GYPSUM IN THE SOUTHERN PART OF THE BIGHORN MOUNTAINS, WYOMING.

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INTRODUCTION.

Gypsum has been known in a belt of rocks surrounding the Bighorn and Owl Creek mountains, Wyoming, from the early days of exploration. The amount of this material at several places is great, but owing to the slight demand little attention has been given to the use of it until the last few years. It is quarried at two or three places in the Bighorn Basin and is being manufactured into stucco building blocks at Basin and Greybull. In the vicinity of Sheep Mountain the gypsum-bearing rocks are close to the railroad, and here the only development has taken place. The beds containing gypsum are crossed by the railroad in the vicinity of Thermopolis, but no quarrying on a commercial scale has been done there.

The gypsum occurs at two horizons, the upper at or near the top of the Chugwater formation (red beds) and the other in the upper part of the Embar formation. Only the upper bed, however, is of economic importance at Sheep Mountain and in the vicinity of Thermopolis.

The field work on which this paper is based was done during the seasons of 1914 and 1915. Mr. Condit examined the Embar gypsum in connection with his investigations of the phosphate deposits in this general region in 1915, and Mr. Lupton examined all the sections of gypsum at the top of the Chugwater formation here described, incidentally to oil and gas investigations in the eastern and southern parts of the Bighorn Basin in 1914 and 1915. Mr. Lupton also examined the Embar gypsum a few miles south of Hyattville, near the Ziesman ranch, where he obtained a sample of gypsum for analysis.

GEOGRAPHY.

LOCATION AND EXTENT.

The gypsum-bearing rocks described were examined in a general way in an area extending from Sheep Mountain, a few miles north of Greybull, southeast around the edge of the basin and west as far as Bighorn River near Thermopolis. On the east side of the Bighorn Mountains the Embar gypsum was examined from a point near

Buffalo south to the locality where the Bighorn Range merges with the Owl Creek Range. The area represented on Plate III is about 90 miles from north to south and 75 miles from east to west.

ACCESSIBILITY.

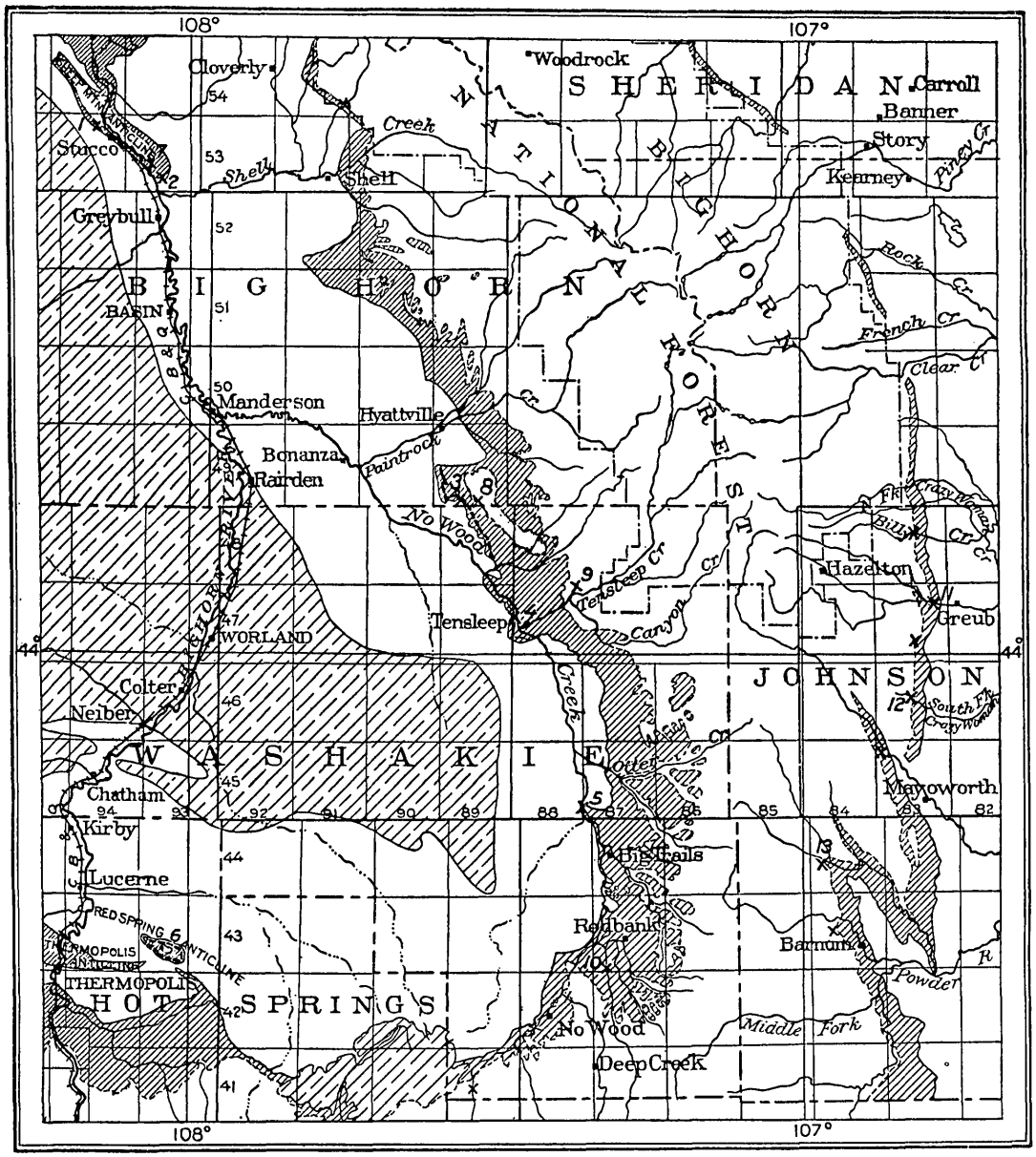
Much of the gypsum herein described lies at a considerable distance from the railroad and will probably not be exploited for decades, but it is worth while to have an inventory of such deposits for use when the demand for them becomes greater.

The deposits of gypsum in the Bighorn Basin that are at present most easily accessible are those that crop out in the vicinity of Sheep Mountain and near Thermopolis, where the Embar and Chugwater formations are brought to the surface by the prominent Sheep Mountain and Thermopolis anticlines. In the vicinity of Sheep Mountain the gypsum is being mined near the railroad and is transported by rail to Basin, 18 miles to the south, where it is manufactured into blocks for use in building. It seems safe to predict that deposits at some distance from the railroad will not be developed until the beds adjacent to the railroad have been nearly exhausted. At present the gypsum is quarried. It is a question whether it will not be more economical to extend the workings underground at the localities close to the railroad than to open new quarries at points more remote from transportation facilities.

The gypsum occurring at the top of the Chugwater formation along the southeast margin of the Bighorn Basin will probably be next developed, especially if a railroad should be constructed up the valley of No Wood Creek from Manderson, where this stream joins Bighorn River. Such a branch line would not only open up a rich territory but would also hasten the development of the gypsum beds that crop out in and near this valley. Good wagon roads extend up No Wood Valley and across country from Worland to Tensleep, but it is very doubtful whether the gypsum can profitably be hauled in wagons this distance (30 or 35 miles) to the railroad. The deposits of gypsum on the east and southeast sides of the Bighorn Mountains, although unusually thick, are of the least value on account of their remoteness from any present or prospective railroad line.

CLIMATE.

The climate of the Bighorn Basin is semiarid. Records of temperature and precipitation kept at a number of places for a period of several years show that the border of the basin, where most of the gypsum beds crop out, receives a rainfall of 11 to 12 inches annually, and that the interior receives about 6 inches. The interior is colder than the border in winter and warmer in summer. The greatest variation in temperature has been recorded at Basin, where, accord-



MAP SHOWING OUTCROPS OF GYPSUM-BEARING FORMATIONS IN SOUTHERN PART OF BIGHORN MOUNTAINS, WYO.

ing to observations extending through a period of 11 years, the thermometer has registered a minimum of 51° below zero in February and a maximum of 110° above zero in June, July, and August.

The variations of temperature, as well as of rainfall, necessarily will have an effect on the cost of development of the gypsum in this region, as for two or three months during the winter work can not be carried on unless the gypsum is mined under cover.

SURFACE FEATURES.

The area represented on the accompanying map (Pl. III) includes the southern part of the Bighorn Mountains and the adjacent part of the Bighorn Basin, to the west. The Bighorn Range attains a maximum altitude of about 14,000 feet at Cloud Peak, and the average altitude along the crest is a little more than 8,000 feet. The country along the base of the mountains, where the gypsum beds crop out, is from 4,000 to 6,000 feet above sea level. Both the mountain slopes and the adjacent foothills furnish summer range for great numbers of sheep. The mountains, except in the more rugged parts, are not thickly forested.

Near the top of the Chugwater formation is a prominent wall of red sandstone and shale which serves as a good marker for the overlying gypsum beds. It extends almost throughout the Chugwater outcrop, forming a prominent hogback near the crest of which the gypsum beds occur. The sandstone wall facing the mountains is separated from them by a valley eroded 200 to 500 feet deep in the softer beds of sandstone and shale forming the lower part of the Chugwater red beds. On the mountainward side of this valley is the Embar formation, near the top of which occur gypsum beds along the Bighorn Mountain front.

Most of the streams flowing from the mountain front cut directly across the sandstone hogback in the red beds or run for a short distance parallel to it before crossing toward the plains. The principal drainage line of the Bighorn Basin is Bighorn River. Tributary to it are Shell Creek, Paintrock Creek, No Wood Creek, Otter Creek, and Bridger Creek, all of which offer easy routes of access to the outcrops of the gypsum beds. The principal streams on the east side of the Bighorn Mountains are Crazy Woman Creek, North Fork of Powder River, Middle Fork of Powder River, and Buffalo Fork, all of which flow across the gypsum-bearing beds.

GEOLOGY.

GENERAL SECTION.

The rocks exposed in the region covered by this report range in age from pre-Cambrian to Quaternary. The Embar and Chugwater formations, which contain the gypsum beds, are described in detail.

Their positions with reference to other formations are represented in the following table. Detailed descriptions of the entire sequence of formations are given by Darton,[1] Fisher,[2] and Hewett and Lupton.[3]

Stratigraphic sequence of formations exposed in Bighorn Mountains and Bighorn Basin, Wyo.

Quaternary:
- Alluvium.
- Later terrace gravel.
- Early terrace gravel.
- Hot-spring deposits.

Unconformity.

Tertiary:
- Wasatch formation.
- Fort Union formation.

Unconformity

Tertiary (?):
- Lance formation.

Cretaceous:
- Meeteetse formation.
- Mesaverde formation.
- Cody shale.
- Frontier formation.
- Mowry shale.
- Thermopolis shale.
- Cloverly formation.

Unconformity.

Cretaceous (?):
- Morrison formation.

Jurassic:
- Sundance formation.

Triassic and Carboniferous:
- Chugwater formation (Triassic, Permian, and Pennsylvanian beds of red color, almost wholly nonmarine, in part overlying and in part contemporaneous with and grading horizontally into the marine Embar formation).
- Embar formation (Lower Triassic, Permian, and Pennsylvanian marine beds of gray and greenish color, together with thick red beds).
- Tensleep sandstone (Pennsylvanian).
- Amsden formation (chiefly Pennsylvanian).
- Madison limestone (Mississippian).

Ordovician:
- Bighorn dolomite.

Cambrian:
- Deadwood formation.

Pre-Cambrian:
- Granite.

GYPSUM-BEARING FORMATIONS.

CHUGWATER FORMATION.

The Chugwater formation (red beds) was named by Darton from Chugwater Creek, in the Laramie Mountain region, Wyo., where it is

[1] Darton, N. H., Geology of the Bighorn Mountains: U. S. Geol. Survey Prof. Paper 51, pp. 13-91, 1906.
[2] Fisher, C. A., Geology and water resources of the Bighorn Basin, Wyo.: U. S. Geol. Survey Prof. Paper 53, pp. 8-36, 1906.
[3] Hewett, D. F., and Lupton, C. T., Anticlines in the southern part of the Bighorn Basin, Wyo.: U. S. Geol. Survey Bulletin—(in preparation).

well exposed. It is presumably for the most part of Triassic age, although but few fossils have been found in it in the Bighorn Basin. It consists principally of red sandstones and shales, with beds of gypsum and gypsiferous limestone near the top. The lower part is predominantly shaly, the middle sandy, and the upper calcareous and gypsiferous. It ranges in thickness from 600 to 1,000 feet and in most places finds topographic expression in a valley and one or more flanking hogback ridges produced by the more resistant beds near the top of the formation. Its outcrop around the Black Hills is described as the Red Valley. The same term is applicable to its outcrop in the Bighorn Mountain region.

The formation is well exposed along the east and south sides of the Bighorn Basin, except in the vicinity of Lysite Mountain, 20 to 25 miles east of Bighorn River canyon, where the Chugwater is overlain by Tertiary beds. On the east side of the Bighorn Mountains it is generally well exposed, but at the south end of these mountains and also south of the Owl Creek Range it is concealed over large areas by Tertiary beds.

Gypsum is present near the top of the formation at nearly every place where it has been examined. The gypsum beds lie from 15 to 120 feet below the top of the formation, as shown by the sections of gypsum and associated rocks on Plate V (p. 146).

Both Darton[1] and Fisher[2] were of the opinion that gypsum beds are included in the lower part of the formation, but the work of Condit in his study of the phosphate deposits of the Owl Creek and Bighorn mountains has proved that the gypsum beds heretofore thought to be included in the lower part of the Chugwater are in the upper part of the Embar formation. The conclusions reached by Darton and Fisher, whose work was of the reconnaissance type, were natural, for the beds that include the gypsum in what they regarded as the lower part of the Chugwater are lithologically very similar to the overlying beds, which without question belong to the Chugwater.

EMBAR FORMATION.

The term Embar designates strata ranging in age from Pennsylvanian to early Triassic, lying between the Tensleep sandstone and Chugwater red beds in central Wyoming. The name was introduced by Darton[3] for these beds in the Owl Creek Mountains, and the type locality is at Embar post office, on Owl Creek, some 25 miles west from Thermopolis. The formation has in recent years attracted

[1] Darton, N. H., op. cit., p. 37.

[2] Fisher, C. A., Geology and water resources of the Bighorn Basin, Wyo.: U. S. Geol. Survey Prof. Paper 53, p. 18, 1906.

[3] Darton, N. H., op. cit., p. 35.

attention on account of its phosphate beds, which have been traced throughout the Wind River and Owl Creek mountains.

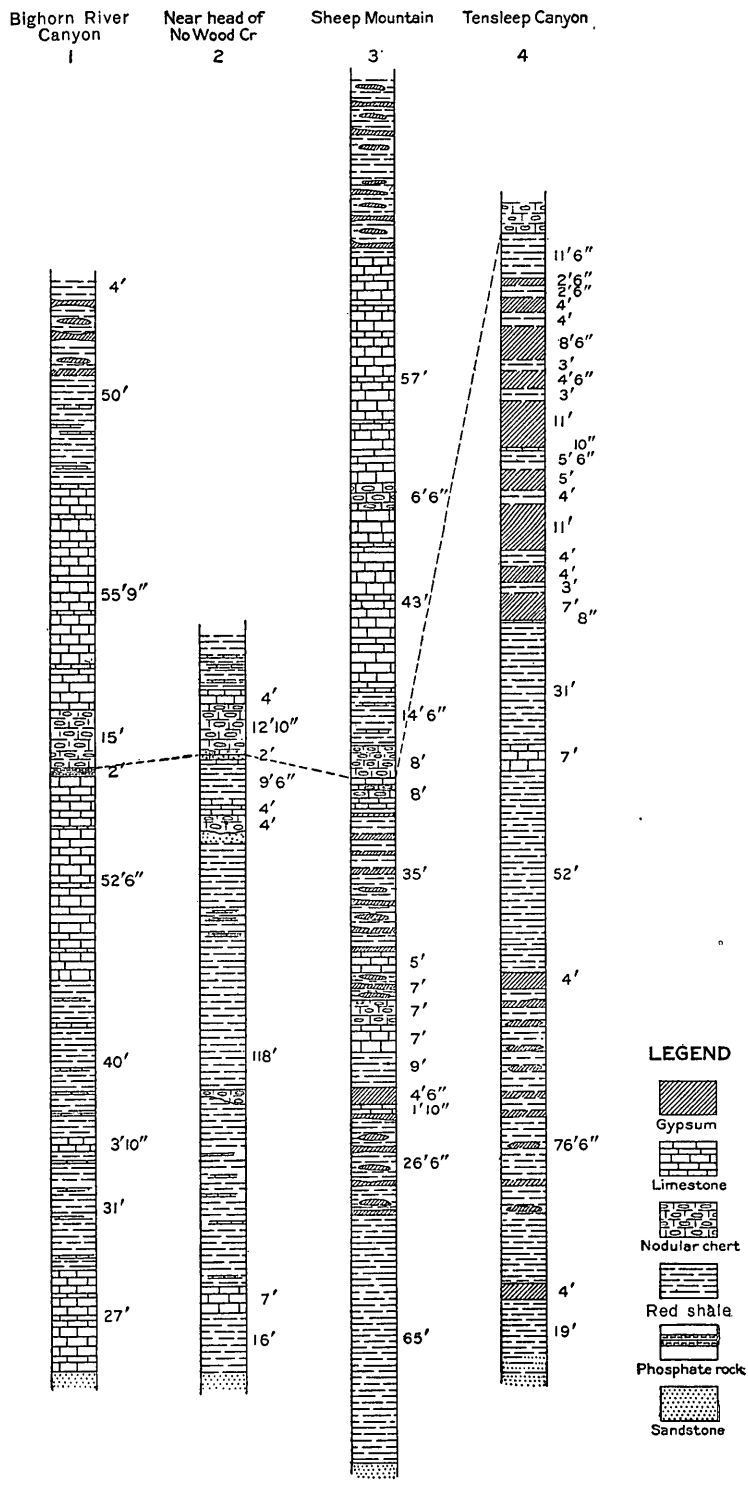
Blackwelder[1] has recommended that the Embar be divided into two formations. For the upper shaly portion he suggests the name Dinwoody, from Dinwoody Lake, in the Wind River Mountains, and for the lower portion, consisting largely of fossiliferous limestone, the name Park City, in accordance with the use of that name for beds in Utah, with which the lower portion of the Embar is correlated. These names have been approved by the United States Geological Survey, but over a part of the area considered in this paper the Dinwoody and Park City units are not recognizable, and therefore it is considered advisable to designate the beds collectively by the old name Embar.

The Embar deposits in the Wind River and Owl Creek mountains consist largely of limestone, with a lesser amount of calcareous or sandy shale and chert. Fossils are abundant, and the strata have every appearance of being almost entirely marine deposits. When followed eastward into the Bighorn Mountains, the deposits are found to undergo a gradual transformation which may be summarized as follows: (1) Increase in thickness; (2) lithologic changes, including thinning of limestone beds and an increase in the amount of shale, almost entirely of red color; (3) the appearance of beds of massive clean gypsum in all but the basal portion; (4) the gradual eastward disappearance of marine fossils except in basal beds; (5) the prevalence of calcareous conglomerate at the principal limestone horizons; and (6) the disappearance of concentrated beds of phosphate rock. With these changes the Embar as found in the Bighorn Mountains so little resembles the typical Embar of the Owl Creek Mountains that their relation would hardly be suspected if it had not been demonstrated by tracing the outcrop continuously from one region to the other.

The lithologic character of the Embar in the Owl Creek Mountains is illustrated by the section measured at Bighorn River canyon. (See Pl. IV.) The upper portion, about 60 feet thick, which lies immediately beneath the Chugwater red beds and which Blackwelder called the Dinwoody formation, consists largely of greenish to brownish shale containing layers of impure gypsum intimately interbedded with the shale.

Beneath the shale is a gray limestone member so much more resistant than beds in overlying formations that it extends far up the mountain side, forming the dip slopes so conspicuous in the vicinity of Bighorn River canyon south of Thermopolis. Beneath this

[1] Condit, D. D., Relations of the Embar and Chugwater formations in central Wyoming: U. S. Geol. Survey Prof. Paper 98, pp. 263-270, 1916 (Prof. Paper 98-O).



SECTIONS OF EMBAR FORMATION AT BIGHORN RIVER CANYON, HEAD OF NO WOOD CREEK, SHEEP MOUNTAIN ANTICLINE, AND TENSLEEP CANYON, WYO.

limestone lies shaly chert, which is underlain by a persistent bed of phosphate rock, 1 foot to 3 feet thick, throughout the Owl Creek Range. The lower half of the Embar contains considerable shale and limestone of variable character. The principal limestone member lies at or near the base, resting on the Tensleep sandstone.

A section measured in T. 41 N., R. 89 W., along a ravine near the head of No Wood Creek (see Pl. IV), illustrates the character of the Embar beds that are transitional from the marine limestone of the Owl Creek Mountains to the shaly gypseous red beds of the Bighorn Mountain region. Above the middle is the usual chert and some limestone, practically devoid of fossils, but the lower part is almost entirely red shale.

The section measured at Tensleep Canyon, in T. 47 N., R. 88 W., near Burke's ranch, is representative of the Embar beds along the Bighorn Mountain front. The thickness here is, however, somewhat greater than usual, being at least 350 feet. Limestone, except for a few thin dolomitic layers, is lacking. In the upper part is the persistent pinkish to greenish nodular chert. Beneath the chert is much gypsum in massive white courses interbedded with red shale, the combined thickness being nearly 100 feet. A few thin layers of gypsum are also distributed at random through the lower part of the section, down to a horizon within about 20 feet of the Tensleep sandstone.

The Embar along the Bighorn Mountains, as would be expected from its shaly character, is physiographically weak and does not extend nearly so far up the mountain slopes as it does in the Owl Creek Mountains. In fact, its lithologic character and physiographic expression are so similar to those of the overlying Chugwater red beds that few distinctively Embar features are recognizable.

The gypsum, on account of its comparative solubility, has been removed from the upper parts of the hills along the mountain base where the relief is considerable, and the thickest exposures are found at the lowest accessible points. Even in level tracts along the valleys partial removal is locally indicated by cavernous openings and sink holes into which streams disappear. The evidence of extensive solution of the gypsum deposits along the Bighorn Mountains raises the question whether beds of certain salines may have been deposited along with the gypsum and whether the removal of these soluble deposits may not have caused the general brecciated, distorted character of the Embar beds noticed at so many localities.

In addition to irregularities in the gypsum deposits that are due to solution, they show great variations that are attributed entirely to differences in conditions of deposition. Thick deposits followed a distance of only a mile or so along the outcrop are commonly found

to disappear and give place to calcareous breccias and conglomerates, succeeded in turn by more gypsum. These features are indicative of the conditions under which deposition of the lenses of gypsum probably took place.

STRUCTURE.

The dominant structural feature of the region is of course the Bighorn uplift, on the flanks of which the beds are inclined at different angles. Those on the west slope dip steeply in places, as in the vicinity of Horse Creek canyon southeast of Cloverly, where the dip is more than 50°. Elsewhere, as in the vicinity of Redbank, the dip is low and the formations accordingly form long dip slopes on the mountain front.

The westward dip of the beds into the basin is varied at numerous localities by folds, three of which are so large that along them are exposed gypsum-bearing beds which in the adjacent synclines lie hundreds of feet below the surface. The most profound of these folds in the Bighorn Basin is the Sheep Mountain anticline, which exposes strata down nearly to the base of the Madison limestone. Other prominent folds are the Thermopolis and Red Spring anticlines, at the south side of the Bighorn Basin, parallel to the Owl Creek Range. No such prominent anticlines are found in the region east of the Bighorn Range, and in none of the folds away from the mountain front are the red beds exposed.

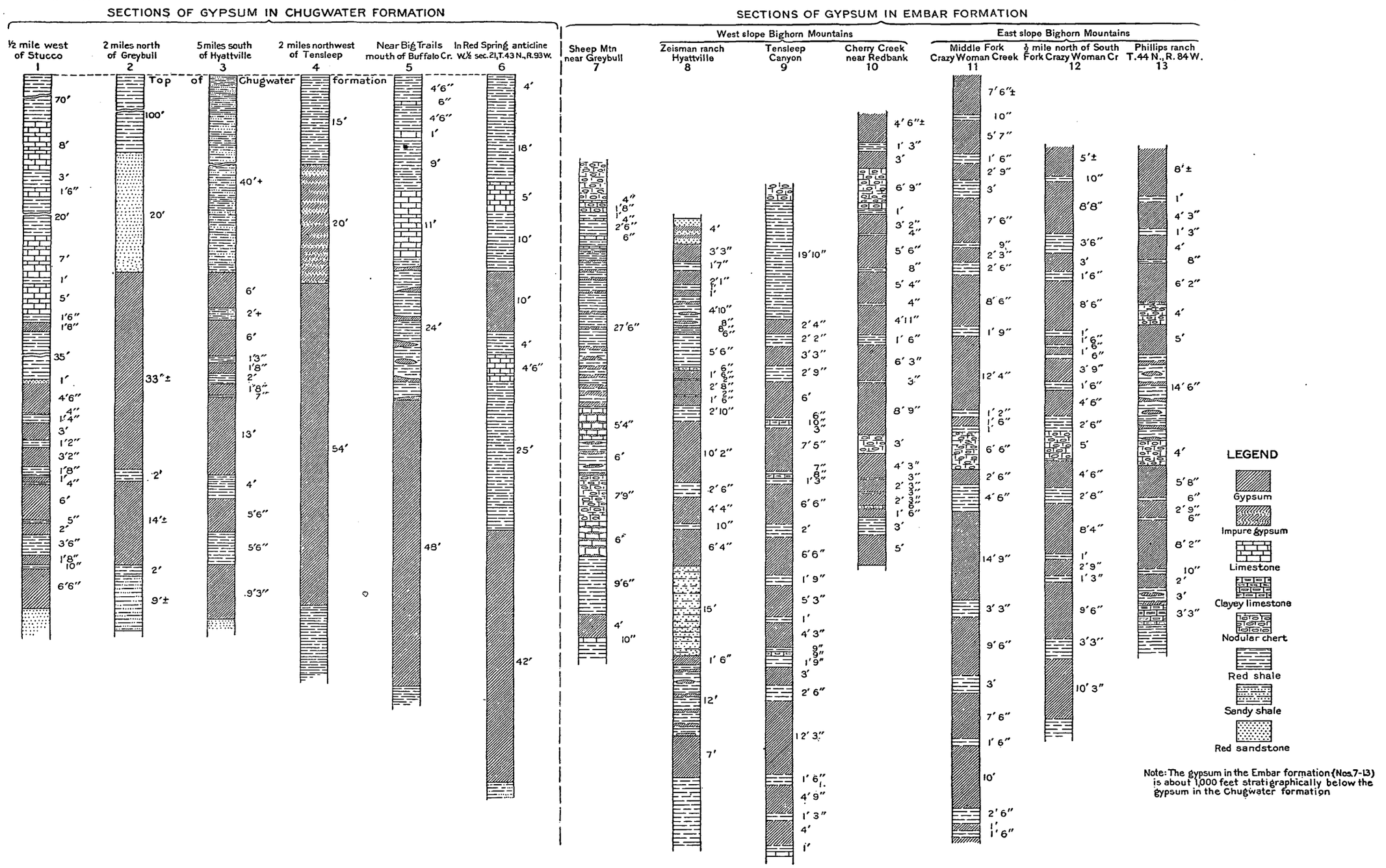
THE GYPSUM.

GENERAL FEATURES OF OCCURRENCE.

The gypsum described in this report is so finely crystalline that the individual granules are not recognizable without the aid of a microscope. It is mainly white and fairly hard except near the surface, where it is somewhat weathered. Certain layers have a flesh-pink or yellowish color caused by the inclusion of mechanical sediments or by mineral stains.

The gypsum is fairly soluble in water and as a rule softer than the sandstone and shale, and therefore it is rarely well exposed. It can best be seen in places where the beds have been recently denuded by streams, or where the gypsum is well protected by sandstone and shale in the faces of cliffs. In many places the gypsum has been partly dissolved and the overlying beds have become twisted and distorted by settling, so that they do not conform with the beds below the gypsum.

The varying thickness and number of the beds of gypsum suggest that they were not deposited as continuous sheets over the region, but rather formed as lenses in isolated bodies of water along the margin of a sea that was subject to intermittent fluctuations in level.



SECTIONS OF GYPSUM BEDS IN CHUGWATER AND EMBAR FORMATIONS.

Partial exposures of the gypsum can be observed at almost every place where the top of the Chugwater and the top of the Embar are exposed. At only a few places, however, is it possible to measure a complete section of the gypsum beds, because of slumps, slides, and talus, which partly or wholly obscure the beds.

GYPSUM IN THE CHUGWATER FORMATION.

The sections of gypsum measured in the Bighorn Basin and east of the Bighorn Mountains are shown graphically on Plate V, arranged in order from north to south. The sections of gypsum in the Chugwater formation are Nos. 1 to 6 and the sections in the Embar formation are Nos. 7 to 13.

GRAPHIC SECTIONS.

In the sections on Plate V, showing the gypsum in the upper part of the Chugwater formation, the highest beds include the top of the Chugwater formation. It may be observed from these sections that the gypsum is not everywhere found at the same distance below the top of the formation and also that the gypsum in sections 1, 2, and 3 is included in two to eight beds of varying thickness, whereas in sections 4, 5, and 6 most of the gypsum is in one bed of considerable thickness, ranging from 42 to 74 feet. Sections 1, 5, and 6 show that some limestone is present in the top of the Chugwater formation, but limestone is not noticeable in the other sections.

NEAR STUCCO.

Gypsum is being mined from the upper part of the Chugwater formation at a point about half a mile west of Stucco (section 1, Pl. V), a flag station on the Chicago, Burlington & Quincy Railroad about 8 miles northwest of Greybull. Although the gypsum at this locality is not in one persistent bed, yet its nearness to the railroad enables the owners to mine it with profit. The gypsum is sent by rail to Basin, 18 miles to the south, where it is manufactured into stucco blocks for building. Information regarding this plant is given below under "Development."

A sample of gypsum was collected near this quarry and analyzed in the chemical laboratory of the United States Geological Survey.

Partial analysis of gypsum from deposit near Stucco, about 8 miles north of Greybull.

[W. C. Wheeler, analyst.]

Lime (CaO)	33.74
Sulphur trioxide (SO_3)	43.92
Water driven off at 300° C	19.50
Chlorine (Cl)	None.
Silica (SiO_2)	.01
Manganese oxide (MnO)	.98
Iron and alumina mixed (Al_2O_3 and Fe_2O_3)	.17

The percentages of lime, sulphur trioxide, and water given in the analysis closely approach those of pure gypsum. The percentage of lime, however, is a little higher than normal, and that of sulphur trioxide more than 2 per cent lower. The water is more than 1 per cent less than that of pure gypsum. The excess of lime and the presence of carbon dioxide, determined qualitatively, indicate that a small amount of calcium carbonate is present.

NEAR GREYBULL.

The gypsum at the top of the Chugwater formation is fairly well exposed near the south end of Sheep Mountain, about 2 miles north of Greybull, on the north side of Shell Creek (section 2, Pl. V). The highest gypsum noted in this section is about 120 feet below the top of the formation. In all, 47 feet of gypsum is exposed. The total amount may be greater than this, however, as part of the section was concealed. This gypsum is similar in appearance to that at Stucco, therefore it is believed that a chemical analysis would be very similar to the one given above.

NEAR HYATTVILLE.

At a point about 5 miles south of Hyattville and half a mile west of the Hyattville-Tensleep road, a section (section 3, Pl. V) of the gypsum at the top of the Chugwater formation was measured. At this locality the gypsum occurs in seven beds, ranging in thickness from 1 foot 8 inches to 13 feet. The total thickness of the gypsum exposed is about 43 feet.

Most of the gypsum at this place is pure white, but some of it is brownish gray, with a red stain on the outside from adjacent beds of red sandy shale. An analysis of a sample of the pure-white gypsum of this place is given below.

Partial analysis of gypsum from the NW. ¼ NW. ¼ sec. 33, T. 49 N., R. 89 W., at a point about 5 miles southeast of Hyattville.

[W. C. Wheeler, analyst.]

Lime (CaO)	32.92
Sulphur trioxide (SO_3)	45.74
Water driven off at 300° C	19.99
Chlorine (Cl)	None.
Silica (SiO_2)	.05
Manganese oxide (MnO)	.44
Iron and alumina mixed (Al_2O_3 and Fe_2O_3)	.03

The percentages of lime, sulphur trioxide, and water given in this analysis closely approach those of theoretically pure gypsum, the lime being a little higher and the sulphur trioxide more than 2 per cent lower. The facts that the lime is more than 1 per cent higher than is present in pure gypsum and that carbon dioxide also is present in small amount suggest strongly that some of the lime is in the form of carbonate.

NEAR TENSLEEP.

The gypsum near the top of the Chugwater formation was measured at a point about 2 miles northwest of Tensleep (section 4, Pl. V), on the west side of No Wood Creek and the north side of the Tensleep-Worland road. At this locality the gypsum is higher in the Chugwater formation than at any other place on the east and south sides of the Bighorn Basin, being separated from the top of the formation by only 15 feet of red shale, as shown by the section. The gypsum is thicker here than at any other outcrop of the Chugwater beds described in this paper, there being 74 feet, of which the upper 20 feet is impure.

Gypsum in this locality has not been quarried and probably will not be until a railroad is constructed up No Wood Creek.

NEAR BIGTRAILS.

The gypsum in the upper part of the Chugwater was examined in detail near Bigtrails (section 5, Pl. V), at the mouth of Buffalo Creek, a western tributary of No Wood Creek, which joins that stream in sec. 1, T. 44 N., R. 88 W. At this place the gypsum is in one bed 48 feet thick, lying 50 feet below the top of the Chugwater formation. It is mainly white and very pure. The overlying rocks, as shown on Plate V, contain three beds of limestone. This is an unusual feature along the east side of the basin, no limestone having been observed at this horizon between this locality and Stucco, north of Greybull. (See section 1, Pl. V.)

Owing to the presence of excellent building stone near by, to the comparatively small population of the region, and to the long distance from railroad transportation, the development of the gypsum at this locality is very remote.

EAST OF THERMOPOLIS.

The gypsum in the upper part of the Chugwater formation is fairly well exposed in the Red Spring anticline, a few miles east of Thermopolis. Section 6, Plate V, is believed to represent an average thickness of the gypsum, which is in two beds. The upper bed, 10 feet thick, lies about 33 feet above the lower bed, which is 42 feet thick. It crops out near the top of an inward-facing wall of alternating red sandstones and shales, which are exposed around the anticline. Any gypsum mined in this locality will necessarily be removed from the depression in which it crops out by way of the narrow canyons of intermittent tributaries of Kirby Creek that are cut through the prominent wall or rim. In view of the large quantities of gypsum in the Thermopolis anticline along Bighorn River, and in the Sheep Mountain anticline, both near the Chicago, Burlington

& Quincy Railroad, it is doubtful whether the gypsum in the Red Spring anticline will be mined until these deposits adjacent to the railroad are for the most part exhausted.

Below is given the analysis of a sample of gypsum collected from the north flank of the Red Spring anticline near the top of the Chugwater formation.

Partial analysis of gypsum from north flank of Red Spring anticline, in the NW. ¼ SW. ¼ sec. 21, T. 43 N., R. 93 W.

[W. C. Wheeler, analyst.]

Lime (CaO)	34.20
Sulphur trioxide (SO_3)	45.50
Water driven off at 300° C	20.00
Chlorine (Cl)	None.
Silica (SiO_2)	.25
Manganese oxide (MnO)	None.
Iron and alumina mixed (Al_2O_3 and Fe_2O_3)	.10

As compared with pure gypsum, this sample contains 1.6 per cent more of lime and 1 per cent less of sulphur trioxide. Its content of water is slightly lower than that of pure gypsum. The excess of lime and the presence of carbon dioxide, qualitatively determined, suggest the presence of calcium carbonate.

GYPSUM IN THE EMBAR FORMATION.

GRAPHIC SECTIONS.

Localities where the Embar formation was examined and gypsum beds measured or found to be lacking are marked on the map and designated by Nos. 7 to 13, which apply to the sections represented on Plate V. The localities lie on both the east and west slopes of the Bighorn Range and include the Sheep Mountain anticline near Greybull. They are described below in order from north to south.

SHEEP MOUNTAIN ANTICLINE NEAR GREYBULL.

The most valuable gypsum beds in the Sheep Mountain anticline lie within the upper portion of the Chugwater formation, but the Ember contains a few beds 3 to 4 feet thick where examined at a point along the southwest base of the mountain, about 2 miles north of the mouth of Shell Creek. In addition to the several thin pure layers there are abundant irregular veinlets of coarsely crystalline gypsum that form a network in the red shales. The gypsiferous portion of the formation is represented in section 7, Plate V. It is noteworthy that on the summit of the mountain due east from the point above described and some 1,000 feet higher, where the same strata are present as an erosion remnant along the crest of the anticline, the gypsum has been entirely removed by solution.

Along the base of the mountain near the river and immediately beneath the red beds of the Chugwater formation, there is about 60 feet of bluish-gray shale, weathering to ocherous brown. This shale, the equivalent of the Dinwoody formation of the Bighorn River canyon, contains many irregular veinlets of impure gypsum.

WEST SLOPE OF THE BIGHORN MOUNTAINS.

HORSE CREEK CANYON.

At Horse Creek canyon, in T. 54 N., R. 91 W., the mountain front is formed by bold cliffs of Tensleep sandstone inclined westward at an angle of about 55°. Fair exposures of all but the upper third of the Embar formation show no gypsum. Although this canyon is only 14 miles east of the Sheep Mountain locality described above, the Embar shows a marked transformation, there being a great increase in the proportion of red beds to limestone and a change from firm marine fossiliferous limestone layers to irregular conglomeratic vesicular limestone of tufaceous appearance.

Gypsum was not seen in the vicinity of Horse Creek canyon, but it may be present in considerable quantity. Good rock exposures are not plentiful owing to the mantle of talus at the bases of the steep mountain slopes. Fisher[1] measured a section along Shell Creek, about 5 miles southeast of Horse Creek, where he found 12 feet of gypsum 24 feet above the Tensleep sandstone. Gypsum is also reported in Red Gulch, east of Cloverly.

ZEISMAN RANCH NEAR HYATTVILLE.

Gypsum beds, probably lying in the upper part of the Embar formation, were measured by Lupton on a tributary of No Wood Creek near the Zeisman ranch, in the SE. ¼ sec. 34, T. 49 N., R. 89 W. (section 8, Pl. V). The section of the beds shows a number of layers of gypsum 4 to 10 feet thick, alternating with red shale and a few thin laminæ of limestone. One bed 10 feet thick was sampled for chemical analysis, and the results are as follows:

Analysis of gypsum from deposit near the Zeisman ranch.

[W. C. Wheeler, analyst.]

Lime (CaO)	32.72
Sulphur trioxide (SO_3)	45.18
Water driven off at 300° C	20.03
Chlorine (Cl)	None.
Silica (SiO_2)	.06
Manganese oxide (MnO)	.42
Iron and alumina mixed (Al_2O_3 and Fe_2O_3)	.05

[1] Fisher, C. A., Geology and water resources of the Bighorn Basin, Wyo.: U. S. Geol. Survey Prof. Paper 53, p. 19, 1906.

The percentage of lime shown by this analysis is only slightly in excess of the amount normal to pure gypsum, which is 32.60. There is a trace of carbon dioxide, indicating a small amount of calcium carbonate.

TENSLEEP CANYON.

Measurements were made near the Burke ranch, on the north side of Tensleep Creek, in T. 47 N., R. 88 W. (section 9, Pl. V), where the beds dip westward at an angle of about 10°. Section 4 in Plate IV (p. 144) is a detailed section from the Tensleep sandstone upward. Two layers of gypsum 2 feet and 4 feet thick were found in the midst of the red shale in the lower part of the formation, but the principal beds lie about 240 feet above the Tensleep sandstone. They consist of many layers interbedded with insignificant shale beds, the total thickness being about 90 feet. The gypsum is stained reddish brown on the outcrop, but beneath the surface it is snowy white and free from mechanical sediment. The texture is so fine that the glistening crystal faces are barely visible to the naked eye. The gypsum exposures in this vicinity in many respects rank among the best deposits seen in the Bighorn Mountain region.

CHERRY CREEK NEAR REDBANK.

The exposures described lie near the base of the mountain along the valley of Cherry Creek, about 2 miles southwest of Redbank, in T. 43 N., R. 87 W. (section 10, Pl. V). In this vicinity the upper limestone member of the Embar formation extends well up the mountain slopes to an altitude of nearly 7,000 feet. All the gypsum once present in the upper slopes has been dissolved away, and none is found above a certain altitude, possibly about 6,700 feet above sea level. From that altitude down the slopes gypsum is increasingly conspicuous and the thickness of the entire formation is accordingly greater than on the upper slopes.

The most valuable gypsum beds lie beneath the nodular chert in the upper part of the formation. The section on Plate V shows about 30 feet of almost continuous gypsum with a few thin layers of reddish shale. Beneath these are about eight massive gypsum beds, each 2 to 4 feet thick, scattered through an interval of about 50 feet of red shale. As followed along the strike, the beds recorded here are found to vary in thickness and to disappear within a short distance, giving place to conglomeratic limestone. A little farther along there appear other gypsum deposits of similar importance. Sections measured 1 mile apart have little similarity except that the gypsum beds occupy the same general position in the section.

VICINITY OF NO WOOD.

About 3 miles northeast of No Wood, where No Wood Creek enters the canyon, in T. 42 N., R. 88 W., the upper part of the Embar consists largely of massive beds of white gypsum many feet thick, with a few interbedded layers of red shale. About a mile southwest of the canyon, toward No Wood, the upper part of the formation shows almost no gypsum and contains an upper member of resistant limestone 13 feet thick.

About 1½ miles southwest of No Wood, where the creek emerges from a small canyon, the Embar is again found to contain prominent gypsum beds. A measurement showed about 42 feet of gypsum interbedded with red shale. This is the most southwesterly locality where gypsum beds of any economic importance were observed. A section of the Embar measured some 6 miles farther southwest, near the head of No Wood Creek and a little west of the center of T. 41 N., R. 89 W., is given in Plate IV (p. 144). No gypsum was found in that vicinity.

EAST OF THERMOPOLIS.

At the Red Spring anticline, which is about 9 miles east of Thermopolis, in T. 43 N., R. 94 W., the Chugwater and about 100 feet of the underlying Embar beds are exposed. Observations made by Mr. Lupton show that the beds are largely gray to brown calcareous shales, alternating with shaly gypsum, with a 16-foot bed of fairly pure gypsum near the top. The lowest exposures consist of the resistant limestone a little above the middle of the formation.

EAST SLOPE OF THE BIGHORN MOUNTAINS.

BILLY CREEK.

The exposures at Billy Creek, in T. 48 N., R. 83 W., include the lower 100 feet of the Embar formation, in which no valuable beds of gypsum were found. Owing to the talus good exposures are few, except along the steep slopes of the ravines. It is possible that the upper part of the formation is gypsum bearing.

MIDDLE FORK OF CRAZY WOMAN CREEK.

The hills on the north side of the valley of Middle Fork of Crazy Woman Creek, in T. 47 N., R. 83 W., contain the thickest gypsum deposits seen on the east slopes of the Bighorn Range. Section 11 in Plate V does not represent the entire thickness, and it is believed that the total is at least 150 feet. The gypsum consists largely of white layers free from mechanical sediment, with a few stained pink or dark by clay or other impurities. The texture is uniformly very fine. Between the massive beds of white gypsum are thin layers of gypsiferous red shale. In the midst of the gypsum is the purplish nodular chert member.

Partial analysis of gypsum from deposit near Middle Fork of Crazy Woman Creek.

[W. C. Wheeler, analyst.]

Potash (K_2O)	None.
Lime (CaO)	32.81
Sulphur trioxide (SO_3)	45.42
Water driven off at 300° C	20.40
Chlorine (Cl)	None.
Silica (SiO_2)	.07
Manganese oxide (MnO)	None.
Iron and alumina mixed (Al_2O_3 and Fe_2O_3)	.11

This analysis approaches closely that of pure gypsum. A slight excess of lime and a trace of carbon dioxide indicate the presence of a small amount of calcium carbonate.

BEAVER CREEK.

Exposures in the ravine near Beaver Creek, in T. 47 N., R. 83 W., show a large amount of gypsum both above and below the purplish chert member. Beds of limestone conglomerate are also abundant in the same vicinity at approximately the same horizon as the gypsum, but the two are not commonly associated in the same section.

Gypsum was also observed in the upper third of the Chugwater formation, in beds 25 to 40 feet thick. About 30 feet higher is oolitic gray limestone 25 feet thick.

SOUTH FORK OF CRAZY WOMAN CREEK.

The variable and discontinuous character of the gypsum beds is evident in the vicinity of South Fork of Crazy Woman Creek. The exposures along the main valley are not good except for the basal portion of the Embar, but it seems probable that gypsum is not present. Half a mile farther north, however, in T. 46 N., R. 83 W. (section 12, Pl. V), there is a great thickness of gypsum both above and below the purplish chert member.

NORTH FORK OF POWDER RIVER.

A section of the Embar was measured near the Webb ranch in the northwest corner of T. 45 N., R. 83 W. The formation consists of a mixture of red sandy shale and conglomeratic limestone, with thin beds of gypsum. The purplish chert member so characteristic of the Embar is present, but has been more or less removed by the erosion that produced the conglomerates. About 100 feet above the chert are beds of white and pink banded gypsum alternating with red shale. Their thickness is about 40 feet. It can not be stated whether these beds lie in the Embar or the Chugwater, because of the indefinite boundary between the two formations.

PHILLIPS RANCH.

The Phillips ranch is on Red Creek at the site of the McKenzie battlefield, in T. 44 N., R. 84 W. A short distance to the east the creek enters a deep, narrow canyon cut below the Tensleep sandstone along the axis of an anticlinal nose pitching southeast. The Embar formation in the structural cove to the west of the anticlinal nose, northwest of the Phillips ranch, consists of the usual red beds with conspicuous layers of conglomerate, on the surface of which the friable pebbles have been largely removed either by solution or wind erosion, which has left the vesicular, spongy, calcareous, cementing material with pockets large enough to be used for nesting places by birds. There is much gypsum along the base of the main mountain front west of the Phillips ranch and for several miles to the south. The deposits are found to be discontinuous when traced along the outcrop. The only persistent stratum in the upper part of the formation is the purplish-pink chert. The section of the gypsum beds (Section 13, Pl. V) can not be considered representative on account of their changeable character. The beds lie both beneath and above the purplish chert member. Those above are the thicker, being as much as 100 feet thick, inclusive of the intercalated thin layers of red shale. In the midst of the clean white gypsum beds is an irregular course of gray and white banded flint geodes, some of which are embedded in bowlders of gypsum.

BARNUM AND VICINITY.

Exposures of the Embar between Beaver and Sheep creeks near Barnum, in T. 43 N., R. 84 W., contain little gypsum, but it is assumed that beds probably of considerable thickness exist under the surface along the base of the mountain and that they were once present on the slopes but have been removed by solution. The general distorted attitude of the red shales and thin limestone layers supports this belief. At the top of the hill is a conglomerate or breccia consisting of pebbles of reddish chert, limestone, and shale, cemented by a spongy, calcareous, sandy material. The rocks below consist of structureless red sandy clay marked at irregular intervals by thin layers of laminated limestone that are much distorted and broken by numerous small faults. These exposures rest on beds of red shale and limestone that show even lines of stratification, with little or no distortion.

In this same vicinity there is little gypsum in the lower part of the Chugwater formation, and that observed consists mostly of irregular veinlets in the red beds

CHARACTER OF THE GYPSUM.

The greater part of the gypsum in this region is white, but in many places it has a slightly pinkish or flesh tint caused by the presence of particles of red clay. The color varies from pure white to reddish or dark, according to the amount and kind of impurities. In places fragments of selenite, a transparent crystalline form of gypsum, are numerous along the outcrop of the gypsum beds, but they are of minor importance compared with the massive gypsum. In some beds considerable fine sand has been mixed with particles of gypsum, thus forming gypsite. This material, however, constitutes a very small proportion of the gypsum deposits of the region.

The analyses of the gypsum given above indicate that most of it contains very little calcium carbonate, or calcite. Pure gypsum contains 32.6 per cent of lime, 46.5 per cent of sulphur trioxide, and 20.9 per cent of water. The analyses show that the samples analyzed range from 32.72 to 34.20 per cent of lime. The percentage of lime in each analysis is greater than that of pure gypsum, and carbon dioxide is present in small amounts in each sample. It is noteworthy that the two samples from the Embar formation contain less carbon dioxide than those from the Chugwater formation. There is a possibility that a small amount of anhydrite is present and thus in part accounts for the excess of lime.

DEVELOPMENT.

The gypsum in the area described in this report is known to have been utilized at only two places, both near Greybull, on the west and south flanks of Sheep Mountain. Most of the gypsum is quarried in the upper part of the Chugwater formation about half a mile west of Stucco (section 1, Pl. V), a flag station on the Chicago, Burlington & Quincy Railroad. It is hauled by wagons to the railroad and shipped to Basin, about 18 miles distant. The gypsum is calcined and made into stucco blocks, which are used in building.

The mill at Basin is of small capacity, using about 200 tons of gypsum a month. In preparing the stucco blocks the raw gypsum is crushed, pulverized, and calcined. Care is taken in calcining not to overheat the pulverized gypsum, for if this is done it is said to be "dead burned," and the particles will not "set" or recrystallize. In calcining the gypsum is usually heated to about 177° C. (350° F.).

The selling price of the stucco blocks is small as compared with the price of lumber in this region. It is reported that blocks sufficient for the walls of a building 25 by 30 by 9 feet cost about $200. Buildings made of this material are durable in a climate such as that of the Bighorn Basin. In a region where the rainfall is great the use of stucco blocks for buildings may not be advisable, but

where the rainfall is only from 5 to 12 inches annually they are sufficiently durable to last a lifetime and within a moderate distance from the mill they are less expensive than lumber.

Near the southeast end of Sheep Mountain, about 2 miles northeast of Greybull (section 2, Pl. V), a small amount of gypsum has been quarried and manufactured into stucco building blocks. It is hauled in wagons from the quarry a short distance to a small open kiln, where it is burned over a wood fire. After burning the gypsum is ground in a burrstone mill driven by a gasoline engine. The kiln is 8 by 11 by 5 feet and holds 12 to 15 wagonloads of material. About 500 blocks 8 by 9 by 24 inches are made from each burning. During three months in the spring and summer of 1915 2,500 blocks were made at this locality by the method above described. The blocks sell at 10 cents each at the kiln and 15 cents each delivered at Greybull.

Gypsum is not known to have been utilized elsewhere in the area described in this report, and it seems doubtful if the development of the gypsum industry in this general region will be rapid, owing to the large amount of good sandstone and limestone of building quality in the Bighorn Basin and adjacent parts of Wyoming.

As this report goes to the printer word comes that a mill is being installed at Stucco which will handle the gypsum quarried at that locality. The situation is so convenient to the railroad that the product will probably be shipped to all parts of the Bighorn Basin.