GEOLOGY OF WEBSTER COUNTY

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FRANK A. WILDER.

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CONTENTS.

INTRODUCTION.

LOCATION AND AREA.

Webster county is somewhat north and west of the center of the state. Four counties lie between it and the Missouri river while three separate it from the Minnesota boundary. The county includes twenty townships of thirty-six square miles each, two of which are subdivided for the purposes of local government, so that twenty-two townships are named on the map. The second correction line passes between townships 98 and 99 north, and throws the northern part of the county two miles to the west, breaking its otherwise regular outline. Humboldt county bounds it on the north, Wright and Hamilton on the east, Boone and Greene on the south and Calhoun and Pocahontas on the west. Its location on the Des Moines river was more significant in earlier days when greater dependence was placed upon water for power and transportation, yet the beauty of the finely wooded valley is a constant source of satisfaction to the inhabitants of the region. It lies in the center of a great agricultural region of which every county in Iowa forms a part.

PREVIOUS GEOLOGICAL WORK.

Some of the earliest geological work undertaken in the state was carried on in Webster county. The Des Moines river exposes along its banks the indurated beds, and gives at times sections of rock and drift 200 feet in thickness. These greatly facilitate geological study. The unique deposit of gypsum is attractive to the student on account of the theoretical problems that it presents, and to others it is interesting on account of its practical value.

In the year 1849 Owen* made a hurried trip up the Des Moines river, noticed the gypsum in Webster county and made certain deductions in regard to its age. In 1856 Worthen† visited the

* Geology of Wis., Iowa and Minn., p. 126, Philadelphia, 1852.

† Geology of Iowa, Vol. I, p. 177. 1858.

region and came to the conclusion that the gypsum does not lie conformably on the Coal Measures. Hall* in 1858 and McGee† in 1884 considered the stratigraphic relationship and age of the gypsum. Webster county was included in the geological studies of C. A. White and references to its coal and gypsum are made in his annual reports of 1868 and 1870.‡ In these reports White pointed out the great value of the Webster county gypsum, and urged that it be developed so that the state might furnish the stucco and land plaster used within its borders. His judgment of the worth and extent of the gypsum has been verified, with but one exception. It has failed to meet his expectation as a building stone. White also called attention to deposits of celestine along the Des Moines river and at the mouth of Soldier creek, and gave a description of the mineral as it occurs at these points. In 1880 Upham‖ studied the inner Wisconsin moraine known as the Gary, and called attention to a morainic tract between Fort Dodge and Tara, which he thought might be associated with this moraine.

Keyes§ reported quite fully on the gypsum area in 1893. He outlined the position and extent of the deposit, considered its stratigraphic relationships and stated clearly the conditions under which in all probability it was formed. He emphasized the economic value of the gypsum and described the methods of quarrying and milling at that time in use. In the preceding year the coal deposits of Webster county were considered¶ in connection with those of other parts of the state. The report included analyses of a number of samples of coal obtained in the vicinity of Fort Dodge.

Arthur C. Spencer, in a paper presented to the Iowa Academy of Sciences, described the crystals of gypsum common about Fort Dodge.**

* Geology of Iowa, Vol. I, p 142. 1858.
† Tenth U. S. Census, Vol. X., Building Stones, p. 258, Washington. 1884.
‡ First Ann. Rept. State Geologist. pp. 26-27, 1868; 2d Ann. Rept., pp 135-140, 1868. Geology of Iowa, Vol. II, pp. 293 and pp 254-256. Analyses of Fort Dodge coal are given on pages 375-376.
‖ Ann. Rept. State Geologist, Minnesota, p. 305, 1880.
§ Iowa Geol. Surv., Ann. Rept., Vol. III, 1893, pp. 259-304.
¶ Iowa Geol. Surv., Vol. II, pp. 197-210. 1892.
** Proc. Iowa Acad. Sci., Vol. II, pp. 143-145. 1894.

PHYSIOGRAPHY.

TOPOGRAPHY.

Webster county lies wholly within the area that was covered by the last great ice invasion, and the drift of this ice sheet, called the Wisconsin, forms almost everywhere the surface material. Limited areas covered by glacial material that has been recently reworked by streams, or by detritus formed by the very recent weathering of cliffs along streams, are the only regions not drift covered. So recently was this drift deposited that erosion has but slightly contributed to the topographic features of the county. Only in the immediate vicinity of the Des Moines river and its tributaries are the results of water action apparent. Viewed from the valleys of the streams, the landscape seems extremely rugged, and it is a matter of constant surprise that, in a region so typically prairie, scenery so beautiful abounds. The sides of the valley are steep and well wooded from top to bottom. After ascending the sharp slope, however, the climber finds himself at once on the level prairie where often for miles he can see the stream as it flows through its V-shaped valley.

The following table of elevations indicates for the country a very uniform surface, with a slight slope toward the south:

TOWN.	AUTHORITY.	ELEVATION.
Clare	C., R. I. & P. R. R.	1,191
Tara	C., R. I. & P. R. R.	1,126
Moorland	C., R. I. & P. R. R.	1,146
Callender	C., R. I. & P. R. R.	1,151
Gowrie	C., R. I. & P. R. R.	1,138
Barnum	Ill. Cent. R. R.	1,178
Fort Dodge	Ill. Cent. R. R.	1,032
Judd	Ill. Cent. R. R.	1,114
Carbon	Ill. Cent. R. R.	1,118
Duncombe	Ill. Cent. R. R.	1,111
Dayton	C. & N. W. Ry.	1,084

All of the elevations cited give the upland level at the point named except at Fort Dodge and Dayton. The Illinois Central station at Fort Dodge is part way down the Des Moines river slope, while the Chicago & Northwestern station at Dayton is in the valley of Skiller creek. Barometric observations show that the upland level at these points is about 1,140 feet, which corresponds with the level of the rest of the county. The elevation at

Clare, the highest town in the county, is due to morainic conditions.

The southern half of the county presents a typical Wisconsin drift plain and includes areas that are remarkably level. From an elevation of only a few feet the country may be seen for miles in all directions. Clay and southern Elkhorn townships form such a great level tract. One exception to the otherwise level surface of this portion of the county must be noted. Three miles east of Gowrie, in the northeast corner of section 9, Lost Grove township, is Coon Mound. Its height is fifty feet and the dimensions of its base are about 500 by 300 feet, the longer axis extending north and south. It rises abruptly from the prairie and stands alone, save for a few low ridges to the west. The little school house on its summit is a conspicuous object for miles around.

The surface features of the northwestern part of the county differ somewhat from those of the southern half. Hills and ridges are common which cannot be associated with erosive agencies that generally give rise to such topographic features. These hills and ridges may roughly be grouped in two series, both extending east and west, about three miles apart. One follows the northern county line and includes the northern sections of Jackson and Deer Creek townships, and crosses the river into Badger township. Its average width is two miles. Within this broken region are level stretches of considerable extent. In years past one of these was flooded and bore the name of Bass lake, the depth of which is said to have been four feet. In 1890 Bass lake was drained into Bass creek by a ditch four feet deep. At present the area that it once covered is wholly under cultivation. The other series of hills and ridges extends across northern Douglas township, north of Lizard creek, with occasional outliers farther south across the creek. This series appears again across the river in section 19, Badger township. The Ainsworth home and farm buildings, in section 11, Douglas township, are on the crest of one of the ridges in this belt.

The valley of the Des Moines river is the most interesting topographic feature that the county presents. Throughout its course within the county the river has cut through the drift and indurated rocks to a depth varying from 150 to 200 feet. West of Badger, from the prairie at the top of the river bluffs to water level, the descent is 140 feet. At Fort Dodge the upland level is reached at the Mason City and Fort Dodge railway station. The river lies three-fourths of a mile to the west and 185 feet below this point. Across the river the bluffs rise again sharply to the prairie level, the ascent of nearly 200 feet being made within 250 yards. At Blandon's mill, three miles below Fort Dodge, the valley is 165 feet deep, at Coalville 175 feet, and at Lehigh, the water is 190 feet below the upland plain.

High up in the valley, 125 feet above the water, a pronounced gravel terrace frequently appears. Round Prairie at Fort Dodge, on which the fair grounds were located, is a part of this terrace, which is here unusually wide. It is well developed south of West Fort Dodge. In width it varies from twenty to 200 yards. Below this, sixty feet above the water, fragments of an alluvial terrace are frequently found, commonly called the second bench. The alluvial bottom lands are seldom more than 300 yards wide. The broadest point in the Des Moines river valley is at the mouth of the Boone river, where the width of a mile is attained. Standing in the center of the alluvial plain at this point is a very symmetrical hill of circumdenudation fifty feet high and 400 feet broad.

At many points the river is vigorously attacking the base of the bluffs. Landslides result in which at times considerable quantities of material are involved. Where landslides have recently occurred the upper bluffs are so steep that they can scarcely be climbed.

In their upper courses the tributaries of the Des Moines in Webster county have not cut through the drift and commonly have very indifferent valleys. Generally rising in a slough, they follow for some miles the natural inequalities of the surface, adapting themselves to existing conditions rather than as yet materially altering them. Near the river the creeks have cut into the indurated rocks and the lower portions of their valleys appear more mature. A soft Carboniferous sandstone underlies the drift in the southern part of the county, and through this Prairie creek has cut to a depth of sixty feet. Mural escarpments thirty and forty feet high and miniature gorges and canyons are common. These conditions account for Wild Cat's cave in section 11, Pleasant Valley township. Often covered with mosses, ferns and lichens, the walls of these canyons are most picturesque.

Lizard creek flows through a valley of more maturity than any other of the tributaries of the Des Moines within the county. Of the two branches, the North Lizard is the major stream. Badger, Deer, Brushy and Skiller creeks are confined within sharp ravines in the drift, till they near the river, where for one or two miles they have cut through the indurated rock to a depth of ten or fifteen feet.

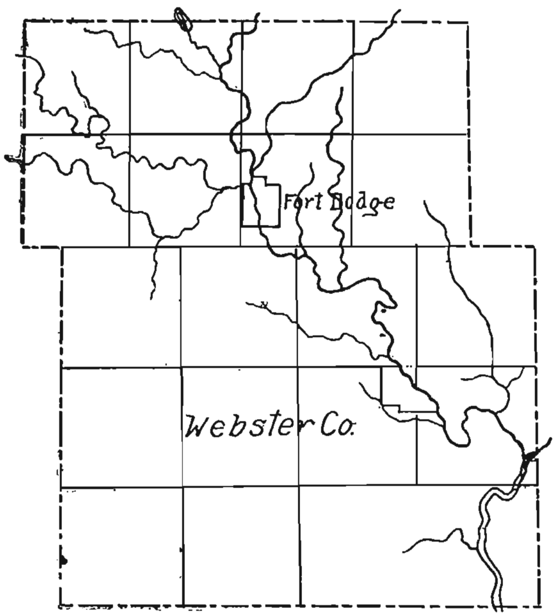


FIG. 2. Sketch of Webster county which shows the immature state of drainage.

DRAINAGE.

The entire county is drained by the Des Moines river and its tributaries. Most of the branches rise within or barely outside of the county and while still within its limits unite with the parent stream. Lizard, Soldier, Deer, Holaday, Brushy, Skiller and Prairie creeks answer this description. East and West Buttrick creeks, which drain four townships in the southwestern corner of the county, contribute their waters to the Raccoon

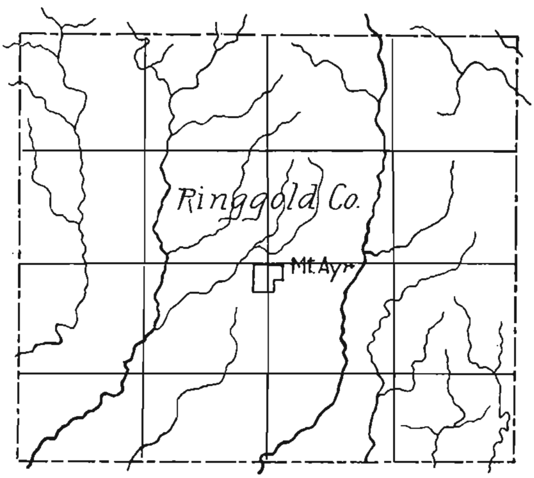


FIG. 3. Sketch of Ringgold county which brings out the maturity of its drainage.

which they meet in Greene county. The drainage system is not elaborate. None of the creeks in the county are perennial farther than a mile from their mouths. The creeks have no well developed subordinate feeders, and large stretches of country are dependent on artificial drainage. The contrast that Webster county presents in this particular with certain other parts of the state is made plain by a map drawn on a scale as limited as that of the Railroad Commissioners. The accompanying sketches which reproduce Ringgold and Webster counties illustrate fairly the difference in drainage between Webster county and the southern part of the state. Any county in the three tiers near the southern boundary would serve for contrast as well as Ringgold. Sloughs and ponds are common throughout Webster county, their number and size varying with the season of the year. The percentage of the land that is for this reason kept from cultivation, however, is not great. Yearly the number of ponds is being reduced by artificial drainage.

The Des Moines river crosses the county, entering near the center of the northern boundary and leaving at the southwestern corner. Its course is sinuous, measuring sixty-five miles in the county, while thirty-five miles is the straight line distance from its entrance to its exit. In width the Des Moines in Webster county varies from 100 to 200 yards, and in average depth from perhaps two feet in summer to seven feet during the rainy periods in the spring months. In addition to the main creeks which will be mentioned separately, there are along the Des Moines many ravines which in time of rain are tributary to it. These ravines extend from the river only a short distance, and often there are long stretches where the bluffs overlooking the river are unbroken.

Lizard creek is the largest stream tributary to the Des Moines

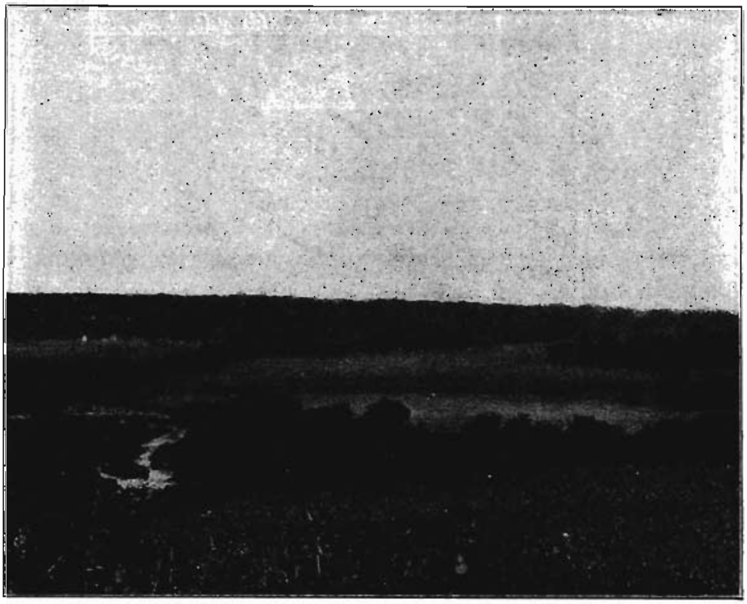


FIG. 4. The Des Moines valley at the mouth of the Boone river. The Boone appears in the foreground, while the Des Moines is hidden by trees.

in Webster county. It drains the five northwestern townships. Two branches of slightly differing size unite two miles from its mouth to form the main stream. The general course of both branches is southeast, save for a few miles near their junction where the southern branch turns north to meet its companion.

Deer creek rises barely across the line in Humboldt county and after traversing Deer Creek township in Webster county empties into the Des Moines. It has no tributaries, aside from short ravines supplying water in time of rain, and drains the region for only a short distance on either side of its immediate valley.

Prairie creek rises in Elkhorn township which it crosses diagonally. Entering Otho township it flows for some distance within two miles of the Des Moines river in a course nearly parallel before it unites with that stream. All of the creeks so far described are on the west side of the river.

Brushy creek, like most of the tributaries on the east side of the Des Moines in Webster county, flows almost due south. It rises at the northern edge of the county and for two-thirds of the length of the county flows within three miles of its eastern boundary.

Holaday creek which is three miles west of Bushy creek rises in the extreme northeastern corner of Badger township and flowing almost directly south drains western Cooper and Pleasant Valley townships. Throughout its course it is nearly parallel to Brushy creek.

Soldier creek rises in the northeastern corner of the county and differs from other streams on the east side of the river in this vicinity by flowing southwest, meeting the Des Moines at Fort Dodge. Like all of the secondary streams within the county it discharges a great quantity of water during the rainy season and is insignificant during the summer months.

East and West Buttrick creeks, tributaries of the Raccoon, which drain the southwestern part of the county, like all the minor water courses within the county, appear extremely immature. Reasons for the extreme youth of the drainage system will be considered later in connection with the Pleistocene deposits. Boone river unites with the Des Moines in southeastern Webster county.

STRATIGRAPHY.

General Relations of Strata.

Excepting limited Carboniferous outliers, Webster county contains the most northern of the Iowa Coal Measures. These lie just beneath the drift throughout all of the southern and the greater part of the rest of the county. The Saint Louis limestone, a characteristic member of the Lower Carboniferous, underlies the drift at certain points in the northern part of the area, and appears along the Des Moines in two places well to the south where the stream has cut through the Coal Measures which are there thin. Within the Coal Measures, in the central part of the county, probably during some part of the Permian or Jura-Trias period, a hollow of considerable extent was filled with saline deposits, the gypsum beds.

After being exposed as surface rock for a long period, the coal and associated shales, gypsum and limestone, were covered by material deposited by three great glaciers. Between the invasion of these ice sheets there was a considerable interval of time. Of the material deposited by the first and second glaciers the greater part was subsequently removed by erosion, stream and glacial, all that now remains appearing in scattered beds of badly rusted and decayed gravel. A later ice sheet deposited great quantities of clay, pebbles and bowlders, which still remain and slightly modified by plant and animal life form the soil of the region.

The relation of the formations is shown in the following table:

GROUP.	SYSTEM.	SERIES.	STAGE.	FORMATION.
Cenozoic.	Pleistocene.	Recent.		Tufa, Humus, Alluvium.
		Glacial.	Wisconsin.	Drift.
			Aftonian(?)	Gravel.
Paleozoic.	Carboniferous.	Permian(?)		Gypsum Red Shale and Sandstone.
		Upper Carboniferous or Pennsylvanian.	Des Moines.	Coal. Sandstone. Shale.
		Lower Carboniferous or Mississippian.	Saint Louis.	Limestone.

The Des Moines river gives a series of exposures nearly continuous across the county from north to south. Prairie creek reveals the indurated rocks for three miles west of the river in the center of the county. Near Fort Dodge sections occur near Soldier and Lizard creeks. Exposures along Holaday creek add greatly to our knowledge of the formations in the west central portion of the county. Near its mouth Skiller creek has cut through the drift and into the Coal Measures. Two Mile creek, near Fort Dodge, has excavated the ravine known as Gypsum Hollow, in which are revealed full sections of the gypsum beds with a few feet of the underlying shale and clay which are associated with them.

In addition to these natural exposures well data throughout the county and the records of holes sunk while prospecting for gypsum and coal are instructive.

Carboniferous System.

MISSISSIPPIAN SERIES.

Only the upper member of this series, the Saint Louis limestone, is exposed in Webster county. It frequently appears along the Des Moines river from the northern boundary of the county south to Lehigh and for two miles back from the river, to the east on Soldier creek, and for an equal distance to the west on Lizard creek.

In all of these exposures the limestone is quite consistent both in its lithological and stratigraphic characteristics. It is made up of layers of quite pure limestone, varying in thickness from an inch to a foot. Above the limestone layers from three to six feet of calcareous sandstone are common. Above the sandstone from six to ten feet of shaly marl are often found. A definite layer of this marl is extremely rich in fossils, while the rest is barren. Frequently the limestone layers are brecciated. The layers are folded gently, resulting in undulations in the stone averaging about thirty feet in length with a vertical distance of four feet from crest to hollow. Vertical cracks are common, but no faulting was observed and the stone shows only slightly the defects of crushing.

A typical section is found on the right bank of the Lizard, a mile from Fort Dodge, in Douglas township, section 24, center.

LIZARD CREEK SECTION—SAINT LOUIS LIMESTONE.

		FEET.
4.	Fossil-bearing marl, *Spirifer littoni* Swallow, *Pugnax ottumwa* White, *Seminula subquadrata* Hall, *Dentalium* sp., abundant	6
3.	Marl, gray, without fossils, containing many small selenite crystals	40
2.	Sandstone, yellow, moderately hard, showing little lamination, calcareous	2
1.	Limestone, slightly folded, in definite layers, average thickness of largest eight inches, in places brecciated, though not showing a layer that is brecciated throughout, as in exposures in the Des Moines river north of Fort Dodge	17

Above the marl is a drift slope seventy feet high, while Coal Measure shales, which probably lie between the marl and the drift, are concealed by the wash of the slope and the growth of vegetation.

The fossil-bearing layer of marl was cut through by the Illinois Central railroad and a great number of excellent specimens may be picked up along the cutting. Fossils are also abundant on the slope of Lizard creek. The sandstone, which generally lies just above the limestone, though seldom absent, varies greatly in thickness in different localities. At the wagon bridge near the mouth of Lizard creek a sandstone layer is present also in the limestone.

SECTION AT MILLER'S QUARRY, NEAR THE STONE BRIDGE OVER SOLDIER CREEK IN FORT DODGE.

		FEET.
7.	Soil	2
6.	Gravel, fresh, cross-bedded	10
5.	Clay, yellow, not jointed, unleached, many limestone pebbles	15
4.	Soil and clay mingled, both unleached, soil dark and containing many wood fragments	15
3.	Sand, uncemented, containing lumps of coal and large pieces of wood, in layers varying greatly in color from white to gray	8
2.	Calcareous sandstone, a single layer very firm	1½
1.	Limestone, layers coarse, often two feet thick, stone of even fine texture, no fossils	25

In the creek bed at the foot of this exposure the limestone gives place again to calcareous sandstone, the thickness of which could not be determined.

A little above Miller's quarry, on Soldier creek, the Saint Louis limestone gives place to Coal Measure shales. One-half mile further up Soldier creek in Cooper township, section 19, Nw. ¼, the limestone again comes to the surface and appears for 200 feet in the creek bed.

Following the river north from Fort Dodge, limestone appears continuously for two miles. On the west bank it underlies the alluvium in the river flat. On the east side it appears beneath bluffs or Coal Measure shales and sandstone, which rise fifty feet above it. The limestone is exposed from the water's edge upward from twenty to forty feet, often forming a continuous mural escarpment for a considerable distance.

The section given below, taken in Cooper township, section 7, Sw. ¼, is typical for this series of exposures:

		FEET.	INCHES.
13.	Sand	5	
12.	Limestone layer	1	
11.	Limestone layer with persistent band of flint one inch thick	1	2
10.	Limestone layer	2	6
9.	Limestone layer	1	
8.	Limestone layer	1	
7.	Limestone, at some points massive and others showing layers slightly distinguishable	4	
6.	Limestone layer, light color		1
5.	Limestone layer	1	
4.	Limestone layer	1	
3.	Sandstone, in places containing a flint band one inch thick		6
2.	Limestone layer	1	6
1.	Sandstone to water's edge	1	6

The next section given is around the bend of the river, a mile above where the section just recorded was taken and just above the old coal mines two miles north of Fort Dodge, in Cooper township, section 7, Sw. ¼:

		FEET.
3.	Drift	4
2.	Coal Measure shales, fissile, very ferruginous	10
1.	Limestone, with characteristics of the Saint Louis, on which the Coal Measures rest unconformably	10

Farther up the stream the surface of the limestone dips down at an angle of ten degree and soon disappears below water level. Within half a mile it emerges again and underlies the lower alluvial terrace to a point about a mile above the mouth of Badger creek, where it gives place to sandstone. This portion of the river valley is unusually broad and is doubtless underlain with Saint Louis limestone. The alluvium over the limestone is very thin and the sandstone, which at many points appears in and over the Saint Louis, is here absent.

After passing numerous sandstone exposures, which will be considered under Carboniferous deposits, the limestone is again encountered one-half mile above Badger bridge, on the east bank of the river. At this point appear:

		FEET
3.	Brecciated limestone	4
2.	Covered so that the nature of the rock is concealed	3
1.	Calcareous sandstone appearing at water level.	

On the west bank a cliff shows:

		FEET.
3.	Sandstone, red, soft, thin-bedded, without joints, with coating of calcium carbonate over the rock in all of the cracks	20
2.	Covered by talus	15
1.	Limestone partly concealed by talus, brecciated, with much quartz and many layers of flint	20

Similar exposures continue to the north. Within eighty rods of the county line there appear:

		FEET.
2.	Limestone, brecciated in layers 8 to 12 inches	3
1.	Limestone, fine-grained, almost lithographic, in layers averaging 8 inches	6

The stone here is arched and folded more than at any other place visited in the county.

The most northern limestone exposure of any size in the county is forty rods south of the county line. At this point we have:

		FEET.
8.	Drift	2
7.	Gravel	1
6.	Marl	1
5.	Limestone, no fossils, layers one foot, six inches thick	12
4.	Sandstone, calcareous, yellow, fine-grained	6

	FEET.
3. Limestone, layers six to twelve inches......	4
2. Limestone, brecciated, containing much quartz and flint, very irregularly bedded	6
1. Limestone, evenly bedded to water's edge..	3

The striking peculiarity of the limestone in the northern part of the county is the great amount of drusy quartz and flint that it carries, most of it in the upper brecciated layers. Frequently the masses weigh 200 pounds. Calcite is also abundant.

Going down the river from Fort Dodge nothing but Coal Measure deposits are seen until a point is reached one-fourth of a mile below the Minneapolis & St. Louis railroad bridge near Duncomb's mill, in Pleasant Valley township, section 5, Sw. ¼. Here the Saint Louis limestone rises to the surface and appears ten feet above summer water level. The upper part consists of the characteristic marl with many specimens of *Pugnax ottumwa* and *Spirifer littoni*. The exposure is not a large one, and perhaps ten acres will include all of the limestone at the surface in the river bed. The next exposure of Saint Louis limestone down the river is half a mile below here, in section 8, Ne. ¼. The limestone shows for a thousand feet along the stream and rises ten feet above the water level. The upper five feet are marly, and the lower five feet are made up of solid stone, heavily bedded. Some quarrying has been done at this point. The limestone may underlie the alluvium in the valley, which is here 1,000 feet wide. The alluvium above the marl is at least fifteen feet thick. Below Kalo in section 16, the limestone occupies two small areas in the river bed.

West of Fort Dodge the limestone is exposed in the bed of Lizard creek for one and a half miles, to the junction of the two branches. It shows also in the creek bed of each branch for half a mile. The geological map makes clear the location of the various exposures just described.

Relations of Saint Louis Limestone to Coal Measures and Gypsum.—Wherever contacts have been observed between the Saint Louis limestone and the Coal Measures there is a marked unconformity. The surface of the limestone is very uneven and was evidently exposed to erosion for a very long interval before the Coal Measures were deposited. A mile north of Fort Dodge the

Saint Louis limestone rises fifty feet above the river. A mile above this point the section already quoted shows that it descends to within two feet of the water, its place being taken by Coal Measure shales. To the south the limestone also descends, so that along the river at Fort Dodge only Coal Measure shales and sandstones are exposed. This is not due to an anticlinal fold, but to unequal erosion of the limestone.

Along Soldier creek, as will be shown by sections cited farther on, the gypsum at certain points rests directly upon the Saint Louis limestone. Not far from these exposures of gypsum and limestone the gypsum is replaced by Coal Measure shales. The marked unconformity between the gypsum and Coal Measures furnishes a partial explanation for these conditions. The unconformity between the limestone and Coal Measures is doubtless another factor that gives rise to this peculiar relationship of strata. The unevenness in the surface of the limestone before the Coal Measures were deposited would, after the shales were laid down upon it, bring the limestone nearer the surface at some points than at others. If the subsequent erosion of the Coal Measures were even the limestone would outcrop at certain points, while at others it would still be covered. Th Coal Measures were, of course, unequally eroded thus doubling the opportunities for exposures of limestone. It is not strange therefore that the gypsum, which later was deposited in Coal Measure depressions, should often lie directly on the Saint Louis, while near by the Coal Measures intervene.

PENNSYLVANIAN SERIES.

DES MOINES STAGE.

The productive Coal Measures of Iowa belong to the Des Moines stage of the Pennsylvanian series. These strata directly underlie the drift in most of the central and southern part of Webster county, the main exception being a strip extending across the center of the county from northeast to southwest, where gypsum intervenes. The Coal Measures consist of shale, coal, sandstone, fire clay and thin beds of argillaceous limestone and limonite. Productive coal seams are found at a number of points.

Fire clay is almost invariably found beneath the coal. The shales are fissile, generally arenaceous and free from line. They vary in color from very dark gray to yellow. At many points they abound in crystals of selenite. Prints of ferns, lepidodendrons, and calamite are often well preserved in them. Fossils taken from the pit of the Fort Dodge clay works have been identified by Professor Macbride as *Alethopteris lonchitica* Schloth., *Eremopteris flexuosa* Lesq., *Neuropteris* sp. (probably *hirsuta.*) Good specimens of *Ulodendron ellipticum* Sternb. were also found at the same place and with these specimens of *Sigillaria* and *Calamites* occur. Bands of clay ironstone varying in thickness from one to ten inches and nodules of the same material are not uncommon in the shale. In the center of the nodules there is often pyrites of iron. A peculiarity of the Coal Measure shales

FIG. 5. Portion of Lepidodendron found in the pit of the Fort Dodge Clay Works.

throughout the county is shown in the accompanying illustration. One bed of shale rapidly gives place to another or to sandstone in a way which suggests an unconformity, yet which lacks at least one phase of the process to which that term is properly applied. It is hardly equivalent to the cross bedding so common in the Coal Measure sandstone, nor is it due to the thinning out of one bed. The material is of equal fineness across the section, and the laminæ are of equal thickness. The following explanation is suggested. The lower beds when formed con-

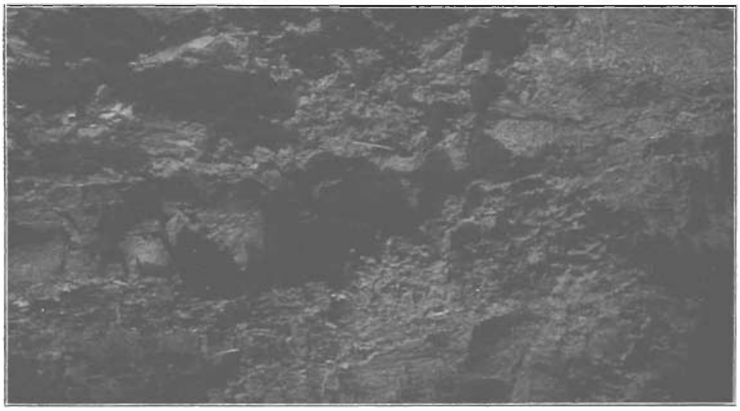


FIG. 6. View showing parallel deposition at the right; while toward the left there is a line along which, owing to current action, the parallelism is interrupted. Clay pit of Fort Dodge Brick and Tile works.

tinued parallel across the section. Current action, however, shortly after their deposition and while the material was yet plastic, being increased over the surface of the section shown in the picture on the right, scoured out some of the silt, producing the slope now shown in the lower bed. Subsequent changes in the current permitted deposition again, and the upper beds were laid down.

The Coal Measure sandstones are the striking stratigraphic feature in the southern part of the county where a maximum thickness of sixty feet is exposed. Most of the layers are ferruginous, but near Lehigh the upper courses at certain points are cemented with carbonate of lime. The bond between the grains is slight when iron is the cementing substance. The layers containing carbonate of lime, however, are firm and suitable for building. Typical exposures of these sandstones may be seen on Prairie creek in Otho township, section 35, the so-called copperas beds, and at Wild Cat cave in Pleasant Valley township, section 11, Sw. ¼.

SECTION AT "COPPERAS BEDS" NEAR THE MOUTH OF PRAIRIE CREEK.

		FEET.
4.	Drift	5-50
3.	Sandstone, cross-bedded, soft, ferruginous, containing concretions	30
2.	Sandstone, conglomeratic, containing large blocks of the sandstone found in the vicinity, with fossil wood in large pieces. The surface of this portion of the bluff is usually white with $Fe SO_4$	15
1.	Conglomerate, consisting of northern pebbles, quartz especially abundant, though some granites and greenstones, waterworn, small, none above half an inch in diameter, cemented by iron so that perhaps 25 or 30 per cent of the whole mass is iron. In the center there is a two-inch streak of clay ironstone and three inches of soft shale	4

The concretions in the sandstone are very abundant and of all sizes from a foot to a fraction of an inch. Many of the smaller ones are hollow. Cross-bedding is everywhere conspic-

FIG. 7. Concretionary structure in Carboniferous sandstone, near mouth of Prairie creek, Webster county.

uous. At times the laminæ are curiously contorted, not merely slanting, as is common in cross-bedding, but bent over so that they arch like a bow. Such a structure is difficult to explain. Lateral or vertical pressure on plastic, cross-bedded sand may account for it. Very common in the Coal Measure sandstones are small shining particles of selenite.

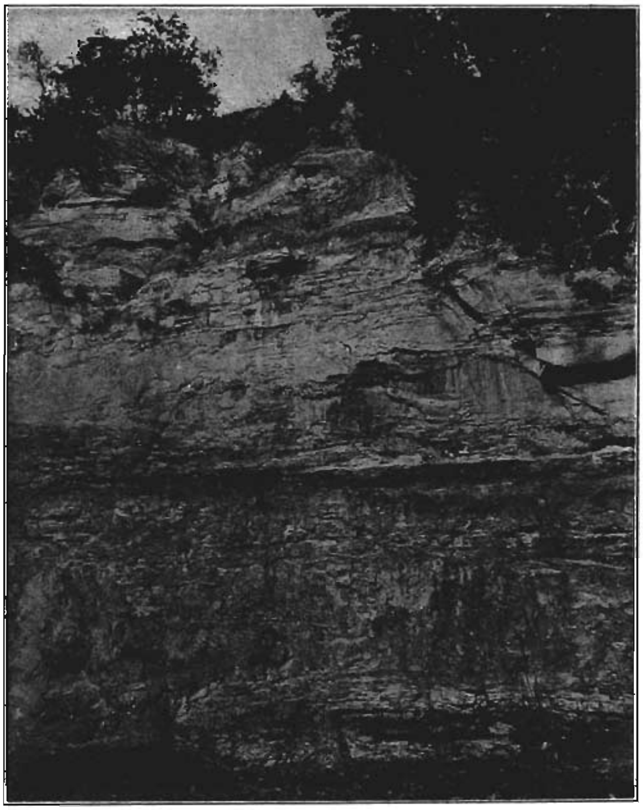


FIG. 8. Sandstone near the mouth of Prairie creek. 1. Conglomerate consisting of small foreign pebbles cemented by iron. 2. Coarse conglomerate containing large fragments of native sandstone.

The iron conglomerate, containing iron and northern pebbles, was found only near the mouth of Prairie creek and in a ravine a mile farther south. Perhaps one-half of the rock consists of small pebbles and the rest of the cementing iron. The rock so formed is very hard and seems to weather very little. Where it has been long exposed to the air the pebbles have fallen out and the rock has a vesicular appearance, in color and structure resembling lava.

The coal seams of the county cannot be correlated to make a continued series. In the localities where coal has been found it seems to be limited to rather definite areas each only a few square miles in extent. Two, three and four seams may occur separated generally by only a few feet of shale. The districts now producing most of the coal are the Lehigh, Crooked creek and the Kalo and Coalville. Smaller quantities are mined at Tara, Limburg and at the old mines north of Fort Dodge.

The Lehigh coal belt is not more than two-thirds of a mile wide and extends from northeast to southwest across section 7, Webster township and section 13, Burnside township. It is crossed nearly in the center by the Des Moines river. On the west side of the river Crooked creek cuts through it, and coal is mined on this creek two miles from its mouth. On the east side of the creek the prospect holes of the Crooked Creek Railroad and Mining Company have found coal a mile back from the river. All of the mining has been done along the river and Crooked creek. The coal lies in four seams, one above the other, so that prospect holes often pass through more than one seam. The seams vary considerably at different points. All of the seams have produced or are producing coal, but the coal from the Tyson seam is regarded as the best and this seam up to date has been most extensively worked. The Harper seam is thirty feet above the water of the river; the Tyson is twenty feet above water level; the Pretty seam is ten to twenty feet below water level, while the Big is forty feet below the Pretty seam. The two seams above water level have been worked by drifting into the banks of the river, the banks of Crooked creek, and the sides of the numerous ravines in the vicinity. The Pretty seam and the Big seam are reached by shafts. The Big seam is said to lie at a uniform level, but the other seams are not so regular. The Tyson seam is never more than fifteen hundred feet wide, and it dips uniformly towards the center. There are no signs of faulting in the region.

The following is a composite section through the Lehigh coal seams:

		Feet.
9.	Drift	120
8.	Shale	20
7.	Coal, slate, six inches, Harper vein	0-2½
6.	Sandstone and shale	15
5.	Coal, Tyson seam	4
4.	Sandstone and shale	30
3.	Coal, Pretty seam	2-3
2.	Shale	30
1.	Coal, Big seam, four inches bone in center	3½-4½

The following is a record of a typical prospect hole in the Lehigh region. This hole was put down by the Crooked Creek Company at what is now their shaft No. 5, in the valley of Crooked creek*.

		Feet.	Inches.
22.	Soil	10	
21.	Red shale	5	
20.	Light shale	6	
19.	Coal (Harper vein?)		6
18.	Light shale	4	6
17.	Sandstone	2	
16.	Shale	1	
15.	Black shale	3	
14.	Coal (Tyson vein)	1	
13.	Fire clay	9	
12.	Sandstone	1	
11.	Black shale	2	
10.	Sandstone	3	
9.	Black shale	4	6
8.	Coal		6
7.	Light shale	6	
6.	Dark shale	35	
5.	Coal (Pretty vein)	2	
4.	Dark shale	22	
3.	Light shale	2	
2.	Black shale	5	2
1.	Coal (Big vein)	3	

The Coalville coal basin includes five square miles in Pleasant Valley and Otho townships, parts of six sections. The coal

* Authority, Craig Coal Company.

lies in three horizons, the lowest or cannel coal, second, a relatively thin and insignificant bituminous seam, and third, the upper bituminous, which is the most important. The upper

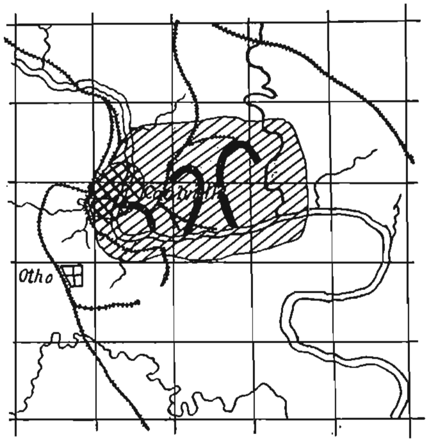


FIG. 9 The Coalville coal basin.

bituminous horizon is commonly regarded as made up of two seams, but this opinion is probably erroneous. The upper bituminous coal extends from Holaday creek on the east to a point not far beyond the river on the west. On account of the bend in its course, the river is again made the southern boundary, while its northern limit is approximately marked by the northern boundaries of sections 8, 9 and 10, Pleasant Valley township. A limited portion of this area, shown in figure 8, contains coal varying in thickness from six to eight feet. This is known as the "Big coal." The Big coal is confined to a curiously narrow and contorted strip. It is rarely over 300 feet wide and often only 200 feet. Its center lies twenty-five feet below the rest of the upper bituminous horizon. Its edges rise rapidly, however, and all of the upper bituminous coal forms with it a continuous seam. Because it lies below the rest of the seam and is of better quality, it is often regarded as a distinct seam. The coal in the upper horizon outside of the Big coal varies in thickness from three feet to five feet. It is generally inferior in quality and some of it is of value only as steam coal. It lies fifty feet below the prairie level, is horizontal in position and free from fault. The Big coal ranks with the best coal produced in the county.

The Coalville basin seems to be part of the trough of an ancient river. The Big coal was formed in the stream channel, while the rest of the seam represents the bottom lands. The Big coal is too pure to admit the belief that water was flowing through the channel when the coal was deposited, and that the vegetable matter was drift material. The fact that as yet it has not been possible to connect the tortuous sections of the Big coal, also leads to the belief that the hollow in which the Big coal lies represents portions of a deserted channel, which in places was

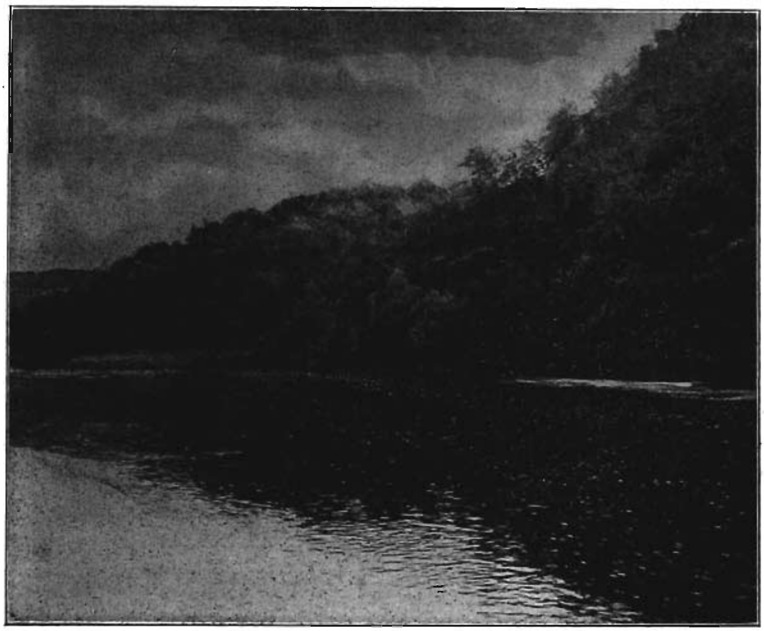


FIG. 10. Sandstone bluffs on the Des Moines river in central Webster county.

filled in and consequently is at times barren. The Big coal has an excellent shale roof and is worked very economically.

The next seam is known as the Colburn. It is found only along the river and near the mouth of Holaday creek, and where the lower or cannel coal is present it is lacking altogether. It is rarely more than two feet in thickness and usually appears as two seams slightly separated by a layer of shale. The shale is so thin, however, that the two seams are mined together. The Colburn seam is not confined to the Coalville region, but from Holaday creek follows the river north to a point two miles above Fort Dodge. It will be described later in connection with the coal about Fort Dodge. At Holaday creek it lies twenty-five feet above the water of the creek and fifty feet below low water level in the river.

The cannel coal forms the lowest seam in the Coalville region. Its edges rise above the water of the river eighteen or twenty feet, but in the center, as shown at the Collins mine, it is on the level of the river water, while across the river at this point it is ten feet below water level. Its cross-section as shown on the river then, shows that it is like a saucer which is tilted slightly to the west. All of the cannel coal in the region belongs to this seam. On account of the difference in the position of the seam at various points, two and even three seams are sometimes reported. The cannel coal is found in sections 5, 7, 8 and 17 of Tp. 89 N., R. XXVIII W. These sections belong to Pleasant Valley and Otho townships. The exact extent of the seam cannot be stated, but as far as can be determined it is indicated in figure 8.

The following records of prospect holes sunk in Douglas township, section 8, Sw. ¼, indicate fairly the nature of the strata just above and below the upper bituminous coal*. These holes were sunk in the river slope, forty feet below prairie level.

		FEET.	INCHES.
5.	Soil and drift	24	
4.	Shale	9	6
3.	Coal	3	6
2.	Fire clay	1	6
1.	Sandstone	4	
4.	Soil and drift	24	6
3.	Shale	5	7
2.	Coal	3	7
1.	Black jack	1	

Coal in the vicinity of Fort Dodge is practically limited to the

* Authority, Craig Coal Company.

Colburn vein. This vein is well shown at the pit of the Kime brickyard, where the following section is given:

		FEET.	INCHES.
12.	Drift and soil	3	
11.	Shale, black, bituminous	4	
10.	Coal	1	2
9.	Clay	3	3
8.	Coal		5
7.	Sandstone, soft		8
6.	Fire clay	5	
5.	Shale, dark colored, bituminous	1	4
4.	Shale, bituminous, fissile	1	2
3.	Shale, dark colored	2	
2.	Shale, light colored	2	4
1.	Shale, dark colored, exposed	10	

The Colburn seam about Fort Dodge lies just below the drift, in the upper part of the Coal Measures. If the seam is really continuous to Holiday creek, as is commonly thought, its elevation as compared with the water level of the river remains fairly constant while the Coal Measures thicken rapidly above it toward the south. Across the river from the Kime brickyard coal appears at a lower level. This is shown by the following section which is taken one mile below the Minneapolis and St. Louis station, on the railroad track, in section 29, Sw. ¼. Cooper township:

		FEET.	INCHES.
8.	Limestone, argillaceous, a single solid layer	1	6
7.	Coal		10
6.	Shale and clay	3	
5.	Impure coal	1	
4.	Carbonaceous shale	1	6
3.	Coal, fair quality	1	6
2.	Sandy shale, yellow (level of railroad track)	4	
1.	Shale, nearly covered with talus to water level	25	

In this section numbers three, four and five probably represent the Colburn vein. In the old mines above Fort Dodge the Colburn vein has been of considerable economic importance. Just above "the slide" in Douglas township, section 7, Sw. ¼, on the west bank of the river the following section is given:

		Feet.
5.	Drift	8
4.	Argillaceous limestone, single heavy layer	2
3.	Coal	2
2.	Shale, fissile, very bituminous	44
1.	Sandstone, red and white, with fossils of coal plants—to water	6

At the old mines one-fourth mile below this point there are two coal horizons, one corresponding to the coal in the sections already given which lies directly under the limestone, while the other, which is a few feet lower, is probably the Colburn vein. It shows:

		Feet.	Inches.
3.	Coal	2	
2.	Shale	2	
1.	Coal		6

These sections up the river taken together seem to be equivalent to the two sections just below Fort Dodge in the vicinity of the Kime brickyard.

The Limberg coal basin. At the mouth of Skiller creek in Dayton township a single seam has produced considerable coal. The mines are all located in the central part of section 16. This seam is about five feet above the level of the creek bed and is mined both by drifting into the banks of the creek and by shafts. The coal is from two feet to two feet four inches in thickness. It lies very unevenly, rising sometimes two feet in thirty. The roof is a tough gumbo through which pebbles are scattered. The coal at times suddenly gives out as though sharply cut off by stream erosion. There are no signs of faulting. Another coal seam is reported below the one now worked but no definite proof of its existence was obtainable. The seam encountered in Dayton township, section 18, which is shown in a section that will be quoted later on, is certainly lower than the one now worked at Limberg. The belief which seems to be common, that the coal horizons at Limberg are to be correlated with the seams at Lehigh, is not warranted. The various basins in the county are detached and cannot be worked into a common system.

The Tara coal basin is the only portion of the county away from the river at present producing coal. This basin includes sections 33, 34 and 35, Douglas township, section 6, Elkhorn township, and probably adjacent territory that has not been prospected. The coal lies 130 feet below prairie level and the seam is from four to five feet thick in the Martins and Timmens mine on Ne. 1/4, Sec. 6, Elkhorn township, in the Colford mine, Nw. 1/4 of the same section, and in the Parel mine on the Scalley place, in Sw. 1/4, Sec. 33, Douglas township. Borings in the adjacent territory indicate that the basin is of considerable extent, but do not show the thickness of coal that is found at the

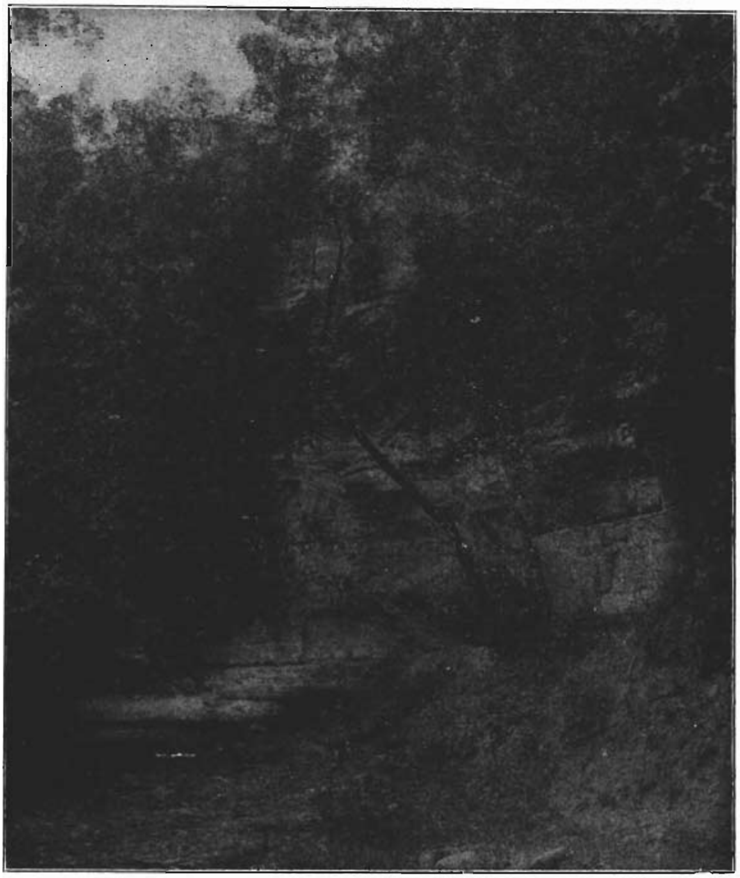


FIG. 11. View showing mural escarpment of Carboniferous sandstone in Bone Yard Hollow, four mles above Lehigh, Webster county.

mines named. In Douglas township, Sec. 34, Se. ¼, five prospect holes were sunk and coal found in each case at about the same depth and under the same general condition. A record of one of these holes is given below:

		FEET.	INCHES.
11.	Soil and drift	75	
10.	Shale	3	
9.	Blue clay	8	4
8.	Coal	1	6
7.	Clay ironstone ?	2	10
6.	Fire clay	4	6
5.	Sandstone	8	9
4.	Red clay	3	2
3.	Sandstone	7	4
2.	Red clay	2	4
1.	Rock (undet.)	4	

In section 35, Douglas township, Sw. ¼, the following series was found:

		FEET.	INCHES.
15.	Soil	2	
14.	Drift	71	
13.	Red clay	4	
12.	Sand	1	6
11.	Sandstone	4	
10.	Shale	8	6
9.	Coal	2	3
8.	Sandstone	2	
7.	Shale	2	2
6.	Coal		6
5.	Fire clay	3	3
4.	Shale	2	1
3.	Coal	2	2
2.	Fire clay	8	9
1.	Red clay	21	6

There is no reason for believing that other coal basins may not be found in the county. Prospectors whose experience deserves respect do not think that extensive basins will be found away from the river. It is hardly probable that new seams will be found on the river. The Tara basin, however, is of sufficient importance to justify prospecting away from the Des Moines. Two miles east of Dayton, in Dayton township, Sec. 18, Nw. ¼, the Craig Coal company reports the following section:

		Feet.	Inches.
36.	Gravel	2	
35.	Yellow clay	12	4
34.	Sand	1	9
33.	Clay and sand	8	2
32.	Clay	41	
31.	Clay and sand	9	9
30.	Sandstone	3	6
29.	Clay		6
28.	Sand		4
27.	Clay	2	7
26.	Sandstone		7
25.	Clay		3
24.	Sandstone	3	1
23.	Clay		2
22.	Sandstone		7
21.	Clay		5
20.	Sandstone	2	8
19.	Clay	3	
18.	Sandstone	11	4
17.	Gray shale	5	
16.	Sandstone	4	3
15.	Shale	1	
14.	Rock (undet.)		4
13.	Gray shale	1	4
12.	Black shale	1	3
11.	Rock (undet.)	4	3
10.	Gray shale	18	5
9.	Hard rock (undet)	8	
8.	White clay		4
7.	Hard shale		2
6.	Gray shale	1	5
5.	Gray shale	26	10
4.	Black shale		11
3.	Coal	3	6
2.	Fire clay		7
1.	Rock (undet.)	5	3
		177	6

One mile northeast of Dayton the Craig Coal Company obtained the following section:

		Feet.	Inches.
23.	Surface	10	
22.	Blue clay	18	4
21.	Sand	2	3
20.	Yellow clay	7	4
19.	Gravel	1	6
18.	Gray clay	11	10

		Feet.	Inches.
17.	Blue clay	8	8
16.	Yellow clay	5	4
15.	Blue clay	10	10
14.	Sand	11	5
13.	Clay	17	10
12.	Sand	1	
11.	Clay	20	4
10.	Sand		11
9.	Clay	1	6
8.	Shale	1	10
7.	Coal	3	6
6.	Fire clay	1	
5.	Shale	4	9
4.	Rock (undet.)	8	11
3.	Shale	1	7
2.	Shale and black jack	41	9
1.	Coal	4	

These records indicate that there is considerable coal in the vicinity of Dayton and the region at some time may become productive.

In the bed of the Boone river, just across the line in Hamilton county, two coal seams about ten inches thick may be seen. These seams probably extend into Webster county.

Coal Measure Sandstones in the Northern Part of the County.—Along the river in sections 13 and 24, Badger township, sandstone is exposed which probably belongs to the Coal Measures. It lies directly on the Saint Louis limestone and at certain places the line of unconformity between them may be seen. In section 24 the limestone in the form of great blocks, irregular in shape, is cemented by the sandstone.

The following section is found on the east bank of the river a little below the mouth of Deer creek in Badger township, Sec. 24, Nw. ¼:

		Feet.	Inches.
6.	Drift	3	
5.	Sandstone, soft, calcareous	5	
4.	Shale		2
3.	Sandstone full of small flint and quartz fragments	6	
2.	Sandstone, cross-bedded, white, calcareous	1	
1.	Sandstone, ferruginous, with small concretions, to water	3	

The sandstone along this portion of the river is more definitely jointed than any seen in the county. This jointing shows well in an exposure one mile south of the county line on the east side of the river. The exposure is one-fourth of a mile back from the river on the edge of the second bench; the section reveals:

		FEET.
2.	Sandstone, disintegrated	6
1.	Sandstone, massive, regularly and conspicuously jointed, the joints running north-south and five to six feet apart. Stone in layers 6 to 15 feet thick, moderately hard	6

A distinct unconformity between this sandstone and the Saint Louis limestone which underlies it excludes the idea that it may be merely a thickening of the upper sandy layers of the Saint Louis formation. It may possibly be the sandstone which occurs above the gypsum. It is much more reasonable, however, to associate it with the Coal Measure sandstone which it more closely resembles and which is known to occur both north and south of these exposures.

In a ravine on the east side of the river just below Badger bridge sandstone forms a mural escarpment twenty feet high for 200 yards. In many ways it resembles the Coal Measure sandstone in the southern part of the county; it is yellow and cross-bedded, but it lacks fossils.

PERMIAN.

GYPSUM AND ASSOCIATED DEPOSITS.

Directly on the Saint Louis limestone or on the Coal Measure shales, in the central part of the county, lies the gypsum. Above it and associated with it are thin sandstone layers and shale, while below it and evidently of the same age is a layer of clay which on the average is four feet thick.

Except along the Des Moines river and tributary creeks the gypsum is wholly covered by drift. Away from the streams, wells and a limited number of prospect holes furnish the only data for determining the gypsum area and by these means it is impossible to decide with great definiteness the extent of underlying formations.

Natural exposures of gypsum may be seen at intervals along the river from the mouth of Soldier creek to one mile north of Coalville, and along Soldier and Two Mile creeks. Of these exposures the following are selected as typical:

Section at "the slide," on west bank of river, just opposite Blandon's mill.

		FEET.
7.	Drift, yellow, unleached, with many limestone pebbles	35
6.	Drift, blue gray, unleached, with many limestone pebbles, not sharply separated from above	20
5.	Drift, yellow, somewhat darker than 7, unleached, with many limestone pebbles	10
4.	Drift, blue gray, unleached	30
3.	Gypsum, badly weathered, exposed	10
2.	Limestone containing *Orbiculoidea nitida*, Orbiculoidea, species larger than the preceding, *Productus muricatus*, *Spirifer rockymontana*, a Pelecypod like an Aviculopecten, and a species of Orthoceras. The stone is argillaceous and like the limestone which generally caps the Coal Measures in Webster county	2
1.	Coal Measure shales, poorly exposed on account of the hillside wash	60

Exposure on Two Mile creek in Gypsum Hollow, at quarry of Lower Plaster mill.

		FEET.
5.	Drift, yellow, unleached, oxidized very moderately at surface and along joints, abounding in limestone pebbles, containing at one point a pocket 12 feet long and one foot thick of stratified sand in the shape of crescent	30
4.	Red sandy shale	0-4
3.	Gypsum, massive, in places moderately folded, in layers from six inches to two feet, laminæ averaging three-fourths of an inch, alternating in color, gray and white	20
2.	Fire clay, thickness undetermined.	
1.	Shale and sandstone (passed through in drilling well at lower mill of the Plaster Company)	100

Along the river above the Minneapolis & St. Paul railroad tracks the gypsum appears for 500 feet, in section 32, Cooper township.

Exposures along Soldier Creek.—In following Soldier creek towards its mouth nothing but drift was seen above section 17, Cooper township, Ne. ¼. Here, in cuttings along the Minneapolis and St. Louis track, which follows the creek bed from this point to Fort Dodge, red sandy shales appear. A little farther down, in the Sw. ¼ of the same section, the railroad in grading its road bed has cut through these shales exposing above them four feet of firm calcareous sandstone upon which rest thirty feet of drift. On the road leading to the cemetery much grading has been done to bring the road bed down to the valley of Soldier creek. In this cutting the following section is given:

	FEET.
2. Drift, fresh looking, with limestone pebples unleached	15
1. Shale, red, sandy, somewhat disintegrated.	6

Two hundred yards farther down the creek, just south of the cemetery, the first gypsum on the creek appears. A ledge ten feet high, heavily bedded, rises from the water's edge. Along the stream near this point Coal Measure shales are exposed and without doubt underlie the gypsum at this exposure.

On going down the creek 200 yards farther, in Cooper township, Sec. 17, Sw. ¼, one of the best exposures on the creek may be seen:

	FEET.
3. Drift, yellow, unleached	10
2. Red, sandy, calcareous shales—with layers of pure sand usually white, from ½ inch to a foot in thickness	30
1. Gypsum, massive to water's edge	7

One hundred yards farther down the stream, at the water level and for three feet above it, the Saint Louis limestone is exposed, which in turn within another 100 yards gives place to shale. This change at water level from gypsum to Saint Louis limestone, and from limestone to Coal Measure shale, is unusual; but, as has already been explained, it simply illustrates the unevenness of the surface of both limestone and Coal Measures.

The exposure at what was formerly known as Kohl's brewery, near the mouth of Soldier creek and within the Fort Dodge city limits, has long been regarded as typical for the gypsum and associated red shale.

		FEET.
9.	Gravel, fresh, clean, well water-worn, containing much limestone	5
8.	Drift, slightly unoxidized, unleached	28
7.	Gravel, rusted, many decayed fragments, showing only at certain points along bluff	2
6.	Sandstone, soft, friable, buff colored, though at points not far away it is white and heavily bedded	5
5.	Shales, argillaceous, sandy layers alternating	5
4.	Sandstone, buff, friable	2
3.	Shale, gray	2
2.	Thin bands of gypsum and shale	7
1.	Gypsum, massive (exposed)	11

FIG. 12. Cross section east and west through the gypsum area, illustrating unconformities between the Saint Louis limestone, the Coal Measures, and the gypsum. St. L. Saint Louis limestone. C. M. Coal Measures. G. Gypsum. D. Drift.

Section in the pit of the Fort Dodge Clay Works

		FEET.
3.	Drift, yellow, unleached, lower part a little darker than the upper	35
2.	Red sandy shale with occasional thin bands of sandstone	10
1.	Gray Coal Measure shales, often containing fossils of ferns and lepidodendrons. A few iron nodules present, and crystals of selenite. Separated from red shales above by sharp line of unconformity. Along the line of separation there is a layer of gumbo, one foot thick	30

No. 2 includes the red shales found in so many places above the gypsum. These red sandy shales are so characteristic and are associated so conformably with the gypsum that they may safely be regarded as of the same age as the gypsum. The occurrence of the light colored, calcareous sandstone free from fossils with these red shales is also significant. In a ravine running back from the North Lizard near the railroad bridge in Douglas township, section 8, Nw. ¼, the following section is given:

		FEET.
4.	Drift	10
3.	Gravel and bowlders	3
2.	Red sandy shales	10
1.	Sandstone dipping 10 degrees to the east, cross-bedded, in places fissile, often uncemented and appearing as sand, white or yellow, without fossils, conformable with 2	10

Keyes associated the sandstones and shales in this exposure with those which overlie the gypsum and this is apparently their proper place. There can be no doubt that the red shales of the Fort Dodge Clay Works, both in the south end of their old pit and in their new pit on the left bank of Lizard, belong to the gypsum series. The unconformity between the red shales and Coal Measure shales is distinct. The presence of sandstone with both of these shales renders more difficult the proper correlation of certain sandstones in the northern part of the county. These

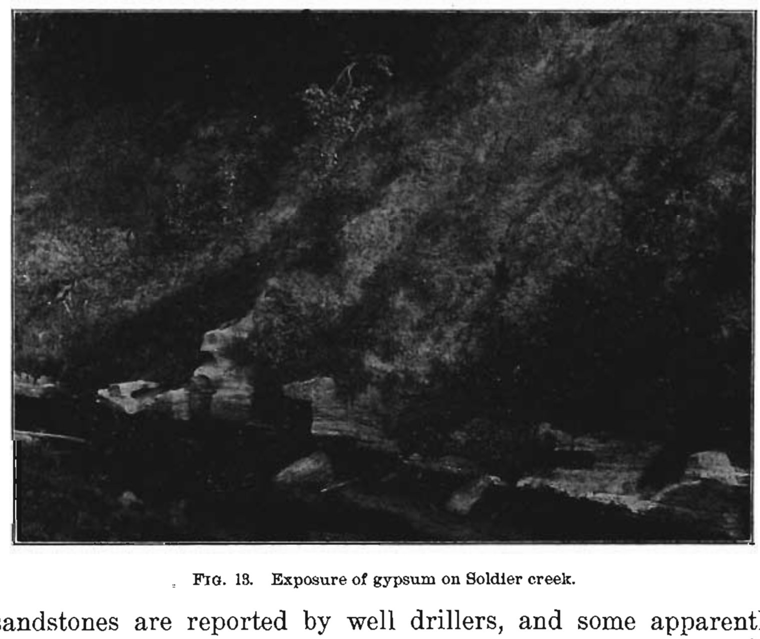


FIG. 13. Exposure of gypsum on Soldier creek.

sandstones are reported by well drillers, and some apparently belong to the Coal Measures while others may be associated with the gypsum. The last statement applies to those sandstones which are said to occur with shales of a deep red color or "ocher."

To determine the extent of the gypsum where there are no natural exposures is a difficult problem. The width of the deposit north and south is probably given accurately by the exposures along the Des Moines river. Its length or extent east and west must be determined by borings passing through the drift, which here averages eighty feet in thickness. Reference to the maps accompanying this report will show that the wells in the following table, in which gypsum was found, lie in a rather definite zone.

WELL DATA FOR CENTRAL AND NORTHERN WEBSTER COUNTY.

TOWNSHIP.	SECTION.	AUTHORITY.	DEPTH IN FEET	STRATA PASSED THROUGH. THICKNESS IN FEET.
Newark	Sec. 27, Sw. ½	Schmaker	126	Drift and blue clay, below which was gypsum.
Newark	Creamery at Vincent.	Schmaker.	80	Drift, 66; gypsum, 14.
Newark	Sec. 32, Nw. ¼	J. J. Meyer	118	Wholly in drift.
Badger	Sec. 25, Nw. ¼	J. J. Meyer	130	Drift, 70; sandstone, 4; clay, 25; sandstone, 30.
Badger	Sec. 31, Sw. ¼	J. J. Meyer	96	Drift, 80; sandstone, 16.
Badger	Sec. 31, Nw. ¼	J. J. Meyer	110	Wholly in drift.
Badger	Sec. 31, Sw. ¼	J. J. Meyer	......	Depth not known, entered sandstone under drift.
Badger	Sec. 29, Nw. ¼	J. J. Meyer	70	Drift, 68; sandstone, 72.
Badger	Sec 22, Sw. ¼	J. J. Meyer	120	Drift, 100; sandstone, 20.
Badger	Sec. 34, Sw. ¼	J. J. Meyer	125	Drift, 55; sandstone, 8; soft sandstone, 40; clay, 2; sandstone, 20.
Badger	Sec. 11, Sw. ¼	J. J. Meyer	120	Drift, 19; sandstone, 30.
Badger	Sec. 14, W. ½	J. J. Meyer	140	Drift, 90; sandstone, 50.
Badger	Sec. 17, Sw. ¼	J. J. Meyer	100+	Drift, 100; entered sandstone.
Badger	Sec. 22, Nw. ¼	J. J. Meyer	144	Drift, 80; sandstone, 4; red clay, 60.
Badger	Sec. 20, Nw. ¼	J. J. Meyer	118	Drift. 100; hard sandstone, 18.
Badger	Sec. 16, Sw. ¼	Lappint	108	Wholly in drift.
Badger	Sec. 33, Nw. ¼	Lappint	70	Drift, 50; limestone, 20.
Badger	Sec. 33. Nw. ¼	Lappint	120	Wholly in drift.
Badger	Sec. 20, Sw. ¼	Lappint	113	Drift, 50; sandstone, 6; clay, 50; sandstone, 7.
Badger	Sec. 20, Sw. ¼	Lappint	116	Drift, 60; sandstone, 6; clay, 20; limestone, 30.
Badger	Sec. 32, Se. ¼	Lappint	120	Drift, 80; red clay, 40; sandstone.
Badger	Sec. 33, Sw. ¼	Lappint	90+	Drift, 90; stopped in sandstone.
Badger	Sec. 34, Sw. ¼	Lappint	68	Drift, 50; sandstone, 1; limestone, 17.
Colfax	Sec. 18, Sw. ¼	Lappint	50	Drift, 49; enter gypsum 5 inches.
Colfax	Sec. 17, S. ½.	Lappint	158	Drift, 90; shale, 6?; limestone.
Colfax	Sec. 8, Sw. ¼.	Lappint	83	Drift, 60; gypsum, 23.
Colfax	Sec. 9, Nw. ¼	J. J. Meyer	132	Drift, 125; sandstone, 7.
Colfax	Sec. 7, Nw. ¼	J. J. Meyer	106	Wholly in drift.
Cooper	Sec. 4, Ne. ¼	Lappint	67	Drift, 40; red clay, 20; limestone, 7.
Cooper	Sec. 9, Nw. ¼	Lappint	90	Drift, 85; limestone, 5.
Cooper	Sec. 12, W. ½	Lappint	75	Drift, 60; sandstone, 4; gypsum.
Cooper	Sec. 33, Ne. ¼	Craig Coal Co	42	Drift, 26; gypsum, 16.
Cooper	Sec. 23, Sw. ¼	Lappint	125	Drift, 120; limestone, 5.
Cooper	Sec. 23, Sw. ¼	Lappint	81	Drift, 70; sandstone, 2; gypsum, 9.
Cooper	Sec. 26, S. ½	Lappint	101	Drift, 100; limestone, 1.
Cooper	Sec. 26, Nw. ¼	Lappint	80	Drift, 60; gypsum, 20.
Cooper	Sec. 34, Sw. ¼	Lappint	72	Drift, 47; gypsum, 25.
Cooper	Sec. 28, Se. ¼	J. J. Meyer	68	Drift, 57; gypsum, 21.
Cooper	Sec. 8, Nw. ¼	J. J. Meyer	70+	Drift, 70, sandstone.
Cooper	Sec. 16	J. J. Meyer	87	Drift, 75; sandstone, 4; clay, 4; sandstone, 4.
Cooper	Sec. 10, Nw. ¼	J. J. Meyer	100	Drift, 80; sandstone, 20.
Douglas	Sec. 36, Se. ¼	Craig Coal Co	109	Drift, 76; gypsum, 18.
Douglas	Sec. 11, Se. ¼	J. J. Meyer	150	Drift, 135; sand, 14.
Washington	Sec. 12, Ne. ¼	Lappint	95	Drift, 50; sandstone, 45.
Otho	Sec. 7, center.	Keyes' report	......	Drift, 57; gypsum, 1.
Elkhorn	Sec. 25, Sw ¼	Lappint	70	Drift overlying sandstone.
Elkhorn	Sec. 6, N. ½	Lappint	120	Drift and Coal Measures. No gypsum.
Clay	Sec. 8, Nw. ¼	Rasmusson & Stone	296	Drift, shale and 50 feet of limestone.
Elkhorn*	Sec. 32, Se. ¼	Rasmusson & Stone	252	Shale and 12 feet of limestone.

* Other wells of which records were obtained in Elkhorn township, were shallow and did not go through the drift.

RECORDS OF PROSPECT HOLES.

The following records of prospect holes also throw light upon the extent and stratigraphic relationship of the gypsum.

Cooper township, Sec. 33, Ne. 1/4, near bottom of valley of Two Mile creek.*

		Feet.	Inches.
29.	Creek silt	6	
28.	Yellow clay	14	
27.	Red shale	6	
26.	Gypsum	16	10
25.	Fire clay	1	6
24.	White sandstone	2	
23.	Brown sandstone	1	
22.	Red clay	2	
21.	Yellow clay	2	4
20.	Shale	13	6
19.	Clay ironstone ?	1	
18.	Fire clay	3	1
17.	Shale	3	
16.	Coal	1	7
15.	Sandstone	3	
14.	Fire clay	2	2
13.	Shale and black jack		3
12.	Sandstone	1	
11.	Shale		7
10.	Fire clay	4	3
9.	Sandstone	1	
8.	Shale	4	
7.	Soft sandstone	2	
6.	Shale	4	
5.	Fire clay	1	6
4.	Shale	3	
3.	Soft sandstone	4	
2.	Shale		3
1.	Limestone		6
		100	6

Pleasant Valley township, Sec. 4, Se. 1/4*.

		Feet.	Inches.
9.	Soil	3	
8.	Yellow clay	16	
7.	Blue clay	30	
6.	Red shale	4	
5.	Shales	30	
4.	Rock (undet.)	1	10
3.	Shale	9	
2.	Coal	2	7
1.	Black jack	..	8

* Authority, Craig Coal Company.

On the same quarter section:

		Feet.	Inches.
6.	Soil	2	
5.	Yellow clay	17	
4.	Blue clay	25	6
3.	Red shale	2	6
2.	Gypsum	12	
1.	Shale	5	6

Douglas township, Sec. 36, Se. ¼ (on what is known as the Bassett farm).

		Feet.	Inches.
15.	Soil	2	
14.	Yellow clay	8	
13.	Blue clay and sand	36	
12.	Red sandy shale	30	
11.	Gypsum	1	
9.	Yellow shale		7
8.	Gypsum	17	7
7.	Shale	15	6
6.	Rock (undet.)	1	3
5.	Sandstone		6
4.	Coal		5
3.	Fire clay	5	1
2.	Shale	1	
1.	Brown sandstone	1	6
		119	9

Well on the Webster County Poor Farm, Elkhorn township, Sec. 3, Sw. ¼.

		Feet.	Inches.
23.	Soil	2	
22.	Yellow clay	13	
21.	Blue clay	47	
20.	Sand	1	6
19.	Red shale	19	4
18.	Gypsum	17	
17.	Blue shale	6	2
16.	Limestone	2	
15.	Coal		9
14.	Fire clay	1	6
13.	Shale, light colored	1	4
12.	Coal	1	3
11.	Sandstone	4	
10.	Black shale	4	2
9.	Coal		3
8.	Fire clay	1	

		FEET.	INCHES.
7.	Sandstone, white	4	6
6.	Shale, with limestone bands	34	6
5.	Shale, light colored	5	
4.	Shale, blue	4	
3.	Calcareous shale	6	5
2.	Shale, blue	21	2
1.	Limestone (penetrated)	40	

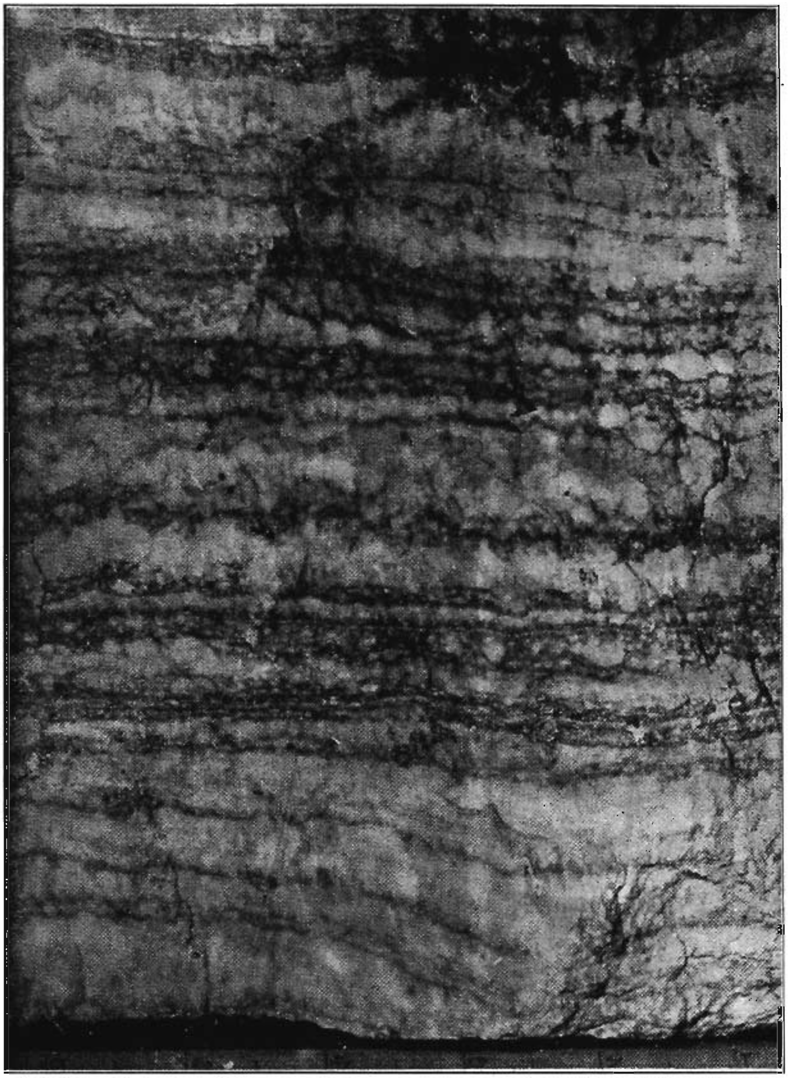
On the Sw. ¼ of Sec. 6, Otho township, on which are located the mines that supply the Duncomb Plaster Mills, ten prospect holes gave the following records:

No. 1. 46 feet all in drift.
No. 2. 50 feet in drift and shale, 10 feet gypsum.
No. 3. 45 feet in drift and shale, 15 feet gypsum.
No. 4. 50 feet in drift and shale, 7 feet gypsum.
No. 5. 50 feet in drift and shale, 4 feet gypsum.
No. 6. 41 feet in drift and shale, 11 feet gypsum.
No. 7. (In a hollow) 6 feet of drift, 11 feet gypsum.
No. 8. 38 feet drift and shale, 6½ feet gypsum.
No. 9. 54 feet drift and shale, 12 feet gypsum.
No. 10. 45 feet drift and shale, 20 feet gypsum.

At the Mineral City Plaster Mill, in Cooper township, Sec. 34, Nw. ¼, three prospect holes, 58, 70 and 74½ feet deep, gave sixteen to eighteen feet of gypsum, covered by red, sandy shale.

The Region in which Gypsum Underlies the Drift.—The well data and records of prospect holes neither positively confirm nor deny the suggestion of Keyes that the gypsum extends on from the Fort Dodge region through the southwestern part of the county and connects with the chalk deposits that are found near Auburn in the southeast corner of Sac county*. In the southwestern part of the county most of the wells do not go through the drift and little positive data in regard to the formations under the drift were attainable. Gypsum was not definitely reported by any well driller farther west than the Bassett and the Poor farms, two miles west of the river. Evidences of gypsum as far west as Moorland and Callender are too uncertain to make it wise to extend the gypsum area to those towns. A prospect hole drilled for F. J. Deischmidt just east of Moorland by the Jasper County Coal Company in search of coal, is said to have pene-

* Iowa Geol. Surv., Vol. III, p. 285.



Structure of the gypsum.

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trated gypsum. The parties who possessed primary knowledge of this prospect hole have died and it is impossible to corroborate the report. The owner of the land, however, is positive that eleven feet of good gypsum was found and it is fair to include this region in the possible gypsum area, as is done on the accompanying map. North and east the gypsum area may now be extended beyond the limit which was definitely known when Keyes made his report. At Vincent gypsum was reported by those who drilled the creamery well. A number of reliable persons examined the material brought up by the bucket and pronounced it gypsum. In order to verify as far as possible these statements water from this well, which was said to stop just below the gypsum, was analyzed with these results:

Calcium oxide	226	pts. per million
Sulphur trioxide	302.5	" "
Equal to calcium sulphate	528.5	

The high percentage of calcium sulphate, one part in two thousand, would indicate the existence of gypsum in the neighborhood.

The geological map accompanying this report indicates localities in which gypsum certainly exists and suggests a larger area in which gypsum may be found.

NATURE OF THE GYPSUM BEDS.

All of the gypsum in Webster county, excepting the scattered crystals of selenite in the Coal Measure shales, is regularly stratified in heavy layers which are rarely less than six inches thick, commonly twelve inches or more, attaining a maximum thickness of two feet. The layers are separated by traces of clay. In thickness the deposit varies from ten to thirty feet. Instead of thinning out gradually through a considerable area, it seems to diminish but slightly before it abruptly gives place to shale. At Kohl's brewery, for instance, ten feet of gypsum appear while half a mile farther north in the clay pit of the Fort Dodge Brick and Tile Company only drift and Coal Measure shales are found. Everywhere in the Webster county gypsum the laminæ alternate regularly in color, gray and white. The gypsum is remarkably pure calcium sulphate ($CaSO_4+2H_2O$) The lower layers, generally the lower three feet, are not as pure as the upper and are not used in the manufacture of plaster. Even in these lower layers, however, the amount of the impurities is so small that they seem hardly sufficient to injure the plaster. An analysis* of the upper layers shows:

	PER CENT.
Calcium sulphate ($CaSO_4$)	78.44
Water of crystallization (calculated)	20.76
Insoluble matter (impurities)	.65

An analysis made by Professor J. B. Weems of gypsum taken from the lower, middle and upper part of those layers that are rejected in making plaster shows:

	PER CENT.
Silica (SiO_2)	1.92
Alumina (Al_2O_3)	1.00
Calcium sulphate ($CaSO_4$)	76.28
Water†	20.72
Total	99.92

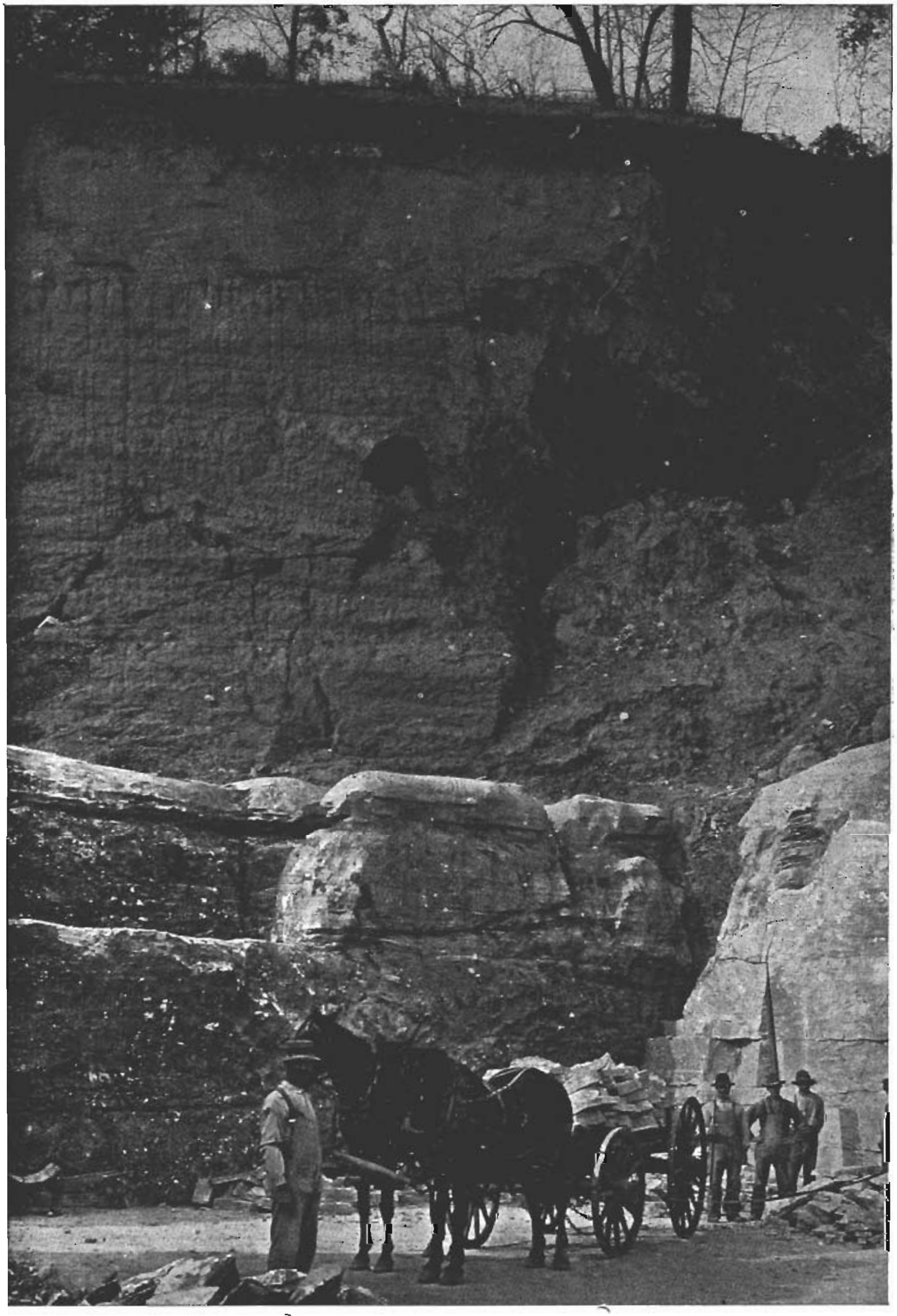
When made into plaster this lower layer while soft will not adhere to the lath satisfactorily. In the calcining kettles it sticks to the sides and so causes trouble. After hardening it is as firm and durable as the plaster made from the upper layers of gypsum.

The following divisions in the gypsum beds are commonly recognizd by the miners:

		FEET.
5.	Upper rock suitable for plaster varying in thickness on account of differences in loss due to preglacial erosion	3-12
4.	Six foot seam, the best of the plaster rock	6
3.	Hard ledge, not good for plaster	4
2.	Eighteen inch ledge not good for plaster	1½
1.	Bottom ledge, not good for plaster	5

The gypsum is crystalline throughout, the slender needle-like crystals being arranged at right angles to the planes of sedimentation. Though the gypsum is now well preserved by the thick mantle of drift that overlies it, at one time it formed the surface

* Analysis by G. E. Patrick. Iowa Geol. Surv., Vol. III, p. 291.
† With traces of magnesia and carbon dioxide.



Gypsum quarry face. Iowa Plaster Company, Fort Dodge.

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Illustration
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rock and in consequence suffered considerably from erosion and solution. When the overlying drift is removed, the surface of the gypsum everywhere appears deeply trenched and worn. Some of the trenches cut half way through the entire deposit. At times the gypsum is wholly cut out and records of drillings at points wholly surrounded by gypsum show only gravel. Trenches are frequently encountered in mining the gypsum, when they cause considerable trouble. When exposed along ravines the gypsum is decayed on the surface to a depth of three or four inches. The deep trenches in the gypsum are probably due as much to the action of water as a solvent as to its power as an erosive agent. Wherever the gypsum has been exposed in ledges for a period of years, it is picturesquely grooved and fluted.

AGE OF THE GYPSUM AND ASSOCIATED DEPOSITS.

In considering the age of the gypsum the red shales which accompany it must be kept in mind for they are very closely associated, as shown by exposures along Soldier creek, where thin layers of gypsum are found in the shales. Wherever they were not removed by preglacial erosion these shales overlie the gypsum conformably. Their extent is greater than that of the gypsum and in the pit of the Fort Dodge Clay Works, as already described, they may be seen resting unconformably on the Coal Measures. In Douglas township, section 8, there is a good exposure of these red shales which is six miles northwest of any known gypsum. Their color is striking, often brilliant, and for this reason they have been used to some extent as a natural pigment.

The fact that the gypsum and the red shales lie unconformably on the Coal Measures is good ground for believing that if they belong to the Paleozoic era they were formed near its close, during the Permian. The Permian beds of Kansas, Indian Territory and Texas, which contain quantities of gypsum, are so highly and so characteristically colored that they are known as the "red beds." These red beds like the red shales and gypsum of Iowa are nearly destitute of fossils, due probably to the fact that the climatic conditions favoring deposition of gypsum were hostile to organic life. Aridity is the climatic characteristic most essential for great deposits of gypsum, and the redness of the sandstones and shales usually accompanying gypsum deposits of all ages and localities may fairly be assumed to be an effect of climate, direct or indirect, on the iron content of the soil. All of these considerations, namely, the arid climate that prevailed during the Permian, shown by great gypsum deposits associated with red shales occurring in both Europe and America, and the striking resemblance which the series bears to the Permian only 300 miles to the west, carry great weight. The Iowa series might reasonably be interpreted as an outlier of the Permian of Kansas and Indian Territory. During the long interval between its deposition and that of the drift which now protects it erosion had an abundant opportunity to remove the Permian from the intervening territory. The gypsum was doubtless protected by heavy beds of the red shales, for had it been exposed long it must have yielded to the solvent and erosive action of water.

It is possible to refer the gypsum to the Triassic or to the Cretaceous. Like the Permian, the Triassic of the west is red and contains large deposits of gypsum, notably those of the Black Hills. Known outcrops of Triassic strata occur only far to the west of the area under consideration, much farther west than the most eastern exposures of recognized Permian in Kansas. While this fact favors a reference of the Iowa gypsum to the Permian rather than the Triassic, the fact that the Permian of Kansas rests conformably on the Coal Measures while the gypsum of Iowa does not, throws a certain amount of weight the other way.

The claims of the Cretaceous have been considered in previous reports on the region*. Reference to the geological map of Iowa shows that Cretaceous deposits are present throughout the greater part of northwestern Iowa and that they approach within thirty miles of Webster county, at Auburn in Sac county, where they appear as chalk. The Cretaceous in Iowa consists of sandstone of the Dakota stage, and shales, limestone and chalk of the Colorado stage. Sandstone, shales and limestone have yielded abundant fossils which definitely fix their age. Other things being equal, it would be somewhat more natural to regard the Webster county gypsum series as an outlier of the Creta-

* Iowa Geol. Surv., Vol. III, p. 193.

ceous than of the Permian which is farther away, yet the distance is not so great as to render a correlation with the Permian in any degree improbable if the preponderance of other evidence favors such a view. A review of Cretaceous climatic conditions is first of all necessary, for if aridity is a more striking characteristic of the Permian than of the Cretaceous, the Cretaceous age of the gypsum can hardly be established. The Dakota sandstone is at times red, but this color does not everywhere prevail and it does not characterize the Cretaceous shales and limestones in any degree. The Dakota sandstone abounds in fossils, as does the limestone of the Colorado stage, in which *Inoceramus labiatus* is found in great numbers. The Benton shales, while not so rich in fossils as the limestone, contain *Ostrea congesta, Prionocyclus wyomingensis* and other species, none of which are brackish water forms. They contain also some selenite, but in view of the fossil contents of the shales it is probable that the selenite was not formed by precipitation from concentrated brine at the time that the shales were laid down, but is due to subsequent chemical reaction in which sulphuric acid, generated perhaps from iron pyrites, converted part of the lime carbonate of the shales into the sulphate. In barrenness of fossils, in color and in association with gypsum the red shales which accompany the Iowa gypsum resemble the Permian of Kansas much more than they do the Cretaceous shales of Iowa. The presence of chalk in Sac county, close to what must have been the Cretaceous shore indicates that for a time sediments from land were at a minimum and organic sediments unmixed with land waste were able to accumulate near the shore. This would indicate an absence of the barren surface usually attending aridity, or the absence of elevation, or both, so that climatic conditions favoring deposits of gypsum are not implied by the chalk of the Cretaceous. Regions devoid of rainfall are characterized by windstorms of great violence capable of transporting much earthy material as dust and carrying it out to sea where it would ultimately be deposited. The arid regions of America are subject to brief but violent rain storms during which erosion is vigorous on the surface barren of vegetation. Low land surfaces covered with an abundant vegetation are most favorable for pure chemical and organic accumulations in the neighboring seas. The great purity of many gypsum deposits presents a difficulty for this very reason, for the land must have been barren during the concentration of the sea water and conditions favorable for dust storms seem likely to have prevailed. Microscopic examination of the Iowa gypsum reveals particles of sand scattered through the gypsum, probably by wind, but the total amoant is small, amounting to about one per cent of the whole.

The age of the great gypsum and salt deposits of the world is shown below:

FOREIGN.		AMERICAN.	
PLEISTOCENE AND RECENT.			
Caspian Sea and Asiatic Lakes.	1.	Great Salt Lake.	
PLIOCENE.			
Transylvania, near Prague (salt).	2.		
Caspian sea in Karabhogas bay (salt and gypsum).	3.		
Austria at Wieliczka, Siebenbürgen (salt and gypsum).	4.		
MIOCENE.			
None.			
OLIGOCENE.			
Transylvania and Carpathian Mts. (gypsum and salt).	5.		
Germany, Sperenberg (gypsum).	6.		
France, Montmartre (gypsum).	7.		
EOCENE.			
None.			
CRETACEOUS.			
None.			
JURASSIC.			
None.			
TRIASSIC.			
Germany: Hanover, Austadt. Erfurt, Thuringia. Lothringer (gypsum and salt).	8.	Black Hills (gypsum).	10.
England: From Scotland to Devonshire (gypsum and salt).	9.		

FOREIGN.		AMERICAN.	
PERMIAN.			
Germany:	11.	Iowa (gypsum).	
The Hartz (gypsum).		Texas (gypsum).	13.
Stassfurt, Sperenberg (gypsum and salt.)		Kansas (salt and gypsum).	14.
South Tyrol (gypsum).		Oklahoma and Indian Territory.	
Russia (gypsum, salt).	12.	Black Hills, (gypsum).	15.
UPPER CARBONIFEROUS.			
None.			
LOWER CARBONIFEROUS.			
		Lower Michigan (gypsum).	16.
		Nova Scotia (gypsum and salt).	17.
		Virginia (gypsum and salt).	18.
		Montana (gypsum).	19.
DEVONIAN.			
None.			
SILURIAN.			
Russia, Baltic provinces (gypsum).	20.	New York (gypsum and salt).	21.
		Ohio (gypsum and salt).	22.
		Pennsylvania (gypsum).	23.
		Upper Michigan (gypsum).	24.
ORDOVICIAN.			
None.			
CAMBRIAN.			
Punjab Salt Range, India.	25.		

1. Geikie Text Book of Geol., 3d Ed., pp. 737-739.
2. Geikie Text Book of Geol., p. 1018.
3. Geikie Text Book of Geol., 3d Ed., p. 1004.
4. Credner Geologie, pp. 639-700.
5. Geikie Text Book of Geol., 3d Ed., p. 933.
6. Credner Geologie, p. 679.
7. Credner Geologie, p. 675.
8. Credner Geologie, p. 520.
9. Geikie Text Book of Geol., 3d Ed., p. 866.
10. U. S. Geol. Surv., Darton's report on Black Hills, 21st Ann. Rep., part IV.
11. Credner Geologie, pp. 503-511.
12. Geikie Text Book of Geol., 3d Ed., p. 853.
13. Third Ann. Rep. Texas Surv., p. 212.
14. University Geol. Surv. of Kansas, Vol. V.
15. U. S. Geol. Surv., Darton's report on Black Hills, 21st Ann. Rep., part IV.
16. Geol. Surv. Michigan, Vol. V, (1881-93), part II, pp. 14-30.
17. Mineral Resources, Canada, 1897, pp. 105-111.
18. Resources Southwestern Virginia, Boyd., 1875, pp. 260-304.
19. U. S. Geol. Surv., Benton Folio, p. 6.
20. Geikie Text Book of Geol., 3d Ed., p. 789.
21. New York Geol. Surv., Vol. III, No. 15, p. 550.
22. Geol Surv. Ohio, Vol. VI, pp. 691-702.
23. Geol. Surv. Pennsylvania, Summary Final Reports, Vol. II, pp. 913-915.
24. Geol. Surv. Michigan, Vol. I. 1869 73, part III, pp 29-31.
25. Geikie Text Book of Geol., 3d Ed., pp. 737-739.

Climatic conditions in both hemispheres, therefore, seem to have been favorable for deposits of gypsum during the Permian, whereas if the Iowa gypsum were referred to the Cretaceous it would be the only gypsum deposit of economic importance in Europe or America assigned to this period of geological history. The gypsum may therefore be reasonably regarded as Permian, though the possibility of its being Triassic cannot be denied.

ORIGIN OF THE GYPSUM.

Gypsum deposits are generally ascribed to two causes: (1) the transformation of deposits already formed by various chemical reactions, and to precipitation from sea water, due primarily to concentration by evaporation, and (2) to reactions between the salts in solution.

The most frequent transformation of deposits already formed is the change of limestone ($CaCO_3$) into gypsum, ($CaSO_4 + 2\ H_2O$) through the agency of sulphuric acid, according to the equation $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$. The sulphuric acid may be generated by the oxidation of the sulphuretted hydrogen of sulphur springs or of volcanoes, or by the action of water on some sulphide ore like pyrites. The deposits which Dana attributes to the action of sulphuric acid generated from the sulphuretted hydrogen given off by sulphur springs in New York* are quite extensive. In certain instances the gypsum occurs in masses with irregular outline in limestone, and layers of shale in the limestone pass unaltered through the gypsum. In view of this evidence the gypsum must be regarded as derived from the limestone. Deposits of this sort are exceptional, however, and it is probable that most of the gypsum of New York had a different origin.

Insignificant gypsum deposits occur about the fumaroles of craters and lava streams in Hawaii where sulphurous acid (SO_2) is converted into sulphuric, and attacks rocks which contain lime. The frequent occurrence of small amounts of gypsum with hematite in the upper part of ore veins may be accounted for by the following reaction†, $Fe_2O_3(SO_3)_2 + 2CaCO_3$

* Dana, Manual of Geology, 4th Ed., p. 554.
† Beck Erzlagerstattenlehre, p. 393.

= $2CaSO_4$ + Fe_2O_3 + $2CO_2$, the original form of the iron being FeS_2. Cerussite and smithsonite with gypsum in a mineral vein are similarly accounted for. Anhydrite when exposed to air containing moisture gradually takes on water and forms gypsum.

That great quantities of gypsum in all parts of the world and at different times in geological history have been derived from sea water by evaporation is generally recognized. Sea water contains three and one-half per cent of mineral matter distributed as follows:

	PER CENT.
Chloride of sodium	77.758
Chloride of magnesium	10.878
Sulphate of magnesium	4.737
Sulphate of calcium (gypsum)	3,600
Sulphate of potassium	2.465
Carbonate of lime	0.345
Bromide of magnesium	0.217
Total	100.000

Gypsum is deposited from typical sea water when 80 per cent of the water has evaporated,* whereas common salt is not deposited until the bulk of the water is reduced more than 90 per cent. Gypsum deposits are more widespread than salt, but salt usually occurs in thicker beds. These facts taken with the relative amount of each salt in sea water and the amount of evaporation necessary for precipitation in each case, accord with the theory which regards the evaporation of sea water as the cause of most salt and gypsum deposits. It is evident that conditions allowing the 80 per cent of evaporation necessary for a gypsum deposit would occur more often than those giving rise to 90 per cent of evaporation and a deposit of rock salt. When the amount of evaporation necessary for a salt deposit took place, however, the high percentage of salt in the water would yield a stratum of notable thickness as compared with gypsum.

The accompanying diagram (Fig. 14) indicates the relation of deposition to density in the case of the salts common to sea water. The magnesium chloride alone is not actually precipi-

* M. Dieulafait in Pop. Sci. Mon., Oct., 1892.

tated but remains in solution always under ordinary atmospheric conditions. It may be precipitated, however, with potassium chloride as carnallite. Three-fourths of the gypsum is deposited

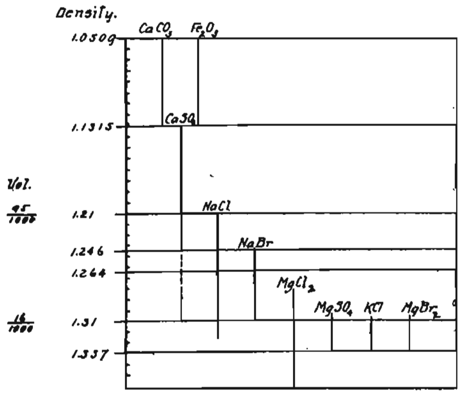


FIG. 14. Sketch showing the order of precipitation of salts from sea water, with increase in density due to evaporation.

between the densities of 1.1315 and 1.21, whereas the deposition of salt does not begin until the latter point is reached. The remaining one-fourth is precipitated with the salt, but constitutes so small a part of the whole that the commercial value of the salt is not appreciably lowered. The normal order of deposition on evaporation from sea water, beginning with the first which occurs, of course, at the bottom of the deposit, is:

1. Limestone with limonite, $CaCO_3$ and $2\ Fe_2O_3 + 3\ H_2O$.
2. Gypsum $Ca\ SO_4 + 2\ H_2O$.
3. Sodium chloride (common salt) Na Cl.
4. The bitter salt (in carnallite) $KCl + MgCl_2 + 6\ H_2O$.

Practically this order is observed in the great salt deposits of Stassfurt, Germany.

While gypsum has been formed and is still forming in all of the ways described, most of these explanations are manifestly not adapted to the Webster county deposit. The definite lamination and layering of the gypsum indicate an aqueous origin. Pointing to the same conclusion is the fact that no limestones are associated with the gypsum which by alteration could yield gypsum. Salt may be regarded as absent from the Iowa gypsum area. If it existed it would probably have been detected in some of the many wells and prospect holes. Its absence is not surprising for the degree of concentration necessary for a salt deposit may never have been reached, or the salt after having been deposited may have been removed by subsequent erosion and solution.

The great thickness of some occurrences of gypsum and salt must be considered in seeking to determine their origin. The combined series of Stassfurt amounts to more than 1,000 feet and at Sprenberg to more than 3,000 feet. To yield even fifteen feet of gypsum, the average thickness in the Iowa field, an immense amount of water must have been evaporated. A cubic foot of gypsum weighs 140 pounds and the amount of gypsum in a cubic foot of sea water today is three-fiftieths of one pound. The amount of water necessary to yield a cubic foot of gypsum then is 2,332.4 cubic feet. If the sides of the containing basin were vertical the depth of the water necessary to produce fifteen feet of gypsum must have been 34,986 feet. If the average thickness of the Iowa gypsum be taken as fifteen feet and the gypsum area seventy square miles in extent, the amount of sea water necessary to deposit it, assuming that its content of gypsum was the same as in sea water today, was sixty-eight trillions of cubic feet. If a basin twenty miles wide be assumed, with two shores sloping to a center at an angle of 10 degrees, the length of the basin which would contain this amount of water must have been twenty-six miles and the depth at the center more than 9,000 feet, diminishing uniformly in depth from the center. Such a trough manifestly never existed and the hypothesis that the gypsum was deposited in a detached arm of the ocean, unaided by considerable supplies of salt from rivers or from the main body of salt water, is untenable. There remain to be considered: 1. Arms of the sea which were at least part of the time connected with the ocean and which received more or less water from land; 2. Enclosed seas fed wholly by rivers and without outlet except by evaporation.

Taking up the second case first, it will be instructive to review the conditions actually existing in enclosed salt seas in Asia and America.

The nature of the salt deposits made in a lake not connected with the ocean and without outlet, where evaporation is as great as or greater than inflow may vary as widely as do the relative proportion of salts in the inflowing streams. If the lake was at one time a part of the ocean this fact is of consequence in determining the nature of salt deposition. The variation in the nature and amount of salts carried in solution by different streams is a natural consequence of differences in mineral constitution of their drainage areas. In the Elbe and Thames chlorides predominate* (in the latter with gypsum) and the evaporation of these waters would give rise to lakes containing a large percentage of common salt. In the Seine sulphate of lime (gypsum) predominates, while the waters of the Rhine, Danube and Arr contain small amounts of chlorides and large percentages of sulphates of lime and magnesia. The Loire contains in 100,000 parts 13.46 of solid matter of which 35 per cent is calcium carbonate, while two-thirds of the soluble salts are carbonate of soda. In nearly all rivers bicarbonate of soda is present in large quantities. The water of the river Jordan gives the following analysis:†

Sodium chloride (common salt)	.35
Magnesium chloride	.03
Calcium chloride	.07
Calcium sulphate (gypsum)	.04
Water	99.50

The waters of the Dead Sea are the result of concentration by evaporation of waters containing salt. Quoting Bischof‡: "In spring when the streams are turbid with the particles of carbonate of lime and clay, mere mechanical deposits take place for at this period, when large masses of water are carried into the Dead Sea, and the saline solution thereby diluted, while at the same time the evaporation is but slight, no common salt is deposited. During the ensuing warmer months the chemical deposition of common salt and carbonate of lime take place. Should the stream become turbid at this season in consequence of continued rain deposits are formed which contain a less amount of common salt. In this way there must arise a constant alternation of different irregular layers of greater or less thickness. All

* T. Sterry Hunt. Chemical and Geological Essays.
† Bischof. Vol. I, Chem. and Phys. Geology.
‡ Ibid, p. 397.

these layers must contain gypsum, since in a water which contains so much chloride of magnesium as is present in the Dead Sea, gypsum, as we shall subsequently see, is dissolved with difficulty, as is also shown by the small proportion in which this salt exists in that sea."

Lake Elton, a brine pool of the Russian steppes, may once have had an oceanic connection. If this is true the calcium carbonate and gypsum of the original sea water have been deposited, for the water now contains but small quantities of lime salts but chlorides of sodium and magnesium with sulphide of magnesium are present in abundance*. Bischof describes the lake as follows: "The Elton lake, whose greatest diameter is 20 and its smallest 16 versts, lies 19 feet below the level of the ocean. It has flat banks and may be waded through almost anywhere. On its margins and upon its bed there is almost everywhere crystalline salt. This forms layers from one to two inches in thickness which are separated from one another by layers of mud and earth. The streams which empty into it are eight in number. They all contain more or less salt, and consequently carry supplies of this substance into the lake. The most considerable among them is the Charisacha, which is also the only one which continues to flow during the whole year. In the loamy soil which surrounds the lake numerous small crystals of gypsum are imbedded." A deposit of salt is formed in this lake every summer, in the winter and spring the water is diluted by the rivers which are then copious and a layer of silt, probably carrying some gypsum is formed. The decrease or complete disappearance of $Ca\,SO_4$ from the water of Lake Elton into which it is being constantly conveyed by the Charisacha river, the waters of which have been analyzed, shows that the gypsum goes down with the salt.

Great Salt Lake in Utah furnishes an excellent example of salt deposits in a lake without oceanic connections. The present lake is but a remnant of the much larger Lake Bonneville, which was fresh and was drained by a stream flowing into the Snake river. Its present salinity is high, the specific gravity of the water being 1.1 + and its saline contents, varying with the seasons

* Analysis by Gobel, quoted by Bischof, Chem. and Phys. Geol. Vol. I, p. 404.

from 14 to 22 per cent, is distributed as follows, as shown in five analyses*:

Sodium chloride	90.7	79.1	65.9	81.3	80.5
Potassium chloride		....	14.1	....	....
Magnesium chloride	1.1	9.9	8.9	6.7	10.3
Sodium sulphate	8.2	6.2	8.1	8.5	5.4
Potassium sulphate		3.6	....	2.6	2.4
Calcium sulphate		.6	1.5	.9	1.4
Chlorine (in excess)		.6	1.5	....	....

In these analyses the absence or the very small content of calcium, both as sulphate and carbonate, is remarkable. Analyses of the fresh waters tributary to the lake show that the lake could accumulate its total content of calcium in eighteen years while the accumulation period for the chlorine would be 34,200 years.† Manifestly the lake is disposing of the calcium as fast as it is received. Deposits of tufa occur on the old Bonneville, Intermediate and Provo shore lines, on their weathered faces, and a few feet below their crests. It is absent in sheltered bays and most abundant on points that were especially exposed to wave action. Calcareous oolitic sands are now forming along certain parts of the shore of Salt Lake "between the delta of the Jordan and Black Rock, where it constitutes the material of a beach, and is drifted shoreward in dunes."‡ Of the three important fresh water tributaries of Great Salt Lake, the water of Utah Lake is characterized by sulphate of lime, over 60 per cent of the total solids held in solution by it consisting of this salt, while the waters of Bear river and City creek are characterized by carbonate of lime."‖ Strictly speaking, in the last case as commonly when carbonate of lime is in solution, the lime is in the form of the bicarbonate. During the process of aeration caused by the beating of the waves against the shore carbon dioxide is given off and the lime, reduced to calcium carbonate, is deposited.

The oolitic sands may be ascribed to the action of plants which have the power of withdrawing carbon dioxide from soluble calcium bicarbonate, which would precipitate the insoluble carbonate.§ Deposits of calcareous tufa and oolite are particularly

* U. S. Geological Survey, Monograph 2. Lake Bonneville, p. 254.
† Ibid. p. 256.
‡ Ibid. p. 169.
‖ Ibid. p. 207.
§ Russell. Lakes of North America, p. 76.

abundant near the mouths of streams which convey carbonate of lime to the lake and possibly the lime carbonate is wholly withdrawn from the inflowing water before it has an opportunity to mingle with the more remote waters of the lake.

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

Many writers on gypsum and salt have called attention to the fact that the Mediterranean Sea furnishes conditions which if but slightly modified would result in deposits of these substances.† Although it receives the waters of many rivers, some of them of considerable size, evaporation takes place faster than inflow and if no water entered through the Strait of Gibralter, or if the supply entering were considerably reduced, much of the mineral matter held in solution would be deposited. A steady current pours in from the ocean, however, and the density nec-

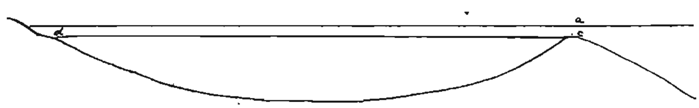


FIG. 15.

essary for precipitation is not reached. The bottom of the sea rises sharply near the Strait of Gibraltar cutting off communication between the lower part of the sea and the ocean, but permitting a free interchange of water in the upper level. The depth at the strait is less than 200 fathoms while the average depth of

* Bischof, Vol. I, p. 392.
† Geol. Surv of Mich., Vol. V, 1881-93, part II, pp. 1-13.
University Geol. Surv. of Kansas, Vol. V, Gypsum. Introduction.

the Mediterranean is 1,000 fathoms. The accompanying diagram roughly illustrates existing conditions.

The amount of salt in the water of the Atlantic is 3.6 per cent, while in the Mediterranean it is 3.9 per cent. The specific gravity of the water of the Atlantic off the strait of Gibraltar is 1.026; while at the west end of the Mediterranean, near the surface, it is 1.028, increasing in the east end to 1.03. At a depth of 300 fathoms the density is considerably greater than at the surface. A current of water flows in constantly at the surface of the strait (Fig. 15, a). This water is concentrated by evaporation and sinks. The bottom below the line c d has been previously filled by this dense water and the water is being constantly condensed, sinks and flows out at c as a lower current into the ocean. The outlet at the strait is so free that the condensation does not reach the point which results in the deposition of lime, gypsum or salt.

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

In applying "enclosed sea" conditions like those now prevailing about Great Salt Lake, to the Iowa gypsum, two questions arise. Was there a supply of gypsum in the rocks of the region subject to the solvent action of stream water sufficient to yield the existing deposit? If this question may be answered in the affirmative, do the deposits formed in enclosed seas structurally and chemically resemble those of Webster county? The Coal Measure shales and sandstones with here and there a limited area of Saint Louis limestone formed the land surface when the gypsum was deposited. There is a considerable amount of gypsum in all of these strata which appears frequently in large selenite crystals. Rivers flowing over this surface would carry a large percentage of gypsum in solution, provided the gypsum now contained in these strata was present at that time. It is hardly probable that the gypsum of the Coal Measure shales was formed at the time of their deposition, for the presence of great numbers of ferns indicate fresh water. A more probable origin lies in the action of water on pyrites, giving rise to ferrous sulphate, which in turn changed part of the lime carbonate of the shales into gypsum. This may have taken place before the great gypsum deposit was made and if so the gypsum dissolved out of the Coal Measure shales may have been sufficient to form it. The same waters which carried the gypsum would, however, carry much lime carbonate and mud, and it is difficult to conceive of fifteen feet of pure gypsum forming in an enclosed basin fed by streams. It is true that at the top in one or two localities thin layers of limestone, sandstone or shale occur with thin layers of gypsum, but the presence of fifteen feet of gypsum with only one per cent of sand and clay practically precludes the possibility of its origin in an inland basin fed by land streams. Turning to the "Mediterranean hypothesis," there are two apparent difficulties. In the series of deposits due to deposition on account of evaporation in such a basin, limestone would be the lowest member. If the amount of calcium carbonate in the waters tributary to the basin was small limestone might not appear beneath the gypsum as a distinct formation, but mixed with the finer impurities would still be present as a notable calcareous element in a clay or shale. The Iowa gypsum overlies a fire clay, the analysis of which shows but a very limited amount of lime. Moreover, the lime carbonate in the inflowing water after the density necessary for the deposition of gypsum had been reached in the basin, would, it would seem, be deposited with the gypsum. The phenomena observed about Great Salt Lake perhaps relieve us of these difficulties. As already stated, the water of the lake is almost free from calcium carbonate, while deposits of calcareous tufa and oolite have been and still are forming along the shores where water action is violent. This localizing of the calcium carbonate, if it were complete, would render possible deposits of pure gypsum like that of Iowa, in which no calcium carbonate appears. Unfortunately calcium carbonate due to precipitation from solution appears widely distributed in the marl of the old Bonneville bed, as well as along the shore.* Still the fact that calcium carbonate deposits were favored at the shores by the aeration associated with wave action is particularly significant. Even more significant is the fact that near the streams which contribute to the lake the greatest amount of lime carbonate, the calcareous oolite already mentioned, accumulates as a shore deposit in considerable quantities. If in this or some similar way the lime carbonate was localized the Mediterranean hypothesis would appear satisfactory. It is possible also, holding to this hypothesis, to assume that chemical reactions took place between the salts in solution, which resulted in the elimination of this lime carbonate, either by converting it into gypsum or into a salt which was more soluble than gypsum, thus keeping it in solution till after the gypsum was deposited. It is well known that reactions between the various salts contained in sea water may cause divergence from the series which results from evaporation alone. According to Usiglio sea water deposits limestone abundantly when the density reaches 1.0506 and again at 1.1304. The last deposit he ascribes to the decomposition of sodium carbonate and gypsum with the formation of sodium sulphate and calcium carbonate.† Ochsenius holds that sudden and well marked deposits of gypsum may be caused by the addition of sodium or calcium chloride.

The same line of reasoning which is used to explain great de-

* U. S. Geol. Surv., Monograph 2. Lake Bonneville, p. 190.
† Hubbard, Geol. Surv. of Mich., Vol. V, part II, pp. 1-13

posits of gypsum may be applied to many limestones. Calcium carbonate in sea water is one-tenth as abundant as calcium sulphate and for every twenty feet of gypsum two feet of limestone must be precipitated, unless the calcium carbonate is converted into some other substance. Since the density required to precipitate limestone is far below that required for deposition of gypsum it is highly probable that in many shallow seas but slightly connected with the abyssmal ocean limestone was continuously and abundantly deposited. Such deposits must be more widespread than gypsum for the same reasons that gypsum deposits must be more abundant than salt. While laying stress on this point the fact probably remains that most of the limestone of the earth is of organic origin.

While conditions like those now existing in the Mediterranean sea may in the main be regarded as giving rise to gypsum deposits, this sea presents one peculiarity which could not have characterized many of the regions where gypsum occurs. Structural conditions indicate that most of the gypsum deposits were formed in arms of a shallow epi-continental sea. The Mediterranean sea with its average depth of 1,000 fathoms is truly abyssmal.

Although there may be some doubt as to the exact manner in which the calcium carbonate is removed from the brine during concentration, the fact that it is removed in some one or more of the ways suggested, or by some process not yet brought to light, may be assumed. This removes the only serious difficulty in conceiving of extensive and very pure deposits of gypsum forming in basins only slightly yet continuously through long periods connected with the ocean. The Mediterranean hypothesis, with the modifications pointed out, may be accepted as accounting for the Iowa gypsum as well as similar deposits in various periods of geological history. It must be admitted, however, that chemical investigations in regard to the reactions between salts in solution during the process of brine concentration must be undertaken before the problem can be regarded as fully solved.

Pleistocene System.

Throughout the county the surface material has been derived from sources other than the decay of the underlying rocks. The soil-forming agents to which the county owes its fertility were the ancient glaciers and their deposits which consist of clay, bowlders and pebbles lawlessly mixed and spread evenly over great stretches of country are called drift. The geological system to which these deposits belong is the Pleistocene. Positive differences in the nature of the drift have led most students who are engaged in its study to the conclusion that these deposits were not all made at one time and by a single invasion but rather by a series of ice sheets. The last ice invasion was comparatively recent, so recent that the drift deposits that it left behind are but slightly oxidized and are almost unmodified by subsequent erosion. This latest drift is called the Wisconsin. Under topography attention was called to the slight amount of erosion over the surface of Webster county as contrasted with counties in the southern part of the state which are covered with the older Kansan drift.

Webster county lies within the boundaries of the Wisconsin drift as determined by geological observations through this portion of the state. The drift was not always deposited with uniform surface or thickness. This natural unevenness of the drift aids the drainage, which is still very imperfect. Streams have been able to modify the surface but slightly and then only in their immediate vicinity. At many points in the county the slope is away from the stream. A striking instance of this may be seen on the river at Fairview, two miles above Fort Dodge.

In addition to the topographic features, which aid only in determining the age of surface drift, its physical and chemical characteristics throw much light on the age of the deposit. Fortunately there are many localities in Webster county which give complete vertical drift sections. Some of these are as follows:

Section in the pit of the Fort Dodge Brick and Tile Works:

	Feet.
4. Drift, light yellow, not very compact, slightly jointed, unleached, with many lime pebbles	4
3. Drift, in most places sharply defined from above, but at times thin layers are worked in with it, gray in color, with many limestone pebbles, some are oxidized but show no ferretto, effervesces with acid less than 4	13
2. Drift, not sharply defined from 3, yellow, deeper in color than 4, jointed, very compact, oxidized, especially along joints, effervesces almost as vigorously as 4	10
1. Coal Measures	50

On the south side of the same pit another interesting section is given. This is well down in the valley of the Des Moines, about thirty feet above the alluvium.

	Feet.	Inches.
5. Drift, giving place to silt in the lower part of the section	6	
4. Sand, yellow, cross-bedded, gradually growing harder from top to bottom, gradually shading into 3		10
3. Sandstone, yellow, soft above, very firm beneath, cross-bedded, in turn shading into 2	1	6
2. Conglomerate composed of northern bowlders, granite, etc., cemented by sand and iron all highly oxidized. The largest bowlders 10 inches in diameter, some of the bowlders perhaps faceted though oxidation renders surface features indistinct	1	
1. Shale, Coal Measure	6	

The sandstone in this section lies in a small hollow, running north and south, in the Coal Measures. The relationship between the different members of this section is shown in the accompanying sketch (Fig. 17). The gravels and bowlders in No. 2 are badly rusted, and many of them are decayed, in which case they show oxidation throughout. Beneath the sandstone they are firmly cemented to form the conglomerate, which gradually shades into the sandstone above. To the right, as shown in the sketch, the sandstone shades gradually into sand, which for a few feet over-

FIG. 16. Portion of clay pit of Fort Dodge Brick and Tile Company, showing the upper yellow drift sharply separated from the lower blue-gray drift.

lies the cemented bowlders and pebbles and then gives place to silt. As the distance from the sandstone layer increases, the cementing in the conglomerate becomes weaker until the conglomerate appears simply as a very old gravel deposit. Gravels fully as old as those shown in this section occur on a level about ten feet higher, at the foot of Central avenue, above Heath's Oat Meal Mill.

AFTONIAN GRAVELS.

The presence of the sandstone layer in the second section given above, taken in the pit of the Fort Dodge Brick and Tile Company, is remarkable. The stone, although appearing only as a single layer, is as substantial as the Dakota sandstone of the Cretaceous. If it were seen away from its surroundings it would certainly be regarded as much older than the Pleistocene. The following considerations, however, lead to the belief that it is merely a very old and very firmly cemented glacial sand. This sandstone lies just above and unconformable with the Coal Measures, and if it is not Pleistocene, it is to be associated with the gypsum. In the pit of the Fort Dodge Clay Works just across the river shales of the gypsum series are exposed in direct contact with the Coal Measures. At that point on such conglomerate or sandstone appears. While the surface features of the bowlders are so indistinct on account of oxidation that none of them can be said to be striated, some of them appear to have been planed on one or more sides. The overlying sand, which no one would hesitate to call Pleistocene, shades so gradually into the sandstone that it is impossible to draw any line between them. This sandstone and the gravel, viewed as Pleistocene deposits, are doubtless very old and may perhaps best be classed with the Aftonian gravels found elsewhere in the state.

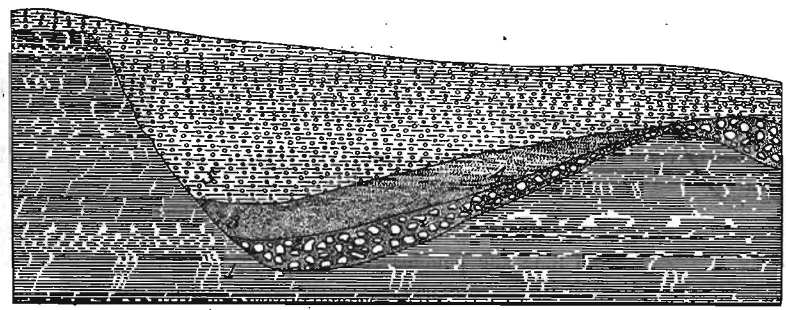


FIG. 17. Old gravel in the pit of the Fort Dodge Brick and Tile Works. 1. Coal Measure shale. 2 Glacial conglomerate and uncemented bowlders and sand. 3. Sandstone, Cross-bedded, shading up into. 4. Uncemented sand. 5. Wisconsin drift.

WISCONSIN DRIFT.

Drift section in the pit of the Fort Dodge Clay Works.

	FEET.	INCHES.
5. Drift yellow, unleached, with few bowlders, those which are present being fresh, many of them of limestone and striated, many limestone pebbles	6	
4. Drift, yellow, but slightly darker than 5, imperfectly separated from 5, except in color like 5	6	

		Feet.	Inches.
3.	Red sandy shales, calcareous, in places showing thin layers of sandstone containing no fossils, unconformable with the drift, and with the underlying Coal Measures	4	
2.	Dark gumbo layer, conforming to the uneven surface of the underlying Coal Measures		6
1.	Coal Measure shales	30	

Slide two miles below Fort Dodge, on the river opposite Blandon's Mill.

		Feet.
6.	Drift, light yellow, not compact, unleached, many limestone pebbles	35
5.	Drift, gray, except in color like 6	20
4.	Drift, bright yellow, except in color like the drift above	10
3.	Drift, gray, with same characteristics as 5.	30
2.	Gypsum (exposed)	10
1.	Shale, Coal Measures	60

In the drift of this section careful searching failed to reveal any difference in leaching from top to bottom.

Section at Bradshaw and Moeller's clay pit in West Fort Dodge.

		Feet.
5.	Silt like material, fine-grained and free from lime and pebbles	5
4.	Gravel, fresh, water worn	1
3.	Drift, yellow, unleached, no distinct oxidized zone	15
2.	Aqueo-glacial sands and clay, finely stratified, an occasional bowlder near the top, sand getting coarser and more abundant toward the bottom till all is sand	30
1.	Shale, Coal Measures (exposed)	10

This clay pit is near the valley of the Des Moines on a tributary ravine. The upper silt which is free from lime (5 in the section just given) probably represents the silt of the second bench and similar deposits may be found at a number of points along the river.

Section at Miller's quarry (formerly Baehring's) near the stone bridge over Soldier creek in Fort Dodge.

		FEET.
8.	Soil	2
7.	Gravel, clean, fresh, water worn, cross bedded with much limestone	10
6.	Drift, not compact, yellow, unleached, somewhat jointed	15
5.	Soil, very dark, unleached, containing many foreign pebbles and wood fragments	15
4.	Sand, uncemented, varying in color from gray to white containing lumps of coal and large pieces of wood	8
3.	Sandstone, single heavy layer	2
2.	Limestone, Saint Louis	25
1.	Sandstone, in creek bed	1

Drift sections at Kohl's brewery, in Gypsum Hollow and on the hillside near the Fort Dodge cemetery have already been given. An interesting series of drift exposures may be seen on the Lehigh branch of the Mason City and Fort Dodge railroad, where the road descends to cross the river, two miles above Lehigh. The cuttings are eight or more in number and most of them are forty or fifty feet deep. In a number the upper drift is yellow and overlies a blue-gray stratum from which it is rather sharply distinguished. Yet very close to sections showing both yellow and blue drift are others fully as deep in which only yellow is found.

Other sections might be recorded but they would add nothing to the data already given. After studying many of the sections found in the county and considering the data given by well drillers, the following general statements seem to be warranted. In thickness the drift varies from fifty to one hundred and thirty feet. The upper drift, always yellow, frequently differs in color from the lower. The latter in many sections, however, is exactly like the upper, though generally more compact. When drift of two colors is found in a section the separating line is not always sharp, though it is frequently very distinct. The drift nowhere shows much difference in leaching from top to bottom. At no point was a highly oxidized or ferretto zone observed. At two localities in the valley of the Des Moines river soil beds were found covered by drift. The light colored pebbles characteristic of the Wisconsin drift were found throughout all drift sections regardless of depth. Nowhere was loess found, the only substance resembling it being the silt occurring at the Bradshaw brickyard.

Old Soils and Gravels.—Excepting the very old gravels in the pit of the Fort Dodge Brick and Tile Works and at the foot of Central avenue, Fort Dodge, and the soil beds with the thin drift layer beneath them, the drift of the county may be regarded as Wisconsin. The absence everywhere of loess and of the dark brown oxidized zone so characteristic of the Kansan surface, the absence also of leaching in any part of the drift, render doubtful the correlation of any considerable portion of the drift with the Kansan. The soil and drift found at Baehring's quarry beneath the Wisconsin drift (described under Stratigraphy) may be thought to represent the Kansan and the long interval which elapsed before the Wisconsin. The extraordinary thickness (fifteen feet), however, shows that it is a soil formation out of the usual order. The abundance of wood in large pieces with fragments of coal, especially the cross-bedded sand shown in No. 4 in the Baehring quarry section, render likely the supposition that the deposit was delta-like in origin.

Variation of Color in the Wisconsin.—The presence of light-colored limestone pebbles and of limestone blocks, many of them striated, so generally prevalent, are positive Wisconsin characteristics. The frequent variation in color, however, is not common in the Wisconsin drift. This phenomenon is explained by supposing that the Wisconsin within itself varies somewhat in age. It is certain that across the Wisconsin drift in Iowa a series of moraines may be traced which are rightly regarded as moraines of recession. One of these is conspicuous south of Webster county, at Pilot Mound. Two others cross northern Webster county. Between the deposition of these moraines there may have been a decided retreat of the ice, leaving the surface bare for a considerable period. A subsequent advance would result in a drift deposit above the first, from which probably the first would be differentiated. In Illinois Leverett* finds an early Wisconsin drift outside of a late Wisconsin series of moraines. In the Wisconsin he has noticed variations in color similar to those found in Webster county. They differ, however, in being

* U. S. Geol. Surv., Monograph, 38. The Illinois Glacial Lobe, p. 191.

more persistent. It would be impossible to found a belief in an earlier and later Wisconsin simply on the color variations in the drift of Webster county.

Coon Mound Esker.—In connection with the topography of the county a hill in Lost Grove township, section 9, locally known as Coon Mound, was described. It belongs to the esker type of glacial deposit. The country around it is extremely level, the nearest series of morainic hills lying six miles to the south. Its height is fifty feet, and the dimensions of its base are 500 by 300 feet, the longer axis extending north and south. Pebbles and water worn sand enter largely into its composition.

Morainic Belts in Webster County.—The hills and ridges of northern Webster county, described in connection with the topography of the county, were shown to be constructional and independent of erosion, which is the ordinary agent producing an uneven surface. They may be grouped in two series, each having a trend from west-northwest to east-southeast. The northern range extends from section 3, Jackson township, eastward to a point a mile beyond the river, and has an average width of two miles. It includes many comparatively level tracts. The hills are but thirty or forty feet high, and their slopes are gradual,

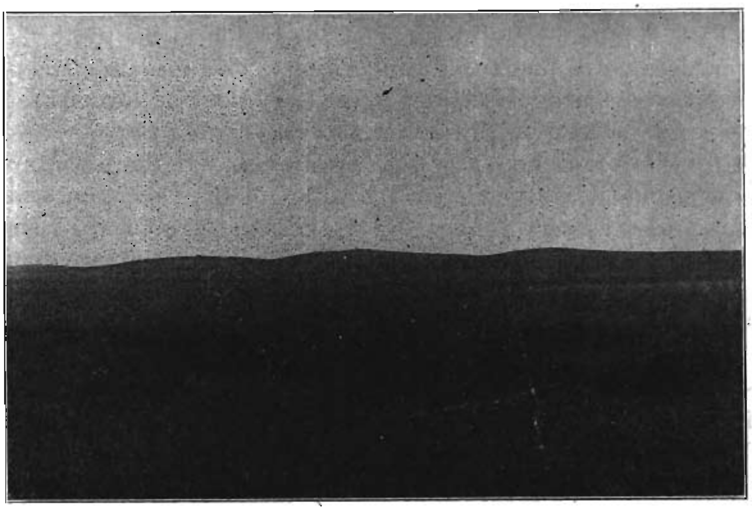


FIG. 18. Morainic knobs in Wisconsin drift, northern Webster county.

offering no hindrance to agriculture. Bass lake formerly filled a hollow between these morainic hills. Associated with these hills are kames, which are capable of yielding great quantities of gravel. One is found in Deer Creek township, section 10, Sw. 1/4, and another in Badger township, center of section 8.

The town of Clare is situated on the western end of the second morainic belt, which extends eastward from Clare across Deer Creek township, its northern limit passing through the center of sections 15, 16, 17 and 18, and thence extending southeast to section 25. Its average width is two miles. Forming a part of this moraine, in Deer Creek township, section 26, Sw. 1/4, is the highest hill in the county. The southern extension of this moraine is found in Douglas township, sections 2, 3, 4, 11, 12 and 13. By the roadside in the middle of section 10, outwash gravels may be seen. A small morainic area east of the river, including the kame in Badger township, section 19, Sw. 1/4, may be associated with this range.

A third morainic tract, smaller than the two just described, is found east of Tara and south of the Illinois Central track. This tract is referred to by Upham,* who suggested that it might be a part of the Gary moraine, and that it might be found to connect at the south with the moraine which is so well developed at Pilot Mound. Careful study of the region to the south, however, does not support this supposition. This morainic tract extends across parts of sections 27 and 28, Douglas township. In the middle of section 28 there is a kame yielding gravel.

Pre-Wisconsin Valley of the Des Moines.—If the topographic evidence alone is considered, the valley of the Des Moines must be regarded as very young. Its width is not great and its sides, although for the most part composed of soft material, are exceedingly steep. The country adjacent to the river is but slightly dissected and tributary streams within the county, great and small, are few. The stream seems to be reworking a pre-Wisconsin, perhaps pre-Kansan, valley. The evidence is revealed in deep cuttings in both banks, the best instances being the pits of the Fort Dodge Clay Works and the Fort Dodge Brick and Tile Works, which are on opposite sides of the river. At these points

* Ann. Rept. State Geologist Minnesota, p. 305, 1880.

the Wisconsin drift is seen to come far down the slopes, to the very edge of the flood plain, while the indurated rock, here Coal Measure shale, has a contour quite independent of drift, which on the steep banks is unassorted and cannot be regarded as hill-side wash. The position of the shale is practically horizontal and the old valley was independent of synclinal folding. Mining in the gypsum along Two Mile creek shows that the courses of minor streams are determined by pre-Wisconsin drainage. Near the creek the gypsum, though covered by a very heavy layer of drift is found to be badly cut up by the erosion of a stream which followed the course of the present creek. Wisconsin drift apparently nearly filled the valley, but a depression sufficient to determine the course of the subsequent stream remained. The inability of the Wisconsin drift to materially alter drainage lines within the county raises a question in regard to the thickness of this drift. If all of the eighty or one hundred feet of drift within the county is Wisconsin, it would seem sufficient to wholly obscure a small valley like that of Two Mile creek. Yet the nature of the drift precludes the possibility of ascribing any of it except certain gravels insignificant in extent, to any agent except the Wisconsin ice. The old gravels already described, which occur in a depression a little above the present flood plain of the Des Moines river, indicate a hollow here before the Kansan drift covered the region. If the valley has been continuously occupied by a stream as large as the present Des Moines, the extent of the cutting in the Coal Measures seems small. Allowance of course must be made for the fact that the drift from two ice sheets filled the valley and had to be removed before the stream could attack the indurated rock. Taking this fact into account, it still is probable that the interglacial stream was smaller than the one now occupying the valley.

Terraces on the Des Moines.—Remnants of an extensive gravel terrace high up on the banks of the Des Moines river are found in the vicinity of Fort Dodge. A portion of it constitutes the fair ground and the gravels are well exposed on Soldier creek at Miller's (formerly Baehring's) quarry, near the stone bridge in Fort Dodge. It appears also back of the city hospital and on the bank of the river in west Fort Dodge, Cooper township, section 30, Ne.

¼ of Se. ¼. Such gravel terraces along streams traversing or bordering the Wisconsin drift are not uncommon. During the retreat of the glacier vast quantities of water were discharged into the streams till their energy was sufficient to carry heavy loads of detritus in the form of sand and gravel for many miles. The feature of this gravel terrace that is unusual is its elevation above present water level.

The facts considered in the preceding paragraph suggest an explanation. If the valley at the retreat of the Wisconsin ice was nearly filled with drift while yet some depression remained, the glacial stream issuing from the ice during its retreat would naturally follow this old channel. Gravels would be deposited abundantly, the greater part of which would be carried away as the stream cut down through the soft underlying drift, leaving only here and there fragments of the deposit in the form of a terrace. The gravel terrace is now 150 feet above water level. The river has cut only a few feet into the indurated rocks since the Wisconsin ice, and the conclusion follows that the valley was filled with drift to a depth of nearly 150 feet. This is probable, for the drift on the level often reaches this depth.

In the lower valley, where a gravel terrace might be looked for, a terrace of silt, brown in color, fine-grained, free from sand and pebbles, and containing very many shells of the land snail Mesodon, is found. Dr. Beyer speaks of a similar terrace in his report on Boone county.* It is twenty feet above the alluvial bottom land and is made up of the same material that is found in the lowest part of the valley. The silt terrace along the Des Moines is shown in figure 27 and its relation to prehistoric remains found above Lehigh is discussed in a separate paragraph.

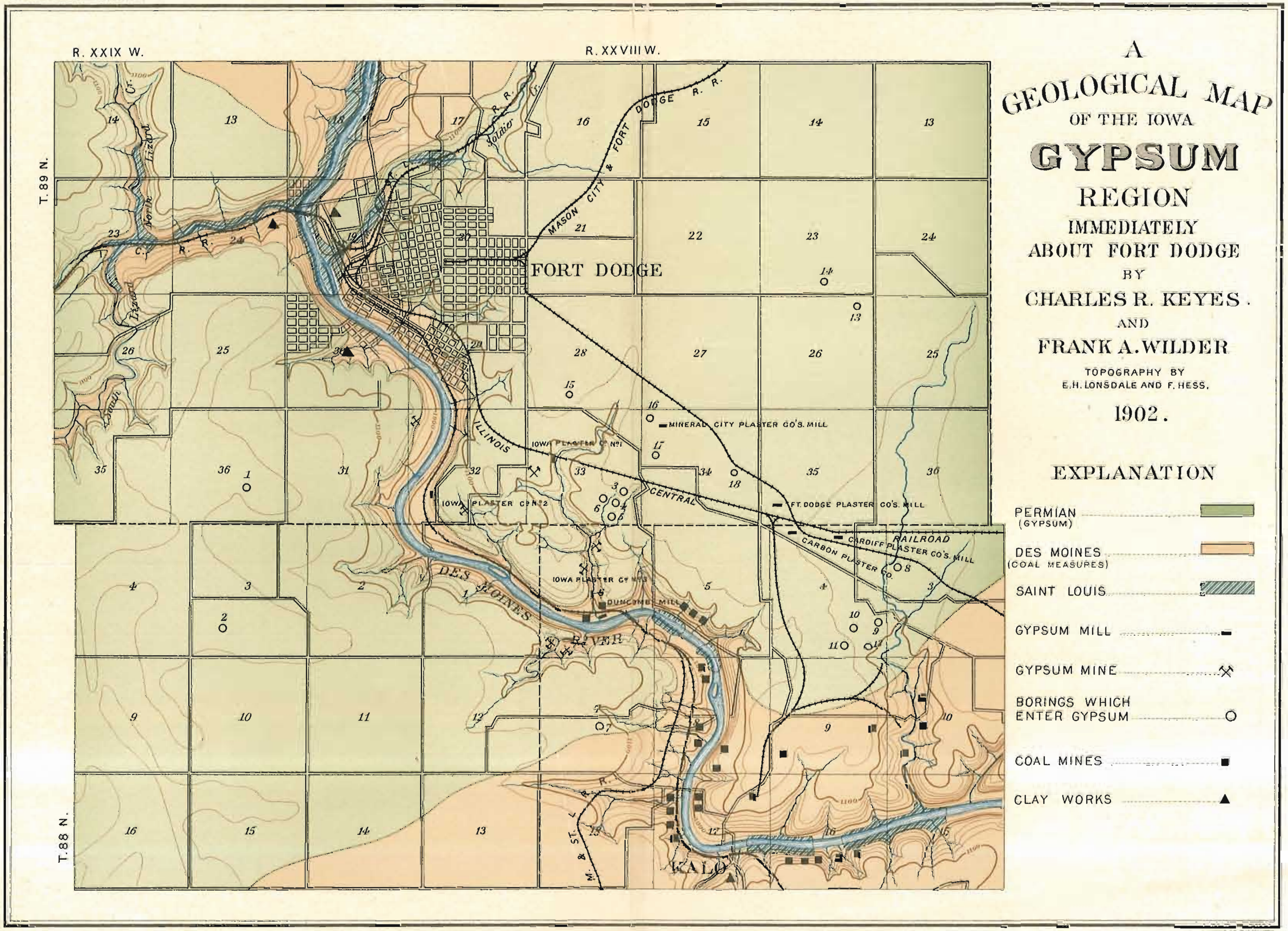
ECONOMIC PRODUCTS.

Gypsum.

COMPOSITION AND CHARACTERISTICS OF GYPSUM.

Gypsum is sulphate of calcium with water of crystallization. It is represented by the chemical formula $CaSO_4 + 2H_2O$, the water of crystallization forming 20.93 per cent of the whole. Gypsum

* Ann. Rept. Iowa Geol. Surv., Vol. V, p. 182.


A
GEOLOGICAL MAP
OF THE IOWA
GYPSUM
REGION
IMMEDIATELY
ABOUT FORT DODGE
BY
CHARLES R. KEYES.
AND
FRANK A. WILDER
TOPOGRAPHY BY
E.H. LONSDALE AND F. HESS.
1902.
EXPLANATION
PERMIAN (GYPSUM)
DES MOINES (COAL MEASURES)
SAINT LOUIS
GYPSUM MILL
GYPSUM MINE
BORINGS WHICH ENTER GYPSUM
COAL MINES
CLAY WORKS
R. XXIX W.
R. XXVIII W.
T. 89 N.
T. 88 N.
FORT DODGE
KALO
DES MOINES RIVER
MASON CITY & FORT DODGE R. R.
ILLINOIS CENTRAL RAILROAD
M. & ST. L. R. R.
C. R. R.
MINERAL CITY PLASTER CO'S. MILL
IOWA PLASTER CO. No. 1
IOWA PLASTER CO. No. 2
IOWA PLASTER CO. No. 3
DUNCOMBE MILL
FT. DODGE PLASTER CO'S. MILL
CARDIFF PLASTER CO'S. MILL
CARBON PLASTER CO.
Lizard
North Lizard Cr.
South Lizard
Soldier Cr.

occurs most abundantly in sedimentary rocks with sandstone, limestone and rock salt. In volcanic regions it is often found in limited quantities filling cavities in lava. Its presence there is ascribed to the sulphur exhalations always present in volcanoes. Gypsum crystals are common also in the clays and shales of various geological ages in Iowa, particularly in those of the Coal Measures. Anhydrite is a mineral having the same chemical formula as gypsum, but lacking the water of crystallization. On exposure to the air it may take on this water and become gypsum. In its crystalline form gypsum is called selenite. By mineralogists selenite is placed in the monoclinic system. The common form is the vertical prism. Cleavage is nearly perfect parallel to the face 010, and this gives rise to the common belief that the mineral is mica. Twin crystals are common, the twinning taking place along the orthopinacoid. Gypsum according to its natural structure is considered under the heads of, 1. crystalline gypsum or selenite; 2. fibrous gypsum, when fibers are very long, called satin spar; 3. granular gypsum, when white called alabaster; 4. gypsum powder or gypsum earth.

Gypsum may be wholly colorless and transparent, as in selenite; or may be white, red, green, blue, gray or brown. It is quite soft, its hardness ranging in terms of the Mohr scale, from 1.5 to 2. Its specific gravity with that of products made from it, contrasted with limestone and lime mortar, is shown in the following table:

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

Gypsum is somewhat soluble in water, the solubility varying with the temperature, as shown in the following table of Marignac* which has been verified by Grimsley*:

* Annales de Chimie Paris, 5th Ed., Vol. I, pp. 274-281. Quoted by Chatard, 7th Ann. U. S. Geol. Surv., and by Grimsley in the Univ. Geol. Surv. of Kansas, Vol. V, p. 86.

TEMPERATURE.	ONE PART GYPSUM DISSOLVES IN—	ONE PART ANHYDROUS SULPHATE LIME DISSOLVES IN—
At 32° F=0° C........	415 parts of water..........	525 parts of water.
At 64.5° F=18° C......	386 " "	488 " "
At 75.2° F=24° C......	378 " "	479 " "
At 89.6° F=32° C......	371 " "	470 " "
At 100.4° F=38° C.....	368 " "	466 " "
At 105.8° F=41° C.....	370 " "	468 " "
At 127.4° F=53° C.....	375 " "	474 " "
At 161.6° F=72° C.....	391 " "	495 " "
At 186.8° F=86° C.....	417 " "	528 " "
At 212° F=100° C......	452 " "	572 " "

NATURE OF THE WEBSTER COUNTY GYPSUM.

The mode of occurrence of the Webster county gypsum has been more minutely set forth in this report under the heading stratigraphy. A concise restatement, however, is in place at this point. It lies directly under the glacial drift which varies in thickness from one to one hundred feet. Natural exposures occur along the Des Moines river which crosses the gypsum area and along many of its tributaries. The gypsum forms a practically horizontal bed, varying in thickness from ten to twenty-five feet. It is of the finely fibrous variety, nearly free from impurities and not interspersed with layers of foreign material. Crystals rarely occur in the layers of fibrous gypsum, though they are common in the Coal Measure shales of the county.

EXTENT AND AVAILABILITY OF WEBSTER COUNTY GYPSUM.

It may be safely affirmed that there are from sixty to seventy square miles of territory underlain by gypsum. Future prospecting will enlarge this estimate rather than diminish it. At least forty square miles may be considered available for economic purposes. A limited portion of the total area will prove unavailable on account of the thinness of the deposit. Prospecting has also demonstrated that at points within the gypsum area the gypsum has been removed by preglacial erosion. For this reason careful prospecting should precede the choosing of a site for mill purposes. As is shown by the map, the gypsum area is cut in two by the Des Moines river, and large quantities of the mineral have been removed by the erosion of this stream and its tributaries. Away from the river

Upper surface of gypsum bed.

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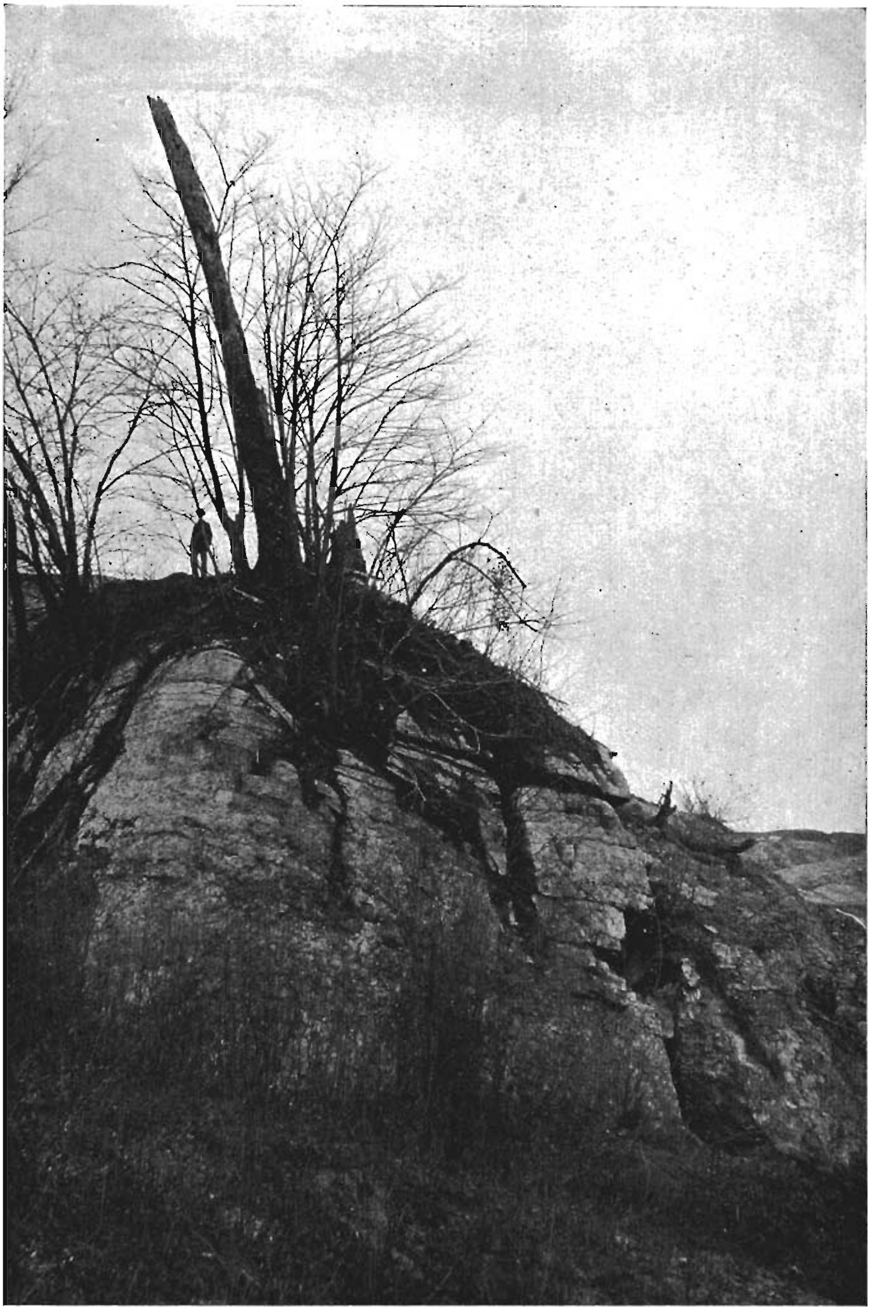
faces plate VIII (v.12)

Illustration

Faces pg 140 (V.12)



Topography of gypsum area.

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Illustration

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of Plate VII (v. 12)

the topography of the gypsum area is that of a very level prairie. In the early days of the gypsum plaster industry the natural exposures in the bluffs along the river and along Two Mile creek were regarded as most available. At present, however, the gypsum on the prairie away from the river is conveniently mined by means of shafts. The gypsum area is crossed by four railroads; the Chicago, Rock Island and Pacific, the Minneapolis and Saint Louis, the Illinois Central and the Mason City and Fort Dodge. Shipping facilities, therefore, are excellent.

PERMANENCE OF THE GYPSUM SUPPLY.

The great thickness of the gypsum in Webster county and its purity, together with its extent make the supply practically inexhaustible. The Iowa Plaster Company estimates that, since beginning operations in 1872 it has removed the gypsum from only fifteen acres. A conservative opinion as to the total amount of gypsum removed up to date (summer, 1900) places it at twenty-five acres. If the gypsum area is regarded as only fifty square miles in extent, certainly a moderate estimate, there remains twelve hundred and eighty times as much gypsum as has been removed since the beginning of the plaster industry. The average thickness of gypsum suitable for plaster is ten feet and the yield per acre of such gypsum is at least 30,000 tons.

DISTRIBUTION OF GYPSUM AND MARKETS FOR GYPSUM PRODUCTS IN THE UNITED STATES.

As an initial step in an analysis of the future of the Iowa gypsum plaster industry, it is necessary to review the development of the industry in the country at large, in order to determine the likelihood of more vigorous competition in the future and from what quarters it may be expected.

In the first place deposits of gypsum are restricted to very limited and widely scattered areas. Since the finished product is heavy, cost of shipment will always be a large factor in determining the portion of country that can be reached by any producing area, and will give each area an advantage over the others in a certain amount of territory. Gypsum near the Rocky Mountains and farther west will never compete with the Iowa mineral and deposits in this region need not here be considered. In the region east of the Rockies gypsum is found at the following localities:

New York.—Gypsum is found at a number of points from Buffalo as far east as Madison county. Deposits of considerable thickness lie at moderate depths beneath the city of Buffalo but are unavailable on account of the amount of water present which prevents mining. The largest quarries in the state are at Union Springs where sixty tons a day are quarried.

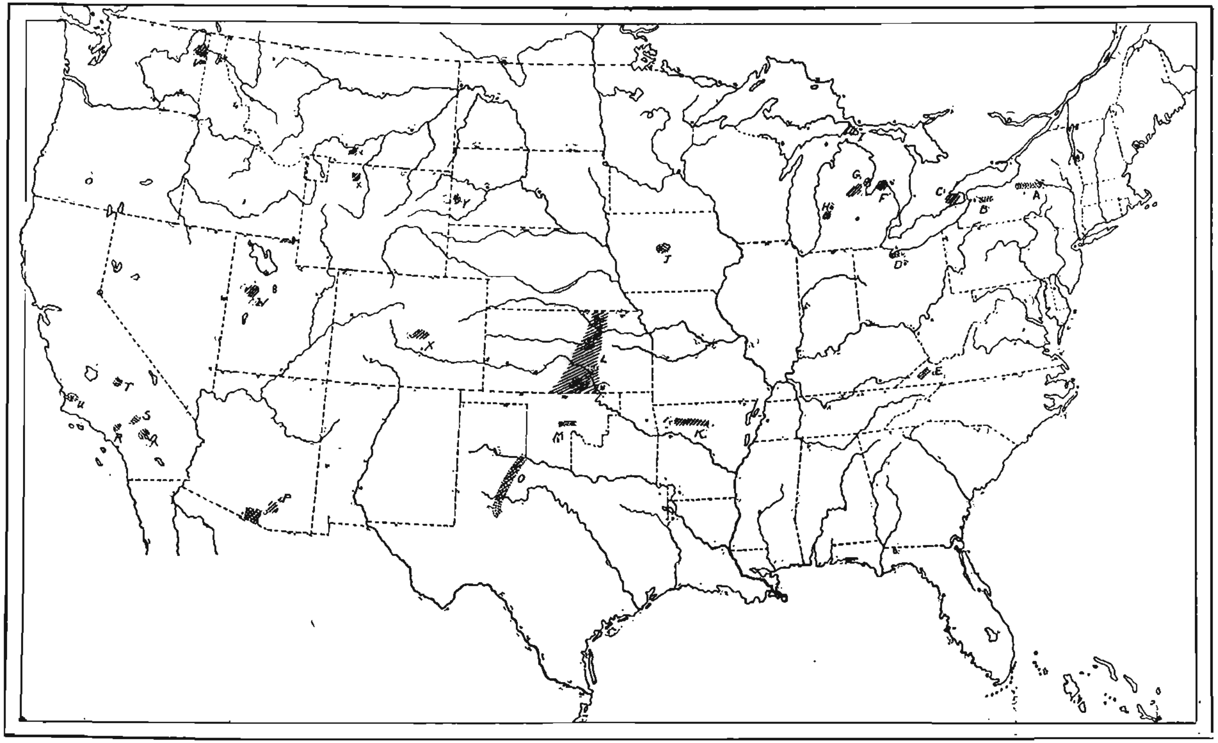
Gypsum in layers of considerable thickness occurs near Syracuse and much of it is reported as suitable for plaster of Paris and wall plaster.

Ohio.—Deposits of gypsum of economic importance occur at a single point in Ohio, in Ottawa county, ten miles west of Sandusky. The area is small and is nearly all under the control of mills already established. A large portion of the product is converted into crayon.

Michigan.—In this state gypsum has been most extensively developed in Kent county near Grand Rapids. Here five mills each with a daily capacity of seventy-five tons are in successful operation. The mineral is obtained by stripping and mining, as its depth varies from two to seventy feet. These mills are not able to avail themselves of cheap lake freight rates since the Grand river is navigable for only part of the forty miles which lie between Grand Rapids and the lake.

The Michigan gypsum series forms a ring nearly ten miles wide about Lansing as a center. It varies in depth and thickness and not until the eastern side of the state is reached are the deposits again economically significant. At Alabaster in Iosco county on Lake Huron, the gypsum outcrops directly on the lake and is utilized by a large plaster mill which is located there. From the same point the uncalcined rock is shipped to Chicago where it is converted into wall plaster. Across the bay, in Huron county, gypsum is also found but the extent of the deposits here is not known.

In the vicinity of St. Ignace gypsum exists in considerable quantities in close proximity to the lake and though the deposits promise well they are at present wholly undeveloped.



Map showing distribution of gypsum in the United States; areas at least partly developed are dotted, while undeveloped areas are indicated by diagonal lines.

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Illustration
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Virginia.—Stretching across Smyth county and entering Washington county in southwestern Virginia is a gypsum area of large proportions. The amount exposed on the surface covering a tract twenty miles long and two miles wide, is not remarkably great but a known thickness of 592 feet for the deposit makes the quantity of mineral per acre very large; estimated by Boyde* at 666,000 tons. The region is traversed by the north fork of Holstein creek and by the Norwalk and Western railroad.

Kansas.—Eleven operating mills in Kansas place that state in the front rank of gypsum producers. The raw material is found at very many points through a tract averaging eighty miles in width and stretching from the northern to the southern boundary of the state. Mills are most numerous near Blue Rapids in the northern part of the state; in southern Dickinson county, in the center and near Medicine Lodge, in the extreme south. The gypsum deposits are of two varieties: (1) gypsum rock not unlike the Iowa mineral, (2) earth and mud plaster which consists of fine gypsum crystals loose, through which a certain amount of clay is disseminated. Six mills use gypsum rock and five gypsum earth. The gypsum earth requires no mining or quarrying for, lying on the surface in deposits from six to ten feet deep, it can be excavated with scrapers. The clayey impurities do not seem to be an especially undesirable element.

Texas.—The gypsum deposits of Texas are said to be the most extensive in the United States. In thickness they vary from one to twenty feet and extend from the union of the North Fork and Red river on the north-central boundary to the town of Sweetwater in the center of the state.† The Texas and Pacific railroad reaches the deposits at Stillwater and the Fort Worth and Denver near Quanah.

South Dakota.—An abundance of gypsum in the Black Hills has resulted in the erection of one or two small mills in the vicinity of Hot Springs. The deposits are excellent but the absence of a convenient market and limited fuel will always greatly restrict the industry.

Canada.—Immense deposits of gypsum in Canada conveniently located for ocean shipment have had a definite effect on the gyp-

* Resources of Southwest Virginia, 1881.
† Geol. Surv. of Texas, 2d Ann. Rept., 1890.

sum industry of America. These are the deposits in Nova Scotia which are quarried and sent to New York for development. The extent of this industry is shown in the tables below.

*Production of Gypsum in the United States, in tons of 2,000 pounds.**

STATES.	1898.	1899.	1900.
California	3,875	3,663	*e* 3,500
Colorado	1,570	1,600	4,000
Indian Territory and Oklahoma	15,229	20,750	16,975
Iowa	38,338	51,958	92,201
Kansas	49,720	82,016	*e* 90,000
Michigan	93,181	144,776	150,000
Montana	400	304	325
New York	46,477	39,390	42,874
Ohio	*e* 23,000	25,000	25,000
Oregon	150	500	450
South Dakota	3,750	600	750
Texas	24,417	34,214	42,000
Utah	*e* 3,000	1,700	2,247
Virginia	8,125	12,773	10,885
Wyoming	3,633	2,817	2,995

e estimated.

The average price per ton in 1899, for crude gypsum was $1.14; for land plaster $2.01; for plaster of Paris $3.91.† The average value of wall plaster for 1900 may be estimated at $4.75.

*Gypsum imported into the United States in metric tons.**

YEAR.	GROUND OR CALCINED.		UNGROUND.		Value of manufactured plaster of Paris.
	Quantity.	Value per ton.	Quantity.	Value per ton.	
1896	3,348	$ 6.58	183,165	$ 1.06	$ 11,722
1897	2,707	6.29	165,812	1.08	16,715
1898	3,021	6.12	168,723	1.09	40,970
1899	3,317	5.80	199,724	1.10	58,073
1900	3,159	6.07	21[illegible],239	1.08	66,473

Most of the unground gypsum was shipped from Nova Scotia to mills in New York.

* From Mineral Industry, R. P. Rothwell, 1900.
† 21st Ann. Rep. U. S. Geol. Surv., 1899-1900.

*Production of gypsum in the principal countries.**

YEAR.	CANADA.	FRANCE.	UNITED KINGDOM.	UNITED STATES.
1894	202,877	....	155,905	273,553
1895	205,187	2,456,150	180,738	237,399
1896	187,818	2,051,124	196,404	201,305
1897	217,392	2,004,339	184,287	272,493
1898	198,909	2,115,261	199,174	285,644
1899	221,862	1,978,963	215,974	382,891

The production in Germany cannot be stated exactly, no statistics being given for Prussia where the industry is best developed, but it probably falls but little short of that of France.

On account of limited shipping facilities the mills of South Dakota cannot send their goods to a field where they compete with the Iowa product. Freight rates also favor the Iowa over the Michigan and Kansas mills throughout a considerable territory. There is no gypsum in Iowa outside of Webster county, and competition from other points within the state is impossible. With the growth of population the demand for gypsum plaster will increase. The dark days in the history of the gypsum industry were at the time of the introduction of hard plaster. Those times have long since passed and every year gives a fuller recognition to the worth of gypsum plasters. The accompanying report on the German gypsum industry suggests a number of ways in which gypsum products may be multiplied.

Those who hold land underlain with gypsum will meet with disappointment if for this reason they value it at an extravagant figure. The great production of gypsum per acre limits the demand for gypsum land. Not before some hundreds of years have elapsed will the amount of available gypsum land become limited. Nearness to railroads gives certain tracts an advantage of course, which will appear in an increased valuation.

HISTORY OF THE GYPSUM PLASTER INDUSTRY IN WEBSTER COUNTY.

The first gypsum mill in Webster county was erected in 1872 at the head of Two Mile creek, better known as Gypsum Hollow, close to the Illinois Central track. It has recently been remodeled and is now known as the Central mill of the Iowa Plaster Asso-

* From Mineral Industry, R. P. Rothwell, 1900.

ciation. The founders of the gypsum plaster industry in this state were Captain George Ringland and Messrs. Webb Vincent and S. Meservey.

At this time gypsum was used only for making finishing plasters. Experiments were undertaken to prove the worth of calcined gypsum in making hard wall plaster. In 1878 small quantities of material prepared for this purpose were put upon the market. It was not taken up readily by builders, but in time its worth was made clear. Had the use of gypsum been confined to the making of finishing plasters the industry could never have attained its present proportions. In 1882 the lower mill in "Gypsum Hollow" was erected, and this was followed in 1885 by the Blandon mill. The interests represented by these three mills were later consolidated, and are now known as the Iowa Plaster Association. Shortly after the erection of the Blandon mill, the Duncomb mill was built at the mouth of Two Mile creek. Thus three mills stand today on "Gypsum Hollow," through which Two Mile creek flows. In 1895 the Cardiff mill, representing Fort Dodge capital, began operations. This was the first of the mills built on the prairie. On account of the thickness of the drift stripping was impossible, and mining by means of a vertical shaft was begun. The success of this mill encouraged the erection of other mills on the prairie, and in 1899 the Crawford mill was completed, and in the spring of 1900 the Mineral City mill made its first shipments. Another mill is at present (August 1900) under consideration. Most of the stock for this mill has been subscribed in Waterloo and Fort Dodge. The location selected is in Pleasant Valley township, Nw. ¼ of section 4. Drillings at that point show forty feet of soil and red shale, and seventeen to twenty-two feet of gypsum. The seven mills in operation at present have a total capacity of 600 tons of stucco per day of ten hours. The location of all of the mills and mines is shown on the small geological map of the region immediately about Fort Dodge.

NATURE OF GYPSUM PLASTER.

Gypsum plaster is gypsum that has been finely ground and then calcined. This latter process consists in uniformly heating the gypsum to a temperature of 120°-130° centegrade (250°-270° Fahrenheit.) During the process the gypsum loses 14 per cent of its water of crystallization. Chemical analysis shows that the gypsum ($Ca\ SO_4 + 2H_2O$) by calcining is changed to the hydrate ($(Ca\ SO_4)_2\ H_2O$). A temperature as low as 80° centigrade has been found sufficient if calcining is continued for a very long time.

The property on which the value of gypsum plaster depends is its tendency to "set," or form a hard, firm mass when water is added to it. It is of interest for both theoretical and practical reasons to know the causes of the setting of stucco. The following statement is a condensation of the more elaborate explanation of Grimsley* whose experiments confirm and enlarge on the previous work of Marignac and Chatelier.

When water is added to gypsum plaster, a certain amount of the gypsum is taken into solution. When a solution is saturated, it requires but little to start the process of crystallization from solution. The presence of crystal fragments is an excellent incentive to crystallization from such a solution. These fragments are furnished by the coarser particles of stucco. About these as nuclei the crystals of gypsum rapidly grow, each molecule of the hydrate taking to itself three molecules of water, either in the process of solution or of crystallization or of both, in accordance with the following formula:

$$(Ca\ SO_4)_2\ H_2O + 3\ H_2O = 2\ (Ca\ SO_4 + 2\ H_2O.)$$

The growth of gypsum crystals in this manner, from the saturated solution of the stucco or hydrate, constitutes the "set" of plaster.

It is well known that the setting power of calcined plaster is lost or injured if the ground gypsum is either over calcined or under calcined. Calcining accomplishes two things. It breaks up into fine particles the ground gypsum, and drives off part of the water of crystalliation. If the gypsum is under calcined, therefore, the hydrate is not formed, and if it is over calcined the particles are so comminuted that they no longer furnish the crystalline nuclei necessary to start the setting. The finer the gypsum is ground, the more readily it is taken into solution, and the more readily plaster made therefrom sets. Coarser fragments

*Univ. Geol. Surv. of Kansas, Vol. V, pp. 94-96.

are still abundant enough to furnish the necessary nuclei. Fine grinding does not destroy the setting power of gypsum plaster, as over calcining does.

NATURE OF RETARDER.

Nearly all of the calcined gypsum made in Iowa is used for hard wall plaster and only a limited amount is sold for finishing. At the mills the calcined gypsum is mixed with retarder and hair for the convenience of the user. Seven pounds of retarder and one and one-half pounds of hair are added to each ton of calcined gypsum. Stucco sets naturally in from six to fifteen minutes. In spreading on walls and in manipulating in other ways, it cannot be handled so rapidly and consequently it was found necessary to introduce something into the plaster that would check the setting. Anything that will interfere with the rapid growth of the crystals will bring about the desired result. Blood was used as a retarder by the ancient Romans. Glue water was formerly mixed with the plaster by the workman as he used it. At present the trade demands a plaster through which the retarder is already uniformly mixed. The amount of retarder necessary is small. Very many combinations to be used as retarders for gypsum plasters have been invented. In the Fort Dodge mills, a retarder made at Webster City, Iowa, is commonly used. In many of the patent retarders, glue, glycerine, sawdust, slaked lime and fiber are the chief ingredients. In regard to the effect of retarder on the strength of plaster opinions differ. A good retarder should simply hinder the growth of crystals and contain nothing which by decay will cause disintegration in the mass in which it is contained. Retarders having these properties probably do not weaken the plaster. Less retarder is used in summer than in winter. After retarder is added to calcined gypsum it keeps a much shorter time. When retarder is mixed in calcined gypsum the plaster deteriorates somewhat after two months in summer and six months in winter.

PRODUCTS OF AMERICAN GYPSUM MILLS.

Hard Wall Plasters.—Most of the calcined gypsum of America, as has already been said, is used in plastering interior walls. For this purpose it is mixed in proportions given in the preceding paragraph with hair and retarder. In this form it leaves the mills packed in sacks or barrels, and is given to the building trade. The builder mixes it with sand and water just before he is ready to apply it as a covering for an interior wall. The higher the percentage of sand that can be mixed with a gypsum plaster, the better from the standpoint of economy. The gypsum which the building trade supplied by the Iowa mills demands, and with which it is furnished, is a gypsum plaster which will make an enduring wall when mixed with twice or three times its own bulk of sand. Gypsum plaster has important advantages over lime plaster with which it is in direct and active competition. It is more decidedly a nonconductor of heat. It sets and dries out more rapidly than lime plaster, and interiors where it is used as wall covering may be pushed to completion much more rapidly. Ceilings and walls in which gypsum plaster was used have been thoroughly water soaked without injury. As a fireproofing material it is rapidly assuming importance. For this purpose it may be used alone, or be mixed with asbestos. When mixed with ten per cent of lime and allowed to set its hardness is greatly increased and it sustains a high polish.

Calcined Plaster and Plaster of Paris.—This is simply ground and calcined gypsum to which no retarder or hair is added. Large quantities of this plaster are used by the glass factories of the country. So great is the amount used by these that its ability to supply economically a limited number of them with gypsum plaster would alone be sufficient to warrant the development of a gypsum area. The gypsum plaster is used to make the level beds on which the glass is poured. Having been used once it may be reground and so reused a limited number of times, but its setting power is soon exhausted and it must be put aside for fresh material. When ground very fine and calcined gypsum constitutes plaster of Paris, which is used for a variety of purposes in many of the arts. Calcined plaster has, among other uses, been mixed with Paris green and sold as a poison for insects attacking potatoes and other vegetables. While not a poison itself, it dilutes the Paris green so that it does not injure the plants. It prevents the poison from being washed off by rains and greatly adds to its effectiveness. Calcined plaster is used also as a filler for some of the finer grades of paper. For this purpose gypsum is usually ground, calcined, mixed with water, allowed to set and then reground.

Limited quantities of calcined plaster are used in making Keene's cement and various imitations of marble, according to methods about equivalent to those described in the accompanying report on the German gypsum industry.

New uses for gypsum plaster are being developed in connection with electrical fittings. Ordinary plaster of Paris is porous, readily absorbs water and having done so becomes a conductor of electricity. This water absorbing property may be overcome and the material hardened at the same time. It then becomes a useful material in electrical fittings, when the parts are neither under high tension nor exposed to high temperatures or sudden changes of temperature. In these cases the expensive putty of litharge and glycerine must be used. The following hardeners for gypsum plaster to be used in electrical fittings are recommended by a recent writer in the Scientific American.

1. Add 2 to 4 per cent of powdered marshmallow root and knead to dough with 40 per cent water. The mass resembles fat clay, and may be cut, filed and drilled; 8 per cent of marshmallow root makes it still harder. Dextrin, gum arabic and glue may be used.

2. Six parts gypsum, one part fresh slaked lime; the articles made therefrom to be soaked in concentrated magnesium sulphate solution.

Water absorbing power may be removed by saturating in a solution of ozokerite or wax in oil of turpentine or varnish.

Uncalcined plasters are used as fertilizers and in the manufacture of paint. Limited quantities are mixed with the shale and limestone used in making Portland cement.

GYPSUM AS A FERTILIZER.

Land plaster, which is the name commonly applied to ground but uncalcined gypsum, has long been recognized as a fertilizer of considerable and in some cases of remarkable merit. Allusion is made to it in Roman literature of classic times. In the eighteenth century its successful use in Germany as a top dressing for clover was recorded. Benjamin Franklin scattered land plaster in a field of clover, so as to form the sentence, "This has been plastered with gypsum," and the sentence is said to have been legible on account of the great height and color of the clover thus fertilized. Mr. C. W. Johnson in 1841 wrote a prize essay for the Royal Agricultural Society of England, entitled, "An Account of the Application of Gypsum as a Manure to the Artificial Grasses." He quotes from the letter of a Hampshire farmer as follows:*

"The soil of my farm is of a clayey nature and would be very stiff but for the number of stones there are in it. I have sown gypsum six or seven years and never on clover or saintfoin without satisfactory proof of its efficacy, having usually grown one-half ton more of hay per acre by its use. But the effect in 1838 was wonderful. I put on a bag (2½ cwt.) per acre on a two year old piece of saintfoin on the first of May with the plants very forward, just leaving the ground and coming to stalk; the gypsum had so increased the growth of the grass by the ninth of the same month that when crossing the land with a friend we observed the difference from one of the fields to the other; and at harvest time the extra produce of hay was quite one ton per acre. * * * I can even see the effect where three years ago the gypsum was spread. I always leave a strip or two in every field to prove the effect. There is one thing more I wish to observe, that I never put in gypsum before the last week in April or first in May, and choose if possible a moist morning. I have not found much good effect from its application on either chalk or cold clay soils." Boyd in his "Resources of Southwest Virginia" records experiments of a like nature, by which lands practically worthless are made very productive by a moderate application of gypsum plaster.

Boussingault in 1841 analyzed clover grown on land fertilized with gypsum and found a great increase in the mineral constituents, notably in lime, magnesia and potash.

Many experiments, undertaken scientifically and carried out by practical men, show that for certain soils and crops gypsum is a fertilizer of great value. There have been many theories to

* Univ. Geol. Surv. of Kansas, Vol. V, p. 126.

account for its beneficial action. It has been thought that the gypsum holds the carbonate of ammonia which rain water takes from the air. The fact that gypsum absorbs moisture readily and gives it off during times of drouth has by others been regarded as its useful property in agriculture. Sir Humphrey Davy thought that gypsum yielded directly lime and sulphur for plant food. At present, the value of gypsum as a fertilizer is thought to depend on properties wholly different from those just suggested. It has been demonstrated that gypsum decomposes the double silicates that are abundant in many soils, especially in clay, and sets free a soluble potash sulphate. This potash is of great value to plants, especially to the Leguminosæ which include clover, beans, etc.

Land plaster is essentially a clover manure, and generally gives more satisfactory results with this crop than any other. It is most suitably applied during moist weather, in the autumn or in the spring, while the crop is young. Two hundred pounds to the acre is the amount generally used. The native grasses are rapidly disappearing in Iowa, and the acreage of clover annually increases, and in the same ratio the importance of land plaster as a fertilizer for Iowa soils increases.

While gypsum has but little importance as a solvent for atmospheric ammonia, it is of great value if scattered about decaying manure, or sprinkled freely through the stables. Under these conditions it holds the ammonia that would otherwise be dissipated and when scattered on the soil with the manure yields it as food for plant growth.

Land plaster as put upon the market varies greatly in purity. Tests made by the Wisconsin Experiment Station show that the amount of pure gypsum contained in a number of samples varied from seventy-six to ninety-seven per cent, while one sample contained no gypsum whatever; the impurities were largely water and carbonate of lime, and certain insoluble substances which were of no value as fertilizers. The following tables of analyses were taken from Bulletin No. 14, University of Wisconsin, Agricultural Experiment Station.

In order to protect the farmers against imposition of this kind and to learn more about the quality of the different brands of plaster sold in the state, the Station offered to examine free of charge all samples of land plaster sent before May 1st. In response to this offer the following samples were received and analyzed, with the results given below.

STATION NUMBER.

373. Sent by T. C. Decker, Beloit. This plaster was purchased in Milwaukee, and is probably a Michigan plaster.
374. Sent by E. P. Richardson, Ableman, Fort Dodge plaster.
375. Sent by S. E. Gernon, Waukesha, Michigan plaster.
377. Sent by S. C Fish, Reedsburg, Fort Dodge plaster.
378. Sent by H. J. Sutherland, Madison, Fort Dodge plaster.
380. Sent by Wm. N. North, La Crosse, Fort Dodge plaster.
382. Sent by R. B. Kellogg, Green Bay, Sandusky, Ohio, plaster.
383. Sent by S. C. Fish, Reedsburg, brand unknown.
384. Sent by Hiram Smith, Sheboygan Falls, Fort Dodge plaster.
385. Sent by Charles V. Guy, River Falls, Fort Dodge plaster.
386. Sent by Charles V. Guy, River Falls, brand unknown.
387. Sent by N. E. Becker, Random Lake, brand unknown.
388. Sent by Wm. Toole, Baraboo, brand unknown.
391. Sent by A. F. Noyes, Beaver Dam, Fort Dodge plaster.

The price for which these plasters were sold varied from $6.10 per ton to $10.50 per ton, much of the difference being due to cost of transportation.

STATION NUMBER.	INSOLUBLE IN ACID. PER CENT.	PURE PLASTER. PER CENT.
373	1.74	90.4
374	....	95.3
375	1.78	87.72
377	2.17	89.72
378	2.08	95.64
380	2.46	94.75
382	.31	93.61
383	1.50	93.15
384	1.29	93.24
385	2.37	95.31
386	1.09	93.85
387	2.08	87.81
388	2.21	94.32
391	2.12	95.98

"All of these plasters are of good quality, some of them being of exceptional purity. The difference in their quality may be largely attributed to the amount of moisture which they contain. Plaster kept in damp places will often retain several per cent of hygroscopic water, which adds just so much to its weight. Before making large purchases of plaster, one should be sure that it has been kept kept in a dry place, and that it is ground quite fine. A coarse plaster does not dissolve readily and is not as prompt in its action. As a rule, light colored plasters are purer than dark colored ones."

GYPSUM AS A BASIS FOR PORTLAND CEMENT, WITH SULPHURIC ACID AS A BY-PRODUCT.

Keyes, in his report on the Iowa gypsum in 1893, suggested that profit might be derived from gypsum if it were used in the manufacture of Portland cement and sulphuric acid. He pointed out that the shales which must be used with the gypsum to produce cement and acid are abundant in the immediate vicinity of the gypsum. A patent numbered 342,785, issued on June 1, 1886, to Uriah Cummings of Buffalo, New York, outlines the process. The greater part of the description given in this paper is reproduced below:

"Hydraulic or Portland cement is usually manufactured by mixing together clay and carbonate of lime in such proportions that after calcination the resulting compound will contain about sixty-two parts of lime, twenty-eight parts of silicic acid and ten parts of alumina by weight. During the process of calcination the carbonic acid contained in the carbonate of lime is expelled, and the silicic acid combines with the base and forms therewith silicates of lime and alumina, which are afterward reduced to powder, and known as hydraulic or "Portland" cement. The carbonic acid which is expelled during the process of calcination has no commercial value, and is allowed to escape into the air.

The object of this invention is to reduce the cost of the cement by its production as a by-product in the manufacture of sulphuric acid; and the invention consists to that end in manufacturing sulphuric acid from clay or silicic acid and sulphate of lime, as will be hereinafter fully set forth, and pointed out in the claims.

In practicing my invention I mix together gypsum or sulphate of lime and clay in the proportion of about twelve hundred and sixty-six pounds of gypsum to four hundred pounds of clay. I prefer to pulverize the gypsum and dry the clay and pulverize the same, then intimately mix the pulverized gypsum and clay and add a small quantity of water, and mold the mixture into blocks substantially in the manner practiced in making Portland cement from carbonate of lime and clay by the well known dry process. I then subject this mixture to calcination in a suitable kiln. At the high degree of heat which is maintained during the process of calcination the silicic acid contained in the clay expels the sulphuric acid contained in the sulphate of lime and combines with the lime and alumina and produces therewith silicates of lime and alumina, which, upon being reduced to powder, are in every particular a hydraulic or Portland cement. The sulphuric acid is expelled during this process of calcination either in the form of vapor, or it is decomposed and forms sulphurous acid and oxygen; or perhaps the escaping gas is a mixture of vaporized sulphuric acid, sulphurous acid and oxygen, according to the degree of heat which is maintained during the process of calcination, and which may vary somewhat at different times, owing to differences in the quantity or quality of fuel employed, strength of draft, etc. The gases escaping during the process of calcination are cooled in suitable chambers or passages lined with lead, in which the sulphuric acid is condensed and collected. The sulphurous acid, if any, is converted into sulphuric acid in the ordinary manner by means of steam and nitric acid. The sulphuric acid so obtained is then concentrated or further treated in any usual manner practiced in the manufacture of sulphuric acid. The mixture of gypsum and clay above specified produces about seven hundred and eleven pounds of hydraulic or Portland cement and five hundred and eighty pounds of sulphuric acid from every sixteen hundred and sixty pounds of the mixture, the balance being moisture, which is expelled. The cost of the sulphate of lime is about the same as that of carbonate of lime and the cost of manufacturing hydraulic or Portland cement by this improved method is about the same as that of the old method in which carbonate of lime is employed; but the sulphuric acid which is obtained in my improved method is valuable, and the value which it represents materially reduces the cost of the cement.

In practicing this invention any suitable kiln in which the process of calcination can be carried out may be employed, and any ordinary apparatus may be used for recovering the sulphuric acid.

The condensing and converting chambers are connected with the top of the kiln by a suitable flue, and the waste gases are discharged from the condensing or converting chambers by a stack or chimney or a suitable fan which maintains a proper draft through the kiln and chambers.

The proportions herein specified are found to be well calculated to produce the desired results; but they may be varied in accordance with the nature of the gypsum rock and clay employed within certain limits without changing the general results. If the proportion of clay used be too great, the cement will be of an inferior quality but the sulphuric acid contained in the sulphate of lime will be driven off and recovered. If an excess of gypsum be used, the lime contained therein is in excess of the true combining proportions with the silicic acid, and the sulphuric acid will not be driven off and the resulting cement will be inferior in quality by reason of the presence of sulphate of lime, although a small percentage of the latter may be present without exerting any specially deleterious influence.

It is well known that silica or silicic acid contained in the clay is the active ingredient in the production of the cement and it is therefore obvious that silica in a finely pulverized condition may be substituted for the clay, if desired.

I am aware that it has been proposed to manufacture cement from carbonate of lime and clay with the addition of a small quantity of sulphate of lime or some other sulphate, for the purpose of rendering the mixture quick setting, and I do not claim such manufacture or process, as it does not produce sulphuric acid.

I am also aware that it has been proposed to manufacture sulphuric acid by fluxing gypsum with quartz, sand, clay, etc., to a fusible slag, for the purpose of driving off the sulphuric acid; but this process is essentially different from the process herein specified, as it produces a valuable slag, which is not a cement.

I claim as my invention—

1. The herein described method of manufacturing sulphuric acid, which consists in calcining a mixture of clay and sulphate of lime, substantially in the proportions specified, and recovering the sulphuric acid which is driven off, substantially as set forth.

2. In the manufacture of sulphuric acid, the herein described method of producing hydraulic or Portland cement as a by-product, which consists in calcining a mixture of clay and sulphate of lime in the proportions to form a hydraulic or Portland cement, substantially as set forth."

This process for making Portland cement and sulphuric acid has never come into use and there is doubtless some practical difficulty which the parties to whom this patent paper was issued did not foresee. It may be possible by further study to make the process practical, though in the preparation of this report experimenting along this line was impossible, and the outcome of such experiments cannot be foretold.

Frank P. Van Denberg, Buffalo, N. Y., holds patent No. 642,390, issued in 1900, for a process of making sulphuric acid from gypsum by subjecting the mineral to heat and electrolysis produced by an electric current within a furnace and applied to the material while molten. In the presence of an excess of free oxygen, sulphur oxide is formed which is hydrated later, yielding sulphuric acid.

METHODS OF HARDENING GYPSUM TO IMITATE MARBLE, CHALCEDONY, ETC.

Nearly a hundred patents have been issued covering processes by which it is proposed to harden gypsum and make therefrom an enduring ornamental stone. At times owners of these patents have endeavored to interest Iowa capital along this line, but without success. A description of one of these patents (549,151. Process of Treating Gypsum Rock to Imitate Chalcedony) is as follows:

"This invention relates in part to processes for treating gypsum rock to impart to it a hardness and polish resembling marble; but my object is to produce a product not only superior to marble in hardness and fineness of surface, grain and luster, but resembling in colors and in general appearance the different varieties of chalcedony, such as onyx, agate, etc. To this end the crude gypsum rock is first shaped in any desired form and configuration by carving, sawing, planing, etc., and this is then freed from the water constituting one of its constituent elements, next colored in accordance with the desired effect and then it is treated to the action of hardening chemical solutions, all as more particularly set forth below. Beautiful onyx, agate, etc., effects can be produced, in accordance with the tastes and desires, in statuary, furniture ornamentations, and the like, and in finishing of rooms, using the material in lieu of marble or woodwork. By my treatment the colors are made to appear as if a constituent part or element of the rock in its native condition and formation, and the condition of the product, as stated, is superior in hardness and finish to either marble or chalcedony.

To carry my process into effect, the gypsum rock from the mines, having been given the desired configuration, as stated, is submitted to the drying action of hot air for twelve hours (more or less) until all the moisture has been eliminated. The material is now calcium sulphate, porous from surface to center, and capable of absorbing sufficient chemical solution to produce the desired effect of the rock and colors. To the surface of the dehydrated rock is now applied the mineral colors—such as, for an illustration, solution of copper nitrate and aqua ammonium, or a solution of a sulphate of iron, nitric acid, and potassium sulpho-cyanide or other mineral colors. After coloring, the rock is immersed in a solution of aluminium sulphate ($Al_2(SO_4)_3$) for about fifteen hours or until the pores of the rock are completely filled. The material is then removed and exposed to the open air for a few hours at a low temperature and then polished." * * * * *

HARDENING OF CEMENT PLASTERS.

If gypsum is heated and thrown into a ten per cent solution of alum, and then heated to redness, the plaster made therefrom is much harder than the common plaster. By mixing lime with stucco a very hard plaster may be obtained. Grimsley in his report on Kansan gypsum* describes the following process: "Landrin placed the crude gypsum in a ten per cent solution of sulphuric acid for fifteen minutes, and then calcined it and obtained a plaster of good set and hardness. Heat must be applied in sufficient amount to drive out all the sulphuric acid, and the best temperature was found to be between 600° and 700° Fahrenheit. Hydrocholoric acid was used, but with poor results.

"Keene's patent cement is made by drying a mixture of plaster of Paris with one part of borax, one part cream of tartar, and

* Univ. Geol. Surv. of Kansas, Vol. V, pp. 116-117.

eighteen parts water. The mixture is burned at a low heat for six hours.

"Parian cement is made from gypsum hardened by means of borax. One part of borax is dissolved in nine parts of water, and the gypsum is treated with the solution; sometimes one part of cream of tartar is added to the solution with good results.

"The hardened cement plaster is made at one mill in Kansas, the Best Brothers' mill, at Medicine Lodge. The gypsum blocks are burned in the kiln, and then treated with a secret solution and reburned. This plaster withstands a crushing force of 3,000 pounds and a tensile strain of 698 pounds after seven days in air. It is claimed to be equal to the imported Keene's cement, and superior to Portland cement for plastering purposes or for laying dry walks. This cement is not used much in Kansas, but has been received with favor in the eastern cities."

GYPSUM AS A BASIS FOR PAINT

For some years the Iowa Paint Manufacturing Company has operated a mill at Fort Dodge and has built up a large and profitable demand for its paints. They have been well received by the trade and have stood successfully the many severe tests to which they have been put. A striking instance of their durability is seen in the Fort Dodge water tower. This structure is of iron and steel and is unusually exposed to the action of the elements. The water rises and falls in the large tank that surmounts it, and the paint that covers it is subject to constant changes in temperature. Three years ago the tower and tank were covered with paint made at the Fort Dodge mill and the paint has not as yet been injured by this constant exposure.

Gypsum is used as a basis for the paint. It is crushed in machinery similar to that used in the plaster mills and ground by passing through two impact oscillators made by Raymond Brothers, Chicago. These oscillators consist of covered cylinders in which revolve metal blades that are attached to iron collars; the oscillators are run at a very high rate of speed and the crushed gypsum is quickly reduced to powder by the blades. A fan forces a current of air through the oscillators and when the gypsum reaches the desired fineness, which is regulated by the strength of the air current, it is lifted by the air to the upper oscillator where it goes through a similar process. The gypsum is ground much finer than when used for plaster. Ninety-nine and nine-tenths of it will pass through a No. 74 mesh, 99.7 per cent will pass through a No. 100 mesh, and 82.3 per cent will pass through a No. 200 mesh. The machines in use will grind to this fineness one and one-half tons per day, while they would grind to the fineness required for wall plaster five or six tons. Proper pigments are mixed with the ground gypsum and a very pleasing variety of colors result. All of these pigments are at present imported into the state. The gypsum used in the manufacture of paint is not calcined.

MECHANICAL PROCESSES IN MAKING HARD WALL PLASTERS, PLASTER OF PARIS, ETC.

During the earlier days of the plaster industry about Fort Dodge, the gypsum was obtained by first stripping off the drift which at the points where the gypsum was quarried varied in thickness from one to twenty feet. The gypsum was quarried by the simplest methods of drilling and blasting. The definite lamination of the gypsum greatly aided in this process. The large blocks that were blasted from the face of the ledge were broken by sledges into convenient size and hauled to the mills in wagons. Today, however, most of the gypsum is mined either by drifting into the deposit at natural exposures along streams or by shafts. The system of mining is still in evolution but in general the room and pillar method common in coal mines is followed. Hand drills are used for the most part, and after the drill has been set it is possible to bore a hole in the gypsum three feet long and two inches in diameter, in twenty minutes; ten minutes are required to set the drill. Coarse powder is used in blasting. For an ordinary blast the two-inch hole is filled with powder six inches, and tamped with clay or gypsum powder. On the average two tons of rock are removed at each blast. In most of the mines the miners are paid by the ton, forty-five cents being allowed for each ton when loaded on the cars. The miner furnishes the powder. At the mine of the Fort Dodge Plaster Company pneumatic drills have been used and pronounced satisfac-

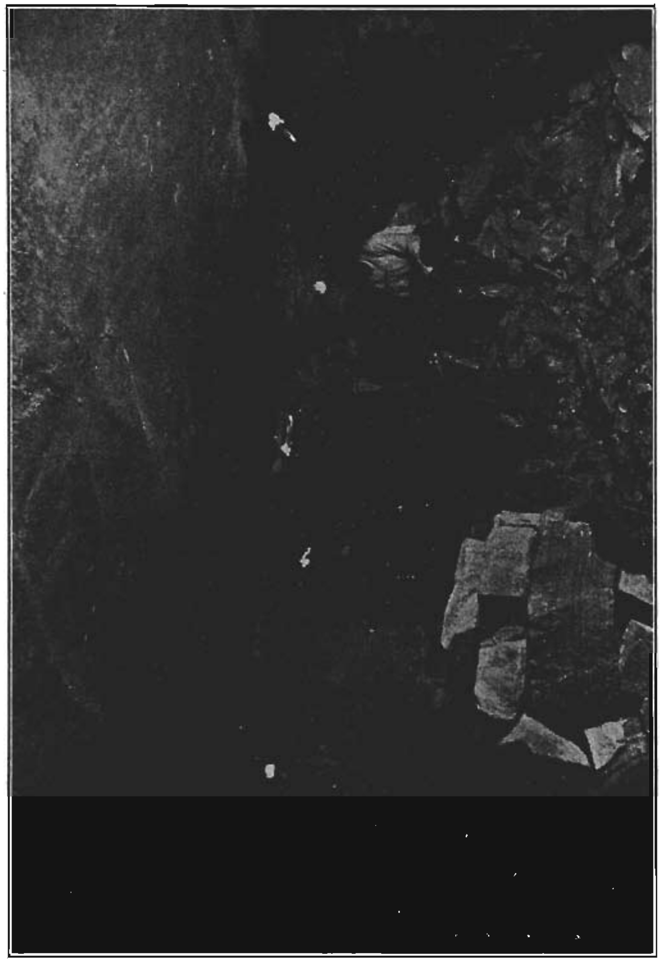


Fig. 19. Interior of Crawford mine.

tory, while at the Cardiff mine an electric mining machine has given good results. The great thickness of the gypsum aids materially in mining. By leaving two or three feet above a good roof is obtained. In most of the mines the passages are nine feet high. At the Mineral City mine passages from fourteen to twenty feet wide are excavated and ten foot pillars are left. Water has not proved troublesome, although pumping more or less constantly is necessary in the mines on the prairie. Where the gypsum is reached by shafts, it is carried underground on tramways to the shaft, which is always located near the mill. Some of the older mills are situated half a mile or more away from the mines that supply them. Tramways run from the mouth of the drift to the mill and the gypsum is hauled on small cars by mules or horses. After arriving at the mill it is stored for some time under sheds to permit the hygroscopic water to pass off. If the material is not thus dried, the power required for grinding is greatly increased and a considerable amount of fuel is wasted in driving off this water in the calcining kettles. It is considered desirable also to keep a supply on hand so that the mills may not be compelled to shut down on account of labor troubles or other difficulties in the mines. After drying in the sheds, the gypsum is again loaded on trams and run to a crusher which operates on the principle of an ordinary store crusher. The gypsum being soft offers little resistance to the heavy metal jaws, and on passing through the machine is reduced to fragments, the largest ones an inch in diameter. It falls directly into a nipper, which resembles an immense old-fashioned coffee mill. It consists of a large iron funnel with flanges set vertically on the inner face. Within it revolves a shaft armed with similar sharp flanges. Between the two sets of flanges, the movable and non-movable, the gypsum is ground till it falls out of the bottom of the funnel in pieces not larger than peas. These small fragments are carried by the buckets of a belt elevator to an upper floor where they are fed down through a spout into burr mills. Three of these mills grind the mineral as fast as it can be calcined in the three kettles with which most of the plaster mills are equipped. On emerging from the burr mills, the gypsum is in the form of a fine powder, seventy per cent of which will pass a No. 74 mesh, sixty per cent a No. 100 mesh, and forty-four per cent a

No. 200 mesh. The average diameters of the largest particles passing these sieves are as follows:*

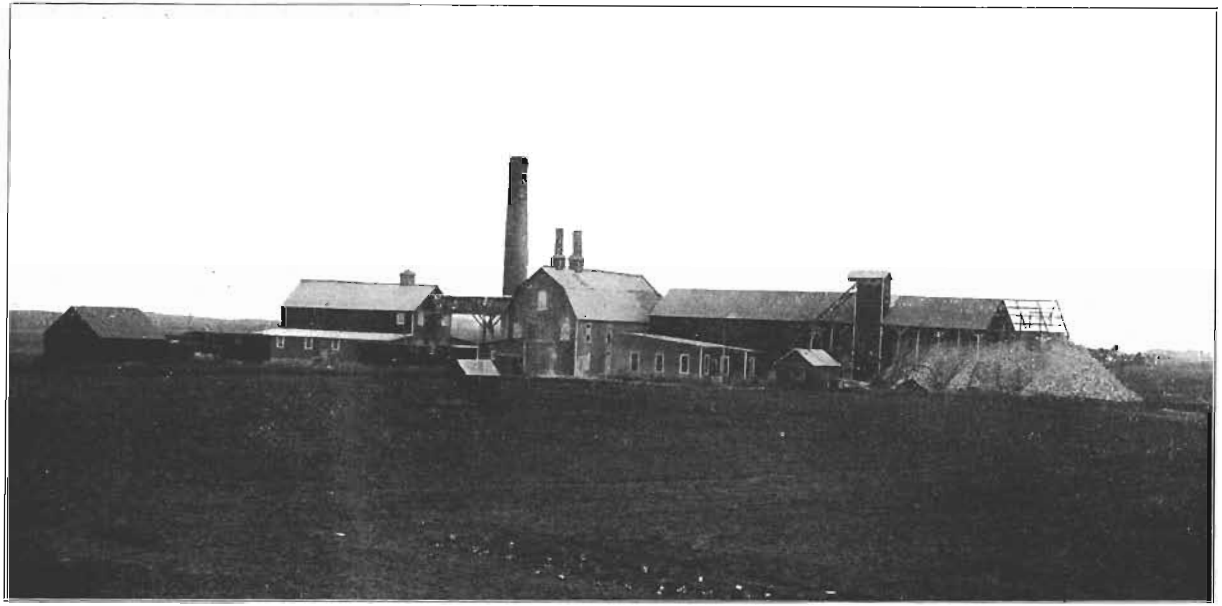
No. 74 ....0.229 millimeters = .00901 inches
No. 100 ....0.115 millimeters = .00452 inches
No. 200 ....0.069 millimeters = .00271 inches

The gypsum powder is again elevated and then pours steadily down on a broad belt which transmits it to a large bin above the calcining kettles. From this bin it flows through spouts into the kettles.

The calcining kettles in use at present in the Iowa plaster mills each hold eight or ten tons of plaster. Sheet steel three-eighths of an inch thick is used in their construction. They are cylindrical, eight or ten feet in diameter and eight feet high. The base of the kettle is built into a furnace in such a way that the bottom and lower part are exposed to the heat of the furnace. Two large flues pass through the lower part of the kettle from side to side, through which the heated gases and smoke are conducted before entering the chimney. A pipe leads from the upper part of each kettle through which the steam from the calcining gypsum passes. Some of the finest of the plaster is carried out of the kettles in these stacks and settling on the mill, the ground and trees, whitens the landscape. At the upper mill of the Iowa Plaster Association these pipes enter a large room on the upper floor which is free from draughts and much of this fine plaster here settles to the floor and is saved. The amount is considerable, about a ton a day. A heavy shaft to which blades and chains, which drag on the bottoms of the kettles, are attached,

* The following tests for fineness of calcined plaster were made by Prof. A. Marston in the summer of 1900, from material purchased in the market. The sieves used were calibrated by standard methods, and the terms, No. 74, No. 100 and No. 200 mesh, stand definitely for the diameters given in the text above.

KIND.	PER CENT PASSING MESH.		
	No. 74.	No. 100.	No. 200.
Gypsum from Stucco Mills, Ft. Dodge	68.3	60.0	44.0
Stucco from Ft. Dodge Plaster Co., Ft. Dodge, Iowa	71.9	65.2	49.3
Baker Stucco, Kansas	72 9	58.3	39.5
Kallolite Stucco, Cardiff Gypsum Plaster Co., Ft. Dodge, Iowa	69.1	63.8	50.2
Baker Plaster, Kansas	68 2	58.7	28.2
Mineral City Wall Plaster, Ft. Dodge, Iowa	72.1	65.4	49.1
Oklahoma Cem. Plaster Co., Okarche, Oklahoma Ter	77.8	70 2	51.3
Flint Wall Plaster, Iowa Plaster Association, Ft. Dodge, Iowa	72.4	64.2	48.1
Acme Wall Plaster, Acme, Texas	74.6	69 2	56.6
Kallolite Wall Plaster, Cardiff Gypsum Plaster Co., Ft. Dodge, Ia	70 8	65.5	53.5
Stonewall Plaster, Ft. Dodge Plaster Co., Ft. Dodge, Iowa	72.4	66.1	54.0
Duncomb Wall Plaster, Duncomb Stucco Co., Ft. Dodge, Iowa	63.8	57.8	43.6



Mill of the Fort Dodge Plaster Company.

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Illustration

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constantly stirs the plaster. This shaft is vertical and rests in a box in the bottom of the kettle, and projects out through the metal cover. It is turned by a large horizontal crown wheel which is driven by a smaller vertical pinion. In filling the kettle a small stream of ground gypsum flows in for an hour or more. It is impossible to start the shaft which stirs the plaster after the kettle is filled.

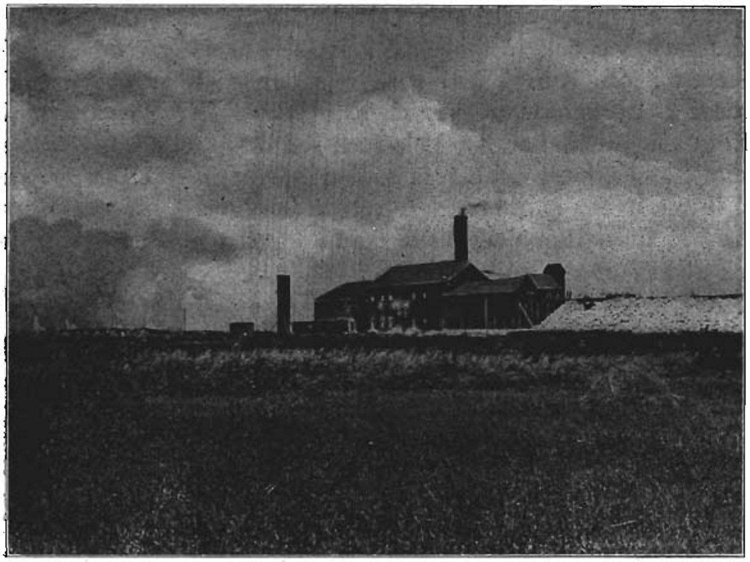


FIG. 20. Mill of the Cardiff Plaster Company, Fort Dodge.

The temperature gradually rises in the kettles and the plaster begins to "boil." All over the kettle the plaster is thrown up into the air in jets by the escape of steam from below. This agitation of the plaster by the escaping steam greatly facilitates the stirring process. The temperature is determined from time to time by lowering a thermometer, by means of a long wooden handle. This must be left in the kettle for a long time if a true record of the temperature would be obtained, for the plaster forms a coating over the bulb, and as it is a good nonconductor of heat, the thermometer for some time fails to record the real temperature. Many of the calciners get along without the thermometer, and determine the time to draw off the plaster by the subsidence of the plaster in the kettle after the water has been driven off. At 270° Fahrenheit the boiling ceases, but begins again with great vigor when the temperature reaches 285° Fahrenheit. At the end of from one to three hours the temperature reaches 340° Fahrenheit, and then the kettle is rapidly emptied through an opening on the side near the bottom. The stucco descends on account of gravity into the cooling bin, from which it is presently elevated by a bucket belt and poured on a broad carrying belt to the bins above the packing room. As it descends again it is mixed with retarder and hair. In this process a Broughton mixer, made at Syracuse, New York, is used in some of the mills. It is then fed into sacks, either paper or cloth, and after weighing, is hauled on trucks to the store room and is ready for shipment. A rebate is allowed for sacks returned to the mill. Very little manufactured plaster is kept in stock at any of the mills.

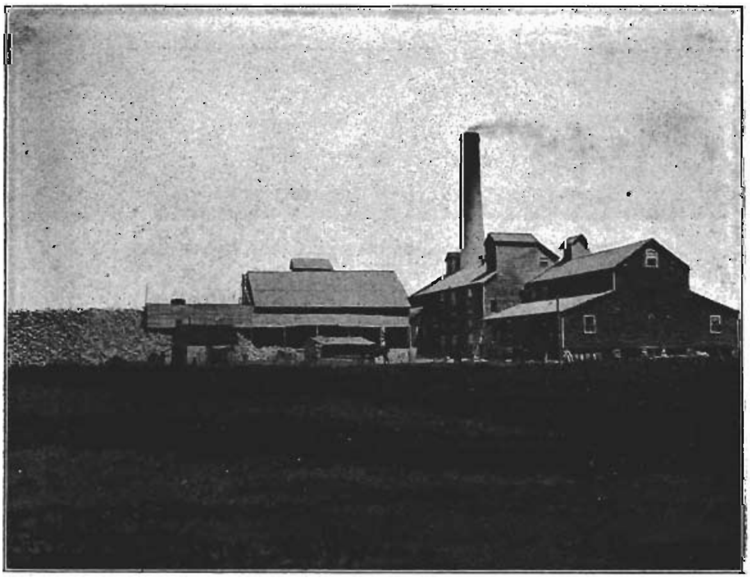


FIG. 21. Mill of the Mineral City Gypsum Plaster Company, Fort Dodge.

Most of the machinery used in the Fort Dodge mills has been furnished by the Des Moines Manufacturing and Supply Company. This firm manufactures crushers, kettles and boilers. In all of the mills the cheaper grades of Webster county coal are used. Cannel coal is employed in many of the mills, both for calcining and for generating steam for motive power. Cannel coal delivered at the mill costs from $1.60 to $1.80 per ton. A car load of fifteen tons of this coal will calcine 126 tons of stucco. The amount of this fuel required to calcine a ton of stucco is then 240 pounds, and the cost about twenty-two cents. The horse power necessary to operate a three kettle mill is about 150. In a mill producing seventy tons of stucco per day, from sixteen to twenty men are employed. They are classified as follows: Five teamsters; six truckers, sack fillers and mixers; two kettlemen, one crusher, one elevator, one engineer, one fireman and one miller.

POSSIBLE IMPROVEMENTS IN THE MANUFACTURE OF PLASTER.

The recent rapid development of the plaster industry in Webster county, with the introduction of mining methods and machinery, brings to prominence the question whether further improvements are not possible. The more recent mills in internal arrangement and machinery differ but slightly from those erected fifteen or twenty years ago. This is due in large measure, doubtless, to the careful experimenting that determined the equipment of the older mills. Their machinery was and still is both simple and efficient. Since the equipment that was so early developed has been so eminently successful, it is not surprising that proposed innovations are regarded with some distrust. In every mill the same style of kettle is used for calcining, and burr mills for grinding. No fault can be found with the effectiveness of the grinding and calcining. When competition becomes sharper, however, more economical methods may be introduced. A single burr mill will grind from fifteen to twenty tons of gypsum in ten hours. When French burrs are used they must be partially dressed or "cracked" every six weeks. A man will crack one burr in a day. Once a year each burr is thoroughly dressed and this requires two weeks. If American burrs are used the dress-

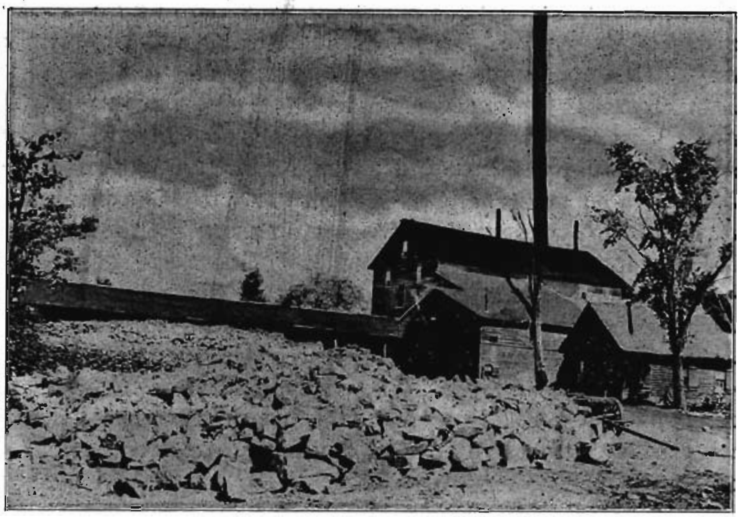


FIG. 22. Duncomb's Gypsum Plaster mill, Fort Dodge.

ings are more frequent. In the Chicago mills of the Western Plaster Works, and in a number of Michigan mills, lime disintegrators are used. The machine is said to work without choking or clogging, and to pulverize from sixty-five to seventy-five tons in ten hours. It is not certain, however, that they are an improvement over the burr mills.

The present method of calcining is wasteful of fuel. In similar industries greater progress has been made in fuel saving. The continuous kiln has been applied successfully to brick making and Portland cement burning. The saving of fuel accomplished by those kilns is considerable. Patents have been issued for continuous kilns suitable for stucco. Such patents are 573,140, U. S. Patent Office, issued to August Dauber, of Bocleum, Germany, 1896; No. 551,390, U. S. Patent Office, issued to F. M. Laude of New York, 1895; No. 519,063, issued to L. House of Montpelier, Indiana, 1894. The great difficulty in using a continuous kiln for calcining plaster is in securing a uniform temperature. The patents mentioned above are for kilns in which oil or gas is used for fuel. This may render them impractical in the Iowa field. A continuous kiln for calcining stucco, or a

FIG. 23. Blandon's Gypsum Plaster mill, Fort Dodge.

similar fuel saving device, is worthy of careful consideration and in this respect the German manufacturer is in advance of the American. Those who are interested in the subject will find a full description of continuous kilns now in use in Germany in the supplement accompanying this report which describes the gypsum industry of Europe.

The fine dust from the calcining kettles may easily be saved, and the amount will be found to be considerable. The heat from the cooling plaster is now wholly lost, and if a saving could be made here it would proportionately reduce the cost of calcining.

Coal.

The position and extent of the Webster county coal fields have been described, in connection with other Upper Carboniferous strata, under stratigraphy.

The coal in Webster county varies considerably in quality in the different basins, and often in different seams of the same basin. Some of it is excellent, while all is of fair quality. Since it constitutes the extreme northern point of Iowa's coal pro-

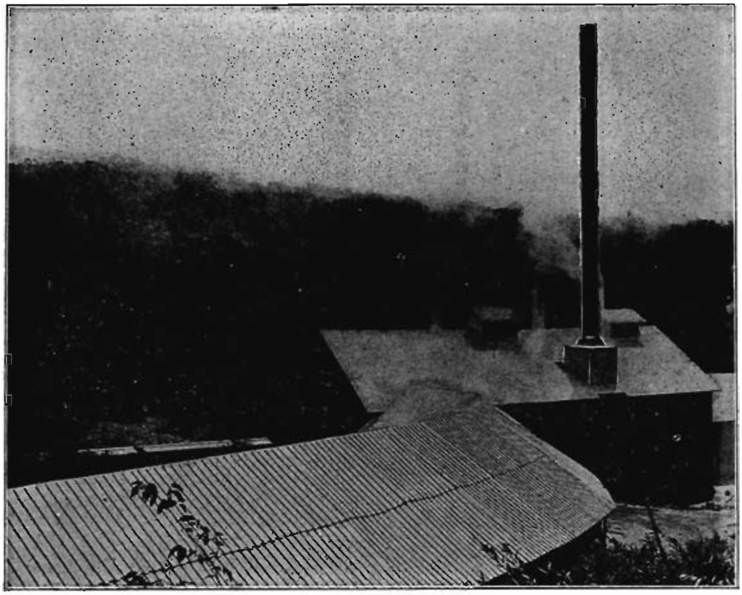


FIG. 24. Lower mill of the Iowa Plaster Company, Fort Dodge.

ducing area, Webster county has a marked advantage in marketing its output. For coal from the better seams a royalty of from twenty to twenty-five cents is paid. The county produced 118,770 tons in 1899. Mining was carried on by fifteen operators. The average value of the coal at the mine was $1.25 per ton and the total value amounted to $193,139. Three hundred men were employed throughout the year.

The Lehigh basin has long been a producer of good coal. At this point most of the coal has been taken out by Corey Bros., the Webster County Mining & Railroad Company, and the Crooked Creek Mining Company. The mines of these companies are equipped with steam hoists and adequate surface works, and each has a capacity of a number of car loads a day. All have worked the Tyson seam. The Crooked Creek Company is working the Pretty seam, and also the Lower or Big seam. Its shafts, 4 and 5, in the valley of Crooked creek, are large producers, the former obtaining its coal from the Pretty seam and the latter from the Big seam. As yet the latter seam has not produced coal in quality equal to the Tyson. The Big seam at shaft No. 5 is 133 ½ feet below the surface and is three to five feet thick. It is worked by the room and pillar method, while the Tyson is worked by the longwall.

One-half mile above the Webster County Mining and Railroad Company's shaft, in the valley of Crooked Creek, in section 14, Patrick Daly has sunk a shaft to the Pretty seam, which at that point is eighty feet below the surface, and three feet eight inches thick. One-half mile farther up the creek is the Hamilton mine, which also obtains coal from the same seam, here showing a thickness of from three and one-half to four feet.

The Coalville and Holaday Creek Basin.—Most of the coal taken out of this basin has come from the upper bituminous seam. The Colburn seam has produced but a limited quantity. Of late years the mines in the cannel coal have assumed some importance. The upper bituminous coal has been mined by drifting along the river and adjacent ravines, and on Holaday creek, and also by shafts put down from prairie level. That portion of the upper bituminous seam which has been described (see stratigraphy) as the "big coal" has been, and for a limited time still will be, a great producer of good coal. It contains the thickest coal in the county. Outside of the "big coal" much of the upper bituminous seam yields coal of inferior quality, excellent for producing steam, but deteriorating rapidly on exposure to the air. Working the "big coal" in the summer of 1900, were the Gleason Coal Company, the Pleasant Valley Coal Company and the Martin Coal Company. The first two companies at that time had well equipped power houses with steam hoists, and the mines were capable of producing a number of car loads daily. The Gleason mine was just beginning operations. It is located on the prairie, in Nw. ¼, section 9, Pleasant Valley township. The Pleasant Valley Coal Company had worked most of the big coal out of the Ne. ¼ of the same section and was drawing the pillars preparatory to abandoning the mine. The J. L. Martin mine, in Nw. ¼ of section 10, is near the bank of Holaday creek. This is an old mine with a draft ninety-five feet deep, which reaches a six foot vein of coal. In September, 1900, this mine was being pumped out. Along

Holaday creek the upper coal has been mined for many years. The Holaday Creek Coal Company has operated on the creek, in Nw. ¼ of section 10; J. L. Martin has a mine in this coal in Sw. ¼ of section 10. From prairie level, in Sw. ¼, section 16, Collins Brothers have developed the upper seam outside of the "big coal" from which they take a number of car loads of steam coal daily. At Kalo, in Sw. ¼ of section 8 and Nw. ¼, section 17, Otho township, the Craig Coal Company has mined the upper coal extensively. The Carlson mine is a little farther down the river and works the same seam, as do the McEwen mines a short distance up the river, on the east bank. Smaller mines in the upper bituminous seam near the river below Kalo are the Atherton and Woodbury, the Moore and Webster, the Mills and the Madison, all situated in a ravine on the west side of the river, one-fourth of a mile below the Kalo bridge. The Fuller mine is in a similar ravine one-eighth of a mile farther down the river. The Bennett, Jim Johnson and Everett mines are found on the river bank in the order named. The Eric Johnson mine is a mile below the bridge and works the Colburn vein, which is said to be two feet thick, and to lie twenty feet below the river.

The cannel coal about Kalo and Coalville will become more important as the output from the other seams diminishes. It is exposed along the river from the Minneapolis and Saint Louis railroad bridge in Se. ¼ of section 6 to the Kalo wagon bridge in section 17. It extends back from the river on the right bank at least three-fourths of a mile. Prospecting has proven that the cannel coal basin includes an area of at least two square miles. In thickness the coal varies from two feet four inches to three feet. It has a good shale roof. On the left bank of the river the coal is mined on the Litchfield land, in Pleasant Valley township, Sw. ¼ of section 5, where five men take out from ten to twelve tons a day. All of this is sold to the Duncomb plaster mill, which is a mile further up the river. The price paid for this coal is $1.65, delivered at the mill, the parties operating the mine paying a royalty of ten cents a ton. Directly across the river, in Otho township, section 8, Nw. ¼, Irwin Brothers have a mine in the cannel coal, which here shows a thickness of two feet two inches. Their prospect holes in this vicinity show two feet of coal ninety rods back from the river. The W. D. Johnson mine, also in the cannel coal, is a few rods above the Irwin mine. Collins Brothers mine the cannel coal on the left river bank, in Pleasant Valley township, section 17, Nw. ¼. The location of most of these mines is shown on the geological map of the gypsum region immediately about Fort Dodge.

In the Tara coal basin three companies are operating. In Elkhorn township, section 6, Ne. ¼, Martin and Timmons reach the coal with a sixty foot shaft. The seam here has a thickness of four feet six inches. They pay a royalty of fifteen cents for mine run. The room and pillar method is used in mining. This mine has been in operation for five years and the coal has been removed from an area of five acres. Piert and Colferd operate a mine on the same quarter section, and under about the same conditions as the mine just described. The coal is four feet thick, with gumbo or black jack for a roof and shale for floor. Drillings sixty rods south of this shaft also show four feet of coal. John Paul as a mine on the Patrick Scalley place, in section 33, Sw. ¼, which shows three feet and a half of coal reached by a forty foot shaft. The seam is practically horizontal throughout this district and differences in the depth of the shafts are due to surface inequalities.

At Limburg postoffice some coal has been mined. The Simpson and Gustafson shafts, both now closed, were operated for two years, about twenty tons being taken out of each mine per day. The Gustafson drift was operated on a small scale in the summer of 1900. Two men were taking out about a ton a day, the coal selling for $2.25 per ton.

A few tons are annually mined ten miles above Fort Dodge, from a seam which is commonly regarded as a part of the Colburn. The coal is of fair quality, though it slacks if exposed for a considerable time to the air.

ANALYSES OF WEBSTER COUNTY COAL.*

LOCALITIES.	Moisture.	Total combustibles.	Ash.	Volatile combustible matter.	Fixed carbon.	Coke—fixed carbon plus ash.	SULPHUR. In sulphides.	SULPHUR. In sulphates.	SULPHUR. Total.
Collins No. 6, Coalville, average	7.48	84.06	8.44	39.52	44.54	52 99	4.98	.26	5.24
Collins No. 4, Coalville, average	7.80	82.88	9.32	37.74	45.14	54.46	3.97	.12	4.09
Old Reese mine, Fort Dodge	9.92	48.77	41.31	29.69	22.08	63.39	......	.....	. .
Carlson mine, Kalo, average	10.10	76.53	13.36	32.83	43.69	57.06	1.68	.18	1.86
Craig Cannel mine, Kalo, "cannel" coal	5.87	78.26	15.87	39.04	39.22	55.09	6.87	.25	7.12
Craig slope, Kalo, bituminous	8 46	81.37	10.17	37.97	43.40	53.57	5.19	.10	5.29
Crooked Creek mine, Lehigh, top	7.74	78.94	13.32	34.47	44.47	57.79	4.83	.81	5.64
Same, middle of seam	8.52	82.65	8.83	38.64	44.01	52.84	3.71	.48	4.19
Same, bottom of seam	8.57	81.86	9.57	37.57	44.29	53.86	3.47	.18	3.65
Crooked Creek shaft, Lehigh	6.99	76.66	16.34	34.40	42.26	58.60	5.67	.37	6.04
Corey mine, Lehigh, average	7.77	81.27	11.00	38.05	43.21	54.21	7.02	.68	7.70

* Iowa Geol. Surv., Vol. II, p. 509, 1894.

	No. 1	No. 2	No. 3	No. 4	No. 5
Moisture	14.05	10.46	10.13	13.91	9.92
Volatile combustible	36.42	37.44	37.25	37.00	26.69
Fixed carbon	41.19	36.93	36.08	41.83	22.08
Ash	8.34	15.17	16.54	7.26	41.31
	100.00	100.00	100.00	100.00	100.00

CALCULATED ON DRIED COAL.

	1	2	3	4	5	
Volatile combustible	42.38	41.80	41.44	42.98	29.63	
Fixed carbon	47.94	41.26	40.15	48.59	24.51	
Ash	9.68	16.94	18.41	8.43	45.86	
	100.00	100.00	100.00	100.00	100.00	
Volatile combustible	50.47	47.90	47.38	50.91	36.61	
Total combustible	77.61	74.37	73 33	78.83	48.77	Of undried coal
	90.32	83.06	81.59	91.57	54.14	Of dried coal
Coke	49.53	52.10	52.62	49.09	63.39	Of undried coal
	57.62	58 20	58.56	57.02	70.37	Of dried coal

COMPOSITION OF COKE.

Carbon	83.00	70.87	68.56	85.19	34.87
Ash	17.00	29.13	31.44	14 81	65.13
	100.00	100.00	100 00	100.00	100.00

No. 1. From Rees' mine, near Fort Dodge.

No. 2. "Lower Cannel Coal" from bank of Des Moines river, Sec. 17, Tp. 83 N.' R. 29 W.

No. 3. From Sec. 17, Tp. 88 N., R. 28 W.

No. 4. "Collins' mine," Sec. 17, Tp. 88 N., R. 28 W.

No. 5. "Cannel Coal" from Rees' mine, Fort Dodge.

An analysis of Tyson coal taken from the left bank of the river in the summer of 1900 gave the following results:

Moisture	12.70
Volatile matter	44.12
Fixed carbon	32.91
Ash	10.27
	100.00
Sulphur	5.33

Clay.

An abundance of suitable clay conveniently exposed along the Des Moines river furnishes material for a variety of clay goods. Brick and tile are made at Fort Dodge, Coalville and Lehigh. A pottery at Fort Dodge produces stoneware of excellent quality, and in considerable quantities. In addition to building brick, Webster county is a large producer of paving and sidewalk brick. Some of the plants are finely equipped with modern machinery and kilns. An excellent market exists on account of the scarcity of material in many of the counties north, east and west, and the price of building brick for the past two years has ranged from five to six dollars a thousand.

Fort Dodge Brickyards.—The Fort Dodge Clay Works is situated on the right bank of the Des Moines river, conveniently near the Illinois Central railroad with which it is connected by short side tracks. The pit extends into the bank, and the clays consist of drift, shales of the gypsum formation and Coal Measures. Sections of this pit have been given elsewhere. The drift is used as sparingly as possible and only when mixed with the other clays, for it carries so much lime that its excessive use would seriously injure the quality of the brick. The clay is loaded into cars in the pit, which are drawn to the mill by a steam windlass. A stiff mud end cut machine made by the American Clay Manufacturing Company is used for working the clay. From the mill the brick go directly into spacious driers. A large continuous kiln and four down draft kilns—two round and two square—give large burning capacity. The plant produces 45,000 brick per day, one-fourth of them of the paving variety. Recently this company has opened up a pit on the banks of the Lizard, near its mouth. The clay here consists of red and green shales which are associated with the gypsum. Saint Louis limestone appears on the banks below the pit.

The Fort Dodge Brick and Tile Works, a firm composed of J. H. Able, Wm. Fessel and F. Moeller, operate a large plant directly across the river from the Fort Dodge Clay Works. It is shown in the foreground of Fig. 25, while the pit and kilns of the Fort Dodge Clay Works appear in the distance. The clay used is a mixture of drift and Coal Measure shales, the former being used in small quantities. The plant has a capacity of 25,000 building brick per day. In addition many four to twelve inch tile are made, and in the course of a year about 500,000 paving brick. One-half of the entire product is marketed outside of Fort Dodge. Convenient side tracks favor railroad shipments.

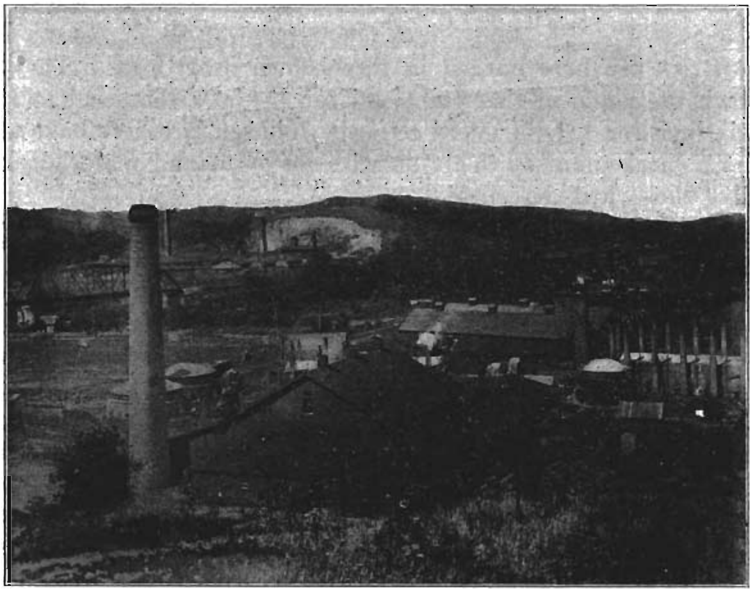


FIG. 25. Two of the Fort Dodge brick plants. In the foreground are the works of the Fort Dodge Brick and Tile Company; in the background the Fort Dodge Clay Works.

Bradshaw & Moeller's yard in West Fort Dodge is located on a ravine which extends back from the river a short distance. The clay is Coal Measure shale and river silt. A Fate and Freeze end cut machine with 20,000 daily capacity is used. The brick are in part steam dried and in part dried by exposure to the air under open sheds. Four down draft kilns are used for burning the brick. Eighteen men are employed from April to November.

The Kime brickyard, which was at one time operated near Fort Dodge, making a good brick from Coal Measure shale and silt, has for some time been idle.

Brickyards at Coalville.—Schnurr Brothers operate a brick and tile plant at Coalville, using Coal Measure clay with which a little glacial drift is mixed. A section in their pit which is on the bank of the Des Moines river shows:

		FEET
4.	Drift, with some lime	6
3.	Shale	4
2.	"Coal blossom"	1
1.	Shale	12

Brick are here burned in three down draft kilns. The four inch tile made at this plant sell for $14.50 a thousand and the six inch for $27.00. Very recently Johnson Brothers have started a brick plant at Coalville with an outfit and material about like those just described.

Brickyards at Lehigh.—Excellent deposits of Coal Measure shales along Crooked creek have led to the development of the brick industry on a large scale. At present three large yards are in successful operation, and the Lehigh brick deserve the reputation that they enjoy as fine material both for interior and exterior work. Limited shipping facilities are the only handicap on the Lehigh yards. Located as they are directly in the midst of the greatest coal producing area in the county they enjoy cheap fuel.

The Corey Pressed Brick Company uses a Boyd four mould press with a daily capacity of 20,000. For brick of the first grade made at this plant $12 a thousand is received. Three round and two square down draft kilns are used for burning. The clay pit shows thirty feet of excellent shale. No glacial clay is used, and this is a prime factor in securing and maintaining the high grade of the brick produced. Much of the clay here is mined in order to avoid removing the glacial clay which overlies it, and by exercising some care in choosing the clay, brick of various attractive colors are secured.

The Lehigh Clay Works, with G. W. Hughes as president, George V. Bailey as vice president, and Fred Essleck as secretary and treasurer, commenced operations in 1900. A stiff mud machine manufactured by the American Clay Working Machinery Company, and an oscillating side cutter are in use. The kilns are of the Brighton type, and of 75,000 capacity. An abundance of

Coal Measure shale is available. An analysis of these shales, taken from the pit of this brickyard, is as follows:

	PER CENT.
Silica	53.08
Iron oxide	8.64
Alumina	17.71
Lime	4.05
Magnesia	.94
Carbonic acid	2.53
Soda	3.70
Potash	1.25
Water in combination	6.77
Undetermined	1.33
	100.00
Insoluble in sulphuric acid and sodium carbonate	71.55

Beem and Wilson are making preparations to start the old Lehigh brickyard, some time ago partially destroyed by fire.

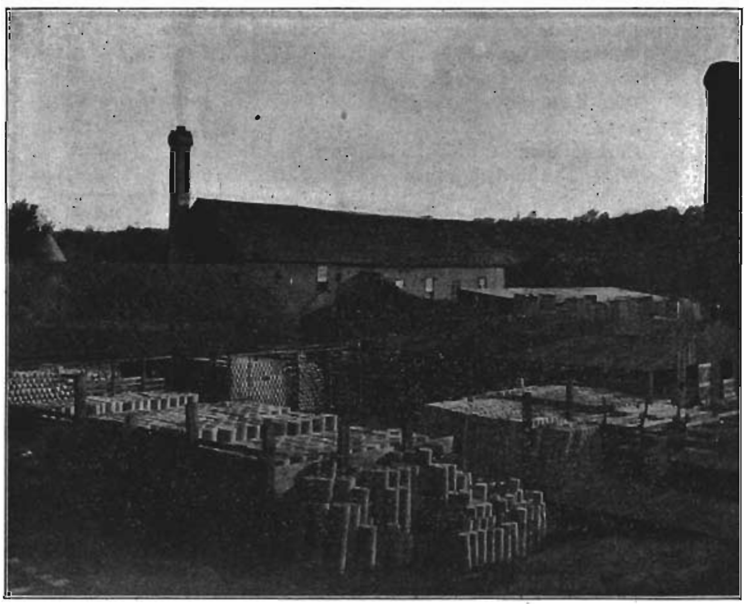


FIG. 26. The Fort Dodge Pottery.

Fort Dodge Pottery.—This industry has passed through a gradual but very satisfactory development and today is a well established and important industry. The wares produced are jugs, jars and butter crocks. Many large pieces of twenty to thirty-five gallons capacity are made. The clay used in these articles is obtained from a mine in the Coal Measure shales on the left bank of the river, a half mile above Fort Dodge. It burns uniformly and there is but little loss from checking or cracking. Fort Dodge plaster, about twenty tons a year, is used for the moulds. Considerable skill is shown in the glazing, and the appearance of the ware put on the market is attractive. The annual output is valued at $30,000.

Below two analyses of clay are given, the "first quality" being in constant use at the Fort Dodge pottery, while the second, which is equally available so far as supply is concerned, proves to be a clay which checks badly in burning.

	FIRST QUALITY.	SECOND QUALITY.
Silica (SiO_2)	66 00	63.83
Alumina (Al_2O_3)	19.32	17 55
Iron oxide (Fe_2O_3)	.80	2.75
Calcium oxide (CaO)	2 85	2 94
Magnesium oxide (MgO)	.54	.57
Potash (K_2O)	1.15	.67
Soda	2 49	.79
Carbon dioxide	.....	2.36
Water and undetermined	6.84	8.54
	100.00	100.00
Insoluble in H_2SO_4 and Na_2CO_3	58.55	68.69

Clay number one is a good pottery clay, as will be seen by comparing it with the analysis of pottery clay from Zanesville, Ohio, given below, which enjoys a wide reputation. The low percentage of iron prevents discoloring and the small quantity of water ensures the material against checking.

ZANESVILLE, OHIO, POTTERY CLAY.

	PER CENT.
Silica (SiO_2)	64.26
Alumina (Al_2O_3)	22.95
Iron oxide (Fe_2O_3)	1.28
Calcium carbonate ($CaCO_3$)	.45
Magnesium oxide (MgO)	.37
Potash (K_2O)	1.81
Soda	.15
Water	8 79

A careful search for a clay that would furnish a good fire brick was made but without success. The clay lying directly under the gypsum seemed to be the material sought, but an analysis showed a high percentage of powerful fluxes, so that the high silica content, which is favorable, is in part overcome. The analysis is as follows:*

	PER CENT.
Silica (SiO_2)	79.99
Alumina (Al_2O_3)	7.49
Iron oxide (Fe_2O_3)	.47
Calcium oxide	2.09
Magnesium oxide (MgO)	2.37
Potassium oxide (K_2O)	2.88
Water	.49
Rational analyses	4.45
	100.23
Insoluble in H_2SO_4 and Na_2CO_3	84.66

The analysis indicates that in burning this clay will require little fuel, but will demand more than ordinary care on account of the narrow margin between incipient and final fusion, the percentage of fluxes being high.

Building Stone.

The Saint Louis limestone has furnished a great deal of valuable building stone, much of which has been used for foundations and terrace walls in Fort Dodge. Most of the stone has been quarried along Soldier and Lizard creeks, and near the left bank of the river, at numerous points for two miles north of the city. Work is carried on intermittently, and at no point do the developments deserve the name of quarry, if by that term permanent fixtures in the form of derricks and heavy machinery is understood. Operations on Soldier creek have been mainly confined to Baehring's quarry, near the mouth of the creek. Here both limestone and sandstone, the latter calcareous, have been quarried for use in Fort Dodge, some of the layers being of considerable thickness and all of the stone of good quality. The excessive amount of drift, which must be removed before quarrying is possible, limits future operations at this point.

* Analysis by J. B. Weems.

Opportunities for more extensive quarries in the limestone are offered at a number of points along the Des Moines river north of Fort Dodge. The Coal Measure shales and drift have been removed by the river and the stone forms a scantily covered shelf often two hundred yards wide. The stone, however, hardly warrants extensive development if large building blocks are desired. It is very durable, but is too badly broken by joints and cracks to furnish material for heavy walls. The rapid increase in the use of Portland cement, however, has throughout the country stimulated the crushed stone industry. Building and paving with concrete are destined to increase steadily as the years go by, and the Saint Louis limestone along the river in Webster county will furnish excellent material for these purposes. The very characteristics that render it unfit for building blocks make it a most economical stone for crushing. In this use of the limestone it is reasonable to anticipate the greatest development in connection with Webster county quarries.

Quarries in Sandstone.—The Coal Measure sandstones in the southern part of the county have at various points attracted quarrymen. The softness of the stone and the fact that it generally carries enough sulphide of iron to cause it to discolor on exposure to the air have greatly discouraged extensive efforts at development. The first of considerable size was the Crawford quarry on the Albee estate, in Tp. 88 N., R. XXVIII W., Sec. 14, Nw. ¼ of Ne. ¼. The quarry is located in a small ravine where the rock is naturally exposed. An average section through the quarry face shows:

		FEET.
3.	Drift	10 to 15
2.	Shale	2 to 3
1.	Sandstone	15

The sandstone is probably much thicker, but has not been quarried below the bottom of the ravine. It is ferruginous and contains many selenite scales which look like mica. Even in a given layer the stone varies often in color and hardness. The colors are various shades of red. Some layers are practically useless for building purposes because they contain many small iron concretions. At certain points in the quarry the rock attains a fair degree of hardness. The layers are of a desirable thickness, varying from six inches to two feet. Jointing is imperfect, but sufficiently well developed to render quarrying easy. Some years ago the quarry was well equipped with steam derricks, and a side track gave good shipping facilities, but at present it is not operated.

The Carter, Laufersweiler and Ryan sandstone quarry is situated in Washington township, Sec. 26, Se. ¼, on the river bank, and close to the tracks of the Lehigh branch of the Mason City & Fort Dodge railroad. At present only a few feet of drift must be removed to render quarrying possible, though as work extends back into the bluff the amount will gradually increase. At present the face of the quarry shows twenty feet of gray and red sandstone, with the colors arranged in no definite order. The gray stone is often three feet thick, is not in well defined layers, and shades off into the red. The particles of sand in the gray stone are cemented with calcareous matter, while the uniting element in the red is iron. The fact that the gray stone effervesces with acid does not in any way indicate lack of durability. It is the most promising sandstone quarried up to this time within the county, although it has not been found as yet in quantities sufficient to justify extensive quarrying. A few men are kept profitably at work, however, and most of it is dressed at the quarries into attractive sills and trimmings for brick structures.

If suitable shipping facilities were present, the sandstones exposed along the river in the northern part of the county would warrant careful investigation. They appear to be harder, of good color and are as a rule more heavily bedded than those south of Fort Dodge.

Portland Cement.

In the development of the natural resources of the United States during the past five years, nothing has been more phenomenal than the progress made in the manufacture of Portland cement. The first attempts to make cement in America date back to 1865. In 1882 our country produced only 85,000 barrels, while 370,000 were imported. Since that time progress has been more rapid, but the demand for Portland cement has increased even more rapidly, and the deficiency has been made up by importation, as is shown by the following table:*

	AMERICAN.	FOREIGN.
	Barrels.	Barrels.
1882	85,000	370,400
1885	150,000	554,396
1887	250,000	1,514,095
1892	547,440	2,440.654
1894	789,757	2,638,107
1896	1,543,023	2,989,597

Since 1898 many new mills have been erected. In Michigan and Illinois especially the production of cement has greatly increased; yet during the ten months ending in April, 1900, cement valued at $2,617,470 was imported.† It appears that the rapidly increasing supply lags nearly as far behind the increased demand as formerly. The time will doubtless come when supply and demand will be more nearly balanced, though the danger of over supply seems remote. In locating new mills, however, the fact must be kept in mind that competition will be sharper in the future, and conditions as favorable as possible for economic production must be sought. The plant, too, must be large enough to allow great economy in management. Under favorable natural conditions would be included an abundance of high grade raw material, cheap fuel, good shipping facilities and a convenient market.

The materials used in making Portland cement are a pure limestone or marl, and clay or shale. About three parts of limestone are used to one of shale. These materials are ground, burned together at a high temperature and then reground. It is very essential that the limestone be free from magnesia, and this greatly limits the number of available limestones. The following description of suitable clays for Portland cement is taken from an article by W. H. Hess in the Cement and Engineering News for February, 1900:

* Cement and Engineering News, Vol. VIII, No. 1, p. 13.
† Ibid, June, 1900, p. 91.

	SECONDARY CLAY.	PRIMARY CLAY. I.	II.
Silica	39.53	58.24	68.21
Alumina	11.46	20.56	18.64
Iron	4.59	5.68	5.32
Oxide of lime	13.78	0.61	0.22
Oxide of magnesia	5.19	0.24	0.16
Sulphuric anhydride	1.62	0.01	0.12
Loss on ignition	23.83	15.40	7.33

"A secondary clay is not an ideal clay, but it can be used. Its disadvantages are: (1) High content of magnesia and gypsum; (2) the high percentage of lime will make frequent analyses necessary; (3) the temperature of calcination may be variable, and therefore, high; (4) in case transportation from a distance is necessary, 20 per cent of the weight is not clay.

Primary clay, No. 1, is an ideal clay. It will combine with carbonate of lime at a comparatively low temperature: It will, therefore, be economical in the amount of fuel required for the calcination of the cement. It has a disadvantage in rotary practice that underlimed slurry clinkers and the fused mass interferes with the burning. With this clay careful chemical work is necessary, and the temperature of calcination must be carefully controlled. It will give the best cement at the least cost when properly handled.

Primary clay, No. 2, is an economical clay for transporting long distances. It will not be economical in fuel; for the temperature of calcination of the clinker must be high. The clinker will not fuse in the rotaries and gives trouble, even though the content of lime varies. This clay can, therefore, be used without necessitating careful chemical control of the mixture of raw materials, and the calcination need not be so troublesome. As the industry progresses and competition becomes keen, this clay will be replaced by a clay that is higher in per cent of alumina and lower in percentage of silica, such as clay No. 1. A slurry of constant composition will become necessary, and the temperature of burning will be gauged so as to be as low as possible without sacrificing the quality of the cement produced."

An analysis of chalk used in the manufacture of Portland cement at White Cliffs, Arkansas, which may be taken as typical for suitable lime for cement, is as follows:

Carbonate of lime	90.23
Carbonate of magnesia	1.15
Silica	5.33
Alumina, iron oxide	3.03
	99.74

This combination would be improved if the magnesia were wholly absent. If the magnesia rises above four per cent it weakens the cement.

An analysis of the Saint Louis limestone and interbedded shale taken from the exposure at the mouth of Lizard creek on the right bank, gave the following results:*

Upper layer, 2 feet.
Carbonate of lime 88.75.
Sulphate of lime 00.28.

Next layer, 2 feet (shale).
Carbonate of lime 53.25.
Sulphate of lime 2.46.

Next layer, 2½ feet.
Carbonate of lime 88.75.
Sulphate of lime 00.17.

A sample of cement was made from these layers and carefully analyzed, with results as follows:

Lime	63.48
Silica	25.53
Alumina and iron	8.80
Magnesia	1.19

The cement was pronounced excellent by experts, and the locality was reported as worthy of careful investigation with a view to the erection of a cement mill. A more favorable locality may be found on the Des Moines river above Fort Dodge, where the Saint Louis limestone is more abundantly exposed, and where the Coal Measure shales are available. In view of the fact that better localities in Iowa have not yet been reported, the conditions in Webster county should be borne in mind by those interested in establishing a cement mill in the state. Fuel is abundant and cheap, and four great railroad systems give direct connection with all parts of the country. The reputation that Fort Dodge already enjoys as a plaster producing center would be in favor of the new material when put upon the market.

Lime.

Formerly limited quantities of the Saint Louis limestone were burned for quicklime along the Des Moines river and Soldier creek. On account of the chemical composition of the stone it is not possible to make from it a high grade of lime. A magnesian limestone is necessary in order to produce a lime that will

* Analyses by Lundteigen, of the Peerless Portland Cement Company.

not too readily slake, and that will bear shipment and attendant exposure to the air. As has been shown, however, the absence of magnesia gives the stone a greater economic value in making it suitable for Portland cement.

Road Materials.

In the gravel terrace along the Des Moines river there are great quantities of excellent road material in the form of sand and gravel. These terraces are remarkably developed at points near Fort Dodge on both sides of the river. This is particularly fortunate, for in the central and southern part of the county there is much flat land that is but partially drained. In the northern part of the county numerous gravel pits have been opened up in the kames that are found in the morainic tracts already described. The location of gravel pits is shown on the accompanying map. The Saint Louis limestone, if crushed, would make a good macadam, and immense quantities of it are available. The bowlders scattered over the fields and piled in fence corners, if broken and placed on the roads as is the custom in northern Germany, would greatly improve existing conditions.

Water Power.

At present water is not used for power at any point within the county, though traces of a number of dams still remain along the Des Moines river. A head of six or more feet could easily be obtained at a number of points on the river without flooding the arable lowlands. During the greater part of the year at least thirty horse power could thus be secured. During the three summer months the power would be reduced one-half. Until fuel becomes more expensive, however, it will hardly be practical to utilize the water power within the county for anything except minor enterprises.

Water Supply.

Most of the farm wells obtain water in sand layers within the glacial drift. The supply so obtained is generally abundant and the depth to which the well must be sunk is not excessive, varying from ten to sixty feet. In the northern part of the county a few wells find water in the Saint Louis limestone, while in the southern part some wells penetrate the Coal Measure shales till a sandstone layer is reached. The water of these wells is apt to carry iron in solution. Water in deep wells in the gypsum area is often impregnated with that mineral. No unusual difficulties are encountered in well drilling. The average price for drilling in the northern portion of the county is fifty cents for dirt and $1.50 for rock, for the first hundred feet, and twenty-five cents per foot additional for greater depths. There are no flowing wells in the county. Excellent springs are found in the bed of Lizard creek, one mile above its mouth, the water coming up through cracks in the Saint Louis limestone. Near the mouth of Prairie creek are small perennial springs. Water for the city of Fort Dodge is taken from the Des Moines river by means of filters placed at the upper end of Duck island. The water is potable and reasonably pure.

Mineral Paint.

The color of many of the clays in Webster county, especially those found just above and below the gypsum, has led many persons to experiment with them with the hope of finding a natural pigment. In a limited measure their hopes have been gratified for at times the clay carries sufficient iron oxide to render it good paint when ground and mixed with oil. It has not proven satisfactory enough to warrant extensive development, however, and no pigments of commercial importance can be reported as occurring in the county.

Mineral Springs.

While many wells, particularly those within the gypsum region, yield water which contains a small amount of mineral matter in solution, but one highly mineralized spring was found within the county. Located on the right bank of the Des Moines one-fourth of a mile above the bridge at Kalo, in Tp. 88 N., R. XXVIII W., Sec. 17, center, is a perennial spring of considerable volume yielding non-potable water. A chemical analysis made by Professor Weems shows that this water contains:

Alumina, Al_2O_3	325.5 parts per million
Ferric oxide, Fe_2O_3	2706.6 parts per million
Sulphur trioxide, SO_3	656.5 parts per million

The alumina and iron are probably present as sulphates, and the impression that the water gives to the taste is that of a strong alum solution.

The amount of alum present is insignificant from an economic point of view, and while sulphate of iron under the name of copperas is used freely in the arts, it is produced so cheaply as a by-product in the manufacture of wire that an attempt to obtain it by concentration of spring water would not prove remunerative.

Minerals.

Selenite.—The massive and fibrous gypsum of Webster county has already been described. The crystalline form, selenite, deserves further notice. It occurs commonly in the Coal Measure shales, and is found also in smaller quantities in the marly layer of the Saint Louis limestone on Lizard creek. The crystals are often remarkably perfect in form and transparency. They are tabular in form, parallel to the clinopinacoid (010). Twin crystals are united along the orthprism. In these twinned crystals impurities are often arranged along the common axis, from which barbs project parallel to the clino axis. Simple crystals are commonly twice as long as broad, with a thickness equal to half their breadth. Small crystals of anhydrite have been reported by Mr. Melvin Somes of Fort Dodge, but this mineral is exceedingly rare.

Iron Ore.—Limited quantities of limonite are found in the Coal Measures of the southern part of the county. The thickest layer is found on Prairie creek, at the Copperas beds. Here it forms the cementing element in a fine conglomerate. On the river south of Fort Dodge, near the old packing house, a layer of limonite a foot thick occurs. Nowhere, however, is iron ore in any form present in quantities sufficient to render it of economic importance.

Pyrite and Marcasite.—These two sulphides of iron are common in the nodules of the Coal Measures. At times they occur beautifully crystallized. Occasionally the woody tissues of fragments of the Coal Measure flora have been replaced by them. The fossils containing marcasite unfortunately soon crumble on exposure to the air.

Cone-in-cone.—In a cutting on the Lehigh branch of the Mason City and Fort Dodge railroad, just above Duncomb's mill, a layer of cone-in-cone eight inches thick may be traced for a hundred yards. This mineral when found in detached fragments is often thought to be petrified wood on account of its fibrous structure. The fibers of the mineral are arranged in bundles in the form of a cone, and when the outer layers are removed, an inner cone appears. Cone-in-cone has previously been reported from Iowa by Owen* and Beyer.† Chemical analysis by Professor G. E. Patrick showed that it is nearly pure calcium carbonate ($Ca\ CO_3$, equalling 83.12 per cent). Calcium carbonate in its ordinary crystalline form, calcite, is not common. Small crystals are sometimes found in cavities in the Saint Louis limestone.

Celestine.—This mineral, the sulphate of strontium ($Sr\ SO_4$), has been found in at least two localities in Webster county in limited quantities. In 1896, near Kohl's brewery at the mouth of Soldier creek, a mass of fine crystals was taken out of the shales overlying the gypsum. It has within recent years been reported from the vicinity of the old packing house on the left bank of the river just below Fort Dodge. White‡ mentions both of these localities and says that celestine has been found in Webster county both in the Coal Measure shales, and in the clays that overlie the gypsum. The layers found by him were not more than a rod in length and three inches in thickness. In all cases the mineral is light blue in color and nearly transparent. Strontium is sometimes obtained from it, but it must occur in large quantities to possess commercial value.

Copperas or Ferrous Sulphate.—($Fe\ SO_4$) On the face of the sandstone ledges in Prairie creek a white powder forms, which is washed off by the rains only to reform within a few days. Instead of powder there are at times slender, white, needle like crystals. Both crystals and powder are the sulphate of iron or copperas as it is commonly called. Massive crystals of copperas

* Geol. Iowa, Wisconsin and Minnesota, p. 123.
† Iowa Geol. Surv., Vol. V, p. 231.
‡ Geol. of Iowa, White, 1870, Vol. II, p. 304.

are said to have been found at the old coal mines above Fort Dodge.

Aluminum Sulphate.—($Al_2 SO_4$.) This mineral was found filling small cavities and forming small layers in the Coal Measure shales exposed along the Des Moines river below Lehigh. It occurred in the form of a brown powder. At no point was it found in considerable quantities, though a few pounds could be obtained readily.*

Tufa Beds.—Near the mouth of a small ravine on the right bank of the river, one-half mile above Lehigh, in Burnside township, Sec. 1, Sw. ¼, there is an extensive deposit of calcareous tufa. The deposit covers to a thickness of several feet the Coal Measure sandstone that forms the bank of the hollow. It contains innumerable beautifully preserved impressions of leaves of the hardwood trees now common to the locality, as well as shells of Mesodon.

It is doubtless the result of an extensive lime bearing spring and the material has recently been deposited, though no spring now exists in the locality.

Soils.

With but trifling exceptions, the soil of Webster county is glacial in origin. It is rich in lime and generally effervesces with acid vigorously from the grass roots down. It yields most abundant crops of the grains and fruits that the climate permits. The surface is but seldom covered with more bowlders than are desirable for the construction of foundations for farm buildings. On the lower river terrace the silt makes a very desirable soil.

Prehistoric Inhabitants of Webster County.

Relics of people that inhabited the country at a period much earlier than the advent of the white man, have from time to time been found, and have always attracted a great deal of popular interest. Conspicuous mounds in the vicinity of Lehigh have long been recognized as the work of the mound builders, and

* Analysis was made by Prof. J. B. Weems.

those that have been opened have yielded fragments of decorated pottery, portions of human skeletons and arrow points.

A locality which has of late years attracted considerable attention on account of its relics of prehistoric age is "boneyard hollow." This is the name given to the mouth of a ravine two and a half miles above Lehigh, on the right bank of the river. The river here develops two terraces, shown in the sketch as T 1 and T 2. On the south bank of this ravine, in the second terrace, bones, arrow points and bone ornaments in considerable numbers have been found. The width of the ravine here is considerable, perhaps a hundred yards. The bones are those of buffalo, and with the exception of the teeth, which are abundant and well preserved, are badly decayed. They are buried under six feet of silt and above them trees of considerable size are growing, among others a hard maple twelve inches in diameter.

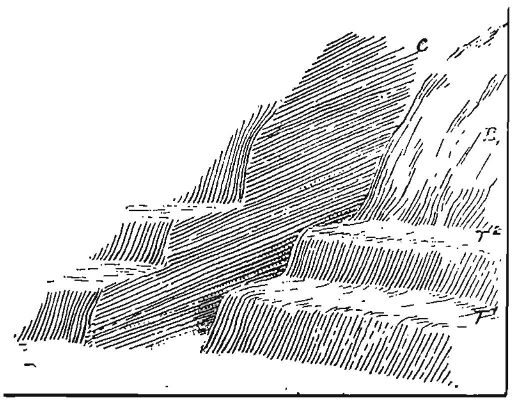
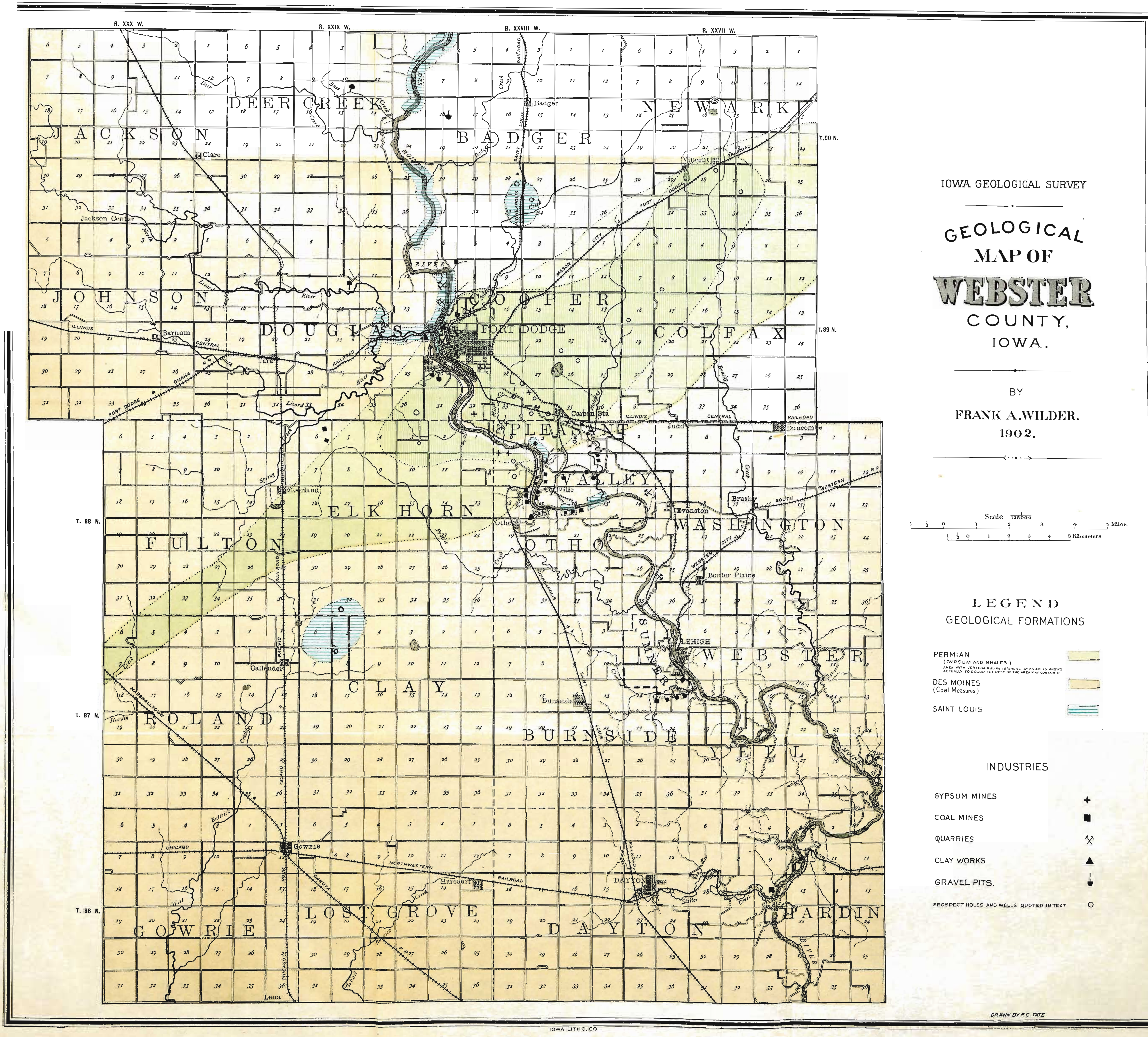


FIG. 27. Sketch of the ravine and terraces at "Bone Yard Hollow"

Shells of Mesodon are common in the silt. With the bones a double ring was found, in pattern like two of the three rings in the Odd Fellows' symbol. They were skillfully carved out of bone, probably the tip of a buffalo horn, and each is an inch in diameter.

If these relics are considered as old as the terrace T 2 in which they are found, their antiquity is considerable and some importance must be attached to them. Unless, however, similar relics are discovered far back in the terrace, away from the edge to-


IOWA GEOLOGICAL SURVEY
GEOLOGICAL MAP OF WEBSTER COUNTY, IOWA.
BY FRANK A. WILDER. 1902.
Scale 1/125000
5 Miles
5 Kilometers
LEGEND
GEOLOGICAL FORMATIONS
PERMIAN (GYPSUM AND SHALES.)
AREA WITH VERTICAL RULING IS WHERE GYPSUM IS KNOWN ACTUALLY TO OCCUR, THE REST OF THE AREA MAY CONTAIN IT
DES MOINES (Coal Measures)
SAINT LOUIS
INDUSTRIES
GYPSUM MINES
COAL MINES
QUARRIES
CLAY WORKS
GRAVEL PITS.
PROSPECT HOLES AND WELLS QUOTED IN TEXT
R. XXX W.
R. XXIX W.
R. XXVIII W.
R. XXVII W.
T. 90 N.
T. 89 N.
T. 88 N.
T. 87 N.
T. 86 N.
JACKSON
DEER CREEK
BADGER
NEWARK
JOHNSON
DOUGLAS
COOPER
COLFAX
PLEASANT
VALLEY
ELK HORN
FULTON
WASHINGTON
OTHO
SUMNER
WEBSTER
CLAY
ROLAND
BURNSIDE
YELL
GOWRIE
LOST GROVE
DAYTON
HARDIN
Clare
Badger
Vincent
Jackson Center
Barnum
Tara
FORT DODGE
Carbon Sta.
Judd
Duncombe
Moorland
Coalville
Kalo
Otho
Evanston
Brushy
Border Plains
Lehigh
Callender
Burnside
Gowrie
Harcourt
Dayton
Lena
DES MOINES RIVER
ILLINOIS CENTRAL RAILROAD
FORT DODGE & OMAHA R.R.
MASON CITY & FORT DODGE RAILROAD
MINNEAPOLIS & SAINT LOUIS RAILROAD
CHICAGO & NORTHWESTERN RAILROAD
WEBSTER CITY & SOUTHWESTERN R.R.
CHICAGO ROCK ISLAND & PACIFIC RAILROAD
MARSHALLTOWN & DAKOTA R.R.
DRAWN BY F.C. TATE
IOWA LITHO. CO.

ward the river and ravine, it is much more natural to suppose that the bones and implements accumulated where they are now found and were afterward covered by material washed down upon them from points higher up on the terrace. Shells of Mesodon abound at higher points and might easily have been washed down, with earth and sand, over the old camp fire of Indians who sought the edge of the ravine for shelter from the wind. It would not seem wise, therefore, to ascribe to them great antiquity. The bone rings, too, are of a pattern which Indians and mound builders did not know, and which suggests contact with white men.

ACKNOWLEDGMENTS.

In the preparation of this report the writer is indebted to many persons. He enjoyed the company of Professor Calvin in visiting the typical drift exposures of the county, and in determining the age of the drift was aided by his judgment. In the discussion of the age and origin of the gypsum the aid and influence of Professor T. C. Chamberlin is gladly acknowledged. Dr. H. F. Bain spent some time in the field searching for suitable material for Portland cement. Dr. Charles R. Keyes' previous report on the Webster county gypsum was of service at many points. Prof. Macbride identified the ferns and other representatives of the Coal Measure flora. Mr. A. W. Ristine, a student at Harvard, carried out successfully many details of the field work in the summer of 1900. The various well drillers whose names are given in connection with data cited were generous and courteous in furnishing this valuable information. The managers of the various coal companies contributed important facts which go far toward making the report complete.

THE GYPSUM INDUSTRY

OF

GERMANY.

THE GYPSUM INDUSTRY OF GERMANY.

During the past ten years the German gypsum industry has made rapid advances. In amount of money invested, in the quantity of the output, in development of machinery and in the variety of uses to which the manufactured products are put, it surpasses the gypsum industry of the United States. This may be accounted for in part by the fact that the chemical and physical properties of gypsum have been more carefully studied in Germany. The demand for more permanent and fireproof building material than is commonly used in America has doubtless been an additional stimulus to the gypsum industry of Germany. On the other hand, the industry in the United States has developed certain valuable characteristics to meet the peculiarities of the American manner of building which are unknown in Europe. Before its recent rapid progress the German gypsum industry underwent a long and gradual evolution. Gypsum plaster was used in many of the old feudal castles, many of which are still standing, and are cited as a proof of its durability. The first grinders of gypsum rock were the millers and the first calciners were the bakers. Traces of these original processes may be seen in many of the methods employed today. Early efforts at economy in fuel were made by those who endeavored to calcine gypsum with the waste heat of the lime pit. Indeed, in some parts of the country these primitive processes linger, and contrast strikingly with a modern mill like that of the Rhenish gypsum industry at Mannheim where fuel and labor are economized by continuous rotating calciners and where the mill is walled, floored and roofed with gypsum plasters.

The German gypsum industry has three great centers; the Hartz mountains north of Nordhausen, about the village of Ellrick; in Thuringia, near Possneck, in the village of Krolpa; and at various towns on the Rhine, near its confluence with the Neckar.

With one of two exceptions, the mills are located near the gypsum beds. These exceptions are instances where the raw material is brought nearer to market and to fuel by river boats.

The industrial conditions differ somewhat from those in America. Labor in quarries, mines and mills is paid about one-half as much as service of the same sort would receive in the United States. Fuel, on the other hand, which in the manufacture of gypsum plaster is secondary only to labor, costs more than twice as much. The price received for plaster is much less than in America, and competition for trade is stronger. An annual meeting of the gypsum manufacturers regulates prices. In a measure this meeting is also beneficial by reason of its discussion of new processes in manufacturing and new uses for the products. At the last meeting, which was held at Berlin, it was proposed that all mills unite in publishing circulars and a magazine, to go to the building trade of Europe, making plain the many uses to which gypsum plaster may be put.

In preparing this report the chief mills in Thuringia, on the Rhine and at Ellrick in the Hartz, were personally visited. German literature bearing on the subject was, as far as possible, carefully studied. Out of date processes which were found in operation or described in the text-books will not be here discussed. An effort has been made to make the report practical and not load it with matter which will be of no value to the American manufacturer. Those who care to study the German industry farther will find the books and magazines given below useful:

1. Der Gips und seine Verwendung, Handbuch fur Bau und Maurermeister, Stuccateure, Modelleure, Bildhauer, Gipsgiesser, u, s, w, von Marco-Pedrotti, mit 45 abbildungen; Vienna, Pest, Leipsig, A. Hartleben's verlag, 1901.

2. Handbuch der Baustofflehre, fur Architekten, Ingenieure, und Gewerbetreibende sowie fur Schuler Technischer Lehranstalten; von Richard Kruger, in zwei banden mit 443 abbildungen; Vienna, Pest, Leipsig, A Hartleben's verlag, 1899.

3. Prometheus, Illustrirte wochenschrift uber die fortschritte in Gewerbe, Industrie, und Wissenschaft, herausgegeben von Dr. Otto N. Wirt, verlag von Rudolph Muckenbuger, Berlin XII Jahrgang, 1900, Nr. 583, 584 und 602.

KINDS OF GYPSUM PLASTER USED IN GERMANY.

In this report the kinds of gypsum plaster used in Germany will be first described, followed by an account of the various methods used in milling and calcining. Crushed and ground gypsum in four distinct forms is put upon the market. These are stuck gypsum, estrick gypsum, porcelain gypsum and dunge gypsum. These four sorts of gypsum are prepared by different methods and are used for different purposes.

STUCK GYPSUM.

By this name the Germans recognize gypsum that has been heated to a temperature of about 300° Fahrenheit (147° C.) and has lost 14 per cent of its water of crystallization. It is ground either before or after this process of calcining. It is practically what is known in America as calcined plaster. In Germany as in the United States stuck gypsum is used chiefly as a covering for interior walls, but on account of fundamental differences in the ordinary methods of building in the two countries, the manner of application is very different. It is also used for purposes to which it is not applied in the United States.

Stuck gypsum (calcined plaster) as material for covering interior walls.

1. As covering for lath. Very little wood is used in building the walls of a German house. The reason for this is twofold:

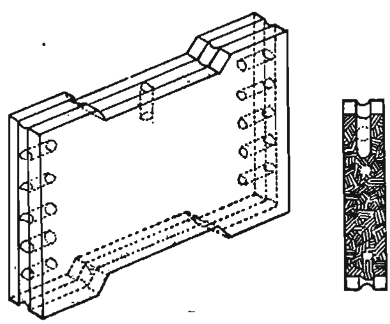


FIG. 28. Gypsum board used in making walls where few uprights are used.

wood is expensive and, moreover, the German seeks to make his buildings as nearly fireproof as possible. For this reason interior walls made of wooden uprights covered with lath and mortar, do not appeal to him as suitable building materials. Yet this kind of wall is not unknown in Germany. When gypsum is employed in making mortar to cover such walls two parts of sand are added to one part of gypsum. No hair or retarder is used.

2. Mortar for interior brick walls.* Another mixture in great favor in Germany as wall plaster consists of three parts quick lime, one part calcined plaster and one and a half parts fine white sand. This is the common mortar employed to cover interior brick walls, which are general in Germany. This plaster is often made smooth by subsequently covering the surface with a coat of gypsum and lime water, and rubbing with sandstone, tripoli and felt. A polished wall surface is also secured in a

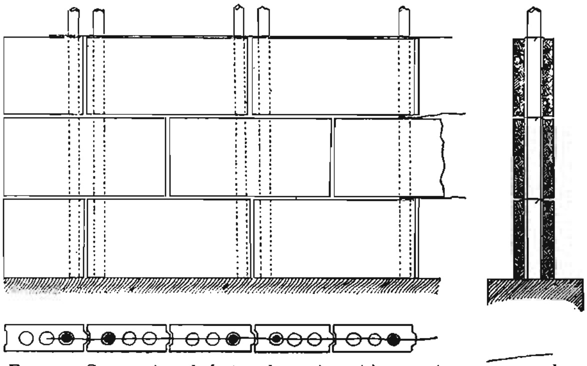


FIG. 23. Gypsum boards fastened together with cement or gypsum rods.

somewhat similar manner. After the plaster has been washed with the gypsum lime water mixture and thoroughly dried, it is covered by means of a trowel to the thickness of three millimeters with a coating of very fine mortar composed of lime and gypsum, to which ten per cent of fine sand or marble dust is added. This is finally rubbed over with polishing wax.

3. Mortar for ceilings. Ceilings are made by using lath or wire as a background on which to spread mortar. A composition somewhat different from that used for walls is recommended for ceilings by German builders, namely, two parts gypsum and one part sand, without any lime. When laths are used the space between them is two and one-half centimeters.

* Baustcffiehe, Kruger, (Wien, Pest, Leipsig a, Hartlebens verlag, 1899.)

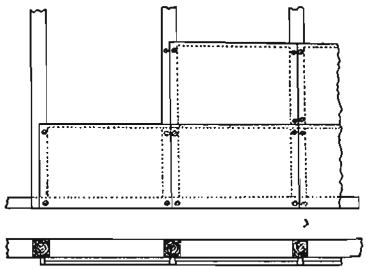


FIG. 30. Gypsum boards nailed or screwed directly to wooden uprights.

4. Stuck gypsum (calcined plaster) as covering for wire walls. Stuck gypsum, lime water, hair and sand, mixed as for ordinary wall plaster, are used in Germany to cover the wire netting which takes the place of lath. The wire used is from one to one and one-tenth millimeters thick, woven with a two centimeter mesh, and held in place by angle iron or by round iron, with a diameter of one centimeter. The gypsum mortar when hard is covered with a wash of gypsum, lime and fine, clean sand. Walls so made are fireproof, are poor conductors of heat and occupy but little space. They are made both single and double.

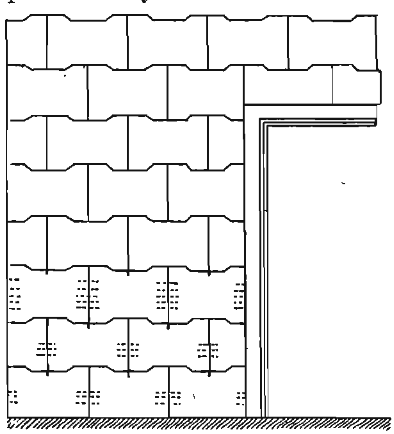


FIG. 31. A wall of gypsum boards in which no uprights are used, the boards dovetailing into one another.

When single their thickness is but five centimeters and when double, with an air space between of five centimeters, each wall has a thickness of three centimeters, making the total thickness of both walls, with enclosed air space only eleven centimeters.

The gypsum mortar to some extent oxidizes the wire. A certain amount of such oxidation is desirable for it binds the mortar firmly to the wire. It will not proceed beyond the desirable point if the wall is normally dry. For walls which are greatly exposed to moisture some other form of construction would be safer.

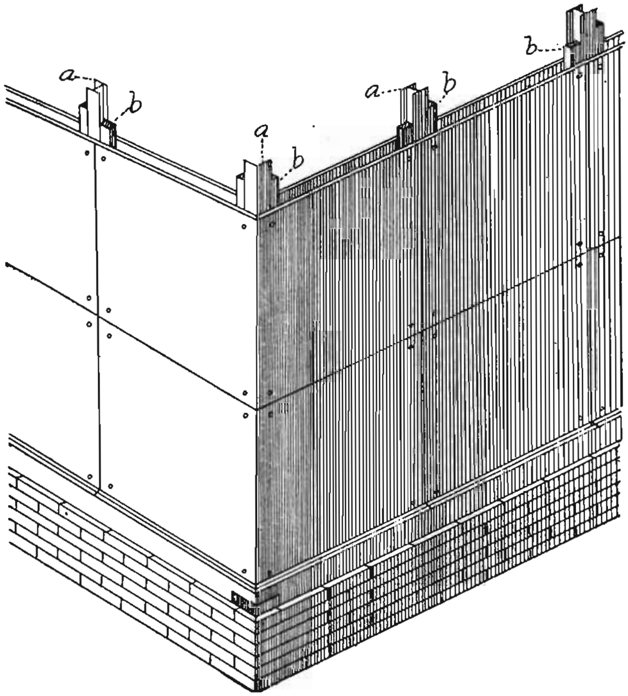


FIG. 32. Gypsum boards fastened to narrow wooden strips in iron uprights. Such a wall is practically fire proof.

Special devices in which calcined plaster (stuck gypsum) is made into boards or slabs which are attached to a framework to form an inner (rarely an outer) wall.—Under this head are included the most interesting and unique features of the manipulation of gypsum in Germany. These are practically unknown in American building methods,* and there are no English equivalents

* In New York and Chicago gypsum boards somewhat like those described here are rapidly coming into favor.

known to the writer for the German terms. In this report, therefore, for the words gypsdielen and schulfbretter, the term gypsum boards will be used. A description of gypsum boards as made at Ellrick will answer in general for many forms made both in Germany and Switzerland. Calcined plaster (stuck gypsum) is mixed with water and a certain amount of sawdust. On an iron table with a heavy iron top are laid iron strips, which have a thickness equal to that intended for the gypsum board. The space enclosed by these strips also determines the length and breadth of the board. Within this space is scattered excelsior, jute and rushes, and over these is poured the gypsum, water and sawdust mixture. The rushes and excelsior are carefully worked to the middle of the mass by hand. An iron bar is drawn over the top of the strips, leaving the surface of the mass either smooth or ridged. It is allowed to stand about five minutes, and then the iron table on which the mass rests is struck vigorously two or three times with a heavy mallet. This loosens the gypsum board from the iron plate and strips. It is already so firm that it may be picked up and carried without injury. A workman takes it on his shoulder and carries it to an open shed where it stands on end till dried by natural heat. The length of time required for drying depends wholly upon the atmospheric conditions. Artificial heat for drying gypsum boards has proven very unsatisfactory, as the boards so dried crumble

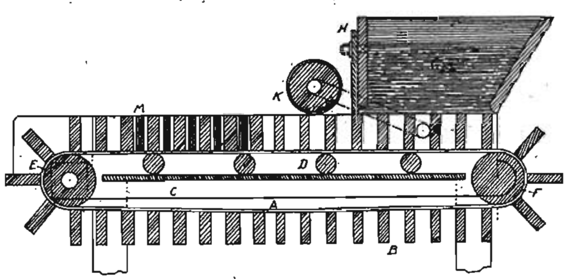


FIG 33. Sketch of machine for making gypsum boards. (Described in text.)

readily on exposure to the air. At Ellrick elaborate attempts to dry them by steam heat have proved failures.

The Rhenisch Gypsindustrie at Heidelberg has devised machinery by which gypsum boards are made with a minimum of hand labor. One form of this machine is shown in figure 33. It consists of an endless belt upon which are a series of strips so set that the spaces between them and the belt form a series of moulds of the size desired for the boards. This belt (A) moves in a box (C) on rollers (D) propelled by the wheels E and F. At one end of the box (C) is a case (G) in which the gypsum mortar is placed. It is fed down into the moulds on the belt as they pass beneath the case (G). By the time the filled moulds reach the wheel (E) the gypsum boards have hardened and may be safely removed. The thickness of gypsum boards varies from three to eight centimeters. Often they are made with large round air spaces within, like hollow brick, and then their thickness reaches twelve centimeters, their length varying from five to twelve feet. They are used mainly for inner walls, being fastened directly to wooden or iron stringers. When used for outer walls the outer surface is made rough while the material is still soft so that some protective covering will adhere to it. For this purpose thin white lime mixed with one-third gypsum is often used, and this is in turn covered with thick white lime without gypsum. Thin white limestone covered with thick lime water, with one-fifth Portland cement, may also be employed. This outer covering is never more than one centimeter thick. Asphalt paper is also used to render the boards impervious to moisture. The accompanying sketches, after drawing in the Handbuch der Arkitekture, show some of the forms of gypsum boards, and methods of fastening them to wooden and iron uprights.

The weight of gypsum boards 2.5 centimeters thick is about fifty pounds per square meter, and for boards 8 centimeters thick about 120 pounds. During a series of experiments made at Berlin in 1890 it was found that a weight of 100 pounds when dropped from a height of six feet upon the middle of a gypsum board produced a dent only 5 millimeters deep. The shape of the weight is not given in the description of the experiment.* The gypsum boards possess considerable elasticity. Their ability to withstand pressure is shown in the following table:

* Kruger, Baustofflehre, II, p. 47.

THICKNESS OF GYPSUM BOARD.	DISTANCE OF POINT AT WHICH PRESSURE WAS APPLIED FROM POINT WHERE GYPSUM BOARD WAS SUPPORTED, IN METERS.							
	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
	WEIGHT IN POUNDS SUPPORTED BY EACH SQUARE METER.							
3 Centimeters	160	100						
4 Centimeters	300	140	70					
5 Centimeters	300	250	130					
7 Centimeters	950	550	350	250	180			
10 Centimeters	1800	1040	660	464	340	260	202	
12 Centimeters	2500	1420	900	620	460	2[illegible]0	250	226

Gypsum boards are also made with both sides hardened and made smooth by oil. These are used chiefly where the walls are to be papered at once.

Another form of board which is highly recommended has a paper center. Heavy sheet paper is suspended in the center of moulds and about this the gypsum plaster is poured. This expands on hardening and the pressure so produced causes an intimate union between the paper and plaster. The moulds are made with readily detachable sides, and the boards when hardened are easily removed. Moulds are usually made so that a number of boards may be cast at the same time.

In similar moulds are made the hollow boards and all the thicker forms made with reeds or paper.

An excellent substitute for reeds and paper would probably be found in the corn stalk, or some product derived from it.

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

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

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

Mixtures containing gypsum which are recommended for ornamental purposes are: One part gypsum plaster and one part lime; four parts gypsum, three parts white chalk or lime, and one part fine sand. For white ornaments one part fine gypsum plaster, two parts white chalk, with a limited amount of lime water; for gray figures, a mixture of gypsum plaster with fine coal dust. The latter mixture gives a considerable degree of hardness, but when objects made from it are exposed to moisture and frost they fall to pieces.

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

Stuck gypsum (calcined plaster) used in making artificial marble.—The ingredients are gypsum, finely sieved and burned limestone, and coloring matter. Lime is used in only limited quantities and its function is simply that of a retarder so that the mass may not set within thirty minutes. The mass is worked up in a ball, the coloring matter being worked through in streaks, like the veins in marble. The ball is cut with wire into slabs, which are placed at once upon the wall or over the surface to be covered. When the surface has hardened it is smoothed with pumice and rubbed with a thin solution of gypsum, which closes any pores. It is then rubbed with tripoli and olive oil and finally polished with a woolen cloth. Earth colors are suitable for this purpose, and also any used by the frescoers which are not destroyed by lime. A great many processes for producing marble-like effects with gypsum plaster have been patented in Europe. One of the most recent was issued to Pietro Viotti. In this process 1500 grams of borax and 150 grams of magnesia are fused together, and when cool mixed with seventy-five kilograms of gypsum.

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

1. Keene's cement or English white cement is a slow setting alum gypsum. Gypsum, preferably a white variety, unground, is burned at a red heat, then soaked in an alum solution, burned a second time at a red heat, and then finely ground. When used it is mixed with an alum solution. If it is used with 20 per cent water, it has a tensile strength of seventy pounds and a crushing strength of 800 pounds per square centimeter.

2. Parian cement consists of 44 parts stuck gypsum (calcined plaster) and one part calcined borax. The gypsum is saturated with water having the borax in solution and burned at a red heat. It sets slowly and dries in five or six hours. It is used as a covering for both inner and outer walls and may be painted or cov-

ered with paper. It should be mixed with as little water as possible, and must not come in contact with fresh lime.

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

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

ESTRICK GYPSUM.

Estrick gypsum differs materially from gypsum plaster of any form known in America, both in its properties and method of preparation, unless the "secret process" used in the Best Brothers mill in Kansas produces it. The German name, therefore, for this sort of gypsum plaster will be used in the following description. In preparing estrick gypsum, gypsum rock is heated for a number of hours at a temperature in the neighborhood of 500° C., in a kiln which will be described later. It is ground coarse, and when mixed with water without any admixture of sand or coal ashes, it very slowly sets and forms an extremely hard mass. Its hardness makes it a suitable material for floors, taking the place of Portland cement and often rendering better service.

Floors made of estrick gypsum have as a bedding sand, coal ashes, brick or wood.

Estrick gypsum reaches its full hardness only when allowed to dry protected from moisture, and for this reason care must be taken to secure a proper foundation. Cracks will appear if it dries unevenly or very rapidly and in this case the surface must again be covered with water till it is soft and the cracks close. The mass must then dry again. After standing about twelve hours and becoming fairly hard, it is pounded with wooden mallets and smoothed with trowels. The pounding materially increases the hardness. In German texts on building material, estrick gypsum is especially recommended as floor material for factories, kitchens, granaries, store rooms and, when suitably colored, for bathrooms and hospitals.

Pure estrick gypsum is considered best for these purposes, but if for economy this is impossible, one-third pure quartz sand or coal ashes may be used. With estrick gypsum marble may be imitated and a very hard as well as ornamental stone is the result. It may be polished with sand or sandstone, then with pumice and water. After rubbing with wax dissolved in alcohol, it is polished again with stiff brushes.

An addition of Portland cement to the estrick gypsum has at times been recommended to increase the hardness. This, however, is generally regarded as useless.

A cubic meter of hardened estrick gypsum weighs about 2,000 pounds.

The following methods of applying estrick gypsum to floors is recommended by German authors. A bedding of sand 5 centimeters thick is first laid down. If sand is expensive, this may be reduced to 3 centimeters. On this the estrick gypsum mortar is spread to a thickness of 3 centimeters. In preparing the gypsum mortar a box about 1.8 meters long, 1.2 wide and 0.4 high is used. In this box the gypsum is mixed with water till a thick mortar is formed. The water is placed in the box first and into it the gypsum is poured. The gypsum mortar so made is laid on the sand foundation in the following manner. At a distance of three feet from one of the walls a wooden strip in thickness equal to that of the desired estrick layer, is placed parallel to the wall. Between this and the wall the gypsum plaster is poured. After the water in the mortar has in part soaked into the sand and in part evaporated, the mortar is rubbed over with a steel bar and partially smoothed. Perhaps an hour later it is rubbed over again and made still smoother. Then the wooden strip is removed to a distance of three feet and the process repeated. The edge of the part previously prepared is beveled or hollowed so that the new strip may lap over it and become definitely a part of the one already made. At the end of twenty-four hours the floor will be so hard that the foot of an adult makes no dent in it. It is then vigorously tamped till water again appears on the surface. Finally it is smoothed with a steel bar.

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

Mortar for masonry.—That gypsum will furnish an extremely durable mortar under certain conditions is fully recognized in Germany. Many old castles, towers and walls that are well preserved today are held together by gypsum mortar. An example often referred to in German literature on gypsum is Walkenried in the Hartz. In this same district, where gypsum is very abundant, tall chimneys for factories are constructed with gypsum mortar. An inner lining of fire brick is essential, as well as an outer wall of regularly set stone. Between these rocks are placed irregularly and over them gypsum mortar is poured, filling the spaces between the blocks. The mortar, which is formed of two parts gypsum and one part sand and one part soft water, is not used for the foundation of such chimneys for it crumbles wherever it is continually exposed to moisture.

In the German texts which treat of gypsum, for instance Kruger's Baustofflehre, estrick is recommended unconditionally for masonry, and its ability to withstand the weather is positively affirmed. The manufacturers who were consulted, on the other hand, indorsed it chiefly for interior work.

Mack's gypsum cement consists of estrick gypsum to which 0.4 per cent calcined Glauber's salts (Na_2SO_4) or potassium sulphate (K_2SO_4) have been added. This cement is unusually hard and durable, sets quickly and unites minutely with the material on which it is placed. It is used as a covering for wire mesh on walls and ceilings as well as for floors and may be mixed with sand or ashes. Its surface is but slightly porous and for this reason absorbs but little oil when covered with paint.

PORCELAIN GYPSUM.

In the German porcelain industry great quantities of gypsum are used. It is prepared in a special manner and has properties differing from those of other varieties of gypsum. It is ground exceedingly fine, and after setting is much lighter than ordinary wall plaster or stucco, and is much more porous. On account of this latter property it is particularly adapted to the part assigned it in the porcelain industry. Nearly every piece of porcelain receives its shape in a mould, which may be made out of clay, wood, wax or metal, but for most of them gypsum is used. Its peculiar property of drawing out the water from the surface of the clay gives gypsum special value for this purpose. Although the surface of the gypsum moulds is made as hard as possible by rubbing with oil, the sharp edges necessary to insure accurate casts wear off, and from time to time the mould must be discarded and replaced by a new one which is made from an original clay model. A hundred imprints may be made from an ordinary gypsum mould. If the pattern is intricate the number is less. Thus a single porcelain factory consumes a great quantity of gypsum and many mills are engaged in supplying gypsum for this industry alone. The chief centers of the porcelain industry are about Dresden and in Thuringia.

DUNGE GYPSUM (LAND PLASTER.)

Dunge gypsum is, as the German name implies, gypsum prepared for use as a fertilizer. As in America, gypsum for this purpose is merely ground, and not calcined. Considerable quantities are so used in Germany.

PROCESSES OF MANUFACTURING THE VARIOUS SORTS OF GYPSUM PLASTER USED IN GERMANY.

Germany has no novel methods for mining or quarrying gypsum and transporting it to the mill. In Thuringia and the Hartz the mineral occurs in great hills where no stripping is required.

In the picture, Fig. 34, the hill on the right is composed wholly of gypsum. At various points on the Rhine gypsum is mined. Tramways and endless conveyors carry it in large fragments to

Fig. 34. Mill and one of the quarries of the Krölpa Gypsum Industry, at Krölpa, in Thuringia.

the mill. Here it is treated in various ways, depending on the nature of the product desired.

MANUFACTURE OF GYPSUM PLASTER (STUCK GYPSUM.)

A great deal of gypsum plaster, especially of the finer sorts, is prepared by the same processes which are used in making porcelain plaster. These will be described farther on. In all other processes the gypsum is ground before calcining. Preliminary pulverizing is done in crushers and nippers of the Blake pattern, as in America. For the final fine grinding machines of various sorts are used.

Grinding.—1. As in America, most of the gypsum is ground between burr stone mills. These mills are of two patterns; in one the stones are placed in a horizontal position and in the other they are vertical. The vertical mills are smaller in diameter but rotate with great speed, are of large capacity and are cheaper than the horizontal mills. They are more generally used than the latter and are regarded by some manufacturers as better fitted for fine grinding. This statement is, however, not undisputed.

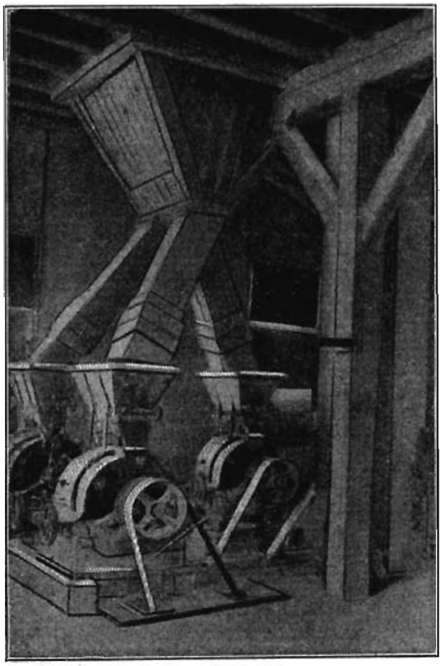


Fig. 35. Vertical mills, as installed by the Rhenish Gypsum Industry.
From Prometheus.

2. At Krolpa in Thuringia an American roller mill of the pattern used for flour is employed in one instance, and the owners reported that it gave satisfactory results. In the same mill also a disintegrator of the Stedman type was in use. The latter, however, had been tried by other manufacturers in the Thuringia district and discarded.

CALCINING OF STUCK GYPSUM.

At least three distinct processes, all regarded as successful, must be described under this heading. In addition to these it will be useful to outline other processes which have been used in Germany, but which have not proven wholly satisfactory. The successful processes are: 1, Calcining in kettles; 2, calcining continuously in rotary kilns of the Mannheim type; 3, calcining in ovens, either individual or continuous.

1. *Calcining in kettles.*—The German calcining kettle consists of a sheet metal cylinder six feet in diameter and three feet high. The bottom is flat and through the cylinder extend no flues as in the American kettle of the same type. This kettle is set in solid masonry directly on a furnace. Usually a battery consisting of three kettles set up together in a series is employed. Firing is generally accomplished by automatic stokers. Each kettle is charged with from one to two tons of gypsum, and, while calcining, the material is agitated by means of a device resembling a steamship propellor, the blades of which extend horizontally across the lower

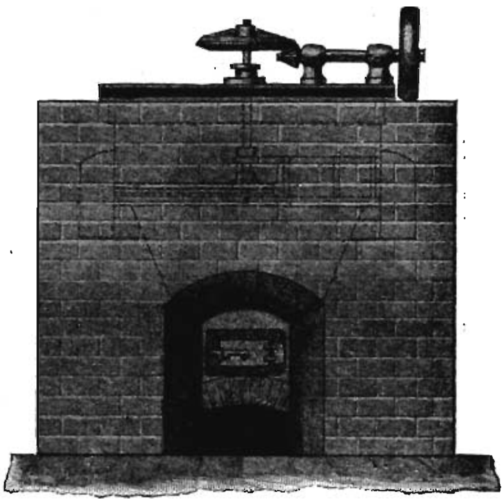


Fig. 83. German calcining kettle, showing agitator.
From Prometheus.

part of the kettle. It is rotated by a shaft connected directly by gearing to the line shafting above.

The kettles discharge into a cooling room which is connected by means of automatic carriers with bins located above the sacking rooms, and also with a room in which the dust arising from the cooling gypsum is allowed to settle. The kettles are also connected with this dust chamber. Through this chamber, therefore, all of the steam given off in the process of calcination is obliged to pass and great quantities of finely divided gypsum, which would ordinarily pass off into the open air with the steam, are caught. The material collected in the dust chamber is removed automatically by means of a spiral conveyor.

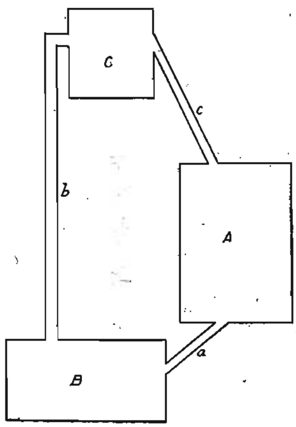


FIG. 37. Sketch showing connections between A. calcining kettle, B. cooling room, and C. dust chamber.

2. *The Mannheim continuous process using rotating cylinders.*—The mill of the Rhenish Gypsum Company, located near Mannheim, is so interesting that it will be well to describe it rather minutely at this point in connection with its unique calcining machinery.

Mannheim is situated on the middle Rhine, fifteen miles northwest of Heidelberg. The works of the Rhenish gypsum industry are located in the village of Wildhof, about four miles north of the city. The plant is modern and fireproof throughout. The roof of the building is made of gypsum boards covered on the outside with asphalt, the inner walls are made of the same material, while the floors are made out of estrick gypsum. In this mill fine grinding of the gypsum is postponed till after calcining. When the material comes from the crushers and nippers it varies in size from the finest powder to fragments as large as an ordinary hickory nut. Varying thus in size, the material goes directly to the calciner.

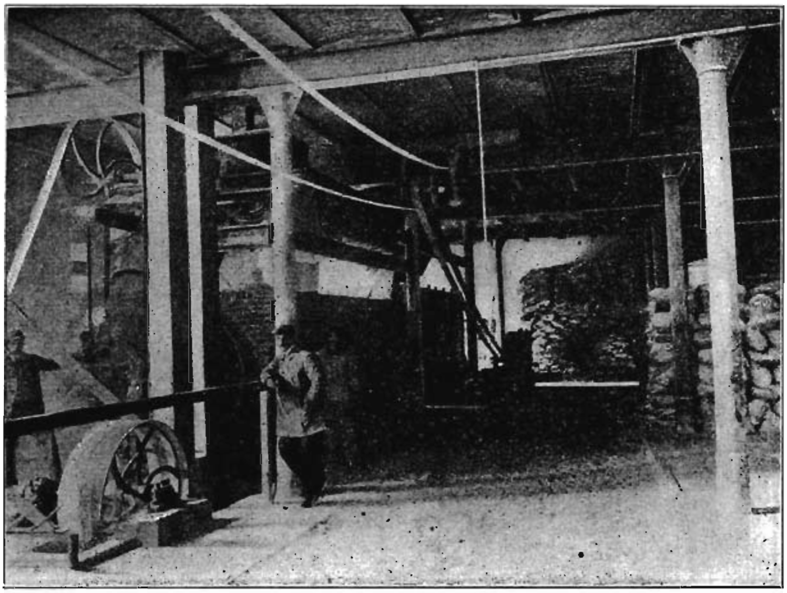


Fig. 38. Interior of Rhenish Gypsum Industry Mill, showing, to the left, the continuous calciner.

From Prometheus.

The calciner consists of a fire box with an automatic stoker, which is placed in front of and connected with a chamber containing a rotating cylinder. Above this cylinder is a chamber called the forewarmer, through which a spiral conveyor passes, from end to end. A pipe leads from the rotating cylinder to the forewarmer, and connects at the other end with the chimney. Connected with the fire box is a fan by which a forced draft is secured. In the figure this fan, instead of being connected with the fire box, is shown connected with the rotary cylinder. The fire box is heated to a high temperature, and the draft, forced by the fan, passes through the rotating cylinder, and then through the forewarmer. The gypsum is conveyed by bucket elevators from the crushers to a bin above the calciner and thence it flows under the influence of gravity into the forewarmer, through which it is carried by the spiral conveyor. It then falls directly into the rotary cylinder below. Shelves or buckets on the inside of this cylinder pick up the material and elevate it as the cylinder rotates. When the material nears the top the slant of the shelves is so great that it falls again to the bottom. This process of raising the gypsum and allowing it to fall is constantly repeated, the strong draft of hot air passing through the cylinder from the fire box strikes the gypsum as it falls from top to bottom and moves the fragments toward the rear with a velocity directly proportional to their size. The coarser material moves much more deliberately, and thus is exposed to the heat longer than the finer and more readily calcined particles. In this way, though the material entering the rotating cylinder varies greatly in fineness, the finer is not "dead burned" and the coarser is sufficiently calcined. All of the heat has not been exhausted from the air in passing through the rotary cylinder, and this is for the most part saved by forcing the air, after it leaves the cylinder, through the forewarmer. In this process the heat is so completely utilized that the air and furnace gases pass to the chimney with a temperature of only 80° C. Between the forewarmer and the chimney the dust chamber is situated. Here all of the finer particles are allowed to settle and the air passes on to the chimney practically free from dust. No gypsum was seen about the outside of the mills and the roof showed no trace of dust, while within everything was dust free except the grinding and sacking rooms. To calcine one ton of gypsum by this Mannheim method experience has demonstrated that on the average only 100 pounds of rather inferior bituminous coal is required. An automatic recorder indicates constantly the heat of the rotary cylinder, and this, with the mechanical stoker, insures an even temperature during the entire process of calcining. From the rotary cylinder the gypsum is again elevated to the floor above, and passes through a spiral conveyor which is surrounded with a water jacket. Here the gypsum is cooled, and passes on to the sieves. That portion of the gypsum which does not need further grinding is separated by the sieves and the rest goes to the vertical mills. The process and machinery of the Mannheim mill are to be recommended:

1. For economy of fuel; the amount of coal consumed is only one-half that required for calcining with cylindrical kettles.

2. The continuity of operation greatly reduces the amount of hand labor.

3. The fact that the gypsum is finely ground after calcining results in a great economy of power. The stones of the burr mills also wear much longer and need to be dressed but seldom. The saving due to these facts is considerable.

Before the Mannheim system is introduced, however, it should be determined carefully that the gypsum is as uniformly calcined as by the present American methods. So far as Germany is concerned, it has been demonstrated that the calcining is uniform enough to satisfy the demands made by the German builder. The American mason, however, may require a finer product than the German. A limited amount of soot also settles in the gypsum and it is slightly coated with calcium sulphide, due to the reaction of the sulphur always present in the coal on the gypsum. For ordinary building purposes, however, these do not injure the quality of the gypsum.

3. *Calcining with either individual or continuous ovens.*—This process is used also, and even more commonly, in calcining porcelain gypsum, and will be described later under that heading.

4. *Other devices for calcining that have been tried more or less successfully in Germany.*—Calcining with superheated steam.* A method of calcining by steam called Violett's method from its inventor, is commended by some German technical experts and discouraged by others. The method in Germany is very new, and was not found in operation in any of the mills personally visited. Theoretically all agree that the principle used by Violett is excellent. At the last meeting of the German gypsum association this and similar processes in which superheated steam is used, were discussed, and while all agreed that the quality of the plaster so produced was most excellent, some of those present argued that this excellence was secured at too great an expense of fuel. When gypsum is calcined with superheated steam there is very little danger of "dead burning." A sufficient and uniform temperature may

* Gips und seine Verwendung, von Marco Pedrotti, p. 48. Prometheus Nr. 583.

easily be maintained. The product is not discolored by soot as in the Mannheim process. Cheapness is claimed for it also by Pedrotti.*

Steam at one-half an atmosphere pressure is used and at a temperature of 140° to 150° C. It is generated in an ordinary boiler and superheated in a coil of pipes. The gypsum, unground and in rather large pieces, is stacked in egg shaped ovens which are capable of resisting a moderate amount of pressure from within. Through these ovens the superheated steam circulates. The gypsum is calcined in six hours. By the combination of a number of ovens, which are heated by one boiler plant, certain ovens may be charged while others are being emptied, and the process is made continuous. Pedrotti† and Kruger‡ claim that by this process one ton of gypsum may be calcined at the expense of 110 pounds of bituminous coal. Professor Lechner§ makes the criticism that the apparatus as now in use often gets out of order and for this reason has not been found economical. Other calciners which are practically obsolete are described by Pedrotti.||

The calcining of porcelain gypsum.—All agree that the porcelain industry demands a gypsum that has been most uniformly burned and ground. Gypsum which will be readily accepted by the builder will not serve the purpose of the modeler. Tradition, apparently more than anything else, leads certain gypsum calciners to adhere to extremely expensive and ancient methods in calcining porcelain gypsum. Ovens like those employed by the baker in which the gypsum is agitated by long pokers are still used. It is generally admitted, however, that this method is not necessary to produce a plaster of the quality desired. Most of the porcelain gypsum is at present burned in a more inexpensive manner. Much stuck gypsum (gypsum plaster) is also calcined in the same way.

Long rooms with thick walls are constructed out of brick. These rooms have a height of seven feet and are built above a furnace. On the floor of the room and extending out for some distance in front of it is a car track. Cars three feet wide, carry-

* Gips und seine Verwendung.
† Ibid. p. 50.
‡ Kruger Handbuch der Baustofflehre Band II, p. 29.
§ Prometheus Nr. 583.
|| Gips und seine Verwendung, pp. 20-50.

ing a rack with five or more shelves quite like the cars used in America in brick driers, are loaded with gypsum and run into the rooms. The gypsum is previously crushed but not ground, the fragments varying in diameter from an inch to one-fourth of an inch. The shelves are loaded and unloaded by hand.

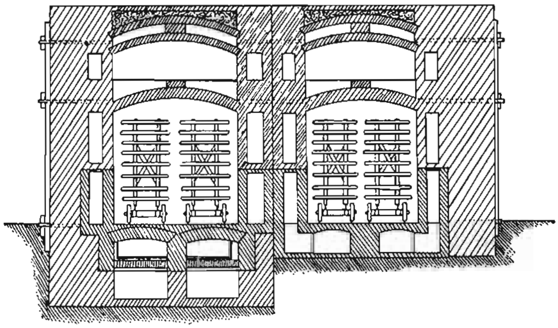


FIG. 39 Cross section of kiln for calcining porcelain gypsum and the finest grade of wall plaster. The crushed gypsum covers the trays borne by the cars, to a depth of an inch.

The smoke and gas from the furnace do not enter the room containing the gypsum, but pass through the walls in flues. From thirty to thirty-six hours are required for calcining. The room is kept at a uniform temperature of 140° C. and long thermometers inserted through the walls and reading on the outer walls, indicate the heat within at any time. An ordinary oven is emptied three times a week and furnishes each time eight to nine tons of calcined gypsum. An effort is made to change the cars quickly so that the heat of the oven may not be lost. Kruger* claims that a ton of gypsum may be calcined in these ovens with 120 pounds bituminous coal, but this estimate seems entirely too low.

The Bock kiln for the continuous burning of brick is used also in Germany for calcining gypsum.† It consists of a straight chamber 150 to 180 feet long. Through this chamber runs a track on which is placed a series of wrought iron wagons loaded with gypsum. In this tunnel under the track a fire is made which is confined to the center of the chamber, so that the cars freshly loaded are gradually warmed. Those directly above the fire have their load thoroughly calcined and those at the farther end are

* Baustofflehe II, p. 20.
† Gyps und seine Verwendung, pp. 27-31. Baustofflehre I, pp. 214-216.

gradually cooling. The cars are moved by a chain which is drawn by machinery outside of the chamber. They are covered and fit into one another with mortise and tennon so that they form virtually a metal tunnel in the chamber. This prevents exposure to smoke and assures a more even distribution of heat through the contents of the cars.

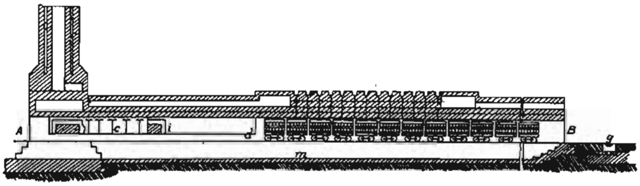


FIG. 40. Section of continuous kiln for calcining the finer gypsum plasters.

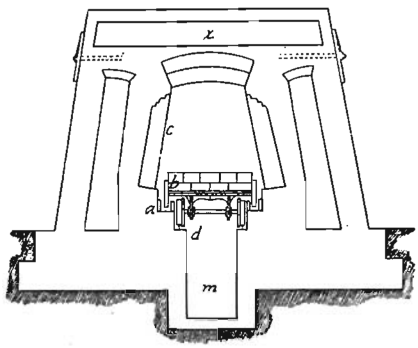


FIG. 41. Cross section of continuous kiln for calcining the finer sorts of gypsum plasters. The fire is at *m* and the cars move slowly along the long tunnel shown in another sketch.

ESTRICK GYPSUM KILNS.

Estrick gypsum is calcined in a kiln resembling the ordinary kiln used for burning lime. When possible, the kiln is located near the quarry or mine, and in a hollow or depression, artificial or natural, so that the trucks carrying the rock from the quarry may be run directly to the top of the kiln and there automatically emptied. The kiln will hold about 200 tons at one time, though all of this amount is not subjected to the full furnace heat. The accompanying diagram will best explain its nature. The sketch is made from the side. The fireplace is represented by D, the ashes falling down into E. The gypsum blocks are thrown in at

A, and the whole interior filled. The fireplace on its upper side and rear is grated, and the flames and heat pass directly up

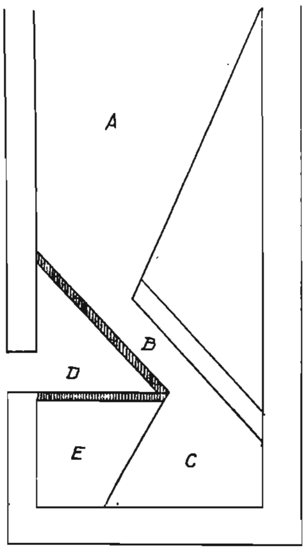


FIG. 42. Sketch of kiln for burning estrick gypsum. (Described in text.)

through A. The hottest part of the kiln is found at B, where a comparatively small amount of gypsum is brought directly in contact with the grates. From time to time the rock which has been exposed to this great heat passes on down into C, the cooling chamber. This will take place whenever the rock already calcined and cooled is removed from C and taken to the mill for grinding. The heat in the lower part of A is so intense that nearly complete combustion takes place, and only gases and hot air, without smoke, pass on up through A, and escape at the top. The process is, then, a continuous one, with but slight loss of heat. There is little danger of overheating the gypsum and no attempt to perfectly control the temperature is made.

Estrick gypsum commands a price twice as great as ordinary gypsum plaster. In every gypsum producing locality the number of estrick kilns is increasing rapidly, and all manufacturers reported a growing demand for this form of gypsum.

TESTS OF GERMAN STUCK GYPSUM.

Samples of stuck gypsum procured in Germany, from the works of Fischer Bros., Krolpa, Thuringia, were tested by Professor Marston at Ames. Stuck gypsum, as previously stated, is made by crushing the raw gypsum to lumps about the size of walnuts and calcining in ovens heated to 300° Fahrenheit for a number of hours, the fine grinding being done after calcining. Stuck gypsum is the only form of plaster of Paris used in the German porcelain factories, and for many purposes in the arts it commands a price double that of kettle calcined plaster. Professor Marston reports as follows:

"Another series of tests was made of German stucco ground very much finer than the Iowa plaster. The fineness of grinding of the different plasters is shown in the table given elsewhere in which it appears that 85 per cent of the German stucco passed a No. 100 sieve as compared with 58.6 per cent to 68.7 per cent of the Flint plaster. More of the Flint plaster was extremely finely ground, however, than the German stucco, as appears from the percentage passing the No. 200 sieve. The tests of the German stucco indicate that it was considerably quicker setting than the Flint plaster, as indicated by the higher strength at the end of one day. There does not appear to be a great difference between the ultimate strength of the German stucco neat and the Flint plaster neat, but with considerable proportions of sand the German stucco gave the higher tests. The peculiar thing about the tests of the German stucco is the lack of adhesion. The result showed very little adhesion for this material."

Two hundred pounds of Iowa gypsum were sent to Germany and burned in "stuck gypsum" ovens, and the plaster so calcined was tested by German porcelain makers and pronounced satisfactory. There is no reason, therefore, why Iowa gypsum should not be used in making stuck gypsum when the American trade demands a plaster with the peculiar properties which this process furnishes.

EXPERIMENTS WITH ESTRICK GYPSUM.

At the suggestion of the writer Professor S. W. Beyer and Mr. I. A. Williams of Ames have undertaken a series of experiments to determine the properties of gypsum calcined at 500° C., the temperature to which German estrick gypsum is heated. The field for estrick gypsum is a large one and it seemed important to prove that gypsum which is commonly regarded as "dead burned" may have valuable properties. Mr. Williams' letter in which he reports on the preliminary experiments is quoted below:

"Our experiments with the material have of necessity been somewhat long drawn out and we have at present reached a stage only preliminary to the tests which you outlined. This delay is entirely due to the preparatory experiments required to determine the best methods of procedure in burning and mixing the water and the most advantageous conditions for setting and hardening. The results of the work so far have been sufficiently encouraging to demonstrate only the advisability of carrying out a much broader series of tests along these lines. I will outline briefly the work that has been done.

All the gypsum made use of was ground in the raw condition as it comes from the bank, to pass an 80 mesh sieve, .28 millimeters, therefore, being the maximum size of grain. In order to ascertain the best length of time to burn the material, samples sufficient in amount to make about seven standard sized briquettes each were heated in a small muffle kiln. The first sample was drawn when the temperature reached 450° C.; the second after standing in a temperature between 450° and 500° C. for one hour; the third after two hours had elapsed; the fourth after three hours; fifth after four hours; sixth after five hours; seventh, six hours; eighth sample, after seven hours' continuous heating at 450° to 500° C.

These were mixed with water to a consistency such that the mortar would by jarring settle into the molds of itself, shaped in briquette molds and allowed to set by keeping them as damp as possible without disintegration, until they had attained sufficient hardness to resist the effects of water poured directly on them. This preliminary setting required a week and a half to two weeks for those which reached the greatest final strength of the series. After this they were kept well wet, though not saturated, by pouring water on them at irregular intervals. On first drying out, the briquettes shrank to dimensions somewhat smaller than the molds. On setting part of this lost volume was regained by swelling to a slight extent. The use of sand as a dilutent, with the gypsum or of any other inert substance, would decrease these changes in volume.

The burning of gypsum is entirely for the removal of chemically combined water. As this is accomplished in ordinary plaster or stucco at from 100 to 170° C., only a part of the water of hydration is removed, leaving a compound of approximately the formula $(CaSO_4)_2H_2O$ according to Le Chatelier. This compound readily takes up water, becoming set plaster of Paris of the formula of the raw material. When burned to red heat, in the neighborhood of 450° to 500° C., dehydration is complete, or the gypsum is 'dead burned' and the $CaSO_4$ remaining combines with water very slowly to form the hydrate.

In the tests under consideration, the sample drawn when red heat was reached acted exactly like ordinary plaster of Paris, setting quickly almost before it could be gotten into the molds, was pure white in color while the others were of a pinkish cast, and attained the strength and hardness of plaster of Paris. All of the others when first mixed with water showed no tendency to set, working like so much flour. My conclusion regarding No. 1 was, that at 450° C., it had not yet lost all of its water of crystallization; the others, having stood at substantially this same temperature for different periods had lost this water entirely.

At the end of thirty-nine days, those that had been burned one hour, two hours, three hours and four hours were broken in a Fairbanks' cement briquette testing machine. Following is the summary of results:

One hour burn, 283 pounds per square inch; two hour burn, 290 pounds per square inch; three hour burn, 287 pounds per square inch; four hour burn, 289 pounds per square inch. The variation among the different sets is not great enough to point to any definite length of time, within the four hour limit, as giving better results than any other. Those heated for longer periods than four hours showed very little if any tendency to set under the same treatment as the ones tested. The limits, however, as to length of time and temparature are pretty clearly established as just beginning red heat, when dehydration is first complete, and a continuation of red heat temperatures for four or five hours, under which the gypsum becomes so completely dead burned that it takes up water so very slowly as to preclude the idea of using it in this condition for a mortar material. All that appears to be necessary is complete dehydration and so far as my work has gone, the shorter the burn after this is attained, the more rapidly will it set.

My experiments have not been extensive enough by far to determine very much as to the best methods of manipulation in burning and especially in the treatment of the briquettes while setting and hardening. Some seemed to do better than others treated in exactly the same way." * * * * * * * *

EXPERIMENTS TO SHOW CAUSE FOR THE DETERIORATION OF STUCCO.

Experience has shown and the experiments of Professor Marston, quoted elsewhere, verify the fact that wall plaster when kept for some time under ordinary conditions loses part of its ability to carry sand, while neat plaster although quite old attains an adhesive strength equal to that of fresh plaster. This loss in ability to carry sand is a practical difficulty in the plaster business. Experiments carried out by Professor Weems and Mr. Williams at Ames show that four year old plaster, which had been kept with ordinary care, contained water equal to 8.6 per cent of its weight while water in fresh plaster is limited to 2.2 to 2.6 per cent. To prevent deterioration, therefore, it would seem wise to ship plaster in packages which are as thoroughly protected from the air as possible and to store in rooms that are dry.

Preliminary Tests of Stucco and Plaster Made by the Civil Engineering Department of Iowa State College.

BY A. MARSTON.

The tests the results of which are given below were undertaken by the Department of Civil Engineering of the Iowa State College in the fall of 1900, as preliminary to a more extensive series of tests to be carried out at a later date. The work was done in co-operation with the Iowa Geological Survey, which obtained the samples and sent them to the department. The gypsum mills at Fort Dodge had previously been visited by the head of the Civil Engineering department. The samples of plaster and stucco obtained were first tested for fineness by sifting them through a series of sieves of varying numbers of meshes per square inch. These are the standard sieves used by the department in mechanical analyses of sand and other similar materials. All of the sieves have been calibrated and the diameters of the largest grains passing the several numbers have been found to be as follows:

Sieve No. 74—0.229 millimeters.
Sieve No. 100—0.115 millimeters.
Sieve No. 200—0.069 millimeters.

The results are given in the table below:

FINENESS TESTS OF PLASTER AND STUCCO.

KIND.	PER CENT PASSING SIEVES.		
	No. 74.	No. 100.	No. 200.
Gypsum from Ft. Dodge Paint Works	99.9	99.7	82.3
Gypsum from Stucco mills, Ft. Dodge, Iowa	68.3	60.0	44.0
Stucco from Ft. Dodge Plaster Company, Ft. Dodge, Iowa	71.9	66.2	49 3
Baker Stucco, Kansas	72.9	58.3	39.5
Kallolite Stucco, Cardiff Gypsum Plaster Co , Ft. Dodge	69.1	63.8	50.2
Baker Plaster, Kansas	68.2	58.7	28.2
Mineral City Wall Plaster, Ft. Dodge	72.1	65.4	49 1
Okarche, Oklahoma Territory, Oklahoma Cement Plaster Co.	77.8	70.2	51.3
Flint Wall Plaster, Iowa Plaster Association, Ft. Dodge.	72.4	64.2	48.1
Acme Wall Plaster, Acme, Texas	74.6	69.2	56.6
Kallolite Wall Plaster, Cardiff Gypsum Plaster Co., Ft. Dodge	70.8	65.5	53.5
Stonewall Plaster, Ft. Dodge Plaster Co., Ft. Dodge	72.4	66.1	54.0
Duncomb Wall Plaster, Duncomb Stucco Co., Ft. Dodge	63.8	57.8	43.6

A preliminary series of tensile tests of the strength of briquettes made of plaster and stucco was then carried out to ascertain the proper percentage of water to use in mixing the materials for the briquettes and to give the experimenter experience in making them. In making the briquettes the water and plaster or stucco were thoroughly mixed by hand and the mortar was then placed in standard cement briquette molds and packed with the finger. The surface of the briquette was smoothed with a trowel. As soon as the briquettes were sufficiently set, which usually took about three hours, the molds were removed; half of the briquettes were then kept in air, and the other half put in water, as shown by the table. At the age of 26 to 28 hours, as shown in the table, the briquettes were broken in a Fairbanks' Cement Testing Machine. The results are given in the following table:

PRELIMINARY TESTS TO DETERMINE THE PROPER PERCENTAGE OF WATER TO USE IN MAKING BRIQUETTES.

Laboratory Number.	KIND.	AGE. In air.	AGE. In water.	AGE. Total.	Per cent sand.	Per cent water.	Strength lbs. per sq. inch.	REMARKS.
		hrs.	hrs.	hrs.				
1	Kallolite Stucco, from Cardiff Gypsum Plaster Company, Ft. Dodge, Iowa.	3	24	27	0	30	122	
2		27	0	27	0	30	172	
3		3	24	27	0	35	138	
4		27	0	27	0	35	186	
5		3	24	27	0	40	126	
6		27	0	27	0	40	178	
7		3	24	27	0	45	115	
8		27	0	27	0	45	125	
9		3	24	27	0	25	165	
10		27	0	27	0	25	160	
43	Kallolite Plaster, Cardiff Gypsum Plaster Company Ft. Dodge, Iowa.	9	19	28	0	30	210	
44		28	0	28	0	30	217	
45		9	19	28	0	35	227	
46		28	0	28	0	35	204	
47		9	19	28	0	40	172	
48		28	0	28	0	40	193	
49		9	19	28	0	45	136	
50		28	0	28	0	45	130	

Laboratory Number.	KIND.	AGE.			Per cent sand.	Per cent water.	Strength lbs. per sq. inch	REMARKS.
		In air.	In water.	Total.				
11	Stucco from Ft. Dodge Stucco Company.	3	23	26	0	45	113	
12		26	0	26	0	45	104	
13		3	23	26	0	40	182	
14		26	0	26	0	40	196	
15		3	23	26	0	35	191	
16		26	0	26	0	35	187	
17		3	23	26	0	30	203	
18		26	0	26	0	30	266	
19		3	23	26	0	25	180	
20		26	0	26	0	25	176	
61	Duncomb Wall Plaster, Duncomb Stucco Company, Ft. Dodge, Iowa.	6	20	26	0	25	......	Dissolved in water.
62		26	0	26	0	25	176	
63		......	......	26	0	30	......	
64		26	0	26	0	30	160	
65		6	20	26	0	35	124	
66		26	0	26	0	35	146	
67		6	20	26	0	40	139	Flaw at center.
68		6	20	26	0	40	135	
69		6	20	26	0	45	149	
70		26	0	26	0	45	101	
91	Stone Wall Plaster, Ft. Dodge Plaster Company.	......	......	....	0	25	......	Crumbled in water would not stand weight of clip.
92		......	......	....	0	25	......	
93		9	17	26	0	30	121	
94		26	0	26	0	30	71	
95		9	17	26	0	35	164	
96		26	0	26	0	35	103	
97		9	17	26	0	40	122	Flaw in briquette.
98		26	0	26	0	40	88	
99		9	19	26	0	45	95	Distorted by water.
100		26	0	26	0	45	160	
		hrs.	hrs.	hrs.				
101	Acme Wall Plaster.	9	17	26	0	25	142	
102		26	0	26	0	25	114	
103		9	17	26	0	30	129	
104		26	0	26	0	30	135	
105		9	17	26	0	35	113	
106		26	0	26	0	35	116	
107		9	17	26	0	40	83	
108		26	0	26	0	40	91	
109		9	17	26	0	45	80	
110		26	0	26	0	45	77	
111	Flint Wall Plaster, Iowa Wall Plaster Asssociation Ft. Dodge, Iowa.	9	17	26	0	25	202	
112		26	0	26	0	25	155	
113		9	17	26	0	30	143	
114		26	0	26	0	30	148	
115		9	17	26	0	35	176	
116		26	0	26	0	35	185	
117		......	......	....	0	40	......	
118		26	0	26	0	40	187	
119		......	......	....	0	45	......	
120		26	0	26	0	45	113	

Laboratory Number.	KIND.	AGE. In air.	AGE. In water.	AGE. Total.	Per cent sand.	Per cent water.	Strength lbs. per sq. inch.	REMARKS.
71	Mineral City Wall Plaster.	9	17	26	0	25	114	Badly worn.
72		26	......	26	0	25	196	
73		9	17	26	0	30	232	
74		26	......	26	0	30	232	
75		9	17	26	0	35	168	
76		26	......	26	0	35	144	Slightly
77		9	17	26	0	40	178	cracked.
78		26	...	26	0	40	130	
79		9	17	26	0	45	149	
80		26	......	26	0	45	136	
21	Baker Stucco, Baker Stucco Company, Kansas.	3	23	26	0	45	146	
22		26	0	26	0	45	135	
23		3	23	26	0	40	173	
24		26	0	26	0	40	200	
25		3	23	26	0	35	207	
26		26	0	26	0	35	188	
27		3	23	26	0	30	131	
28		26	0	26	0	30	180	
29		3	23	26	0	25	223	
30		26	0	26	0	25	217	
81	Baker Plaster, Kansas.	9	17	26	0	25	......	Dissolved.
82		26	.....	26	0	25	53	Cracked.
83		9	17	26	0	30	220	
84		26	......	26	0	30	215	
85		9	17	26	0	35	177	
86		26	......	26	0	35	180	
87		9	17	26	0	40	104	
88		26	......	26	0	40	124	
89		9	17	26	0	45	......	Broken.
90		26	......	26	0	45	95	
51	Oklahoma Cement and Plaster Company.	9	18	27	0	25	118	
52		27	0	27	0	25	86	
53		9	18	27	0	30	120	
54		27	0	27	0	30	114	
55		9	18	27	0	35	69	
56		27	0	27	0	35	111	*Very poor
57		9	18	27	0	40	100	briquette,
58		27	0	27	0	40	104	broken with
59		9	18	27	0	20	49	weight of clip
60		27	0	27	0	20	*	on machine.

The above results show that 30 to 35 per cent of water gave the maximum strength of briquettes. Thirty-five per cent gave a mixture more readily handled in the making of briquettes than 30 per cent, and this percentage was adopted in the remaining tests.

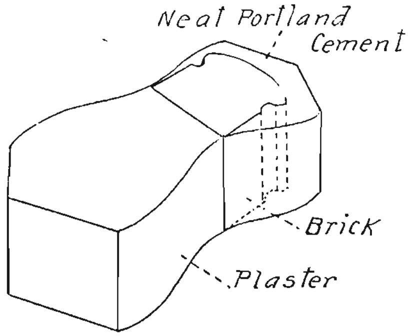
The reason for putting part of the briquettes in water was to ascertain exactly what injurious effect this would have upon them. The results with the short time tests were so favorable that it was thought worth while to continue these in the longer time tests.

On completion of this preliminary work, fresh supplies of plaster and stucco were obtained and what was intended to be a much more extensive series of tests was planned and begun. It was decided to make both tensile and adhesion tests of the material, and to obtain the strength after the briquettes had been allowed to set for different ages, both in water and in the air. It was also intended to make tests with the neat stucco and plaster as well as with different percentages of sand. This series of tests was only fairly begun, and its completion was prevented by the epidemic of typhoid fever at the college, of which the experimenter was one of the victims, and by some other mishaps. As a result, no tests were made with sand, and only part of the heat tests planned were carried out. The results of this series are given in the table below:

KIND OF MATERIAL.	KIND OF TEST.	KEPT IN.	STRENGTH PER SQUARE INCH AFTER—			
			1 Day.	7 Days.	28 Days	220 Days.
Ft. Dodge Stucco.	Tensile..	Air......	226	204	329	274
	Tensile..	Air......	219	210	438	277
	Tensile..	Water...	195	139	187	......
	Tensile..	Water...	208	154	200	......
	Adhesion	Air.	......	87	133	60
	Adhesion	Water...	......	87	75	......
Kallolite Stucco (Ft. Dodge).	Adhesion	Air......	......	45	115	92
	Adhesion	Water.	..	31	.. ..	.....
Kallolite Plaster (Ft. Dodge product.)	Tensile..	Air......	219	188	379	288
	Tensile..	Air......	186	230	245	408
	Tensile..	Water...	175	185	168	.....
	Tensile..	Water...	189	170	209	......
	Adhesion	Air	.....	52	102	42
	Adhesion	Water ..	... ..	43	....	..
Duncomb Plaster (Ft. Dodge product.)	Tens le .	Air......	211	184	375	335
	Tensile..	Air......	208	220	360	205
	Tensile .	Water ..	192	172	180	......
	Tensile..	Water ..	202	175	186	......
	Adhesion	Air......	......	62	81	......
	Adhesion	Water ..	......	......	84	.. ...

KIND OF MATERIAL.	KIND OF TEST.	KEPT IN.	STRENGTH PER SQUARE INCH AFTER— 1 Day.	7 Days.	28 Days.	220 Days.
Mineral City Plaster (Ft. Dodge product.)	Tensile. .	Air......	......	190	237	......
	Tensile. .	Air	......	301	437	......
	Tensile .	Water. ..	215	203	195	......
	Tensile. .	Water. ..	192	196	205	......
	Tensile .	Water. ..	195	......	......	......
	Tensile. .		215	......	......	......
	Adhesion	Air......	......	72	212	......
	Adhesion	Water. ..	......	......	84	......
Stone Plaster (Ft. Dodge product.)	Tensile. .	Air......	131	170	483	386
	Tensile. .	Air......	144	228	470	......
	Tensile. .	Water. ..	187	163	182	......
	Tensile .	Water. ..	214	193	148	......
	Adhesion	Air......	......	31	80	......
Flint Plaster (Ft. Dodge product.)	Tensile. .	Air......	192	224	348	359
	Tensile. .	Air......	204	217	285	......
	Tensile. .	Water. ..	188	207	158	......
	Tensile. .	Water. ..	214	205	163	......
	Adhesion	Air.....	......	64	114	65
	Adhesion	Water ..	......	26	......	......
Acme Plaster (Texas.)	Tensile. .	Air......	107	128	333	193
	Tensile. .	Air......	131	175	303	......
	Tensile. .	Water. ..	82	20	151	......
	Tensile. .	Water. ..	111	112	154	......
	Adhesion	Air......	......	76	103	47
Baker Stucco (Kansas.)	Tensile. .	Air......	227	236	468	405
	Tensile. .	Air......	221	208	461	340
	Tensile. .	Water. ..	216	223	154	......
	Tensile. .	Water. ..	226	201	181	......
	Adhesion	Air......	......	.....	117	50
	Adhesion	Water. ..	....	98	100	....
Baker Plaster (Kansas.)	Tensile. .	Air......	181	195	465	283
	Tensile. .	Air......	134	218	286	375
	Tensile. .	Water. ..	183	196	195	.....
	Tensile. .	Water. ..	185	162	215	......
	Adhesion	Air......	.....	83	105	......
	Adhesion	Water ..	......	55	95	......
Oklahoma Plaster.	Tensile .	Air......	......	......	......	......
	Adhesion	Air......	......	82	......	62
	Adhesion	Water. ..	......	63	133	.....

The adhesion tests in the table above were made by taking pieces of No. 2 paving brick from Des Moines and grinding them on an emery wheel so as to make approximately one-inch cubes. Each cube had one face carefully trued to give a cross section exactly one inch square. These pieces of paving brick were placed in the cement molds with the true surface above referred to exactly at the middle of the mold. The cement or stucco was then placed to fill the remaining half of the mold and the vacant space in which the piece of brick was located was filled with neat Portland cement mortar. The arrangement will be better understood by the following sketch:



Adhesion Test Briquette

FIG. 43.

It was thought that the results of adhesion tests would serve to show whether the tensile strength of the plaster or stucco could properly be taken as a measure of the value for use in plaster. Paving brick was taken as giving the material which could be most readily made standard for such tests. No. 2 paving brick was taken in preference to No. 1 because the No. 1 are so hard burned as to make the preparation of the cubes very expensive. The adhesion surfaces were ground as smooth as could be readily done with an emery wheel.

It will be noticed in the table that as a rule there was a falling off of the strength of the briquettes between the ages of 28 and 220 days. The reason for this is that after the experimenter was taken sick the briquettes were allowed to remain in a basement where they were subjected to contact with very moist air from the condensation of steam from the heating plant. The effect of the moisture in the air shows in the reduction of strength.

Comparison of the strength of the briquettes which were left in water with those left in air indicates that they showed a steady deterioration. In the end these briquettes partially dissolved so that no tests could be made at the end of the 220 days.

The writer considers that the number of tests made is too small to enable any further conclusions to be drawn. A much more extensive series of tests has now been begun.

Additional experiments carried out since the foregoing were completed are given below and seen to justify the following generalizations:

It appears from the tests that the adhesive strength of plaster is only a fraction of the tensile strength, and that this fraction decreases as the proportion of sand used in the plaster increases. The adhesion tests proved to give much more irregular results than the tensile tests. This is probably due to the greater difficulty of carrying out the tests.

All the tests are still going on. Many more briquettes than have yet been broken were made, and these are being broken from time to time at different ages. It is still too early, therefore, to draw decided conclusions from the tests. The following summary of the results so far obtained is, therefore, to be received cautiously, as later results may modify the conclusions to be drawn.

Two kinds of plaster were tested, the Flint plaster made by the Iowa Plaster Company, Fort Dodge, Iowa, and the Crystal Rock plaster from Blue Rapids, Kansas. The tests do not show any great difference between these two kinds of plaster.

Some of the tests were made on plaster as obtained from the mills, and some on plaster which had been sifted, using only that which would pass a sieve having 100 meshes per lineal inch.

The results do not show any very great difference in the strength of the sifted and the unsifted plaster.

In addition to the main tests of Flint plaster and crystal rock plaster a similar series of tests of Flint plaster four years old was made. The results of these show that the plaster did not deteriorate greatly so far as the strength of the neat stucco is concerned, but it had largely lost its ability to take sand. The tests with sand were very much weaker than the corresponding tests with fresh material. Some of the plaster was sifted through a No. 100 sieve, and it was found that the material which would pass this sieve was very much stronger than the unsifted material. Either the coarse particles deteriorated more than the fine particles, or perhaps the absorption of moisture from the air caused part of the material to set into coarser grains which were removed by the sifting. The old Flint plaster showed especially poor results in the adhesion tests.

KIND.	PROPORTIONS.	STRENGTH				
		1 DAY	1 WK	4 WKS	3 MOS	
Crystal Rock Plaster from Blue Rapids, Kansas; fresh, unsifted. Average of 9 tensile tests..........	Neat.	228	393+	445+	4[illegible]6+	
Average of 6 adhesion tests......	Neat.	50	92	131		
Average of 15 tensile tests.....	1:1	87	820	368	370	
Average of 6 adhesion tests......	1:1	27	58	48	66+	
Average of 15 tensile tests....	1:2	55	203	212	255	
Average of 6 adhesion tests.....	1:2	16	16	21	9	
Average of 15 tensile tests............	1:3	35	148	145	156	
Average of 6 adhesion tests.........	1:3	......	.....	7		Very weak in spite of great care.
Crystal Rock Plaster fresh, sifted Average of 15 tensile tests....	1:2	57	231	229+	229	
Average of 6 adhesion tests.....	1:2	12	27	19	15	

KIND.	PROPORTIONS.	STRENGTH.				
		1 DAY	1 WK	4 WKS	3 MOS	
Flint Plaster, made by Iowa Plaster Ass'n, Ft. Dodge, Iowa, fresh unsifted. Average of of 15 tensile tests....	Neat.	135	310	402+		
Average of 6 adhesion tests................	Neat.	59	92	96		
Average of 15 tensile tests.................	1:1	104	303	362+		
Average of 6 adhesion tests.................	1:1	33+	93	51+		
Average of 15 tensile tests................	1:2	64	206	203		
Average of 6 adhesion tests................	1:2	21+	31—	54—		
Flint Plaster, fresh. sifted. Average of 15 tensile tests..........	1:2	61—	233+	242		
Average of 6 tensile tests............	1:2	18—	26	22+		
Flint Plaster, fresh unsifted. Average of 15 tensile tests..........	1:3	39	132	139+		
Average of 6 adhesion tests................	1:3	6	10	20		
Flint Plaster, four years old. unsifted. Average of 3 tensile tests......	Neat.	155	353	433		

KIND.	PROPORTIONS.	STRENGTH.				
		DAY	1 WK	4 WKS	3 MOS	
Average of 6 adhesion tests	Neat.	27	*	9		* Broke putting in ma-machine.
Average of 15 tensile tests	1:2	26+	109	123		
Average of 6 adhesion tests	1:2	*	*	10		* No adhesion.
Flint Plaster, four years old, sifted. Average of 6 tensile tests	1:2	49—	205	256		
Average of 6 adhesion tests	1:2	7	15—	22		Adhesion poor.
German Stucco. Average of 5 tensile tests	Neat	300	461	461		
Adhesion tests.	Neat.	*	*			* No adhesion. Neat stucco too smooth to adhere to the smooth brick.
Average of 15 tensile tests	1:2	119+	336	3[illegible]6		
Average of 6 adhesion tests	1:2	15	66+	11		ome broke putting in machine.
Average of 5 tensile tests	1:3	75	303	252		
Adhesion tests	1:3	*	*	*		* Adhesion poor. Broke in spite of great care in handling. Too much sand Broke putting in machine.

FINENESS TESTS OF PLASTER.

KIND.	PER CENT PASSING.		
	No. 74.	No. 100.	No. 200.
Crystal Rock Plaster	73.7	12.3	2.5
	74 3	55.2	4.3
Flint Plaster, fresh	66.4	58 6	55.7
Flint Plaster, 4 years old	81.9	68.7	52.2
German Stucco	90.5	85.0	19.8