicine Lodge calcium sulfate deposits were formed by the evaporation of saline waters. The sequence of deposition was (a) 10 feet of gypsum, (b) about 2 feet of continuous anhydrite or anhydrite lenses, (c) 18 feet of gypsum. Through some disturbance subsequent to deposition, the gypsum and anhydrite were fractured. Slumping of gypsum along solution channels might account for the fracturing. The fractures served as planes of weakness through which meteoric water penetrated the gypsum and anhydrite. The water, entering the gypsum, took into solution some of the gypsum and continued downward to the anhydrite. As anhydrite is more slowly soluble than gypsum, it is possible that water ponded above the anhydrite bed. Brecciated zones within the Medicine Lodge gypsum occur at about the same horizon as the anhydrite; the porosity of the gypsum, and the presence of red clay along the brecciated zones indicate that these zones probably were formed by solution. The water in contact with the anhydrite may have hydrated part of the anhydrite to gypsum. The solution of gypsum and the hydration of anhydrite probably took place simultaneously, solution of the gypsum perhaps exceeding the hydration of anhydrite. The solution of the gypsum caused a decrease in volume whereas the hydration of anhydrite supposedly caused an increase in volume. In other words, the more rapid solution of gypsum may have provided space for the expansion resulting from hydration of anhydrite to gypsum. This may explain hydration of anhydrite without movement or distortion of the resulting gypsum. Some of the fractures within the anhydrite and gypsum were filled with gypsum veinlets, which have irregular shape and parallel matching walls. Other veinlets show gradation of anhydrite to gypsum, suggesting hydration. With continued simultaneous solution of gypsum and hydration of anhydrite, anhydrite may have been completely removed from parts of the anhydrite beds. The hydration and subsequent solution of the anhydrite may have left lenses of anhydrite and may account for the lateral discontinuity of the anhydrite bed. The gypsum originally taken into solution was partly deposited in fractures in the gypsum formation and partly redeposited in the shale below.

Summary

The Medicine Lodge gypsum member of the Blaine formation (Leonardian) crops out in Barber County, Kansas, and extends westward into Comanche County and southward into Oklahoma. The gypsum ranges in thickness from 10 to 30 feet, the maximum thickness being exposed in the Pioneer mine, Sun City. Anhydrite is exposed at the surface at only a few places in Barber County. In the mine, lenses of anhydrite occur within the gypsum about 10 feet above the base of the gypsum.

The regional dip is about 11 feet per mile to the southwest. Structural contours drawn on the base of the gypsum show slight local irregularities, which may represent initial dips or slump structure.

Where anhydrite is absent in the middle portion of the gypsum in the mine, breccia-filled solution channels generally are present at about the same horizon as the anhydrite. The gypsum in these zones is soft, porous, and sugary. Some red clay is present in the breccia zones. Anhydrite is not present in the lower or upper parts of the gypsum.

Petrographic studies show (1) local gradation of anhydrite to gypsum; (2) filling of fractures in the anhydrite with gypsum; (3)

cutting of anhydrite crystals by gypsum without disturbing the optical continuity of the anhydrite; (4) radial aggregates of the anhydrite; (5) gradation of the basal dolomite into the gypsum; (6) localization of dolomite in the lower part of the gypsum; (7) absence of anhydrite in the lower and upper parts of the gypsum; and (8) presence of iron oxide throughout the gypsum.

Field and petrographic studies indicate that both gypsum and anhydrite were original precipitates, part of the anhydrite subsequently hydrating to gypsum.

GYPSUM IN THE WELLINGTON FORMATION

At present no mines produce gypsum from the Wellington formation, but gypsum has been mined in the past from the Wellington formation at several places along its outcrop area.

The base of the Wellington, defined as the base of the shale above the top of the Herington limestone by Moore and others (1951), is exposed with almost complete continuity from northern Marshall County to southern Cowley County. The top of the Wellington is exposed only in the southern part of the state. Elsewhere it is covered by Cretaceous and younger sediments.

Gypsum beds genetically related to the Wellington formation are not restricted to the Wellington. There is evidence of gypsum directly below the Herington limestone in some places. These deposits are discussed with the Wellington gypsum deposits because of their close association and because they mark the beginning of conditions that caused deposition of gypsum in the Wellington.

Evidence for Gypsum in the Wellington Formation

There are several different types of evidence for gypsum in the Wellington formation. In addition to the direct evidence of exposures and drill-hole samples, indirect evidence consists of secondary gypsum or gypsite deposits and also the widespread subsidence structure throughout the Wellington outcrop area, which shows that some material, probably gypsum, has been removed by subsurface solution.

Gypsum Outcrops

Gypsum outcrops in the Wellington formation are rare, but some of them do give an indication of the thickness and character of the gypsum. Only the old gypsum-mining area of Saline and Dickinson Counties was thoroughly searched for gypsum outcrops and an attempt made to show them all on the map of the area (Pl. 2B).

Gypsum outcrops in other Wellington areas as well as some of those in the old mining area were located from descriptions in the literature or from directions given by local inhabitants.

Most of the outcrops found were in obscure places; therefore, other areas in the Wellington outcrop belt probably contain undiscovered gypsum outcrops. Nevertheless, the old mining area probably contains more gypsum outcrops in the Wellington than any other area of comparable size. These other areas probably are underlain by as much gypsum, but probably erosional conditions are not as favorable for exposure of the gypsum.

Surface Slump Structure Indicating Gypsum

The outcrop area of the lower part of the Wellington formation is marked by surface slump structure as indicated by the attitude of a sequence of thin limestone beds that dip in the direction of the topographic slopes (Pl. 10A). These limestone beds seem to be the most resistant units in a sequence containing gypsum, limestone, and shale; their presence at the surface, therefore, is an indication of the presence or former presence of gypsum near the surface.

Most of the limestones are tan or gray, soft, thin, regularly bedded, chalky limestone or siltstone. Less common are brown, hard, irregularly bedded limestones containing lenticular voids. One type of limestone may grade laterally into the other.

A surface map of Wellington rocks in a part of Saline and Dickinson Counties, where surface and subsurface information could be compared (Pl. 2B), was prepared from field information and from aerial photographs. The Herington limestone is mapped as the base of the Wellington formation. Although Moore and Landes (1937) mapped the Hollenberg and Carlton limestones, and Ver Wiebe (1937), in an area farther south, distinguished several additional limestones in the sequence, limestone beds in the lower part of the Wellington are not differentiated here because (1) all are so similar in character as to show no diagnostic feature that would permit recognition in isolated exposures, (2) exposures are poor; in many places the only evidence of the presence of limestone is a difference in color in a plowed field (Pl. 10B), and (3) the topographic position of a given bed varies with the degree of slumping, which adds to the difficulty of identification. The map shows their discontinuous distribution, indirectly indicating the slump structure.

Subsurface Evidence of Gypsum

Subsurface information about the Wellington formation is not readily available. In Kansas most subsurface information comes from the drilling of oil wells. As the Wellington formation is not oil bearing, few samples from the Wellington formation are saved. Electric logs of some exploratory holes drilled through the Wellington formation were made available for this report; the locations are shown on Plate 2B. These electric logs can be compared in order to trace the gypsum beds in the subsurface. Plate 2C is a series of cross sections made from electric logs provided by the Anderson-Prichard Oil Company. This series of cross sections shows that the beds of the Wellington are persistent in the subsurface and that the slumping that is so prevalent at the surface is superficial.

At depths below the influence of ground water, well samples of the Wellington formation are more usable. Well samples from the Wellington and other rocks between the Stone Corral dolomite (stratigraphically above the Wellington) and the Florence limestone (stratigraphically below the Wellington) were examined. Plate 3 shows a series of sample logs from the Wellington formation. The presence of salt casts in the samples is indicated at the right of each log. The wells are located in an approximately east-west line extending westward from the gypsum-mining area in Saline and Dickinson Counties, to show not only the sequence of beds in the Wellington formation and associated strata but also some relation of the surface exposures to the subsurface sequence. These logs, as indicated, are correlated only on the basis of either the Florence or the Stone Corral; nevertheless, a certain sequence is seemingly consistent in each log. The difference from one log to the next may, in part at least, be attributed to the amount of detail preserved in the samples, but other differences are certainly due to the change in the character of the rocks.

The sequence of deposits between the Florence limestone member and the Stone Corral anhydrite is summarized as follows: Above the Florence limestone member, at the base of the sequence, are limestone beds whose total thickness is 200 to 250 feet. These are overlain by 100 to 150 feet of anhydrite beds, overlain in turn by salt that in this area is as much as 250 feet thick. The beds above the salt are predominantly shale, but include some anhydrite or gypsum beds. Where measurable, this shaly zone is 350 to 400 feet thick. The sequence is terminated by the Stone Corral anhydrite where that bed is preserved from erosion. The Wellington formation itself is herein regarded as beginning with the base of the anhydrite beds and extending into the shale above the salt beds.

This description of the Wellington formation does not follow that of Moore and others (1951). They base their description on the Wellington outcrops, and show the formation as chiefly a shale sequence. The Wellington may actually contain proportionately more detrital matter at the surface in its eastern portion along the outcrop than it does farther west in the subsurface. Also, as shown in this report, the evaporite beds in the Wellington crop out in very few places; hence, a distorted impression may have been obtained as to the character of the Wellington. In any case, the Wellington, where studied in its undisturbed condition, seems to follow the sequence outlined above, and is not a predominantly shale sequence.

Gypsum Mines

Several companies operated gypsum mines in Kansas 50 years ago. Most of these mined gypsum from the Wellington formation. Many of these companies changed ownership several times and often changed names; moreover, some of the companies operated more than one mine at the same time or changed their location from time to time so that a single company may have had several locations. Records of the activities of some of these companies are to be found in the publications of the State Geological Survey and of the State Historical Society (Grimsley and Bailey, 1899; Haworth, 1898, 1899, 1900, 1902, 1902a, 1903, and 1904; Moore and Landes, 1926). Activities during the intervening years are not recorded, however, so information about some of these companies had to be obtained from persons who were familiar with the companies.

The information given here concerning the nature of the deposits, the products, and the types of industry they supported is as complete as possible; a historical report of what happened to one company or another is not attempted.

Gypsite Deposits

One reason for the early activity in mining gypsum from the Wellington formation was the ease of extraction of gypsum earth or gypsite deposits in various places over its outcrop belt. Gypsite is a secondary deposit of gypsum formed by the evaporation of ground water charged with calcium sulfate. This granular to earthy material accumulates at the surface, commonly in low, swampy ground. It dries to a light ash-gray color. It is soft and noncoherent, so it can be shoveled into cars and prepared for calcining at less expense than is required in working the solid rock.

By far the greatest number of gypsum mines in Kansas have been operated in deposits of this type; moreover, as far as is known they were limited to the Wellington formation. It is impossible to calculate exactly how much gypsum has been produced from deposits of this type, but it is thought that, owing to the relatively short period of operation of these mines, the figure would be small in comparison to the total amount of gypsum mined in the state.

Near the turn of the century these gypsite beds were important sources of gypsum for construction, and provided local employment for a large number of men. These deposits contained only a small amount of material, however, and were exhausted in a relatively short time. The fact that the material was gray rather than white after calcining possibly was another factor contributing to the abandonment of some of the deposits.

Gypsite deposits are not readily recognizable from a casual examination of the countryside. Even the sites of some of the old pits are now planted to crops or have reverted to swampland. The deposits, before they were mined, had soils developed on top of them and were not distinctive in appearance. It is reported that soil augers were used to prospect for them. Additional prospecting of this sort was not undertaken in connection with this report; only those deposits that are known to have been mined will be discussed here.

Gypsite is still used to make base-coat plaster (Ver Plank, 1952), but most of the Kansas deposits found in the past were exhausted after a few years of mining. Moreover, a plant operating under present conditions would process a larger quantity and would therefore require a much larger gypsite deposit than those previously mined in Kansas. Inasmuch as numerous mines once produced gypsite throughout almost all the Wellington outcrop area, there must have been an extensive search for these deposits. It is probable that most of the deposits have been discovered, and is doubtful that remaining gypsite deposits in Kansas are large enough to support an industry under present conditions.

Individual Deposits

The individual deposits of gypsum and gypsite in the Wellington formation are discussed in part on a geographic basis.

Gypsum in northeastern Clay County.—One of the thickest beds of gypsum known to be associated with the Wellington formation is exposed on a steep bank of a creek in the NW¼ SW¼ sec. 19, T. 6 S., R. 4 E., northeastern Clay County. This bed lies directly above the Herington limestone, that is, at the base of the Wellington formation, according to C. K. Bayne and K. L. Walters (personal communication). The base of the bed is covered but 8 feet of solid gypsum is exposed here.

Longford gypsite deposit. — Longford, in southwestern Clay County, was once the site of a plant that processed gypsite mined from a nearby deposit. The Longford plant and deposit are typical of the operations of the time; pictures of the pit and plant in operation are available so we have a good idea of the manner in which these gypsite deposits were mined (Pl. 11).

The Longford plant, opened in 1895, operated more or less continuously until it burned in 1903 or 1904. This halted production until a new plant could be built two or three months later. The rebuilt plant operated until 1912, when it was dismantled and moved to Blue Rapids. The plant had three kettles and was reported to have produced as much as 100 tons a day. The product was typically gray.

The gypsite deposit was situated in the SW¼ sec. 24, T. 10 S., R. 1 E. Disks were used to loosen the material, then horse-drawn scrapers were used to dig the material out of the pit. At first, wagons were used to haul the material from the pit to the plant, but later a narrow-gage railroad was built (Pl. 13).

There is a small outcrop of rock gypsum in a plowed field in the NE¼ sec. 25, T. 10 S., R. 1 E., indicating the source of the material in the gypsite deposit. There should be a deposit of rock gypsum close to the surface in the area. Drilling would be required to locate the bed and determine its continuity. The nearest outcrop of Herington limestone (Moore and Landes, 1937) is some distance to the east, suggesting that this gypsum bed is fairly high in the lower Wellington.

Deposit northeast of Solomon.—Latta (1949, p. 108-109) records several beds of gypsum in holes drilled northeast of Solomon. He was interested primarily in ground-water conditions in the Smoky Hill valley; consequently most of his holes penetrated only a few feet of bed rock below the alluvium. Those northeast of Solomon were an exception, as more than 80 feet of Wellington formation was drilled in some holes. The following logs are reprinted from his report.

"67. *Sample log of test hole at the SE cor. sec. 34, T. 12 S., R. 1 E., Dickinson County; drilled by the State Geological Survey, 1944. Surface altitude, 1,310.3 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand		
Sand, fine to medium; contains some gray-brown silt	14	14
Terrace deposits (Pleistocene)		
Silt, sandy, mottled tan and gray green; contains some fine gravel in lower part	10	24
PERMIAN—Leonardian		
Wellington formation		
Shale, soft, gray green, yellow buff, and gray white	23	47
Shale, soft, dark gray, and blocky light-gray and green-gray shale	23	70
Shale, soft, light green gray	10	80
Clay, soft, green gray, and light- to dark-gray shale	10	90
Shale, partly calcareous, light to dark gray and red brown	10	100
Gypsum, massive to crystalline, white to transparent, and some gray and red-brown shale	20	120

"68. *Sample log of test hole at the SW cor. sec. 2, T. 13 S., R. 1 E., Dickinson County; drilled by the State Geological Survey, 1944. Surface altitude, 1,302.7 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand		
Sand, fine to medium, silty, tan and gray	15	15
Terrace deposits (Pleistocene)		
Sand, fine to coarse, and brown silt; contains some fine to medium gravel	6	21
PERMIAN—Leonardian		
Wellington formation		
Shale, blue gray, gray green, and cream; contains few thin veins of calcite	59	80
Shale, dark blue gray	18	98
Gypsum (?). No sample, due to loss of circulation. Possibly a solution channel in gypsum	2	100

"69. *Sample log of test hole in the SW cor. sec. 11, T. 13 S., R. 1 E., Dickinson County; drilled by the State Geological Survey, 1944. Surface altitude, 1,258.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand		
Sand, fine to medium, and light-brown silt	6	6
Terrace deposits (Pleistocene)		
Silt, sandy, tan and light gray to gray black	14	20
Sand, fine to medium, and clayey gray-green and tan silt	9	29

	Thickness, feet	Depth, feet
Clay, silty, soft, gray brown to tan; contains some fine to medium sand	17	46
Sand, fine to coarse, and fine to medium gravel; contains caliche and many pebbles of sandstone and ironstone in lower part. Thin cemented zones at 56 and 58 feet,	14	60
PERMIAN—Leonardian		
Wellington formation		
Shale, gray green, and soft blue-gray clay	16	76
Clay, blue gray and brown, and some blue-gray shale	12	88
Gypsum, massive, white and gray, and thin beds of hard, partly calcareous gray shale	12	100

"72. *Sample log of test hole in the NW¼ NE¼ SW¼ sec. 23, T. 13 S., R. 1 E., Dickinson County; drilled by the State Geological Survey, 1944. Surface altitude, 1,174.8 feet.*

	Thickness, feet	Depth, feet
QUATERNARY		
Dune sand		
Sand, fine to medium, silty	20	20
Terrace deposits (Pleistocene)		
Silt, sandy, clayey, light brown to light gray	7	27
Sand, fine, to medium gravel	9	36
PERMIAN—Wolfcampian		
Shale, red and bright gray green	4	40
Shale, red, gray green, and blue gray; containing thin beds of limestone and gypsum	8	48
Limestone, hard, white, and hard, white to gray-white shale	6	54

PLATE 12. Outcrop of gypsum at old Solomon mine on Gypsum Creek in sec. 3, T. 14 S., R. 1 W., Saline County. Prominent white bed is number 4 in Fig. 8.

Gypsum Creek deposit and Solomon mine.—In the SE¼ sec. 3, T. 14 S., R. 1 W., in Saline County on the banks of Gypsum Creek near its junction with Smoky Hill River is the best exposure of gypsum (Pl. 12) in the Wellington formation known to exist. It is one of the few places where a measurable bed of Wellington gypsum crops out. Figure 8 is a columnar section of this outcrop.

This outcrop was the site of a gypsum mill and an underground mine known as the Solomon mine. Grimsley and Bailey (1899, p. 58) give the following description of the mine.

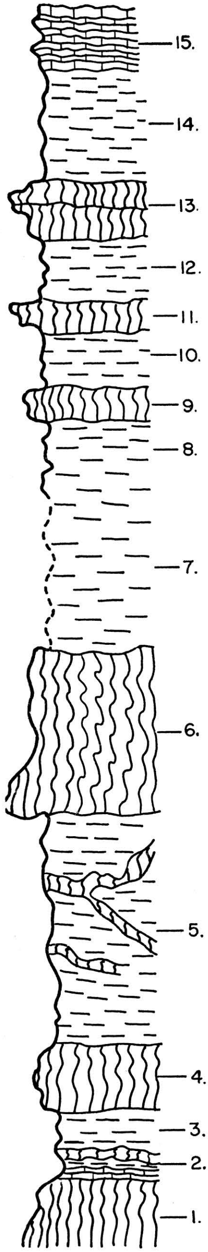
"The mine entrance is 15 feet above the water in the creek, and the stratum worked is 5 feet thick, underlaid by about 4 feet of shaly limestone. Below this there is a series of shales with a 3-foot stratum of gypsum. The roof of the mine is a compact, dark shale with a thickness of 3 feet. Above this come 2½ feet of buff shales and 2 feet of gypsum. There is an alternation of shales and gypsum to the top of the hill. The shales with the intercalated gypsum layers are folded and broken. The folds extend down into the mine, causing the shales of the roof to cut out the gypsum in many places, so that the mine has now, in 1898, been abandoned. The dip of the gypsum is north, toward the creek."

The bed mined here was called Solomon gypsum by Grimsley and Bailey.

According to local inhabitants this mine was opened about 1885 or 1886. Plaster from the mill was hauled in wagons approximately 6 miles overland to the railroad at Solomon. This economic disadvantage was offset by the high quality of the product processed from rock gypsum, in comparison to that made from the gypsite obtained from other mines that were operating at that time. The mill also processed gypsum obtained from a few surface quarries in the area. This gypsum seems to have come from a bed approximately 100 feet higher than the bed in the mine. A small community is said to have existed near the site of the mine and the mill. The mill's equipment was moved to Hope about 1900, and the building was destroyed by a tornado in 1949.

Gypsum is also known to occur in beds below the alluvium of the nearby valley of Smoky Hill River stratigraphically below beds exposed on the banks of Gypsum Creek. If the correlations made later in the report are correct, these beds lie somewhat below the Herington limestone and thus below the Wellington formation.

Gypsum near Salina.—Gypsum was once mined in the SW¼ sec. 29, T. 14 S., R. 2 W., southeast of Salina. Large blocks of gypsum can still be seen at the quarry site along the west end of the fence line between the north and south halves of the section.



	Bed	Thickness, feet
15.	Limestone or siltstone, tan, thin-bedded	2.0
14.	Shale, variegated	3.5
13.	Gypsum, dark-blue	2.0
12.	Shale, blue	1.7
11.	Gypsum, dark-blue and pink	1.0
10.	Shale, gray	1.5
9.	Gypsum, white, bedded	1.0
8.	Shale, blue-gray	2.5
7.	Covered	4.0
6.	Gypsum, white, massive, hard, contains dark selenite crystals at the base	4.5
5.	Shale, gray-green, cut by veins of satin spar	7.0
4.	Gypsum, white or yellowish-white, massive, contains selenite crystals (ave.)	2.0
3.	Shale, gray-green	1.1
2.	Shale and gypsum, alternating thin beds	2.2
1.	Gypsum, black to gray, laminated	2.0

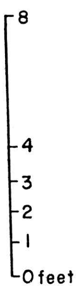


FIG. 8. Stratigraphic section of Wellington gypsum exposed on the bank of Gypsum Creek, sec. 3, T. 14 S., R. 1 W. Bed 6 was mined in the Solomon mine.

Records show that gypsum may have been quarried on a commercial basis here as early as 1887. Operations are known to have ceased by 1907. Some of the gypsum was used as building stone and some is said to have been made into stucco.

No gypsum outcrops other than the quarried blocks were seen at this locality; slump structure can be observed here, indicating solution of the gypsum in the subsurface.

Hope Mine.—The mine that became known as the Hope mine is situated in the SE¼ sec. 32, T. 15 S., R. 3 E., southeastern Dickinson County, and operated in rock gypsum (Pl. 14). More than one bed of gypsum was mined here.

According to Grimsley and Bailey (1899, p. 59-60), gypsum mining west of Hope began in 1887.

"They first used the middle stratum, quarried near the top of the hill, one and one-half miles west of town. [Evidence indicates that quarrying was done on more than one hill.] The rock is about 5 feet thick, and lies 10 feet below a buff, shaly limestone. The gypsum is white and compact in texture, except near the surface, where it is rendered granular and more or less colored as a result of weathering. The satin spar associated with it is of clear white color when viewed from the side, and viewed from above it possesses a cream-white tinge. Over the gypsum is a thin deposit of black, impure, shaly gypsum.

"In 1894 the company abandoned this quarry, and sank a shaft a quarter mile west of the quarry, 80 feet in depth, to the lower stratum, which is nearly 14 feet thick. The rock is white, though much of it is traversed by wavy dark lines which lie close together, giving an appearance somewhat like granite or gneiss, so that plaster made from it is called by the company 'granite cement plaster.' The lower part of the stratum is compact, and contains rounded crystals of selenite, with dark mottled surfaces. It thus bears a close resemblance to the Solomon gypsum, already described, although the crystals are usually large, averaging about two inches by one."

Gypsum City gypsite deposit.—The Gypsum City mine operated in a gypsum deposit located in the NE¼ sec. 26, T. 15 S., R. 1 W., Saline County. Grimsley and Bailey (1899, p. 63-64) report:

"The first deposit was discovered in the spring of 1873 near Gypsum City, by Mr. John Tinkler, in running a fire-guard around a field. . . . In 1889 he with others formed the Saline County Plaster Company and built a mill at the edge of town. This was afterwards sold to the Acme Cement Plaster Company, but they no longer use the mill or deposit. In 1892, 7000 tons of plaster were sent from this mill to Chicago for the World's Fair buildings and a medal was awarded the company in recognition of the qualities of their plaster. It has been used in the government buildings at Forts Riley and Leavenworth, and the product has been shipped to all parts of the United States.

"The Tinkler deposit covers an area of twelve acres, and lies close to the surface with little or no cover. It lies in the valley of a small creek tributary to Gypsum creek. The maximum thickness is 17 feet, while the average is 8. The dirt was hauled in wagons to the mill, one and one-half miles away. The appearance of the deposit resembles very much a fine sand bed or loess formation, and there is a tendency to break in smooth planes or joints. Organic matter occurs through it, and underneath is a layer of clay, and below the clay is a deposit known as the *black gypsum,* regarded as worthless. Strong springs break through the deposit on the east side. The top of the gypsum earth is 20 feet above the water in Gypsum creek, a quarter of a mile to the west. In a well dug on the hill above the deposit rock gypsum of good quality was struck 30 feet down, or 20 feet below the top of the earth. No trace of gypsum was found in the hills above the earth deposit."

The mill in Gypsum City is reported to have burned in 1890. It was rebuilt and operated until 1896. It is not clear why the mine and mill were shut down, but it is probable that they exhausted either the good material or the easily accessible material, as the Acme Cement Plaster Company had operations elsewhere at the time and seemingly needed more deposits.

Dillon gypsite deposit.—The Dillon gypsite deposit is situated in the NE¼ sec. 1, T. 16 S., R. 2 E., Dickinson County. It is described by Grimsley and Bailey (1899, p. 64). This deposit resembles that at Gypsum City. It covered at least forty acres in swampy ground, near a small creek. Its greatest thickness was 18 feet. Gypsum rock crops out about ¼ mile away at nearly the same altitude. The gypsite was worked by plow and scraper, dried for a few days, and loaded into cars and hauled to the mill, one-half mile north. The mill seemingly was opened about 1896 by the Agatite Company, the same company that operated the Longford deposit. The Dillon mill is known to have closed before the Longford mill, some time before 1912.

St. Joe mine.—The old mine known as the St. Joe mine is located in the NE¼ sec. 14 and SW¼ sec. 13, T. 16 S., R. 2 E., Dickinson County. A mine and mill operated on this site. The plant ceased operating about 1908. It is not known when it began operation but probably the date was not long before 1899. Both gypsite from a pit and rock gypsum from an underground mine were used. The rock gypsum crops out in a road cut but the mine operated from a shaft started on top of a hill and sunk 80 feet to the gypsum bed. It is reported that the plant shipped out about a carload of plaster a day. Presumably the surface operation is the Aluminite or Aetna property.

Seemingly Grimsley and Bailey (1899, p. 65) do not mention the mining of rock gypsum in their description of the gypsite of the Aluminite or Aetna deposit:

"The cover is 10 feet thick, and the deposit is 5 feet, but near the top is a layer of 20 inches of sand and gypsum, which sets too quickly, and so is thrown out. Gypsum rock is not reported below this, but a heavy deposit is found on the hill about 30 feet above the gypsum earth. The material from this deposit is hauled to the mill close by, and is the property of the Aetna or Aluminite Cement Plaster Company."

Rhodes gypsite deposit.—A gypsite mine operated at a place called Rhodes in sec. 3, T. 17 S., R. 2 E., Marion County. Grimsley and Bailey (1899) reported that the deposit was 6 to 10 feet thick and that a bed of rock gypsum lies close to the surface at this point. A mill was built on the site of the mine and operated from about 1892 until 1898. Plaster was hauled from the mill either southwest to Tampa or north to Elmo and was shipped by rail from those places. Rock gypsum from a quarry in the NE¼ sec. 4, T. 16 S., R. 2 E., near Elmo, was also processed at this mill.

Henquenet cave.—The Henquenet cave, in the SE¼ sec. 33, T. 16 S., R. 3 E., is formed in gypsum. Grimsley and Bailey (1899, p. 61) describe it:

"The lower 8 feet of the gypsum is veined and spotted, and the polished slabs bear some resemblance to onyx, while the upper 2 feet exposed is fine grained and compact, like alabaster. This layer is covered by 15 feet of shales and 10 feet of the buff shaly limestone. A small stream flows into this cave after heavy rains, and the outlet is not known. This cave is continued eastward for sixty feet as a ravine, with gypsum walls, while the roof has caved in and for a considerable distance has been removed."

Gypsum had been mined at the cave by the U. S. Gypsum Company before the cave was sealed off. In the spring of 1954 it was opened again.

Gypsum near Peabody.—Grimsley and Bailey (1899, p. 67) gave the following report on gypsum near Peabody.

"In 1885 the Peerless Cement Plaster Company built a mill on the farm of Mr. Dean, five miles west of Peabody. The mill was in operation about two years and then abandoned and the machinery sold. The rock was hauled from Liberty creek, one and one-half miles north of the mill, from section 34, East Creek township. There were 2 feet of good gypsum covered by 30 feet of dirt and impure rock, and underlaid by clay. The product is said to have been of high grade and was used throughout the neighborhood. A few years ago gypsum earth was discovered in this same area, covering fifteen acres on the Dean and Brown farms, with a maximum thickness of 7 feet."

The first deposit was in sec. 34, T. 21 S., R. 2 E., on what is now known as Doyle Creek. Records show that the Dean farm was located in the SE¼ sec. 10, T. 22 S., R. 2 E., and the Brown farm was in the SW¼ sec. 11, T. 22 S., R. 2 E.

Gypsum near Annelly.—Grimsley and Bailey (1899) reported that gypsum of good quality was found in wells at and near Annelly at a depth of about 30 feet. Ver Weibe (1937) designated the gypsum beds at Annelly as a stratigraphic subdivision of the Wellington. He reported three beds of gypsum each 3 feet thick exposed on a high cliff on the west branch of Whitewater River in sec. 15, T. 24 S., R. 2 E. Altogether the sequence measures 13 feet from the top of the top gypsum bed to the bottom of the bottom gypsum bed. He reported that this sequence could be traced for a considerable distance throughout the southern part of its outcrop areas. No detailed work was done on the Wellington formation in this area in connection with this report.

Burns gypsite deposit.—Grimsley and Bailey (1899, p. 67-68) reported this of the gypsite deposit near Burns, Kansas.

"Seven and a half miles southwest of Burns, close to Davis creek, in Butler county, Mr. Gottlieb Heller has opened a gypsum earth deposit which will average 6 feet thick over about two acres of land, and a lesser thickness over a much larger area beyond. The deposit is covered by a thin layer of soil, varying from 1 inch to 2 feet in thickness. Where Davis creek cuts through the gypsum the deposit is about 9 feet, and has a jointed structure, breaking out in large blocks. No gypsum rock is found in the region above this gypsum earth deposit, nor is any reported from the wells in that vicinity, so that as far as is known there is none lying below the deposit. It is whiter in color than any of the other deposits known in the state. Under the microscope it is found to be almost entirely composed of minute yet very perfect crystals of gypsum of uniform size. These crystals are more perfect in form than any others which have been examined from the gypsum earth beds.

"A mill of two-kettle capacity has been erected, and began operation with one kettle early in December, 1898, with a prospect of starting the second kettle soon. This mill is erected at Burns, on the El Dorado branch of the Atchison, Topeka, & Santa Fe railway."

The mill at Burns ceased operation in 1904 or 1905. The gypsite pit, near the center of sec. 16, T. 22 S., R. 4 E., lies topographically below the base of the Herington limestone. The source of the gypsite therefore is probably some bed stratigraphically below the Herington (below the base of the Wellington).

Geuda Springs deposit.—Grimsley and Bailey (1899, p. 69) describe gypsum beds about four miles northwest of Geuda Springs, Sumner County. Rock gypsum cropped out along the banks of a small stream in the W½ SE¼ sec. 27, T. 33 S., R. 2 E., where some was obtained for the erection of a large business block in Wellington, generally known as the "marble block".

The beds were known to be at least 15 feet thick, but the base was covered by soil. Well drillers who were interviewed by Grimsley reported that in almost every well for miles around they found gypsum 2 to 6 feet thick.

Grimsley and Bailey described a sizable deposit of gypsum here, but no outcrops of gypsum could be found in this area in the summer of 1953; nevertheless throughout the area there are surface indications of slumping.

Mulvane gypsite deposit.—A gypsite mill operated at Mulvane briefly. Its raw material was obtained from a deposit in the NE¼ sec. 32, T. 29 S., R. 2 E., described by Grimsley and Bailey (1899, p. 68).

> "The material covers an unusually large area along a little stream which cuts through the bed of the deposit, exposing it along the banks, where in places it reaches a thickness of 12 feet or more. It has been estimated that there is enough of the material to produce nearly half a million tons of the manufactured plaster. The quality of the gypsum earth compares favorable with that found elsewhere, . . .
>
> "A company has been formed to manufacture the plaster, and mills are in the process of construction which will be in operation by the 1st of January, 1899. . . ."

Haworth (1902a) reported that the mill closed in 1901.

Sumner County.—Bass (1929) found the sequence of lower Wellington rocks in Cowley County too poorly exposed at the surface to decipher. He found only 80 feet of Wellington exposed in Cowley County, but included in his report the plotted log of a hole drilled in the southeastern part of Sumner County, which lies to the west of Cowley County. This log, slightly modified, is included in this report to show the nature of the gypsum beds in that area (Fig. 9).

Gypsum indicated in Highway Commission drill holes.—The State Highway Commission has furnished information about drill holes that have encountered gypsum at various locations. Information from some holes that penetrated gypsum in the Wellington formation is included here.

Location	Depth, feet
Cen. E. line 21-19-2E	34.6 to 40.0 feet, gypsum; 40.0 to 41.5, gray shale; 41.5 to 43.7, gypsum
NW¼ NW¼ 9-20-3E	38 to 49 feet, interbedded gypsum and shale, 75 percent gypsum
SE cor. 29-19-2E	5 to 12 feet, gypsum
Hydraulic St. Crossing of Arkansas River in Wichita	30 to 60 feet, thin gypsum beds [in shale]

These holes do not reveal any gypsum beds of great thickness, but most of them are fairly shallow or penetrate gypsum lying below alluvium and therefore subject to solution. No attempt was made

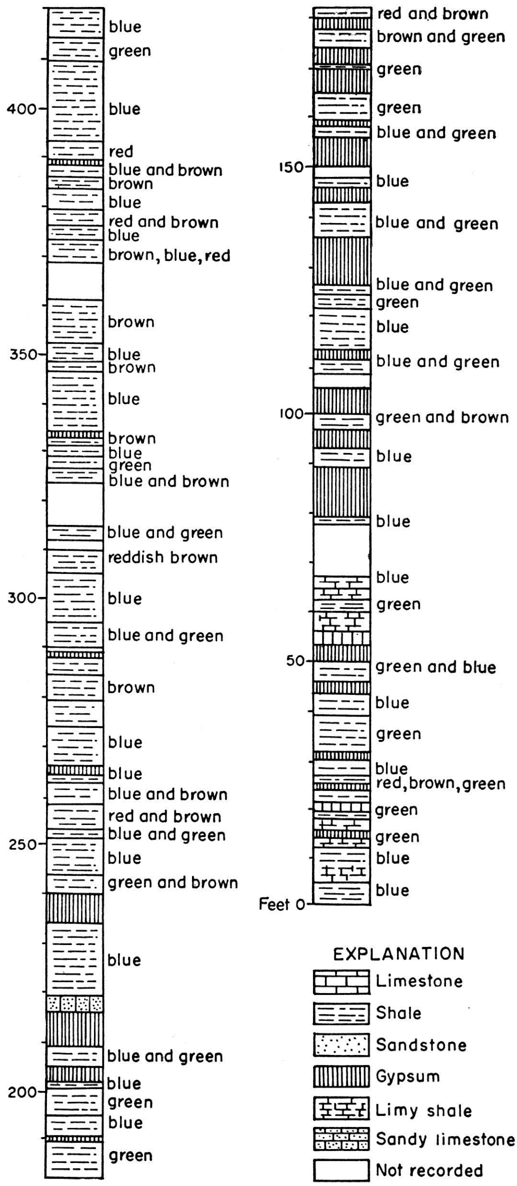


FIG. 9. Section of lower part of Wellington formation as recorded in core-drill hole in southeastern Sumner County. Modified from Bass (1929).

to correlate the gypsum beds found in these holes except to determine that they occur in the lower Wellington.

Stratigraphic Position of the Gypsum Beds in the Wellington Formation

Relation of Gypsum-Anhydrite Beds to Wellington Salt Beds

Two conflicting opinions have been expressed concerning the stratigraphic relationship of the Wellington gypsum beds to salt beds. One opinion is that the gypsum beds change laterally to salt beds. The other is that the gypsum-anhydrite beds are a separate unit and lie stratigraphically below the salt beds.

Bass (1929, p. 101) has interpreted the gypsum-anhydrite beds as a lateral facies of the same age as the salt beds. He states:

"E. L. Jones, of the Roxana Petroleum Corporation, kindly supplied a few logs typical of the region and called attention to those beds that are particularly persistent throughout extensive areas and to the fact that beds of salt, so characteristic of the Wellington formation in the vicinity of Hutchinson and elsewhere in central Kansas, change laterally southward and eastward to interbedded salt and gypsum and finally to beds of gypsum."

Lee, Leatherock, and Botinelly (1948, p. 111) interpreted the gypsum-anhydrite beds as being separate from and lying below the salt beds. They state:

"The combined thicknesses of the parts of the Wellington above and below the salt lentil are essentially the same as outside the area of salt deposition. The salt therefore accumulated in a basin formed by the downwarping of the nearly flat surface of the 'anhydrite zone'."

Data presented here support the view that the gypsum-anhydrite beds are a stratigraphic unit separate from the salt beds (Pl. 3). Electric logs of the shallow holes in the outcrop area show nearly the same thickness of the gypsum-anhydrite beds as do the sample logs (Pl. 2C). Cross sections of the Wellington shown by Norton (1939), Lee, Leatherock, and Botinelly (1948), and Lee (1949, 1953) further bear out this relationship throughout much of the Wellington in the subsurface.

Correlation of Individual Gypsum Beds

Workers previously have correlated gypsum beds in the Wellington formation on the basis of elevation and lithology. These correlations have value to us today because more information was available at the time the correlations were made than is available now. Much less reliance could be placed on them. however, were it not for the fact that correlation of electric logs (Pl. 2C) demonstrates undisturbed relationship of the beds in the subsurface, in contrast to the local disturbance of outcrops as a result of surface slumping.

Cragin (1896) correlated gypsum beds that cropped out near Salina with gypsum beds at Hope, but Grimsley and Bailey (1899) and Haworth (1920) have mentioned that there are two gypsum beds at Hope that are stratigraphically 100 feet apart and it is not clear to which bed Cragin refers. Cragin's correlation traverses 13 miles from Salina to Solomon and then more than 20 miles to Hope. Cragin states that he used the strike and dip of the beds exposed at Salina to make this correlation; he does not indicate whether or not he used information from the intervening area.

On the basis of the elevation and lithology, Grimsley and Bailey (1899) correlated the bed mined 80 feet below the surface in the Hope mine with the beds cropping at the mouth of Gypsum Creek. At both of these places higher gypsum beds occur also. At the Hope mine these higher beds are at slightly higher elevation than the surface at the old mine shaft. This gypsum was quarried from several pits before the deeper bed was mined. Near the Solomon mine and the mouth of Gypsum Creek a higher bed is exposed in a field in sec. 2, T. 14 S., R. 1 W., less than a mile east of the beds that crop out at Gypsum Creek. If the lower bed at the two places is correlative, it should follow that the higher beds are the same. North of the Solomon mine at Gypsum Creek, however, a bed of gypsum is known to exist below the level of the valley of Smoky Hill River. As the beds at Gypsum Creek crop out at a higher elevation than the valley floor, and the beds in the valley of Smoky Hill River occur below the alluvium, the subsurface beds are an additional series. If the preceding correlation is correct, there is no known counterpart of these additional beds near Hope; moreover, this lower deposit near Gypsum Creek would lie below the Herington limestone. Slumping of the Herington limestone in some places on the outcrop likewise is evidence that it is underlain by gypsum.

If these correlations are correct, the area between Gypsum Creek and the Hope mine should be underlain by beds of gypsum existing in both areas. The gypsum that crops out at the old St. Joe mine in sec. 13, T. 16 S., R. 3 E., seems to correlate with that in the old Hope mine. The lithology is similar to that described by Grimsley and Bailey (1899) and the bed is at the correct elevation. The beds known to be present in the subsurface along the Dickinson-Marion County line correlate, on the basis of their position, with the bed at the surface near the Hope mine, or possibly represent a higher bed.

The individual beds in the area of Gypsum Creek are not as easy to trace. Nevertheless, evidence of gypsum can be found up the valley of Gypsum Creek as far south as the Saline-McPherson County line. The valleys of Holland Creek and Turkey Creek, the two principal tributaries to Smoky Hill River between the two areas of Grimsley and Bailey's correlation, also show evidence of the presence of gypsum, but no correlation of individual beds is possible.

As far west of Gypsum Creek as Salina, where gypsum has been quarried, there are indications in the subsurface of gypsum below the Wellington (and below the thin covering of Dakota formation in some areas), but it is not possible to trace individual beds throughout the area.

The outcrop area of these beds is much broader than that of any of the stratigraphic units of similar thickness below the Wellington, as found farther east in the state. Therefore, either (1) the regional dip of the Wellington beds is less than that of beds underlying it and exposed farther to the east, or (2) the section of beds is thicker than can be accounted for by the correlations made.

Conclusions Regarding Stratigraphy

Surface and shallow subsurface data (outcrops, slump structure, electric logs of shallow holes, and old mines) show that the gypsum beds in this area occur in a zone directly above the Herington limestone, and seem to correlate with the anhydrite zone found in deep holes farther west (Pl. 3), supporting the proposal of Lee, Leatherock, and Botinelly (1948) that the salt section overlies the gypsum and anhydrite zone, rather than being stratigraphically equivalent. The gypsum-anhydrite beds are a definite zone that should be traceable throughout the outcrop area of the Wellington formation, although individual beds of gypsum may not. This zone in the lower Wellington may contain abundant gypsum resources.

Relation of Gypsum to Anhydrite

In Plate 3 it can be seen that the gypsum deposits found in Dickinson and Saline Counties occupy the same stratigraphic position as the anhydrite deposits found below the salt deposits farther west. The regional dip is to the west, hence this calcium sulfate zone is progressively deeper in that direction. This relationship of gypsum to anhydrite could be explained as resulting from the surficial alteration of an anhydrite bed to gypsum, or by original deposition. If gypsum were formed by original deposition in the Wellington formation, however, the possibility still remains that some gypsum was formed by the alteration of anhydrite.

Hydration of an Anhydrite Bed

The simplest explanation of the field relationships outlined above is that the gypsum was formed by the alteration of an extensive anhydrite bed. Anhydrite is known to be altered to gypsum in this way (Bailey, 1932; Newland, 1921; Muir, 1934). Other than the field relationship, however, there is little evidence that would support this explanation.

Observations of well samples left much to be desired in determining the origin of the Wellington gypsum. The cuttings are too fine to reveal the genetic relationships between the gypsum and anhydrite, and furthermore, the gypsum in the samples shows signs of being partly dehydrated, either during the drilling process or during the drying of the samples. This dehydration aided in distinguishing gypsum from anhydrite in the samples, but it destroyed the crystalline structure of the gypsum.

The gypsum beds crop out in very few places, but the outcrop at Solomon mine is an excellent exposure of some of the beds, in which their relationship to one another can be observed (Fig. 8, Pl. 12).

Several of the gypsum beds contain large selenite crystals (Pl. 15A), which Grimsley and Bailey (1899) interpreted as being formed by primary deposition. Their evidence that these crystals were formed by original deposition is not conclusive; rather, indications are that the selenite crystals are secondary rather than primary. A polished section of a piece of gypsum from the exposure on Gypsum Creek (Pl. 15A) shows that the selenite crystals cut across the structure in the rock gypsum, indicating that the selenite crystals were formed during recrystallization rather than during original deposition. It cannot be determined whether the recrystallization took place during a change from anhydrite to gypsum or during recrystallization of the gypsum.

Crenulated gypsum found at the outcrop at Gypsum Creek was first interpreted as having possibly been formed by the expansion of the beds during the formation of gypsum from anhydrite. Closer inspection, however, revealed that not all the laminae are crenulated and that the contorted beds lie between relatively straight beds (Pl. 15B). Such features as these seem more logically interpreted as deformational structures formed penecontemporaneously with the deposition of the calcium sulfate. R. H. King (personal communication) states that such features in the Castile anhydrite beds are still preserved in gypsum formed by hydration of the anhydrite. These features, therefore, do not reveal whether the gypsum was deposited as such or subsequently altered from anhydrite.

Original Deposition of Gypsum

As already discussed, either gypsum or anhydrite may be deposited from an evaporating body of sea water, depending upon the salinity and temperature. On the outcrop the Wellington gypsum beds are interspersed with clastic rocks, showing that there was some fresh water runoff from land that lay east of the present outcrop.

When fresh water flows into a body of salt water, it does not mix immediately. The fresh water has a lower specific gravity and therefore remains as a layer on top of the salt water (Scruton, 1953). Unless there is mechanical mixing, diffusion is the only means by which material in solution may be dispersed into the fresh water, thereby reducing the salinity of the salt water. Wave action is the principal cause of mechanical mixing in an evaporation basin, but it cannot operate below wave base. This means that much of the fresh water entering the basin would merely lie at the surface and evaporate without a chance to decrease salinity near the bottom where the solid calcium sulfate had come to rest. Nevertheless, the possibility remains that in the basin of Wellington evaporite deposition the edge of the basin was receiving enough fresh water to change the salinity of the environment intermittently.

Fresh water added to a basin where gypsum was being deposited should dissolve previously precipitated gypsum until saturation with respect to calcium sulfate is again reached. At this point the water would be capable of precipitating calcium sulfate immediately when evaporating conditions again dominate. If anhydrite is being deposited in the basin, addition of fresh water would dissolve some of the previously precipitated anhydrite. Solution of calcium sulfate would continue until the saturation point was reached. If, however, the addition of fresh water lowered the salinity of the sea water to a point where gypsum rather than anhydrite were the stable form of calcium sulfate, at least part of the anhydrite would be converted to gypsum. Deposition of calcium sulfate (as gypsum) could proceed immediately when evaporating conditions again dominate. It is thus theoretically possible that in Wellington time gypsum was deposited near the edges of the basin and anhydrite in the center.

Conclusions Regarding the Relationship of Gypsum to Anhydrite

The Wellington gypsum beds grade downdip into anhydrite beds. There are two possible explanations for this relationship, (1) the hydration of an anhydrite bed, and (2) original deposition of gypsum as a near-shore facies and anhydrite as a deeper-water facies. The two explanations are not necessarily mutually exclusive. There is no conclusive evidence that gypsum was formed by original deposition; furthermore, this mode of origin requires a much more complicated explanation. Because of the general lack of information about the actual relationships, however, this possibility cannot be eliminated.

Summary

A broad area in the outcrop belt of the Wellington formation is underlain by gypsum, as indicated by slump structures and a few outcrops. Although surface evidence is lacking, subsurface evidence indicates that the anhydrite-gypsum zone of the Wellington formation is stratigraphically directly below the salt, that is, gypsum and salt were deposited successively, not contemporaneously. The anhydrite-gypsum zone seems to be found in all places where the lower part of the Wellington formation is present. Although genetic relationships are not entirely clear, this zone comprises anhydrite at depth and gypsum close to the surface.

Electric logs from a series of shallow drill holes in southeastern Dickinson County indicate that the gypsum beds are persistent, maintaining their stratigraphic position with respect to the underlying limestone. Slump structure seen at the surface does not continue into the subsurface.

Future Possibilities of Gypsum Mining in the Wellington Formation

Gypsum is known to occur throughout much of the Wellington formation, but information about individual beds is scanty, mainly because of lack of outcrops. The depth to which solution has affected these beds also is unknown, and probably is not uniform. The fact that the gypsum crops out in some places should mean that there are other places where gypsum lies just below the surface. On the other hand, drilling by Midwest Research Foundation during the summer of 1953 demonstrated that the gypsum beds are dissected by solution channels at some places where they lie close to the surface; therefore it is difficult to find a large deposit near the surface.

If the gypsum in the Wellington was formed by hydration of an anhydrite bed, the depth to which water penetrates is a limiting factor. A gypsum bed formed by hydration of a bed that was deposited as anhydrite would probably be preserved closer to the surface—it would be less soluble than a bed originally deposited as gypsum because its first reaction to fresh water would be hydration, not solution. If original deposition is the controlling factor, the quantity of gypsum present could be larger (any anhydrite bed within the zone of weathering would still be subject to hydration whether or not it was deposited in association with gypsum).

Additional data on position, thickness, quality, and extent of the individual beds must be obtained before any large-scale exploitation of Wellington gypsum beds can be attempted. Subsurface exploration by drilling in and just west of the Wellington outcrop area probably would be most satisfactory. At the present time the potentialities of this area seem large, inasmuch as the thick section of anhydrite underlying the salt beds may grade laterally into gypsum where subjected to hydration by ground water.

GYPSUM IN THE EASLY CREEK SHALE

Mining of gypsum in the Easly Creek shale is limited to the area surrounding Blue Rapids, Kansas. The city is situated in the southwestern part of Marshall County, about a mile southeast of the junction of Big Blue and Little Blue Rivers, at an elevation of approximately 1,160 feet. The population in 1950 was 1,430. Blue Rapids is connected to Marysville, 11 miles to the north, by the Union Pacific Railway, and by U. S. Highway 77. The Missouri Pacific Railway and Kansas Highways 9 and 113 also provide transportation facilities in this area (Fig. 10).

Gypsum Production at Blue Rapids

The only operating mine in the Blue Rapids area is the Certainteed Products Corporation Mine. The mine has recently (1954) been mechanized. Since mechanization the gypsum has been mined according to the system shown in Figure 11. Gypsum was formerly mined to the overlying shale bed, but since the mechanization a foot and a half of gypsum is left for a roof.

Except for the diesel locomotive, all equipment is electrically operated. The 20-foot rooms are undercut, drilled, and shot in the pattern shown in Figure 12. A mobile twin drill is used. The mine has two undercutting machines, which are carried on cat trucks.

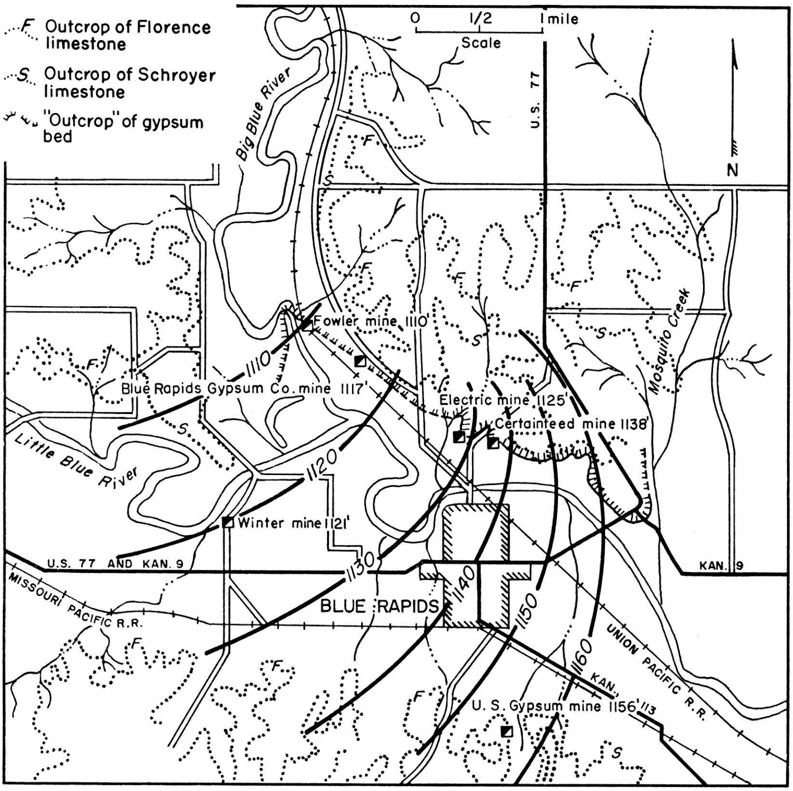


FIG. 10. Map showing geology, structure, and location of mines in vicinity of Blue Rapids. Structure contours are based on the gypsum bed.

After the gypsum is shot it is loaded into shuttle cars of 10-ton capacity by a loading machine. They carry the gypsum to an elevating conveyor, which loads the trains (Pl. 16A, B). A car puller is used to move the trains at the loading point. A diesel locomotive is used to move the trains out of the mine (Pl. 16C). Each trip has 21 to 23 cars of 3-ton capacity each. The cars each weigh approximately 2,600 pounds empty. A battery locomotive is used to carry men in and out of the mine and as a standby for the diesel locomotive.

The Certainteed Products plant is located directly outside the mine. Gypsum is crushed and calcined in kettles. By careful mining, by controlled calcining, and by the addition of certain selected ingredients, high-grade plaster products known to the trade

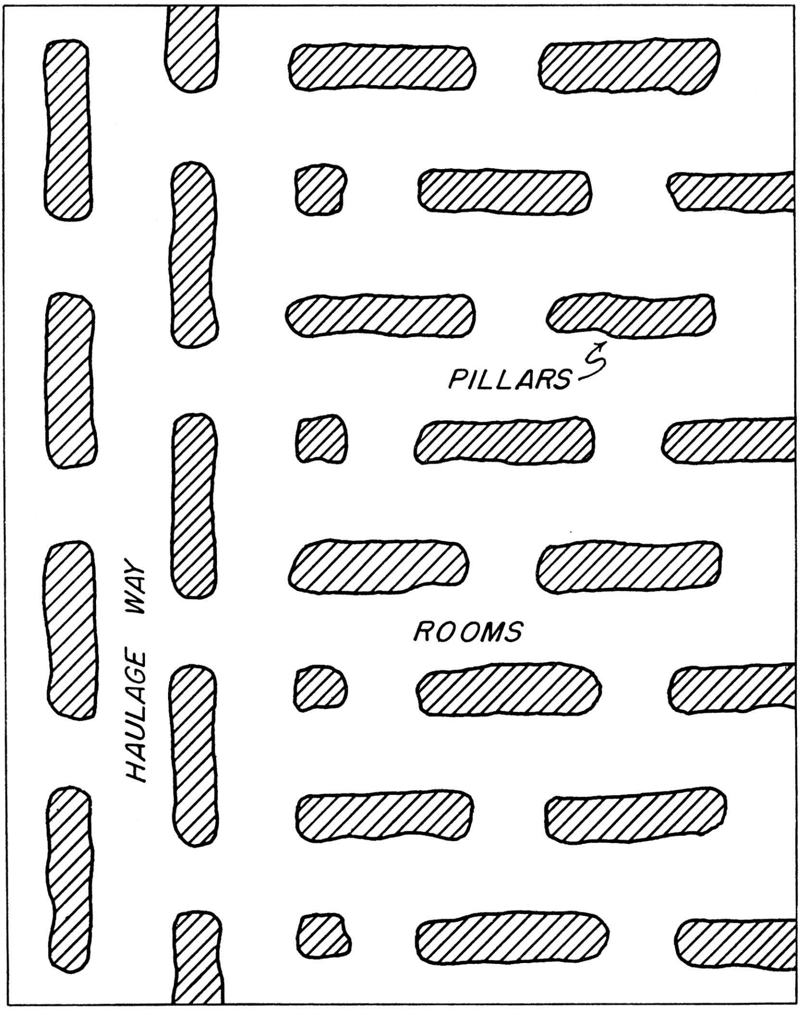


FIG. 11. Diagram showing plan of mining used since mechanization in the Certainteed Products Company mine, Blue Rapids.

as "specialty gypsums" are produced at the Blue Rapids plant. These products are dental plasters, orthopedic plasters, plate glass stuccos, casting plasters, molding plasters, gaging plasters, and statuary plasters. Gypsum is also sold for use in the manufacture of portland cement.

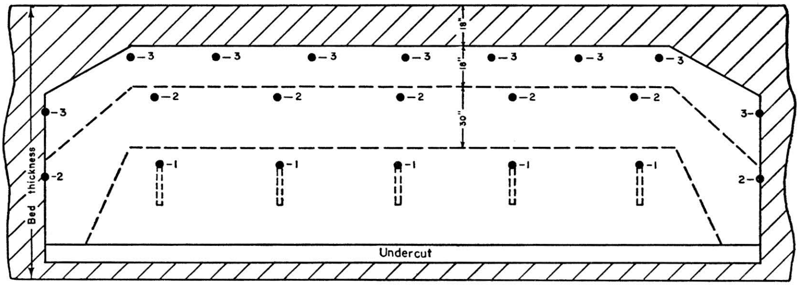


FIG. 12. Diagram showing placement of shot holes and undercut at Certainteed Products Company mine. Holes marked (1) are drilled at a downward angle; the rest are horizontal. Holes marked (1) are fired instantaneously and break the gypsum to the lower dotted line; (2) are fired at 50 millisecond delay and break to upper dotted line; (3) are fired with 100 millisecond delay and break to the roof.

HISTORY

The presence of gypsum in Marshall County was first recorded in the Kansas Annual Register of 1864 (p. 196). Two years later, Mudge (1866, p. 26), described the deposits as being 4 to 10 feet thick.

The first scientific work was undertaken by Grimsley in 1897. He described the early history (Grimsley and Bailey, 1899, p. 51-52) as follows:

"The first gypsum deposits worked within the state of Kansas were in the northern or Blue Rapids area. In November, 1869, the commissioners laid out the site for the town of Blue Rapids. They carefully investigated the natural resources of the region and recognized . . . the value of the gypsum deposits which had been known for some time to exist on the Big Blue, about two miles northwest of the town. On selling their various properties they made a reservation along the Blue of 100 rods, including the known outcrop of the beds and extending back from the river for a distance 320 feet.

"About the year 1871 Mr. J. V. Coon, of Elyria, Ohio, came to the new town, and, as the story goes, he burned some of the gypsum and carried it back to Cleveland, where it was pronounced to be of good quality, and two car-loads were ordered at a good price. He and a brother returned to Blue Rapids in 1872 and built a frame shed on the east bank of the river, below the town. In an iron kettle, which held about five barrels and which was heated by a stove, they commenced the manufacture of plaster of Paris. . . . in 1875 a stone mill was built by Coon & Son on the west side of the river, and the water power of the river was now used for grinding. . . . The town, for purpose of encouragement of the new departure, granted them the north half of their reservation, described as extending from a point at the middle of the outcrop, and thence north. This mill was operated for nearly twelve years, and then the firm unfortunately failed. The mill property and the gypsum grant of fifty rods of outcrop and twenty rods back in the hill came into the hands of Mr. Sweetland, a business man of Blue Rapids. It was leased to several parties, and the mill was run to the year 1889, when the flood of that year caused considerable damage, resulting in the abandonment of the mill."

In 1899 three mills and mines were in operation near Blue Rapids. The largest and oldest of these was that of the Fowler Brothers. Gypsum was mined from the outcrop near the level of Blue River on the town's original grant, and the rock was shipped down the river on barges to a one-kettle mill just south and west of the dam at Blue Rapids. The gypsum was calcined into plaster of paris and shipped east in barrels. In 1912, the Fowler interests were sold to the U. S. Gypsum Company, and the mine was abandoned shortly thereafter.

The second operating mine described by Grimsley and Bailey (1899) was the Great Western Mine, which was opened in 1893 a mile north of Blue Rapids, approximately 50 feet above the valley of Blue River. In 1903, the property was sold to the American Cement Plaster Company. The Great Western Company was liquidated and later reorganized under a new name. As such, it opened the Electric mine on property adjoining the Great Western mine on the west. In 1912, this company again sold its interests to the American Cement Plaster Company. The two mines were subsequently acquired by the Beaver Products Corporation, which operated them until 1937, when the Certainteed Products Corporation assumed control.

In 1905, A. R. Dean of Blue Rapids dug a shaft into the bed of gypsum 1½ miles northwest of the old Great Western mine. The Blue Rapids Gypsum Company was subsequently organized, and built a 3-kettle mill on a railroad spur to the Union Pacific Railway near by. After a few years of operation, the property was purchased by the American Cement Plaster Company, which soon abandoned the mine and dismantled the plant.

The third mine working in 1897 was the Winter mine, which was opened that same year two miles west of Blue Rapids at a point about 15 feet above Little Blue River. A dam was built across the river to provide water power, and a mill was erected adjoining the mine. Initial stripping operation was soon abandoned in favor of a double-entry underground mine. In 1912, the U. S. Gypsum Company, at the same time it purchased the Fowler interests, acquired the Winter mine. A few years later both plants were dismantled and moved to an area a mile south of Blue Rapids on property referred to by Grimsley as the "Yarrick farm". There a new plant was erected in a draw, and a double-entry mine was opened in a hill to the west. In 1929, the mine was closed and the plant was dismantled. Plans to open a new mine on the Lee property south of the Winter mine were abandoned, and the U. S. Gypsum Company ceased production in the Blue Rapids area.

Today, the Certainteed Products Corporation owns and operates the only working mine and mill in the Blue Rapids district, at the site of the old Great Western Company plant. It also holds leases on the Electric mine and the mine of the Blue Rapids Gypsum Company.

The locations of the various mines are shown in Figure 10.

Stratigraphy

A generalized section of the rocks found in Marshall County is shown in Figure 13, modified from Walters (1954). Rocks exposed in the bluffs at Blue Rapids include formations from the Beattie limestone to the top of the Wreford limestone. The following description of this sequence is taken from Walters (1954).

Eskridge Shale

"Green and gray shale is the predominant material in the upper part of the Eskridge shale. The lower half of the formation is composed chiefly of red and maroon shale. Impure limestone beds less than 1 foot thick occur in all parts of the formation but are most numerous in the upper half. Limestone beds in the upper part of the formation are commonly fossiliferous. The thickness of the Eskridge shale ranges from 24 to 28 feet. . . ."

Beattie Limestone

". . . The members of the Beattie limestone are, in ascending order: the Cottonwood limestone member, the Florena shale member, and the Morrill limestone member.

"The lower 1 to 2 feet of the Cottonwood limestone member consists of soft, fossiliferous, light-gray limestone that weathers rather slabby. The remaining 5 to 6 feet of the member is very massive, hard, gray limestone containing an abundance of fusulinids and scattered chert nodules. The Cottonwood limestone member forms a very conspicuous bench that is usually accentuated by a heavy growth of vegetation. . . .

"The Florena shale member consists of 2 to 3.5 feet of tan to dark-gray, calcareous shale. Fossils are very numerous in the Florena shale; locally thin shell beds within the member are composed almost entirely of *Chonetes, Dictyclostus,* [sic] and *Composita.*

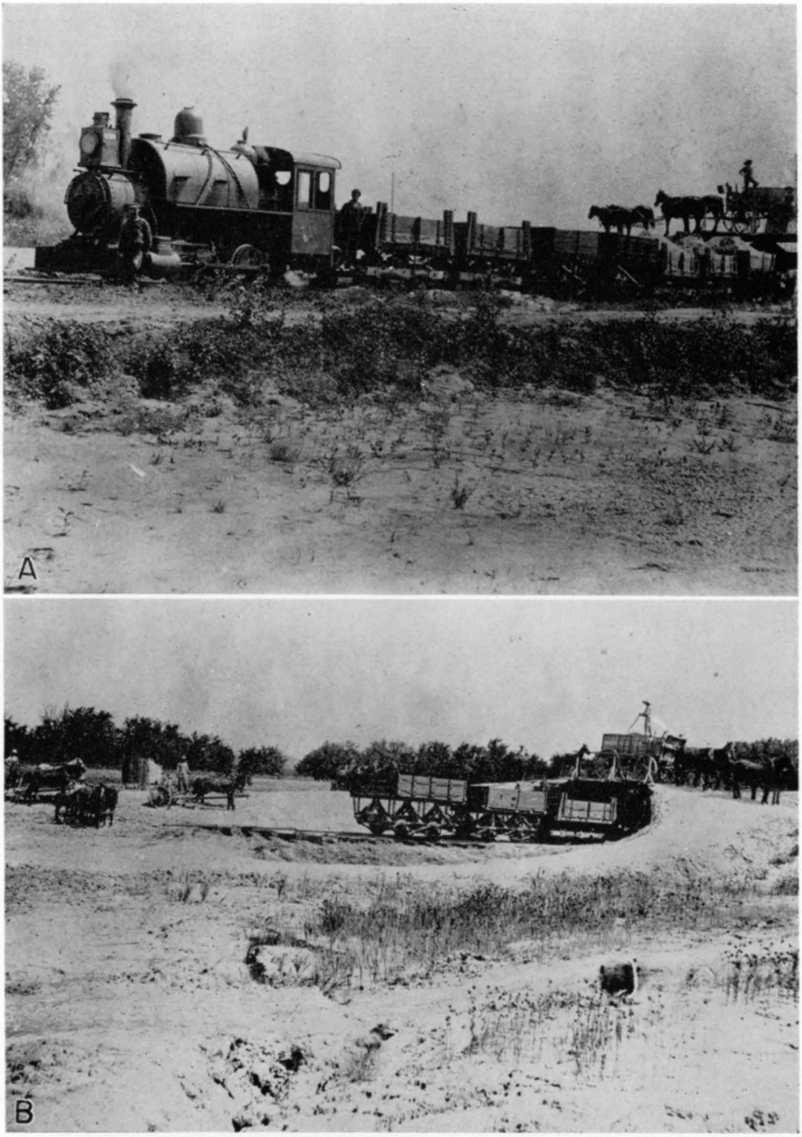


PLATE 13. Narrow-gage railroad from Longford gypsite pit. (*Pictures courtesy of A. Greep, Longford, Kansas*). **A.** Train used to haul gypsite from pit to plant in Longford. **B.** Wagon loading into train car.

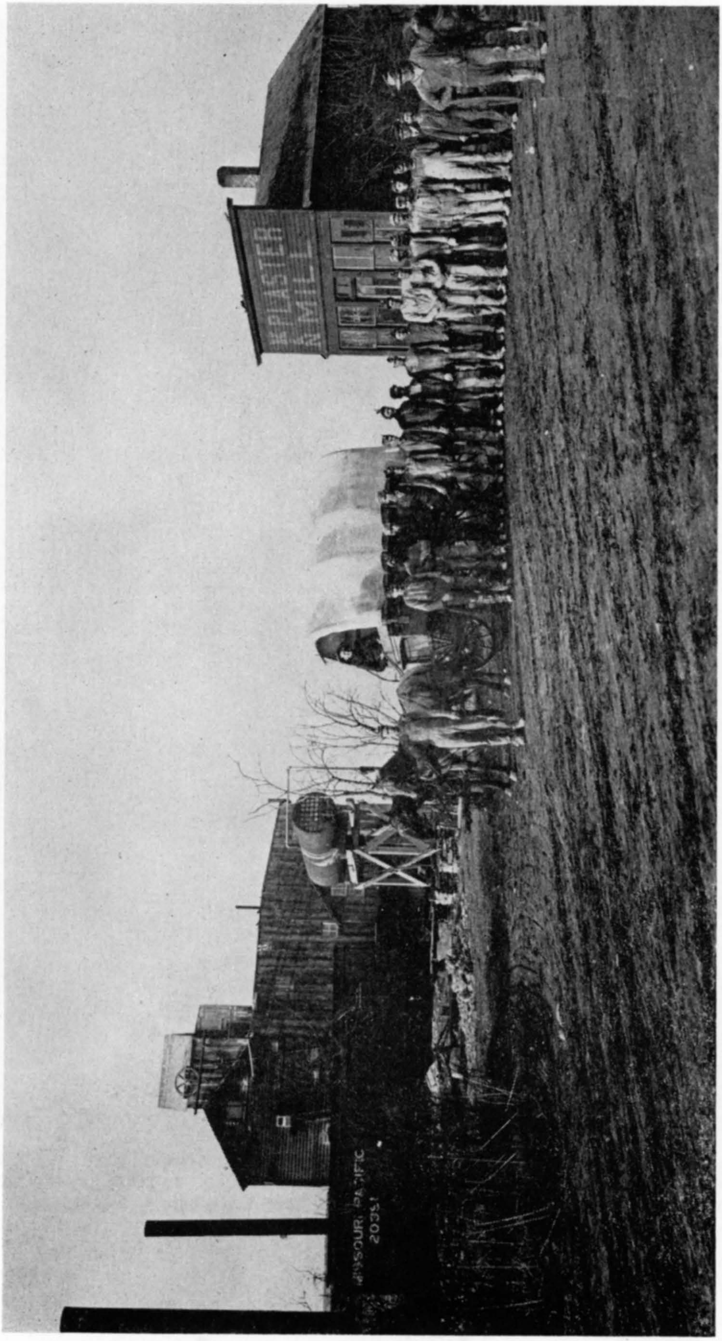


PLATE 14. Headframe, office, and employees of old Hope mine. (*Picture courtesy of Roy Rubin, Hope, Kansas*).

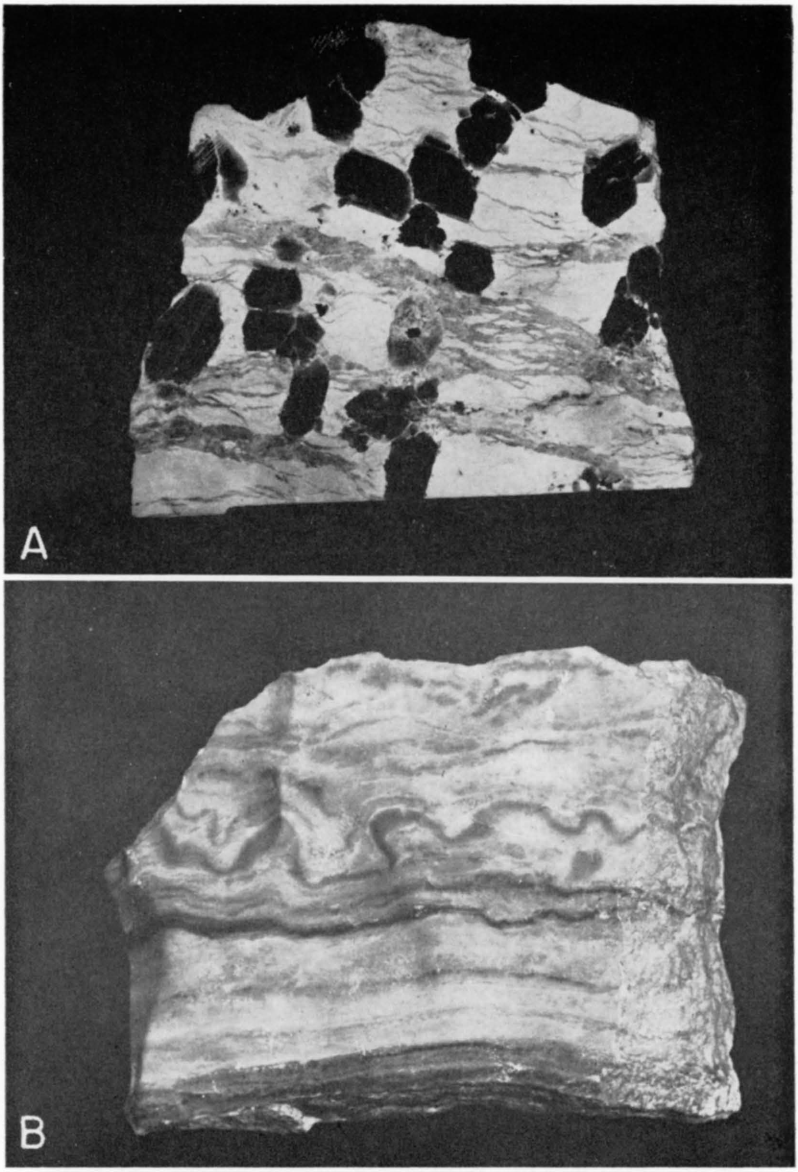


PLATE 15. Special features in gypsum near Solomon mine. **A.** Polished surface of piece of gypsum from outcrop at old Solomon mine. Note that crystals cut veinlets, showing that they are secondary and not formed when bed was deposited. **B.** Crenulated laminae in piece of gypsum from old Solomon mine. Note that crenulated portion lies between relatively straight laminae.

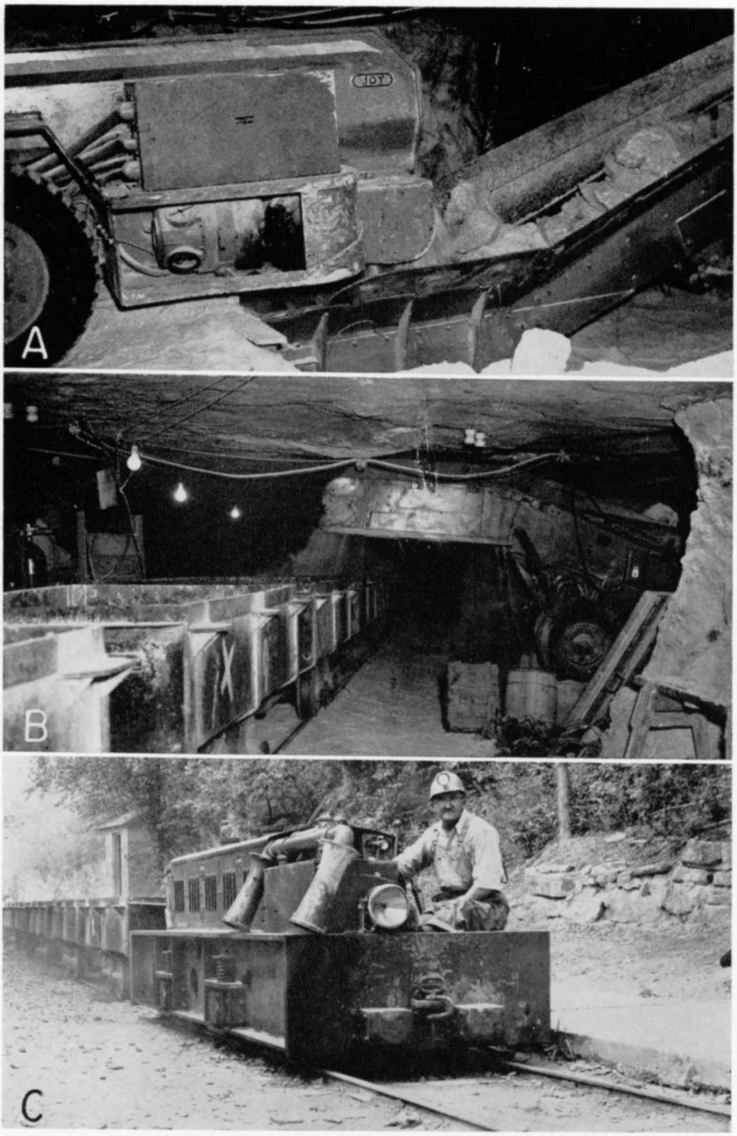


PLATE 16. Equipment operating in Certainteed Products Company mine near Blue Rapids. **A.** Electrically operated shuttle car loading into loading machine. **B.** Loading machine loading mine train. **C.** Diesel locomotive pulling empty train outside mine.

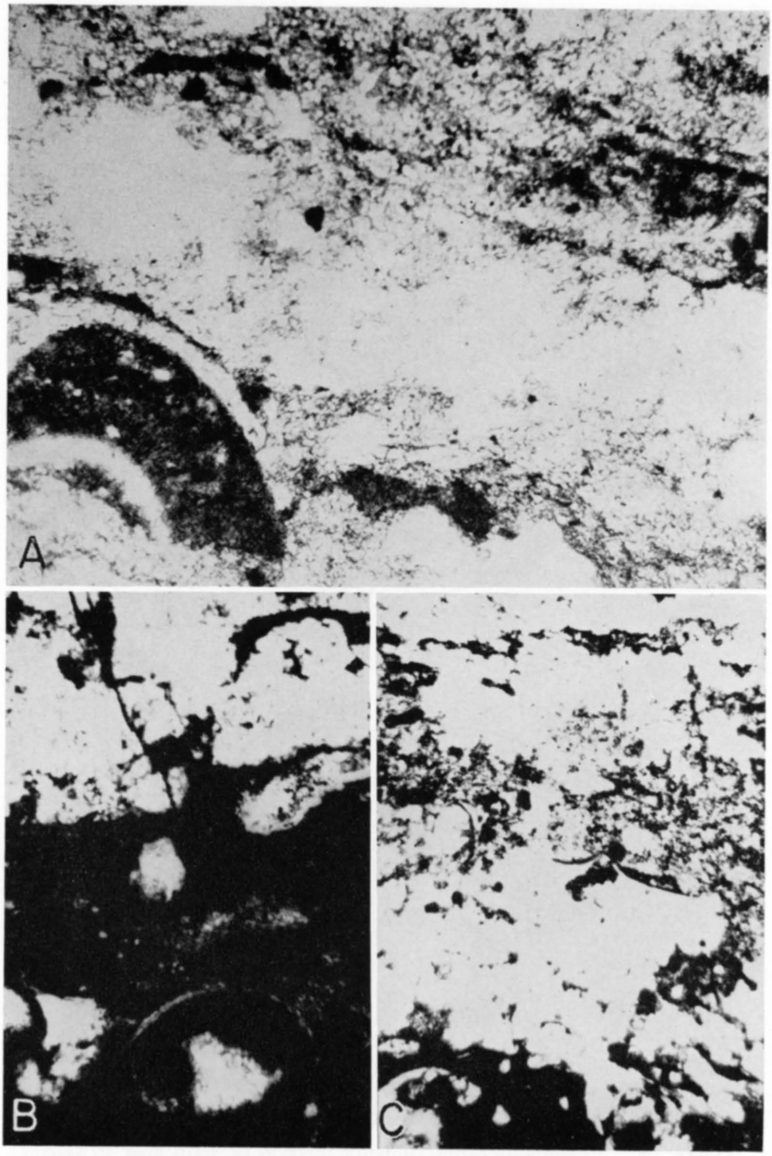


PLATE 17. Photomicrographs of gradational contact of underlying limestone with gypsum in Easly Creek shale. **A.** Gradational zone between limestone (dark) and gypsum (light). Gastropod in lower left of field is cut approximately normal to its axis of coiling. Note probable replacement by gypsum of portions of gastropod. (Crossed nicols, × 98). **B.** Lower portion of "C" enlarged. Gastropod in lower center of field is cut approximately parallel to its axis of coiling. (Plane light, × 98). **C.** Gradation of underlying limestone (dark) into gypsum (light). (Plane light, × 24).

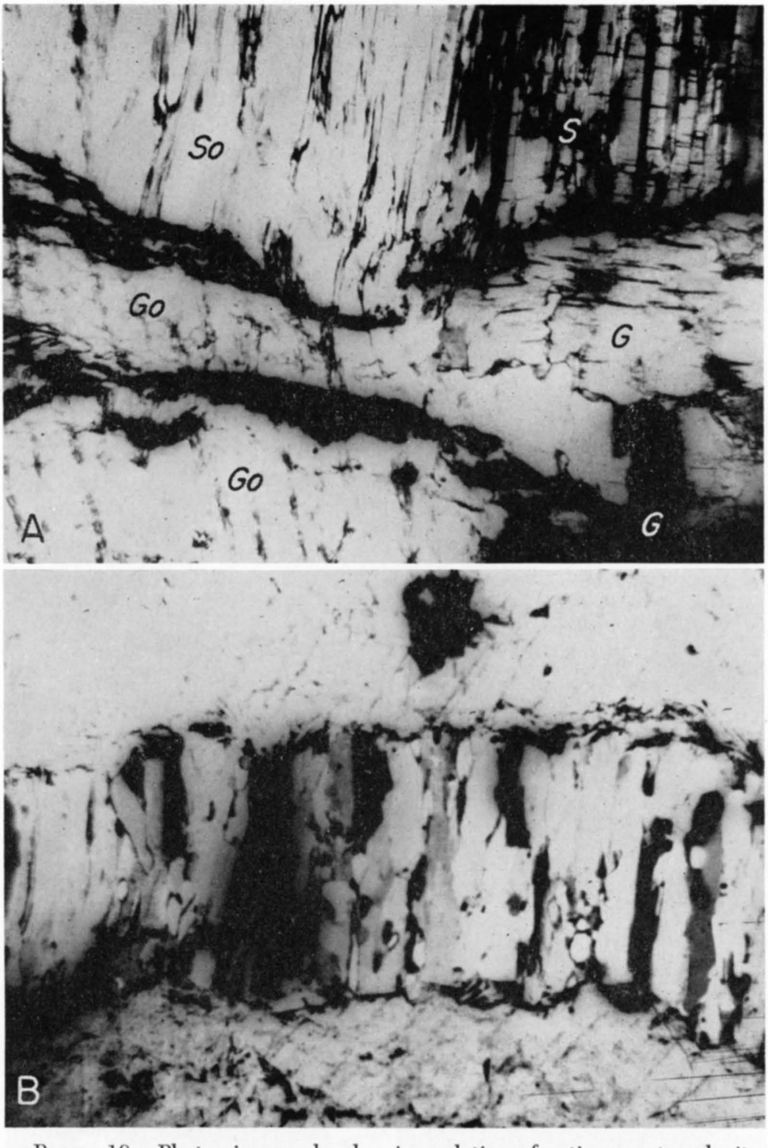


PLATE 18. Photomicrographs showing relation of satin spar to selenite. **A.** Relations near upper contact, showing optical continuity between satin spar (*So*) and selenite (*Go*), but not between satin spar (*S*) and selenite (*G*). Selenite maintains optical continuity around shale (dark). (Crossed nicols, × 22). **B.** Veinlet of satin spar, near lower contact, with sharp, matching walls of selenite. Shale (dark) lies along borders of veinlet. Optical continuity locally between crystals in veinlet and in wall. (Crossed nicols, × 22).

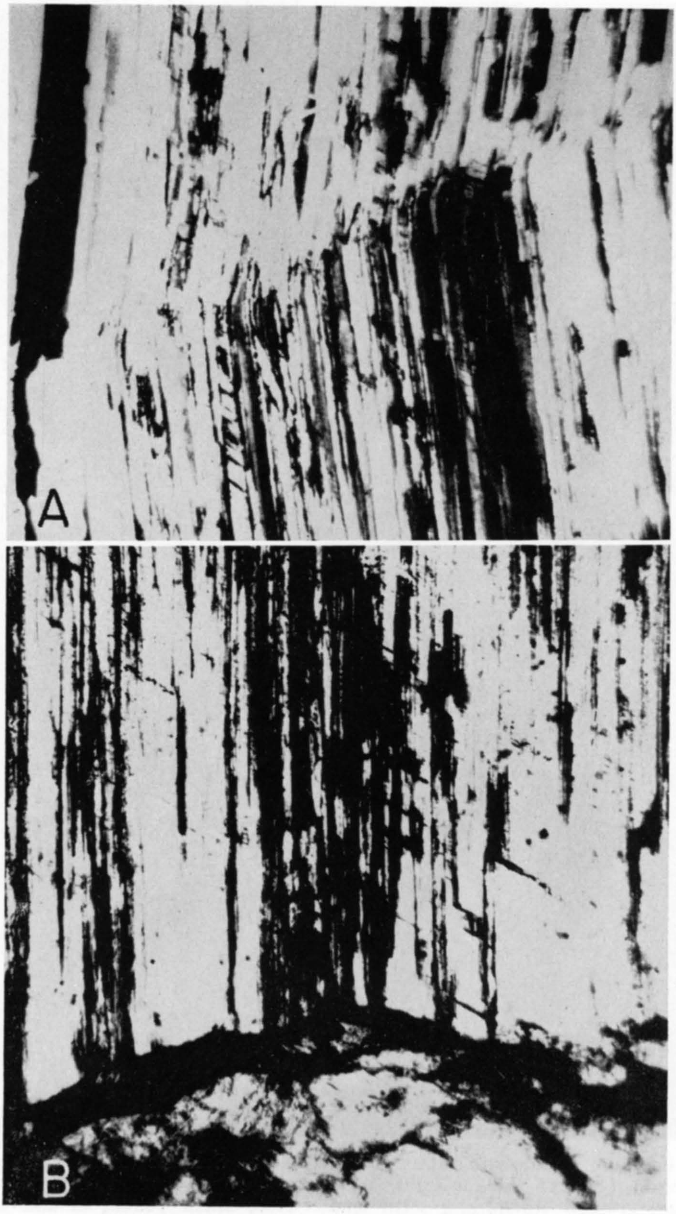


PLATE 19. Photomicrographs of satin spar. **A.** Curvature in satin spar, near upper contact of gypsum. Note that some crystals maintain optical continuity past line of curvature. (Crossed nicols, × 30). **B.** Upper layer of satin spar, separated from underlying gypsum by thin shale layer (dark). Note that satin spar crystals are not oriented normal to upper surface of gypsum (Crossed nicols, × 25).

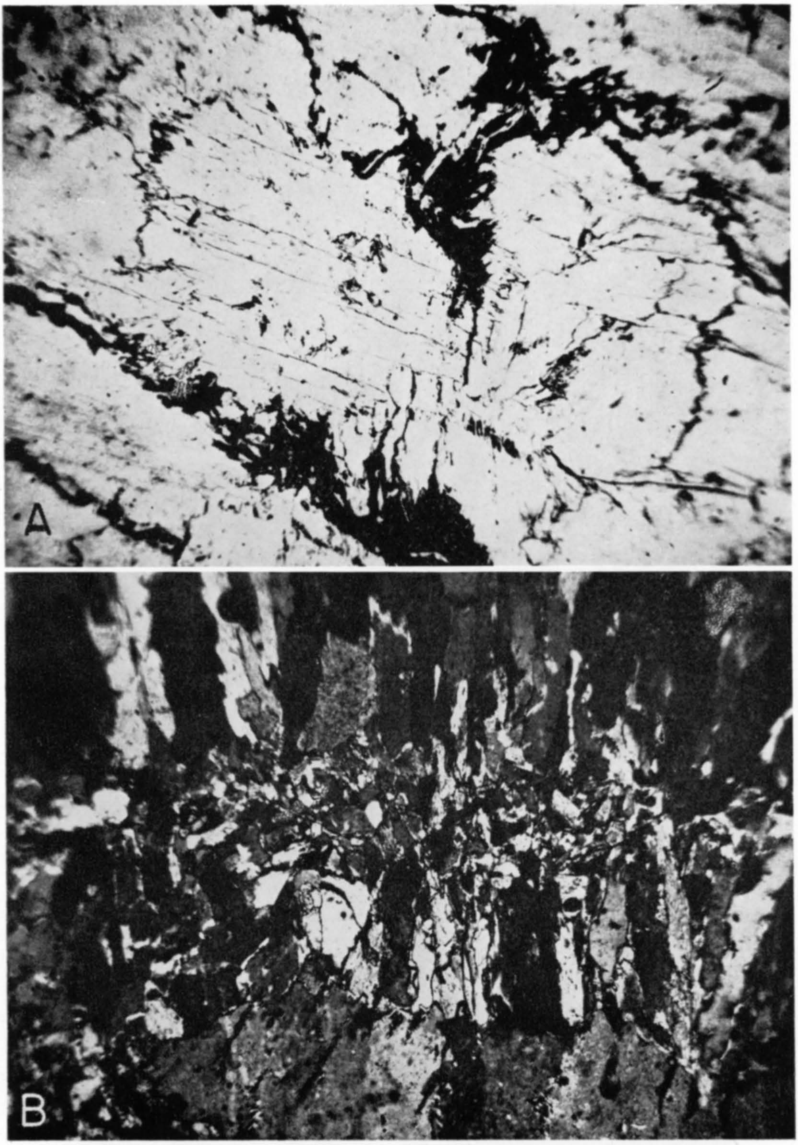


PLATE 20. Photomicrographs of gypsum. **A.** Selenite (light) interfingering with shale (dark). (Plane light, × 50). **B.** Upper portion of gypsum with elongate crystals resembling satin spar. Note small veinlet of fine-grained gypsum trending left to right. (Crossed nicols, × 24).

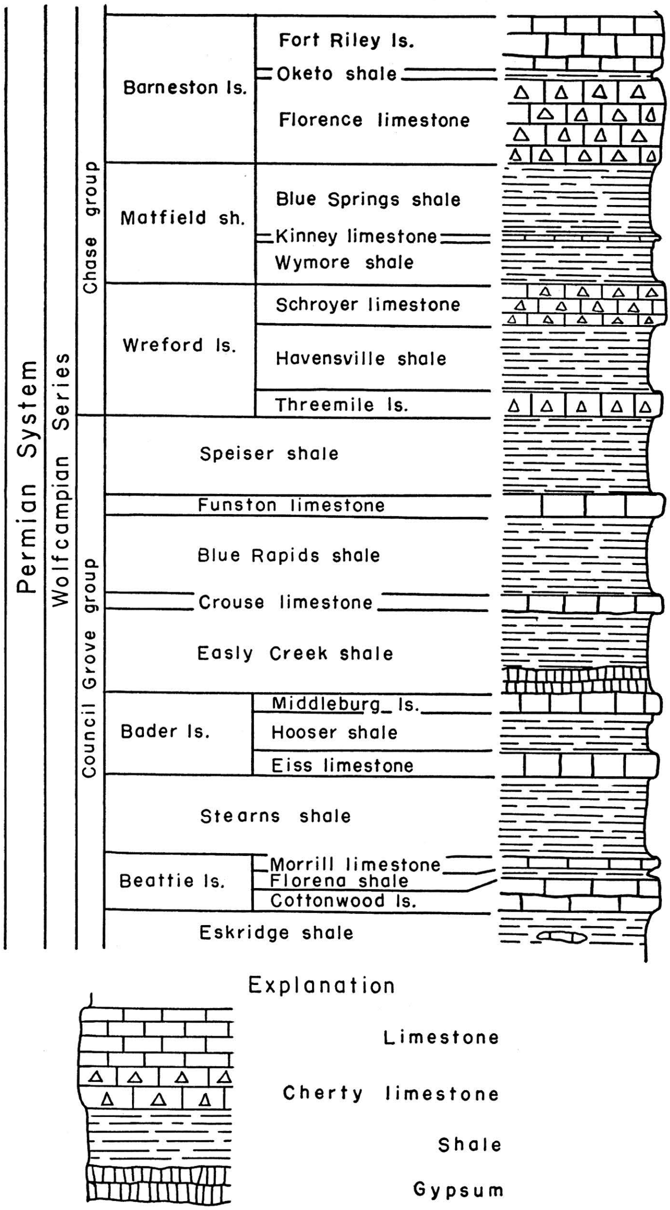


FIG. 13. Stratigraphic section of some lower Permian rocks exposed in the vicinity of Blue Rapids. Modified from Walters (1954).

"The Morrill limestone member ranges in thickness from 3.5 to 7.5 feet. The member is made up chiefly of massive, soft, light-gray limestone. Fossils of brachiopods, echinoids, and crinoids are common in the lower part. The Morrill limestone member is less resistant to weathering than the Cottonwood limestone member, and is not generally well exposed in Marshall County. . . .

Stearns Shale

"Dark-gray, calcareous shale is the predominant material of the Stearns shale, but red and green shale is present in the upper part. Thin, impure limestone beds occurring near the middle of the formation contain brachiopods and pelecypods. The thickness of the formation in Marshall County ranges from 17 to 20 feet. . . .

Bader Limestone

"The Bader limestone is divided into three members, which in ascending order are: the Eiss limestone member, the Hooser shale member, and the Middleburg limestone member. The thickness of the formation in Marshall County ranges from 17 to 22 feet.

"At the base of the Eiss limestone member is a massive, argillaceous, light-gray limestone about 2.5 feet thick. This bed is nonresistent to weathering and is well exposed in few places. The middle part of the member is composed of fossiliferous gray shale generally about 2.5 feet thick. The upper part of the Eiss limestone member is composed of a very massive limestone about 4 feet thick. In weathered outcrops this upper bed is commonly pitted and has solution channels. A very conspicuous bench is formed by the upper part of the Eiss limestone member.

"The Hooser shale member consists of 8 to 11 feet of sparsely fossiliferous shale. A large part of the shale is green and gray, but bands of pink and maroon are common near the center of the member.

"At the base of the Middleburg limestone member is a limestone bed about 2 feet thick, dark gray at the top and yellowish brown below, and containing many fossils. About 1 foot of dark-gray calcareous shale separates the lower limestone bed and an upper limestone bed just about a foot thick. The upper bed of the Middleburg limestone member is fossiliferous and weathers pitted. The Middleburg limestone member does not form a conspicuous bench. . . .

Easly Creek Shale

"A massive bed of gypsum 8 to 9 feet thick occurs at the base of the Easly Creek shale in the area around Blue Rapids. This gypsum bed is readily leached away when exposed to weathering and is not generally present in natural outcrops, but it is exposed in mine workings and has been penetrated in many wells in the area. The gypsum is overlain by about 10 feet of gray, green and red shale. . . .

Crouse Limestone

"The Crouse limestone, typically a platy, thin-bedded, argillaceous, gray limestone, has a bed of gray calcareous shale about 2.5 feet thick near the middle of the formation. The upper limestone bed is more massive and crystalline than the lower bed. Fossil fragments are common, but well-preserved specimens are rare. The total thickness of the formation is about 7.5 feet. . . .

Blue Rapids Shale

"The Blue Rapids shale consists principally of blocky gray shale, but contains a few feet of black shale at the top and some green and red shale in the lower part. Thin impure limestone beds are present in some exposures. . . .

Funston Limestone

"The Funston limestone is not generally well exposed in Marshall County, and the thickness and lithology of the formation vary considerably from exposure to exposure. In general, the Funston limestone consists of two limestone beds with a bed of shale between. The lower limestone is generally massive, argillaceous and weathers pitted. The limestone bed is usually slightly less than 3 feet thick. The lower limestone bed is overlain by about 2 feet of gray, gray-green, and red shale. The upper limestone bed is about a foot thick, somewhat argillaceous, and massive to platy. . . .

Speiser Shale

"The lower part of the Speiser shale in Marshall County consists of about 15 feet of varicolored shale. Only the upper 2 or 3 feet of this part of the Speiser shale is calcareous. The second unit of the formation is a very persistent limestone bed about a foot thick. This limestone is hard, gray, and massive and contains fragments of fossils. The upper unit of the Speiser shale consists of about 3 feet of dark-gray to black calcareous fossiliferous shale. . . .

Wreford Limestone

"The Wreford limestone, which includes two limestone members and a shale member, has an average thickness of about 35 feet in Marshall County. The Wreford limestone is the oldest exposed formation in Marshall County which contains an abundance of chert.

"The Three Mile limestone member, which overlies the Speiser shale, consists of about 7 feet of hard gray limestone in massive beds about a foot thick. The chert occurs in bands or as scattered nodules. . . . The limestone beds near the middle of the member contain less chert than the upper and lower beds. Brachiopods are the most common fossils in the Three Mile limestone member.

"The Havensville shale member ranges from 14 to 20 feet in thickness in Marshall County. The member is typically a gray to gray-green blocky calcareous shale, but locally it is composed almost entirely of soft thin-bedded gray limestone. Small quartz geodes are generally imbedded in the upper few inches of the member.

"The thickness of the Schroyer limestone member ranges from about 10 to 13 feet. The lower 4 or 5 feet of the member is hard, gray, fossiliferous limestone containing only a few thin bands of chert. About 2 feet of buff to brown fossiliferous shale generally separates the relatively noncherty lower beds of limestone from the more cherty upper beds. . . . The upper 4 to 6 feet of the member consists of beds of tan to buff, hard, fossiliferous limestone containing an abundance of chert.

Matfield Shale

"The Matfield shale is divided into three members, which are in ascending order: the Wymore shale member, Kinney limestone member, and the Blue Springs shale member. The average thickness of the formation in Marshall County is about 57 feet.

"The Wymore shale member consists of 20 to 23 feet of gray, gray-green, and red-brown shale. Thin discontinuous limestone beds are locally present in the lower part.

"The Kinney limestone member consists of 2 to 5 feet of massive to platy gray and yellow limestone. The lower part of this member contains many brachiopods and mollusks.

"The Blue Springs shale member consists of about 34 feet of silty varicolored shale. The lower part of the member is generally non-calcareous and contains many gypsum nodules and seams. . . .

Barneston Limestone

"The Barneston limestone, the thickest limestone formation in Marshall County, contains the most massive beds of any formation in the county. The average total thickness of the formation is about 50 feet. It crops out in the bluffs along Big and Little Blue Rivers throughout their courses in the county. The members of the Barneston limestone, in ascending order are: the Florence limestone member, the Oketo shale member, and the Fort Riley limestone member.

"The Florence limestone member is easily recognized because of the abundance of chert or flint imbedded in the limestone. In fact, this member is often referred to as the Florence flint. The member is actually a series of beds of limestone and beds of chert. . . . The noncherty beds are generally only slightly thicker than the cherty beds. Many fossils are present in all parts of the Florence limestone member. A rather persistent shale break about 2 feet thick is present in the upper few feet of the member. The Florence is not resistant to weathering and is dissected into steep-sided, rounded hills. The thickness of the member ranges from 22 to 28 feet.

"The Oketo shale member, which was named from exposures at Oketo in Marshall County, ranges in thickness from a few inches to more than 6 feet. At most exposures in the county the member consists of hard, gray, calcareous shale containing many brachiopods, crinoids, and echinoid remains.

"A hard, gray, very massive bed of limestone about 6 feet thick occurs at or near the base of the Fort Riley limestone member in Marshall County. This is the limestone bed that forms the 'rim rock' or natural rock wall type of outcrop seen near the top of many hills bordering the valleys of Big Blue and Little Blue Rivers. . . . The massive 'rim rock' bed is sometimes underlain by as much as 5 feet of impure, thin-bedded limestone and thin beds of shale. The middle part of the member is composed of alternating thin beds of limestone and shale, the shale beds generally being somewhat thicker than the limestone beds. Beds near the top are generally massive, but are soft and much less resistant than the massive beds in the lower part of the member. Weathered exposures of the upper part of the Fort Riley may have a pitted and cavernous appearance. Massive beds of this limestone have been extensively quarried for use as building stone and road material in Marshall County. The average thickness of the member is about 25 feet".

Figure 10 shows the gypsum outcrop and outcrops of the base of the Florence limestone and the base of the Schroyer limestone in the Blue Rapids area, in part from Walters (1954). The base of the gypsum or its stratigraphic equivalent can be traced from a point where it dips below the alluvium at an elevation of 1,121 feet in the SE¼ sec. 17, T. 4 S., R. 7 E., past the Electric mine (1,125 feet), across old Highway 77 (1,132 feet), past the Certainteed mine entrance (1,139 feet), past the area known as the "Narrows" (1,152 feet), and along the side of the bluff until it passes beneath the alluvium on the west bank of Mosquito Creek in sec. 22, T. 4 S., R. 7 E.

Structural Geology

General Structure

The sedimentary rocks of the Blue Rapids area lie on the western slope of a gentle arch over the buried Nemaha anticline. A few small flexures and minor distortions disturb the general westward dip of the strata.

Similar small structural features are present in Riley County, the northern boundary of which lies 8 miles south of Blue Rapids. Jewett (1941, p. 99-100) has ascribed these structures to differential compaction on the uneven surfaces of the crystalline rocks of the Nemaha anticline. Wells drilled in T. 2 S., R. 9 E., in Marshall County, show the crystalline basement to lie at depths ranging from 1,200 to 1,400 feet.

Local Structure

The elevations of the various mines and, where possible, of the base of the gypsum, were determined in the field by plane table and alidade. From these elevations, from core-drill data, and from known elevations within the Certainteed mine, a structure contour map (Fig. 10) on the base of the gypsum was drawn. From this map it is evident that the dip and strike of the gypsum vary slightly. In the vicinity of the U. S. Gypsum mine, the gypsum strikes northeast, and dips about 13 feet per mile northwest. In the vicinity of the Certainteed mine, however, it strikes north to northwest, and dips 30 to 45 feet per mile west to southwest. At the Fowler mine, it again strikes northeast, and dips about 20 feet per mile northwest.

Occurrences of Gypsum

The gypsum that is mined in the Blue Rapids district is a massive bed averaging 8 or 9 feet in thickness. A layer of satin spar about half an inch thick normally lies along the upper contact and in many places a quarter-inch layer lies along the lower contact. Layers of satin spar also occur in the overlying Easly Creek shale at some places.

The gypsum bed is composed essentially of massive or rock gypsum, ranging from white to gray, tinted somewhat pink. In texture it ranges from saccharoidal to platy, but most of it is granular. Specimens fracture irregularly. Shale is the only impurity visible megascopically.

The gypsum bed has no definite topographic expression. It is naturally exposed only along the banks of Blue River, where the rate of erosion seemingly exceeds the rate of solution of the gypsum.

Certainteed Mine

The plant of the Certainteed Products Corporation (Frontispiece) is situated on the floor of the Blue River valley in T. 4 S., R. 7 E., at an elevation of about 1,115 feet. A northwestward-trending bluff north of the plant averages 140 feet in height. The mine entrance is situated on the face of this bluff at an elevation of 1,140 feet.

Studies within the Certainteed Mine showed that the gypsum has the following general characteristics: (1) The gypsum pinches out fairly abruptly near the outcrop. The overlying shale slumps down and, with some residual material, takes the place of the gypsum. These relations can be observed at the south end of a drift 400 feet east of the main entry, where the gypsum pinches out approximately 100 feet from the outcrop. (2) Solution channels are present in the gypsum near the outcrop. This may be observed in the old workings adjacent to the main entry. (3) The lower surface of the gypsum is relatively uniform, except for a few small reversals of dip. (4) The upper surface of the gypsum is very irregular. (5) Generally, in areas where there are depressions in the upper surface of the gypsum, (a) the amount of shale in the upper portion of the gypsum is noticeably greater, (b) the satin spar along the upper contact is more fully developed, (c) satin spar is more abundant in the overlying shale, and (d) pink gypsum is present locally near the upper contact.

Other Occurrences of Gypsum

A reconnaissance of the other gypsum localities in the Blue Rapids area was made. The general characteristics of the gypsum bed were found to be relatively uniform throughout the region, although some minor variations were noted.

U. S. Gypsum mine.—The entrances to the workings of the U. S. Gypsum mine are so badly caved that the mine is inaccessible, but the Easly Creek shale is well exposed along the west side of the creek about 200 feet south of the mine entry. Weathered specimens of gypsum were found in this area.

Blue Rapids Gypsum Company mine.—The Blue Rapids Gypsum Company mine is also inaccessible. According to the original owner, A. R. Dean (personal communication) the gypsum averages 8 or 9 feet in thickness and satin spar lies along both contacts. The site of the old mill is still visible.

Fowler mine.—The entrance to the Fowler mine is blocked by fallen shale and alluvium, but the gypsum crops out in the bed of Big Blue River about 300 feet north of the mine entry. Along the east bank of the river there is a marked flexure in the Easly Creek shale, which overlies the gypsum. The flexure probably was caused by collapse of the gypsum due to solution by the waters of the river. The Crouse limestone, which is more competent than the shale, is undisturbed above the flexure.

Hand specimens from the outcrop have saccharoidal texture and show effects of solution. According to Grimsley and Bailey (1899, p. 53), the gypsum within the mine contained veins of transparent selenite in crystals several inches long.

Winter mine.—Remnants of the old Winter mill and of a dam across Little Blue River still exist. The mine entrance lies about 300 feet south of the dam, and about 15 feet above the level of the river. Fallen roof now blocks the entrance, but access to several hundred feet of the workings was possible at the time field studies were made. The gypsum averages 8½ feet in thickness, and a quarter to half inch of satin spar lies along the upper contact. Pink, saccharoidal gypsum occurs about 15 feet within the mine. The full extent of slumping caused by collapse of the mine roof can be seen in fields southeast of the mine. The most distant of these is approximately 2,000 feet from the mine entrance.

Electric mine.—Entrance to the Electric mine from the surface is impossible, but the underground workings of the Certainteed mine have joined those of the Electric mine. Samples obtained underground were similar megascopically to gypsum from the Certainteed mine. Most of the Electric workings are now under water.

Other localities.—Near Waterville, along Little Blue River, pink nodules of gypsum occur locally in shale members of the Crouse limestone. On the farm of Fred Stocks, about a mile south of the Winter mine, a shaft dug about 1900 revealed a bed of gypsum 9 feet thick at a depth of 30 feet. Numerous water wells on farms in the area have encountered gypsum at various depths.

Petrology of the Gypsum of the Blue Rapids Area

Observations

Megascopically, the gypsum bed is composed principally of white to gray massive gypsum. Satin spar and selenite are present locally. A small amount of shale is interbedded with the gypsum.

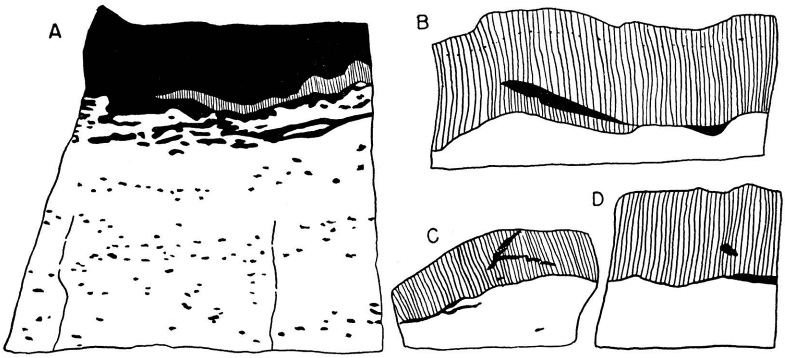


Fig. 14. Sketches showing relation of gypsum to other rocks in the Easly Creek shale. (All are × 0.6). **A.** Gradation of underlying limestone (light) into gypsum (dark). Note layer of satin spar. **B.** Satin spar interfingered with shale (dark) along upper contact of gypsum (light). **C.** Satin spar interfingered with shale (dark) from overlying formation, along upper contact of gypsum (light). **D.** Satin spar containing inclusion of shale (dark) along upper contact of gypsum (light).

No anhydrite is present. Brown, argillaceous limestone lies beneath the gypsum. A diagram of a portion of the lower contact (Fig. 14*a*) shows the characteristic gradation of limestone into gypsum. Grayish-green shale overlies the gypsum. Layers of satin spar lie along the upper and lower contacts. The satin spar layers are composed of slightly curved, white prismatic crystals. The layer along the upper contact increases in thickness where there are depressions in the upper surface of the gypsum. Shale separates the upper layer of satin spar from the gypsum in most places, and is present locally within the satin spar (Fig. 14*b, c, d*).

Microscopically, the gypsum bed is composed principally of small anhedral crystals of gypsum, ranging in diameter from 0.01 to 2.0 mm. Buff to gray shale and grains of calcite are present along some crystal boundaries. Selenite crystals having a maximum dimension of about 5 mm are relatively common in the upper and lower parts of the bed. The selenite exhibits undulatory extinction. Veinlets containing satin spar or finer-grained gypsum also are present locally in the upper and lower parts of the bed.

To facilitate field sampling, the gypsum bed was arbitrarily subdivided into three equal parts—lower, middle, and upper—which terms will be used in the following discussion.

Lower part of the gypsum bed.—The limestone that lies beneath the gypsum is brown and fossiliferous. The gradational zone between limestone and gypsum contains many well-developed crystals of gypsum, which have uniform birefringence and sharp extinction. Calcite stringers are included locally within individual gypsum crystals. These stringers contain some marine microfossils, such as gastropods, ostracodes, foraminifera, and some pelecypods (Pl. 17).

The layer of satin spar along the lower contact is thin and discontinuous. Its position in relation to the gradational zone is variable. Individual crystals are oriented, in most places, with their C axis normal to the walls. In many places crystals from opposite walls interfinger near the center of the layer.

The lower portion of the bed contains many crystals of selenite, particularly near the lower contact, and scattered masses of calcite. There are numerous small veinlets of satin spar and finer-grained gypsum. Figure 15*a* illustrates a veinlet of fine-grained gypsum with comparatively sharp walls, interrupted by a crystal of selenite. Plate 18B illustrates a veinlet of satin spar, with sharp, parallel, matching walls of selenite. Shale selvage lies along both walls of the veinlet. Crystals composing the veinlet are oriented with C axis normal to the walls. Few crystals maintain continuity from wall to wall. Locally, optical continuity exists between crystals in the veinlet and portions of the wall. Many crystal boundaries are obscure. Other veinlets of finer-grained gypsum with less definite walls also are present in the lower part of the bed. Shale lies parallel to the walls of many veinlets. Farther from the lower contact, the lower part of the gypsum is composed principally of small, equigranular crystals of gypsum, showing random orientation. Selenite crystals are few and scattered.

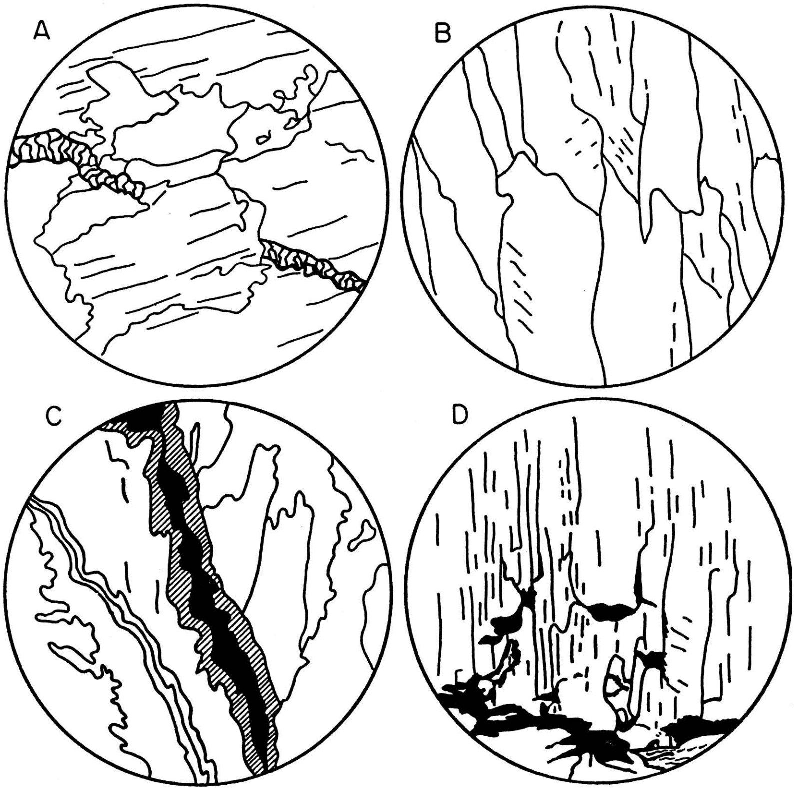


FIG. 15. Camera lucida drawings showing details of gypsum rock in gypsum bed in Easly Creek shale. **A.** Veinlet of fine-grained gypsum, interrupted by crystal of selenite. Near lower contact. (Crossed nicols, × 12½). **B.** Interior of veinlet of satin spar, showing interfingering crystals. Near lower contact. (Crossed nicols, × 25). **C.** Crustified gypsum (shaded) along the walls of an open fracture. Unfilled portions of fracture are black. Near upper contact. (Crossed nicols, × 12½). **D.** Upper layer of satin spar (light), separated from underlying gypsum by shale (dark). Note the occurrence of shale at the end of some individual crystals of satin spar. (Crossed nicols, × 25).

Middle part of the gypsum bed.—The middle part of the bed is composed chiefly of small, equigranular crystals of gypsum, showing random orientation. Shale and some calcite lie along the borders of many crystals. Less calcite is present, however, than in the lower part of the bed. There are only a few scattered crystals of selenite.

Upper part of the gypsum bed.—The upper part of the bed, away from the upper contact, resembles the middle. Very little calcite is present. Near the upper contact the gypsum is composed chiefly of selenite crystals, locally interfingering with grayish-green shale that resembles the overlying shale (Pl. 20A). There are many small veinlets of satin spar and finer-grained gypsum near the upper contact. Figure 15*b* illustrates a noticeable zone of interfingering crystals in a veinlet of satin spar. In some veinlets, however, satin spar crystals are continuous and are orientated normal only to one wall. Figure 15*c* illustrates crustified gypsum along the walls of an open fracture near the upper contact.

The layer of satin spar along the upper contact is continuous and well developed locally. Crystals are orientated parallel to one another (Pl. 19B) and normal to the stratification of the overlying shale, rather than to the upper surface of the gypsum. Most crystals have sharp boundaries and are continuous. Plate 18A illustrates a portion of the bed near the upper contact; optical continuity is maintained between part of the satin spar above the contact and the selenite below. The optical continuity of the selenite is not disturbed by the presence of interfingering shale. Those crystals of satin spar that maintain optical continuity with selenite have indistinct boundaries and exhibit undulatory extinction. Shale, present locally in the satin spar, lies at the end of individual crystals, as illustrated in Figure 15*d*. Fractures in the satin spar are relatively few and discontinuous. Curvature of satin spar crystals is independent of fracture (Pl. 19A), some crystals maintaining their optical continuity past the line of curvature. The direction and amount of curvature differ in different parts of the satin spar layer. Some satin spar crystals in the overlying shale are curved in a similar manner.

Petrologic Interpretations

Original deposition of the gypsum.—The gradational zone between the underlying limestone and the gypsum indicates a gradual approach to sulfate saturation of the sea. Inasmuch as large crystals of gypsum showing uniform birefringence and sharp extinction lie along the lower contact, initial precipitation probably was slow, crystallization being concentrated at relatively few points. Calcite, which was still precipitating, accumulated in stringers, which were incorporated within the slowly growing gypsum crystals. As the sulfate concentration increased, precipitation of gypsum was accelerated, crystallization occurring simultaneously at many places. The mutual interference of crystals (Lindgren, 1933, p. 24) may have been sufficient to prevent the growth of large crystals; thus, most of the bed probably was deposited originally as small, equigranular crystals of gypsum, with random orientation. Calcite and shale, which were deposited at the same time, accumulated along the borders of some of the rapidly precipitating gypsum crystals. The absence of large crystals of gypsum near the upper contact of the bed suggests that precipitation of gypsum may have ceased abruptly.

Evidence of recrystallization.—The microscopic characteristics of some selenite crystals suggest their formation by recrystallization. The characteristics that suggest formation of selenite crystals in the bed by recrystallization are: (1) obscurity of boundaries of some adjacent selenite crystals; (2) interfingering of shale and selenite, optical continuity of some selenite being maintained around the shale; (3) optical continuity between satin spar crystals in a veinlet and the selenite of the vein walls; (4) optical continuity between the satin spar layer along the upper contact and crystals of selenite below the contact; and (5) inclusion of small gypsum crystals within the boundaries of some selenite crystals. Some of these characteristics indicate secondary deposition. Solution, insofar as it has effected enlargement of pre-existing crystals, is regarded as a phase of recrystallization, but insofar as it has effected the removal of part of the gypsum, it will be considered later as a separate process.

Microscopically, the selenite crystals exhibit undulatory extinction, a characteristic that has been observed in selenite from other localities. Undulatory extinction in quartz crystals from low temperature veins has been described by Adams (1920, p. 653), who attributes the phenomenon to slight differences in orientation caused by the coalescence of small crystals to produce large ones, and not by internal strains. Application of Adams' data indicates that the undulatory extinction of selenite may be evidence of recrystallization. Photomicrographs of crustified quartz (Adams, 1920, p. 623-664) show features bearing a close resemblance to those of parts of the gypsum bed that may have undergone recrystallization.

Evidence relative to recrystallization during diagenesis.—Some selenite may have been formed by recrystallization effected by sea waters during diagenesis—that is, before complete lithification of the gypsum. The presence of scattered selenite crystals away from the contacts lends credence to this possibility. It is improbable that ground water penetrated this area, as no open fractures or veinlets are present. The characteristics of other chemical precipitates, particularly limestones (Grabau, 1932, p. 755-756), have been explained as the result of recrystallization during diagenesis.

Evidence relative to recrystallization by ground water.—Most of the selenite in the gypsum bed probably was formed by recrystallization effected by ground water. Recrystallization subsequent to lithification is indicated in two ways. In some specimens of selenite that interfinger with shale near the upper contact there is optical continuity of selenite around the shale, which indicates recrystallization after introduction of the shale. In specimens from the upper part of the bed near the upper contact (Pl. 18A) optical continuity exists between part of the satin spar and the adjacent selenite. The origin of the satin spar and its relation to the gypsum will be considered in detail later.

The action of ground water in effecting recrystallization is indicated also by field observations. Most of the selenite occurs in the parts of the gypsum bed most susceptible to ground-water penetration—that is, near the upper and lower contacts and adjacent to fractures in the gypsum. Only a few crystals of selenite are scattered elsewhere in the gypsum bed. The vertical extent of selenite near the upper contact of the gypsum is greater than near the lower contact, suggesting that the recrystallizing waters moved mainly downward, and thus probably were meteoric.

Evidence relative to secondary solution and redeposition.—The effect of secondary, or meteoric, solution on the gypsum bed is indicated in the field by: (1) the absence of outcrops of gypsum, except where the rate of erosion seemingly exceeds the rate of ground-water solution, as along Blue River; (2) pinching out of gypsum in the Certainteed mine as the outcrop is approached; (3) the presence of water channels in gypsum near the outcrop in the Certainteed mine; and (4) the collapse of overlying shale due to solution of gypsum by Big Blue River north of the Fowler mine.

Redeposition of gypsum is indicated by the numerous veinlets of satin spar in the gypsum bed and in the overlying shale. The probable sequence of events to produce a veinlet of satin spar with indefinite walls (Pl. 20B) is: initial deposition of gypsum, lithification, fracture, deposition of satin spar along the fracture, solution to form irregular walls, and solution and redeposition to form a small irregular veinlet of finer-grained gypsum. Several steps may have been contemporaneous. In a veinlet of fine-grained gypsum having roughly parallel, matching walls (Fig. 15*a*), the sequence may have been: initial deposition of gypsum, lithification, fracture, deposition of fine-grained gypsum along the fracture, solution to form slightly irregular walls, and recrystallization to form selenite, a crystal of which interrupts the veinlet. Recrystallization may have occurred during lithification; if so, two periods of recrystallization are indicated. Some events may have been contemporaneous. For crustified gypsum along an open fracture (Fig. 15*c*) the sequence of events may have been: initial deposition of gypsum, lithification, fracture, recrystallization of the walls, solution, and redeposition along the open fracture. Recrystallization may have taken place during lithification.

Circulating ground water may have introduced mechanically a part of the shale that fills fractures near the upper contact, inasmuch as such shale is identical to that which overlies the gypsum. The shale along veinlets and fractures elsewhere in the gypsum, however, resembles that which lies along the borders of the smaller crystals of gypsum. Residual accumulation of clay may have resulted from ground-water solution of gypsum. The amount of shale present in some veinlets does not exceed the calculated amount contained in the gypsum prior to solution. The sequence of events that may have produced a veinlet of satin spar with shale along both walls (Pl. 18B) is: initial deposition of gypsum, lithification, recrystallization to form selenite, fracture, introduction of shale along the fracture, further fracture along the same plane, deposition of satin spar, and further recrystallization. The first period of recrystallization may have occurred during lithification or after introduction of shale. The second period of recrystallization is indicated by the obscurity of boundaries of adjacent satin spar crystals, and by the local optical continuity between satin spar and the walls.

The exact nature of deposition in veinlets is difficult to determine, as subsequent recrystallization may have obscured some of the original features of veinlets. A zone of interfingering crystals of satin spar in the interior of a veinlet (Fig. 15*b*) indicates the filling of a fracture by the inward growth of crystals from both walls. Locally, growth may have progressed from one wall, as crystals composing some veinlets are continuous and oriented normal only to one wall. As satin spar is present in larger veinlets, and finer-grained gypsum in smaller veinlets, the size of the fracture seems to have determined the crystal form of the fracture filling. Small fractures seem to have been filled completely before preferred orientation could develop.

The formation of the layer of satin spar along the lower contact by filling of fractures is indicated by microscopic studies. The lower contact is gradational, so probably no natural avenue of ground-water movement existed originally, but stresses may have created fractures along planes of weakness in or near the gradational zone. The discontinuity of the satin spar layer near the lower contact, and its varying position in relation to the gradational zone (Fig. 14*a*) may be explained as the result of fracturing and subsequent filling. The local failure of the walls to match may be attributed to subsequent solution.

The layer of satin spar along the upper contact probably was formed by deposition along stratification planes at the base of the overlying shale, for the crystals are oriented normal to the stratification of the shale rather than to the irregular upper surface of the gypsum. As vertical growth occurred, the force exerted by growing crystals of satin spar may have displaced the shale and spread the stratification planes. An almost continuous shale layer thus lies between the satin spar and the upper surface of the gypsum. The displacement of shale by the force of growing crystals is indicated by the relation of shale to satin spar illustrated in Figure 15*d*. Part of the calcium sulfate that was deposited as satin spar along the upper contact may have been derived secondarily from the overlying shale. By chemical analysis, 5.29 percent of the lower part of the Easly Creek shale is gypsum. Elias (1937, p. 426) regarded the lower part of the Easly Creek shale as deposits formed in the littoral zone of a regressing sea. In such an environment, small amounts of gypsum could have been deposited with the shale, either as chemical precipitate or as clastic material derived from the underlying gypsum.

Subsequent local recrystallization of the layer of satin spar along the upper contact is indicated. The probable sequence of events in the area may have been: initial deposition of gypsum, lithification, deposition of satin spar adjacent to the contact, fracturing of the gypsum, introduction of shale along fractures, and recrystallization of part of the gypsum and satin spar to form selenite. Several events may have been contemporaneous.

There is a notable increase in the thickness of the upper satin spar layer where there are depressions in the upper surface of the gypsum. Smith (1918, p. 187), in describing a similar occurrence in the Chellaston gypsum deposits of England, indicates that the increase in thickness may have resulted from the accumulation of ground-water in depressions. Increased thickness of the satin spar layer along the upper contact of the gypsum bed at Blue Rapids probably is to be explained in the same manner. Circulating ground-water would tend to collect and evaporate in the shale above depressions in the upper surface of the gypsum, particularly if the flow of water were diminished. A greater thickness of satin spar thus may have developed in such areas. Field evidence favoring such an origin includes the increase in thickness of the upper layer of satin spar toward depressions in the upper surface of the gypsum, and the decrease in thickness away from such depression; and the increase in the amount of satin spar present in the shale above such depressions.

Local stress may have caused curvature of the satin spar, as the amount and direction of curvature differ greatly in different parts of the deposit. Plate 19A illustrates part of the upper layer of satin spar in which some individual crystals maintain their optical continuity past the line of curvature. Similar curvature can be produced by applying artificial stress to satin spar, as indicated by curvature developed during the grinding of thin sections.

Conclusions Regarding Origin

Original deposition.—The Blue Rapids deposits were formed by direct precipitation of gypsum from evaporating marine waters. The following evidence is presented in support of this conclusion.

(1) The occurrence of the gypsum deposits in a cycle of marine sediments is indicative of an origin from evaporating marine waters. Elias (1937, p. 420), in discussing the causes of cyclic sedimentation, states that "periodic change of sea level was probably the main factor producing the cyclic recurrence of stratigraphic units". It is possible that some slight disturbance could have produced a basin partly cut off from a regressing continental sea. As evaporation progressed, deposition of gypsum would follow that of limestone. Fresh supplies of sea water could have been received from tidal influxes, as suggested by Ochsenius (Grabau, 1920, p. 128-130); or, perhaps, from sea level pulsations similar to those that deposited the rapidly alternating sediments of some of the

cyclic beds. If the rate of evaporation were approximately equal to the influx of sea water, the gypsum could have accumulated in such a basin, with a minimum of other sedimentary impurities.

(2) Calcium carbonate is visible microscopically in many of the samples. Stieglitz (1909, p. 233-264) has shown that after evaporating marine waters become sufficiently concentrated to deposit calcium sulfate, calcium carbonate must continue to be deposited in small amounts, because the carbon dioxide in the atmosphere continues to dissolve in the water and to react with calcium.

(3) The relationship of the underlying limestone to the gypsum indicates an origin from evaporating marine waters. The presence of a gradational zone shows that evaporation probably began while limestone was still being deposited. The increasing salinity of the water may have caused existing fauna to perish fairly rapidly, as indicated by the absence of microfossils above the gradational zone. Life seems to have ceased immediately prior to the time at which gypsum alone began to precipitate.

(4) There is no indication of anhydrite in the gypsum. Although parts of the gypsum bed are relatively unaltered, neither anhydrite nor relict structures of anhydrite were observed in any of the more than 100 samples that were examined microscopically, indicating that the original precipitation of calcium sulfate occurred only in the form of gypsum.

Subsequent alterations.—Petrographic and field studies indicate that the following alterations of the gypsum have taken place subsequent to deposition.

(1) Recrystallization of part of the gypsum to selenite during diagenesis. No other process seems adequate to explain the scattered crystals of selenite that show no evidence of ground-water penetration.

(2) Fracturing of the gypsum, particularly near the contacts. Shrinkage of the gypsum during lithification may have created some fractures, but field evidence indicates that regional stresses were of sufficient magnitude to cause fracturing.

(3) Mechanical introduction of shale along fractures by circulating ground water. Petrographic and field studies show that at least part of the shale present in the gypsum is similar to, and perhaps derived from, the overlying shale.

(4) Subsequent recrystallization of part of the gypsum by ground water to form selenite. Inasmuch as most of the selenite occurs in the part of the gypsum bed most susceptible to ground-water

penetration, it probably was formed by subsequent recrystallization rather than during diagenesis.

(5) Solution and redeposition of part of the gypsum by ground water. Locally, solution may have caused residual accumulation of shale originally interbedded with the gypsum. Redeposition seems to have formed veinlets of satin spar or of finer-grained gypsum within the gypsum bed, as well as layers of satin spar along the contacts. Local thickening of the layer of satin spar along the upper contact probably resulted from the accumulation of ground water in depressions in the upper surface of the gypsum. Local stress may have created the sharp curvature exhibited by some satin spar.

Conclusions

Gypsum deposits, averaging 8½ feet in thickness, crop out in the vicinity of Blue Rapids, Marshall County, Kansas. They occur near the base of the Easly Creek shale formation, of early Permian age. Layers of satin spar, which average a quarter to half an inch in thickness, lie along the upper and lower contacts of the gypsum bed. The strata that contain the gypsum lie on the western slope of a gentle arch over the buried Nemaha anticline. Structure contours drawn on the base of the gypsum show local variations in dip and strike, which may have been caused by differential compaction.

Petrographic studies show (1) the gradation of the underlying limestone into the gypsum, (2) the presence of calcite and interbedded shale in the gypsum, (3) the absence of anhydrite, (4) the presence of selenite in part of the gypsum, (5) the interfingering of shale with selenite, (6) the presence of open fractures in the gypsum, (7) the presence of veinlets of satin spar and finer-grained gypsum, and (8) the interfingering of shale with satin spar along the upper contact.

Evidence presented supports the concept of original deposition by direct precipitation of gypsum from evaporating waters of a regressing sea. Petrographic and field studies indicate these subsequent alterations: (1) recrystallization of part of the gypsum during diagenesis to form selenite; (2) fracturing of the gypsum; (3) introduction of shale along fractures by circulating ground water; (4) subsequent recrystallization of part of the gypsum by ground water, to form selenite; and (5) solution and redeposition of part of the gypsum by ground water, to form veinlets of satin spar or of finer-grained gypsum within the gypsum bed, as well as layers of satin spar along the contacts.

OTHER GYPSUM-ANHYDRITE STRATA IN KANSAS

Day Creek Dolomite

The Day Creek dolomite is high in the Kansas Permian section (Fig. 3). Gypsum is not known to have been exploited from this bed. Moore and others (1951, p. 37) describe it: "Fine-grained dense dolomite cropping out in western Clark County. . . . Thickness in Kansas is about 2 feet". In the subsurface it thickens considerably and consists primarily of anhydrite (D. F. Merriam, personal communication).

The Day Creek dolomite underlies the Taloga formation, the lower 25 feet of which consists of red silty shale. It overlies the White Horse sandstone, which consists of red sandstone, shale, and siltstone having a total thickness of 270 feet. The Day Creek dolomite is thus a thin bed lying between two relatively thick redbed sequences, and its occurrence as anhydrite in the subsurface makes it easily recognized in well samples. Because the Day Creek dolomite is near the top of the Kansas Permian section, it is cut in several places by the unconformity in that stratigraphic position. It is therefore discontinuous.

Stone Corral Dolomite

The Stone Corral dolomite is in the Sumner group, of post-Wolfcampian age (Fig. 3). Most outcrops show it to be a cellular or vuggy dolomite. The maximum thickness measured on the outcrop is about 6 feet. The area of outcrop includes parts of McPherson, Rice, Reno, and Kingman Counties. In the subsurface the Stone Corral is an extensive anhydrite bed much thicker than the dolomite facies on the outcrop.

The Stone Corral is overlain by the Chikaskia member of the Harper sandstone (Fig. 3). This member consists principally of red sandstone, siltstone, and shale, and contains some gray shale. The thickness of the Chikaskia member ranges from 100 to 160 feet (Moore and others, 1951, p. 40). The Stone Corral is underlain by the Ninnescah shale, which also is predominantly red shale and siltstone, but also contains some gray shale. The average thickness of the Ninnescah shale is 300 feet.

The Stone Corral is easily recognized in the subsurface because its lithology contrasts markedly with that of the rocks directly above and below it. This feature and its widespread occurrence make it a formation on which geologic structure has often been mapped.

Oaks Shale Member, Hamlin Shale

The Oaks shale member of the Hamlin shale is of Wolfcampian age (Fig. 3). Stratigraphically it is the uppermost member of the Admire group. It is overlain by the Americus limestone member of the Foraker limestone. The Americus limestone is described by Moore and others (1951, p. 49): "Commonly two limestone beds separated by shale, the upper bed containing flint nodules in southern Kansas. The limestone commonly is bluish-gray and the shale is gray to nearly black. Fusulines and brachipods are plentiful. The upper limestone ranges from about 1 to 5 feet in thickness. It is shaly in part. . . . The shale between the two main limestone units, where identifiable, ranges from about 3 to 13 feet in thickness. The lower limestone, commonly with a shale break, ranges from about 2 to 4 feet in thickness. Rhombic blocks of limestone mark the outcrop of the lower bed across the State". The Oaks shale member is underlain by the Houchen Creek limestone member of the Hamlin shale formation (Fig. 3), which is described by Moore and others (1951, p. 49) as: "Limestone, upper gray, commonly consisting largely of lobate algal deposits, massive; lower part porous, silty, impure, yellow-brown. Thickness ranges from about 1 to 4 feet".

The Oaks shale member commonly comprises gray to almost black shale, but Smith and Anders (1951) show that it contains gypsum in southwestern Wabaunsee County. Their stratigraphic section of the area shows that in the subsurface the Oaks "shale" is a gypsum bed as much as 10 feet thick.

The Oaks shale member is the lowest stratigraphic unit known to contain bedded gypsum in Kansas; consequently, this bed is exposed farther east than any other known gypsum bed, because in general the regional dip of the rocks in Kansas is to the west. Discovery of this isolated deposit suggests the possibility that other similar isolated deposits may be found.

USES AND MANUFACTURE OF GYPSUM

Although considerable gypsum is used in the raw state, most gypsum is calcined before it is used. Calcining consists of heating the mineral to remove the chemically combined water that it contains. This process and its chemical reactions have been described briefly in this report. When water is added to calcined gypsum it soon recombines chemically to produce a material having cementitious properties. The mixture can be applied to a surface or molded to a shape and when it sets (when the calcined gypsum and water recombine), it hardens in the form and place in which it was applied.

Much of the following description of gypsum products comes from Ver Planck (1952).

Calcined Gypsum

Most calcined gypsum, known as gypsum plaster or plaster of paris, is used in the building industry.

Plaster Used in the Building Industry

Base-coat plasters.—The first plaster applied to lath or any other type of surface is called base-coat plaster. There are four types of base-coat plaster; hard-wall plaster, sanded-gypsum plaster, wood-fiber plaster, and bond plaster. The type of base-coat plaster used depends upon the surface to which it is to be applied and upon the qualities desired in the plaster.

Hard-wall plaster is made by mixing gypsum plaster with sand. Vermiculite and perlite may be substituted for the sand as aggregate to make the plaster lighter and to give it greater insulating properties.

Sanded plaster differs from hard-wall plaster in that the sand is added at the place of manufacture rather than at its place of use. It has the same uses as hard-wall plaster.

Wood-fiber plaster utilizes wood as aggregate material. It is said to be stronger and harder and to have more fire resistance than hard-wall plaster.

Bond plaster is applied directly to concrete surfaces. It has the same rate of thermal expansion as concrete, so the possibility of cracks resulting from changes in temperature is reduced.

Finishing plaster.—Finishing plaster is applied over the surface of base-coat plaster. It is mixed with lime before it is used. It is known either as gaging plaster or molding plaster. Gaging plaster is used on flat surfaces. Molding plaster is more finely ground than gaging plaster and is used for ornamental objects.

Keene's cement is a special type of finishing plaster. It is used either with or without lime. After it sets it has exceptional strength, density, and hardness, and can take a high polish.

Acoustical plaster is a finishing plaster that has a cellular structure and will absorb sound. It is mixed at the plant and requires only the addition of water when it is used.

Prefabricated gypsum products.—Prefabricated gypsum products include gypsum wallboard, gypsum lath, gypsum sheathing, and gypsum tile. The first three are board products made on continuous-process machines. Gypsum tile is a molded product.

Gypsum wallboard is used for interiors. It is attached directly to wood framing or furring blocks and can be papered or painted. Wallboard is either ⅜ or ½ inch thick and is made in 4-foot widths and in lengths of 6 to 12 feet. Aluminum foil may be cemented to the back side for insulation.

Gypsum lath is of smaller dimensions, 4 feet long, 16 inches wide, and ⅜ to ½ inch thick. It is available either plain or with aluminum foil cemented on the back side for insulation.

Gypsum sheathing is made with water-repellent paper and is wind resistant. It is available in sheets ½ inch thick, 2 feet wide, and 8 feet long.

According to Ver Planck (1952, p. 94) "The principal uses for gypsum tile are for non-load-bearing interior partitions and for fire-proofing structural steel. Gypsum tile is particularly adapted to buildings in which partitions must be frequently altered to meet changing requirements."

Standard shape for gypsum tile is 30 inches long and 12 inches wide. Gypsum tile is made either solid or hollow and is available in thicknesses of 2 to 6 inches.

Reinforced gypsum concrete.—Reinforced gypsum concrete is used in making prefabricated units or is cast in place. In either process the forms are built with the reinforcing cables inside of them and the gypsum plaster is then poured into the forms. Relatively small amounts of gypsum have been used for this purpose.

Plaster Used Outside the Building Industry

Relatively small amounts of calcined gypsum are used outside the building industry. These plasters require special properties, therefore require special processing as well as extremely pure gypsum in their manufacture. These products are therefore expensive compared to building plaster.

Gypsum finds use in industry as casting plaster, as pottery plaster, as industrial and molding plaster, as dental and orthopedic plaster, and in the plate glass industry.

Casting plaster.—Casting plaster is used for ornamentation and for statuary. It expands slightly when it sets, thus completely filling the mold in which it is cast.

Pottery plaster.—Pottery plaster is used to make molds for ceramic material of all sorts. It must receive and transmit surface detail, retain dimensional accuracy, and absorb moisture.

Industrial and molding plaster.—Industrial and molding plaster is used in making molds and patterns that require great dimensional accuracy. Plaster used in this capacity requires a special mode of manufacture.

Dental and orthopedic plaster.—Gypsum is used to make dental and orthopedic plasters. The heat of hydration must be kept at a minimum in this type of plaster.

Plaster used in the plate glass industry.—In the plate glass industry small amounts of plaster are used to hold glass while it is being polished. Plaster for this purpose must be finely ground and free from any impurities that would scratch the glass.

Raw Gypsum

Raw gypsum also finds considerable use. It is used in portland cement to retard its setting time. It is used as a soil additive for certain types of soils and crops. Raw gypsum, finely ground, is used as a filler in paper and paint, and as a carrier for insecticides. Raw gypsum finds further use as blackboard chalk, as dilutent in drugs, as an oxidizing agent in glass manufacture, and as a water conditioner in breweries. Dead burned gypsum is likewise used as a filler and as brewer's fixe.

Gypsum has found small use as a building stone; its solubility in water makes it undesirable for this purpose. Alabaster, a dense translucent form of gypsum, is used for ornamental stone.

Source of Sulfur

The sulfur shortage of the late 40's caused some study of gypsum as a possible source of sulfur. A process for making sulfur from gypsum is discussed further in this report.

Industrial Processing of Gypsum

Calcining

The application of heat to gypsum until it has lost part or all of its water of hydration is called calcining. The primary uses of gypsum depend upon the hydraulic properties of the products obtained by this treatment with heat, hence the calcining process is vital to the industry. Most gypsum is calcined in gypsum kettles or in rotary kilns.

According to Lippard (1949), a gypsum kettle consists of a cylindrical steel shell with a rounded bottom, which contains some kind of mechanically operated stirring device on the inside, and is heated from the bottom. Diameters range from 8 to 15 feet, and depths from 6 to 14 feet.

A rotary gypsum kiln is similar to those used in the cement industry. It consists of a cylindrical tube lined with fire brick. Sizes range from 70 to 155 feet long and 6 to 8 feet in diameter. The kiln is fired at one end and rotates slowly. It is supported at a slight pitch, and is fed from the high end, discharging from the low end.

Calcining in gypsum kettles is a batch process. Ground gypsum is charged into the top of the kettle when it is at a temperature of 110° C. (230° F.). The temperature is then raised slowly until it reaches about 120° C. (250° F.), at which point the gypsum seems to boil, owing to the steam being emitted from the hydrated calcium sulfate. The temperature remains the same until the boiling has subsided, and then begins to rise again. By the time a temperature of 150° to 165° C. (300° to 330° F.) is reached the boiling has ceased, indicating that the gypsum has been dehydrated to the hemihydrate. The temperature is allowed to rise slightly beyond this point and then the kettle is discharged into a hot pit where any uncalcined gypsum particles may still react.

Gypsum that is to be calcined in rotary kilns is crushed to 1¼-inch particles or smaller. The fine particles may or may not be removed. Gypsum is fed into the high end and the kiln is fired from the low end (counter-flow firing). The discharge temperature is 160° to 195° C. (320° to 380° F.). When Keene's cement is made in a rotary kiln, higher temperatures are necessary.

Manufacturing Special Types of Plaster

Special types of plasters used for industrial purposes require special processes in their manufacture, in order that they shall retain, after setting, the size and shape to which they are formed while plastic. Some of these products are calcined slowly in an autoclave under steam pressure. Resins, lime, and other materials are added to some to give the desired characteristics, and some require a certain amount of regrinding after calcining. Gypsum used in these products is necessarily extremely pure.

Manufacture of Prefabricated Gypsum Products

Gypsum board and other prefabricated gypsum products are made by a continuous process, whereby a mixture of calcined gypsum, or plaster of paris, and water is laid down between two layers of paper. Paper is fed from rolls approximately the same width as the desired width of the board, the plaster being laid on one layer and the other layer used as a cover for the plaster. The plaster is usually mixed with a fiber of some kind, and its setting time must be controlled carefully. In the process the edges of the paper are turned so that the board will have square corners, and provision is made to keep the board the same thickness throughout its entire width. The edges of the continuous strip are then taped. As the last step of the process, the continuous strip is cut automatically into the desired lengths.

Gypsum lath and gypsum sheathing are made by similar processes. Gypsum tile, on the other hand, is made in steel molds. The tile is cast on a mass-production basis, and it is made either hollow or solid.

Process for Manufacture of Sulfuric Acid from Gypsum

Neither sulfur nor sulfuric acid is made from gypsum in the United States but such a process has received much attention recently.

Valleroy (1952, p. 5-6) states:

"By adding silica and alumina, and coke to pulverized gypsum in the proper proportions a mix is obtained which upon calcination yields SO_2 and a sintered product which is suitable for the manufacture of cement. The chemical reactions involved are complex, but probably the $CaSO_4$ is first reduced by the coke to calcium sulfide as shown by the following equations:

$$CaSO_4 + 2C = CaS + 2\,CO_2$$

$$CaS + 3\,CaSO_4 = 4\,CaO + 4\,SO_2$$

$$CaO + (SiO_2, Al_2O_3, Fe_2O_3) = \text{Cement clinker}$$

Overall Reaction

$$4\,CaSO_4 + 2\,C + (x\,SiO_2 \,.\, y\,Al_2O_3 \,.\, z\,Fe_2\,O_3) =$$
$$4\,SO_2 + 2\,CO_2 + 4\,(CaO \,.\, x\,SiO_2 \,.\, y\,Al_2O_3 \,.\, z\,Fe_2O_3)$$

In this simplified version of the kiln chemistry the sulfate first goes to the sulfide, which in turn reacts at higher temperature with more calcium sulfate to form CaO. The calcium oxide then reacts in the hottest zone with the metallic oxides to form the cement clinker.

"The history of the cement-sulfuric acid process goes back to the First World War when Germany, then cut off from her supplies of pyrites, turned to calcium sulfate as a source of sulfur".

SUMMARY OF KANSAS GYPSUM

Deposits

Gypsum deposits in Kansas are found primarily in rocks of Permian age. They may be divided roughly into two general classifications, those of small areal extent and those that cover a large area.

An example of a deposit of small areal extent is the deposit in the Easly Creek shale, in which gypsum is found only in a small area in Marshall County whereas the Easly Creek shale itself can be traced throughout the entire width of the state. Deposits of this type generally are found in the lower part of the Kansas Permian section.

An example of the widespread type of gypsum deposit is the Blaine formation, which can be traced a long distance both at the surface and in the subsurface. Gypsum deposits of this type are found in the middle and upper part of the Kansas Permian section.

Quality and Supply

The high-grade products manufactured for many years from Kansas gypsum are evidence of the quality of Kansas gypsum. Although mined at only a few localities, the deposits are extensive, and undoubtedly gypsum of the same quality as that already mined is widely distributed. No mined resource will last forever; nevertheless, the size of the Kansas gypsum deposits is such that production at the present rate of use can be maintained for a great many years.

Different types of products require different grades of gypsum in their manufacture. Such products as Keene's cement, orthopedic and dental plasters, statuary plasters, and finishing plasters require exceptionally pure gypsum. Other products, such as base coat plasters and many of the prefabricated gypsum products, require less pure gypsum. It is therefore significant that the Kansas gypsum production includes many of the high-grade products.

Transportation

The Kansas gypsum deposits are traversed by several major railroads, although not all areas are equally well served. Distance to market is a major factor in transportation. The deposits themselves cannot move, but the market can. Because of the close association of gypsum products with the building industry, the over-all increase in population and the westward shift of the center of population have increased the market and brought it closer to the Kansas gypsum deposits.

Production

Kansas gypsum production has increased during the last decade. The two main reasons for this are the increased demands for plaster from the building industry and other users, and the increases in the productive capacity of the gypsum mines and plants that have been made. As yet the increased demand for gypsum products has not resulted in any new gypsum-mining operations in the state.

Future Demand for Gypsum

As our population continues to increase, new buildings will have to be constructed for people to use; moreover, gypsum products are continually replacing other products used in the building industry. The demand for gypsum should therefore increase for many years to come. This means that the people of Kansas can look upon their gypsum deposits as an increasingly valuable resource.

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