CEMENT AND CONCRETE MATERIALS.

THE NIOBRARA LIMESTONE OF NORTHERN COLORADO AS A POSSIBLE SOURCE OF PORTLAND CEMENT MATERIAL.

By G. C. Martin.

INTRODUCTION.

SCOPE AND FIELD OF WORK.

The following paper is the result of a hasty and rather superficial examination of a small area made with a view of determining the possibility of local material being suitable for cement manufacture. The general geologic facts are drawn largely from publications by several geologists, notably Eldridge,[a] Darton,[b] and Fenneman.[c] The new material here presented is chiefly the chemical analyses and the local measurements and descriptions of the beds outcropping at localities from which samples were taken.

The area discussed in this paper is a narrow belt lying along the eastern face of the Rocky Mountains in Boulder and Larimer counties, Colo. As represented on the map (fig. 26), it includes part of the Great Plains on the east, part of the front range of the Rocky Mountains on the west, and a narrow foothill belt between. The area that was made the object of especial study is a narrower belt at the extreme western margin of the plains.

The mountains consist of granite masses having altitudes of 9,000 to 14,000 feet. The foothills, which form a narrow belt of linear

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[a] Eldridge, George H., Mon. U. S. Geol. Survey, vol. 27, 1896.
[b] Darton, N. H., Prof. Paper U. S. Geol. Survey No. 32, 1905.
[c] Fenneman, N. M., Bull. U. S. Geol. Survey No. 265, 1905.

monoclinal ridges parallel to one another and to the eastern front of the mountains, rise to elevations of 5,500 to 6,500 feet above sea level, or 500 to 1,500 feet above the general surface of the plains.

The part of the area lying in the plains constitutes an irregularly rolling country, with general maximum relief of 300 or 400 feet, the average elevation above sea level being about 5,000 feet. It is crossed from west to east by four large streams—Cache la Poudre River, Thompson River, St. Vrain Creek, and Boulder Creek—all of which rise within the mountains and are tributary to South Platte River at points east of the region here described. These streams furnish abundant water for irrigation, and consequently the plains are thickly settled and in a high state of cultivation. The chief towns of the region, all of which are located on the plains, are Boulder, Longmont, Berthoud, Loveland, and Fort Collins. These towns are on the main line of the Colorado and Southern Railway, which crosses the region here described from north to south. Longmont is also reached by a branch of the Burlington and Missouri River Railroad, and Boulder is the terminus of the Colorado and Northwestern Railroad and also of a branch of the Union Pacific. Boulder is about 20 miles northwest of Denver.

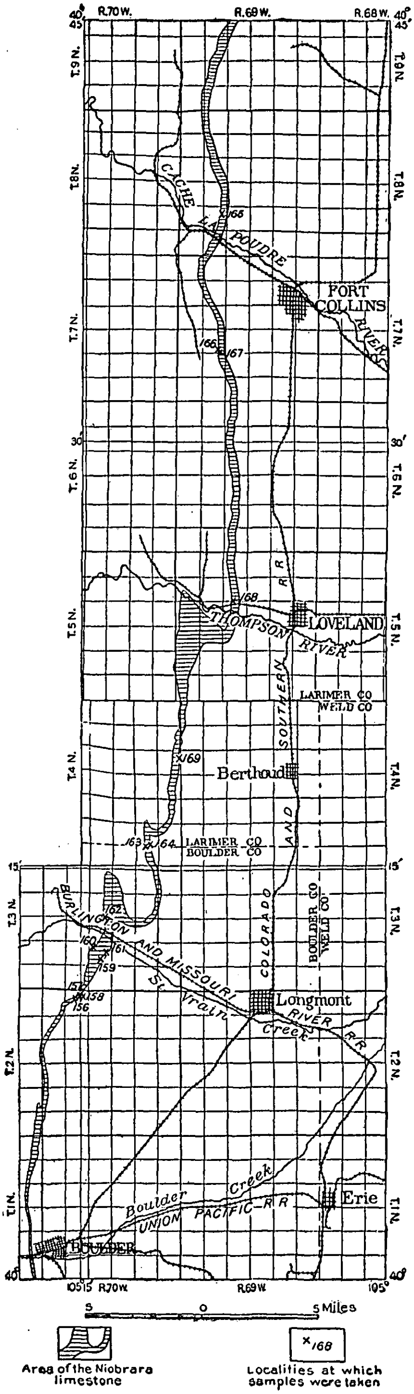

FIGURE 26.—Map of a portion of the foothill region of northern Colorado, showing areal distribution of Niobrara limestone.

GENERAL GEOLOGIC RELATIONS.

The rocks of this region have been divided by Fenneman[a] into the following formations:

Quaternary	Alluvium and terrace gravels.
Cretaceous	Laramie.
	Fox Hills.
	Pierre.
	Niobrara.
	Benton.
	Dakota.
Jurassic	Morrison.
Triassic (?)	Lykins.
	Lyons.
	Fountain.
Algonkian	Quartzite of South Boulder Canyon.
Archean	Granites, etc.

Of these formations the pre-Cambrian granites and quartzite occupy the high mountains. The Fountain, Lyons, and Lykins formations, which constitute the so-called "red beds," and the Morrison and Dakota formations outcrop as steeply dipping beds in the foothills proper. The Benton group and Niobrara limestone also belong to the foothills belt where the limestones of the Niobrara are massive and make ridges; but to the plains where the Niobrara is less resistant. The Pierre, Fox Hills, and Laramie outcrop exclusively on the plains.

The pre-Cambrian rocks of this district consist of granite porphyry and granite gneiss, with local areas of quartzite and metamorphosed conglomerate. These constitute the floor upon which the sedimentary rocks were laid down.

Early Paleozoic limestones occur within this general region, though not within the special area here described. The nearest localities are in the vicinity of Colorado Springs. There is no evidence as to whether these rocks were deposited in this region and subsequently removed by erosion or whether this district was land during the period of their deposition.

The Fountain formation consists of granite arkose, quartzose sandstone, and some shale, all being characteristically red in color. It is now known to be of Carboniferous age. The thickness of this formation varies extremely within short distances, the limits being from a fraction of an inch to 1,500 feet, the general thickness in most places being 500 or 600 feet.

The Lyons sandstone and Lykins formation, which together constitute the "Upper Wyoming" of the older reports, consist of sandstones and sandy shales, with a few thin beds of limestone. These rocks, too, are generally reddish in color, many shades of red and in a few

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[a] Fenneman, N. M., Bull. U. S. Geol. Survey No. 265, 1905, p. 20.

places other colors being present. The Lyons formation is predominantly sandstone; the Lykins formation contains much sandstone, but also considerable shale and a little limestone. The thickness of the Lyons is about 300 feet; that of the Lykins is generally about 800 feet. The age of these formations is somewhat in doubt, but is either Permian or Triassic.

The Morrison formation consists of about 400 feet of sandstones, clays, and marls, all presumably deposited in fresh water. Several thin limestones are also present in this formation. The age of the Morrison is either Jurassic or Cretaceous.

The Dakota sandstone, which is one of the most characteristic beds of the foothills, consists of two massive beds of sandstone, with clay and shale intervening. The thickness of the whole is between 300 and 400 feet. The Dakota is of Cretaceous age.

The Benton group includes the Graneros, Greenhorn, and Carlile formations. It lies immediately above the Dakota and outcrops just east of it on the plains. The Graneros and Carlile consist of dark shales and some sandstone; the Greenhorn is a thin limestone, not well developed in this area. The local thicknesses are from 200 to 525 feet for the Graneros, 20 to 25 feet for the Greenhorn, and about 125 feet for the Carlile, or from 350 to 640 feet for the entire Benton group.

The Niobrara limestone is one of the formations which outcrops in the foothills and is the highest and easternmost one that contributes essentially to the typical foothills topography. It consequently outcrops as a long, narrow belt parallel to the mountains and to the other ridges of the foothills. The position of this belt is in general from 2 to 3 miles east of the mountains, approaching nearer to them or extending farther out toward the plains, according as the dip is steep or gentle. The basal member of the Niobrara usually consists of thick and massive limestone and makes a very distinct ridge, but where this member is thinner or less massive the ridge disappears. The dip is in general noticeably steeper in the basal bed, which lies nearest the mountains, and flattens perceptibly toward the east. The width of this belt is between one-eighth and one-half mile, varying with the amount of dip, as the thickness of the formation remains fairly constant.

The Niobrara is essentially a limestone formation, although calcareous shales make up a considerable part of it. The thickness is about 400 feet. The basal member is a massive white to gray limestone whose thickness ranges from 10 to 20 feet. This bed, which rests with apparent conformity on the top member of the Benton (Carlile shale), is apparently persistent, having been seen through practically the entire length of the region studied. It is succeeded by shaly limestones and calcareous shales, the former predominating and the calcareous nature of all the beds being persistent. These beds vary somewhat in character along the strike, fairly massive limestones being developed at several places. These more massive limestone beds are apparently present at several horizons but predominate toward the middle of the formation.

The Niobrara is overlain by the Pierre shale, which differs from it most noticeably in being noncalcareous. Several sandstones are present, the most characteristic being the Hygiene sandstone member, which occurs at about 1,000 feet above the base of the Pierre. Most of these sandstones are somewhat local in extent and their exact stratigraphic position has not been determined. A few thin calcareous beds are also present. The thickness of the Pierre shale probably exceeds 5,000 feet.

The Fox Hills formation consists of shales and sandstones, with a few thin beds of limestone. The formation is characteristically shaly in its lower part and characteristically sandy in its upper part, the top bed being a very persistent and easily recognized greenish sandstone about 40 feet thick. The thickness of the Fox Hills is apparently about 1,300 feet.

The Laramie formation, which rests with apparent conformity on the Fox Hills, consists of sandstones, shales, and coal beds. The entire thickness of the formation is probably about 1,000 feet.

South of the region here described, in the vicinity of Denver, the Laramie formation is succeeded unconformably by the Arapahoe and Denver formations, neither of which outcrop within this area. Both the Arapahoe and the Denver are probably of Tertiary age. Still younger Tertiary beds occur both south of Denver, where they rest on the Denver formation, and north of Greeley, where they overlie the Laramie. These, also, are entirely absent in the region here described.

The youngest beds of this region consist of the gravels that cap the mesas and the sands and gravels that lie along the flood plains of the streams.

Of all these formations the Niobrara alone is calcareous enough to be considered a possible important source of cement material, although thin and local limestones are present in the red beds and in the Morrison. These thin beds, however, have not been investigated for the purpose of this report.

REQUIREMENTS FOR CEMENT MATERIALS.

Portland cement, according to Eckel,[a] is "an artificial product, obtained by finely pulverizing the clinker produced by burning to semifusion an intimate mixture of finely ground calcareous and argillaceous material, this mixture consisting, approximately, of

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[a] Eckel, E. C., Bull. U. S. Geol. Survey No. 243, 1905, p. 23.

one part of silica and alumina to three parts of carbonate of lime (or an equivalent amount of lime)."

The mixture of calcareous and argillaceous material required for the manufacture of cement can be obtained from a variety of raw materials by mixing in the proper proportion. The essential requirement is that the mixture when ready for burning shall contain about 75 per cent of lime carbonate ($CaCO_3$) and 20 per cent of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) together, the remaining 5 per cent including magnesium carbonate, sulphur, and alkalies. It is essentially important that the proportion of magnesia and sulphur should be small. It is furthermore important that the alumina and iron oxide should be less than half the amount of silica and preferably that they should be about one-third of the silica. This requirement is usually expressed as follows:

$$\frac{SiO_2}{Al_2O_3+Fe_2O_3} > 2 < 3.5$$

If a single rock, such as argillaceous limestone or calcareous shale, contains within itself the percentage of lime prescribed above, with the remaining constituents (silica, alumina, and iron) in the proper ratio, it could evidently be used for cement manufacture without the addition of any other material. The nearer that any rock comes to this composition the less the amount of other material that will have to be added to produce the required mixture. The customary practice in the Pennsylvania and New Jersey cement districts is to use an argillaceous limestone, or so-called "cement rock," with an admixture of a relatively small amount of purer limestone. There are, according to Eckel,[a] obvious advantages in using such a combination of materials. As a larger part of the mixture is made up of a single rock, the grinding does not have to be as fine as if two rocks of entirely different composition were to be mixed together, and probably also less fuel is required when the bulk of the material is derived from a single rock.

It is also essential that these materials should occur in large quantities and in such a position that they can be cheaply quarried. The cement business is essentially a manufacturing industry, and good materials are present in abundance at so many places that they have little intrinsic value unless the localities at which they occur are so situated that the processes of quarrying and manufacturing can be carried on at low cost.

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[a] Op. cit., p. 31.

DESCRIPTION OF LOCAL MATERIALS.

NIOBRARA LIMESTONE.

The following sections of the Niobrara limestone were measured at scattered localities along the outcrop from Laporte (which is about 4 miles northwest of Fort Collins) on the north to a point about 8 miles west of Longmont on the south, the length of the belt thus studied being about 35 miles. These localities are shown in figure 26. Their selection was governed entirely by the occurrence of good natural outcrops. Most of them are situated near points where large streams break through the ridges of the foothills, and are consequently well located with reference to possible industrial development, being on lines of naturally easy transportation. The sections consist of measurements partly of the basal bed of the Niobrara, which is a massive and relatively pure limestone, and partly of less massive and more argillaceous limestones interbedded with calcareous shales that occur somewhat higher in the formation. It is not known whether all of the latter represent the same horizon or whether two or more horizons are represented.

Section in road cut one-half mile north of Laporte (one-third mile south by one-fourth mile west of northeast corner sec. 29, T. 8 N., R. 69 W.).

	Feet.
Limestone,[a] thin bedded and somewhat shaly	18
Strike N. 12° E.; dip 24° SE.	

Section at mouth of Dixon Canyon, 3 miles west by 2 miles south of Fort Collins (one-tenth mile north by one-fourth mile west of southeast corner sec. 20, T. 7 N., R. 69 W.).

	Ft.	in.
Limestone,[b] thin bedded and with much shale	49	
Gray shale, with thin limestone beds	90	
Limestone [c]	1	5
Shale [c]		8
Limestone [c]	1	3
Shale [c]		5
Limestone [c]	1	5
Shale [c]		6
Limestone [c]	11	2
Sandstone, gray, brownish.		
Strike N. 4° W.; dip 24° NE.		

Section in road cut 3 miles west of Loveland (one-third mile east of southwest corner sec. 9, T. 5 N., R. 69 W.).

	Feet.
Limestone,[d] thin bedded, shaly	43
Strike N. 3° E.; dip 25° SE.	

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[a] Included in sample 165, p. 324.

[b] Included in sample 167, p. 324.

[c] Included in sample 166, p. 324.

[d] Included in sample 168, p. 324.

Section in north bank of Dry Creek, 5 miles west by one-half mile north of Berthoud (two-fifths mile south by 2⅕ miles west of northeast corner sec. 13, T. 4 N., R. 70 W.).

	Feet.	In.
Limestone,[a] massive, white	19	4

Strike N. 11° W.; dip 44° NE.

Section on north bank of Little Thompson River, 5 miles west by 6½ miles north of Longmont (one-half mile west of southeast corner sec. 35, T. 4 N., R. 70 W.).

	Feet.
Shale, yellow, sandy (Pierre).	
Shale,[b] black	50
Limestone and black shale,[b] latter predominating toward top	22
Limestone,[b] black, shaly, with *Ostrea congesta*	40±
Concealed	30±
Limestone,[b] black, shaly	18
Concealed	200±
Limestone,[c] massive, white	14

Strike N. 3° E.; dip 20° SE.

Section at east base of Rabbit Mountain, near northeast corner sec. 14, T. 3 N., R. 70 W.

	Feet.
Calcareous shales or shaly limestone, weathering white	66
Shales as below but with less regular bedding and probably more calcareous	100
Dark shales with slaty bedding	98
Concealed, probably limestone	30
Massive limestone	15

Strike N.; dip 70° E.

Section in ditch one-third mile west of northeast corner sec. 21, T. 3 N., R. 70 W.

	Feet.
Limestone,[d] massive, white	15½

Section 7 miles west by 2 miles north of Longmont (one-third mile south by one-fourth mile west of northeast corner sec. 28, T. 3 N., R. 70 W.).

	Feet.
Limestone,[e] black, shaly	30

The above section constitutes the upper 30 feet of a bluff 40 feet high. The lower part of the bluff is concealed by talus. The beds lie almost flat.

Section 7¼ miles west by 2¼ miles north of Longmont (one-fifth mile south by one-fifth mile east of northwest corner sec. 28, T. 3 N., R. 70 W.).

	Feet.
Limestone,[f] massive, white	10

This is the basal ledge of the Niobrara and is exposed on the crest of a hill, just above a ditch. Gritty Benton shales are exposed below. The overlying beds are stripped off.

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[a] Included in sample 169, p. 324.
[b] Included in sample 164, p. 324.
[c] Included in sample 163, p. 324.
[d] Included in sample 162, p. 324.
[e] Included in sample 161, p. 324.
[f] Included in sample 160, p. 324.

Section in road bank 7 miles west by 1¾ miles north of Longmont (one-half mile west by one-fourth mile north of southeast corner sec. 28, T. 3 N., R. 70 W.).

	Feet.
Limestone,[a] black, shaly	20
Dip about 5° E.	

Section in bank of Lykins Gulch, 8 miles west of Longmont (one-third mile west by one-fourth mile south of northeast corner sec. 5, T. 2 N., R. 70 W.).

	Feet.
Limestone,[b] argillaceous, with many thin shale beds	30
Dip 30° SE.	

This section is about 100 feet below the top of the Niobrara.

Section in south bank of Lykins Gulch, 8 miles west of Longmont (one-half mile west by one-fourth mile south of northeast corner sec. 5, T. 2 N., R. 70 W.).

	Feet.
Limestone,[c] massive	15
Strike N. 44° E.; dip 28° SE.	

The Niobrara limestone has already been described as occurring in a narrow north-south belt along a line of low ridges just east of the main foothills. It dips eastward under the plains at angles of 24° to 70° along the western edge. Most of these dips are so steep that within short distances they carry the limestone too deep to be quarried cheaply; consequently it is only where the limestone rises into a ridge of considerable height that there is any large amount of material that can be easily quarried. The most desirable localities for quarries are where the ridge is high but falls off steeply into a transverse valley, thus affording sites where quarries can be opened with their faces above the general drainage level and with a considerable bulk of rock near at hand. Such points exist where the limestone belt crosses the valleys of St. Vrain Creek, Little Thompson Creek, Thompson River, and Cache la Poudre River. At each of these points, except on Little Thompson Creek, a railroad follows the line of the stream and crosses the limestone belt, the topographic conditions favorable for a good quarry site being thus combined with easy transportation facilities. There are numerous localities on either side of these railroads where quarries could be opened.

OTHER SOURCES OF CEMENT MATERIAL.

The following section represents a shale bed in the Pierre, a short distance above the top of the Niobrara.

Section 8 miles west of Longmont (one-fourth mile west by one-fourth mile south of northeast corner sec. 5, T. 2 N., R. 70 W.).

	Feet.
Black clay shale[d]	50

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[a] Upper 12 feet included in sample 169, p. 324.

[b] Included in sample 157, p. 324.

[c] Included in sample 156, p. 324.

[d] Included in sample 158, p. 324.

No other sections in the Pierre or other formations above or below the Niobrara were measured, but the Pierre contains a large amount of shale, much of which would doubtless be suitable for cement manufacture if it were required. Other limestones have also been mentioned above as being present in the lower formations, and some of these possibly occur at such points and with such thickness that they would be available as cement material.

Another source of possible cement material is the waste lime of the local sugar factories. These factories, which are situated at Longmont, Loveland, Fort Collins, Greeley, and other points, use a large amount of limestone in refining sugar. The processes require that this limestone shall be very pure, and it is said that of themselves they add nothing that is objectionable from the cement manufacturer's standpoint. The waste lime consists of a very fine chemical precipitate, composed essentially of carbonate of lime, with a considerable amount of organic matter and moisture. The composition of this material as it comes from the presses is shown in analysis 170, on page 325. This material has no present value, and is washed out of the sugar factory by running water and dumped on ground that has to be purchased for this purpose. Analysis No. 171, on page 325, shows the composition of material from the dump near Longmont, which had probably been lying there for about eighteen months.

A very large amount of this material has accumulated around the sugar factories, and it is increasing at the rate of about 9,000 tons a year for each of the larger factories, or a total of 57,000 tons a year for the factories of the entire district.

ANALYSES.

The analyses given in Tables 1 and 2 represent samples that were taken especially for the purpose of this report. Table 1 represents the basal bed of the Niobrara limestone and Table 2 represents the more argillaceous beds above the base. The localities of these samples agree with those of the sections given on pages 320–322, and the sections show just what beds are represented in each sample. Most of these samples were taken by chipping off small pieces of the rock across the entire face of the bed as exposed in a good natural outcrop, and consequently represent the average composition of the entire bed.

In obtaining samples 157, 161, 164, and 168, however, small representative pieces were broken off at intervals of a few inches across the entire bed. It is probable that these also represent the average composition of the whole bed at the points where they were taken.

Table 3 represents a sample of new waste lime from a sugar factory at Longmont and another of older lime from the dump of the same factory. All these analyses were made at the laboratory of the United States Geological Survey at St. Louis, Mo., by P. H. Bates, A. J. Phillips, and G. R. Brobst, full credit, according to the division of the work, being given in the tables.

TABLE 1.—*Analyses of basal bed of Niobrara limestone.*

	166.	169.	163.	162.	160.	156.
Silica	[a]5.97	[a]7.14	[b]5.33	[a]5.35	[a]5.10	[a]4.79
Alumina	[a]1.74	[a]1.63	[b]1.54	[a]1.45	[a]1.80	[a].99
Ferric oxide	[a].18	[a].14	[b].23	[a].45	[a].03	[a].14
Ferrous oxide	[a].64	[a].48	[b].48	[a].56	[a].56	[a].48
Lime	[a]49.82	[a]49.11	[b]50.69	[a]51.29	[a]50.27	[a]50.54
Magnesia	[a].75	[a]1.04	[b].56	[a].57	[a]1.01	[a].56
Sulphuric anhydride [b]	Trace.	Trace.	....	.09	.12	.10
Soda	[a].16	[a].17	[b].05	[a].03	[a].07	[a].14
Potassa	[a].34	[a].45	[b].21	[a].13	[a].26	[a].37
Water at 100° C.[b]	.17	.33	.12	.08	.17	.17
Water above 100° C.[c]	.07	.19	.51	.24	.49	.29
Carbon dioxide [c]	39.84	39.00	39.90	40.07	40.11	40.38
Organic [c]	.43	.52	.44	.27	.16	1.09
Total	100.11	100.20	100.06	100.58	100.16	100.04

[a] Determined by A. J. Phillips. [b] Determined by G. R. Brobst. [c] Determined by P. H. Bates.

166. One-eighth mile north by one-third mile west of southeast corner sec. 20, T. 7 N., R. 69 W., Larimer County.
169. Two-fifths mile south by two-fifths mile west of northeast corner sec. 13, T. 4 N., R. 70 W., Larimer County.
163. Two-fifths mile east of southwest corner sec. 35, T. 4 N., R. 70 W., Larimer County.
162. One-third mile west by 100 feet south of northeast corner sec. 21, T. 3 N., R. 70 W., Boulder County.
160. One-fifth mile south by one-fifth mile east of northwest corner sec. 28, T. 3 N., R. 70 W., Boulder County.
156. One-half mile west by one-fourth mile south of northeast corner sec. 5, T. 2 N., R. 70 W., Boulder County.

TABLE 2.—*Analyses of shaly members of Niobrara limestone.*

	165.	167.	168.	164.	161.	159.	157.	158.
Silica [a]	17.40	11.10	11.13	18.59	9.60	25.54	15.34	60.31
Alumina [a]	6.17	3.51	4.58	6.03	2.41	8.72	5.34	16.61
Ferric oxide [a]	.54	.18	.40	.31	.18	.54	.54	2.33
Ferrous oxide [a]	.56	.81	.56	.89	.81	.80	1.13	1.70
Lime [a]	39.38	43.86	43.60	38.55	45.87	33.70	40.81	2.91
Magnesia [a]	.67	.99	1.05	.70	.81	.56	.80	2.46
Sulphuric anhydride [b]	.52	.07	Trace.	.10	.32	.14	.12	.12
Soda [a]	18	.11	.20	.24	.19	.12	.29	.99
Potassa [a]	.62	.61	.78	.98	.69	.47	.93	2.95
Water at 100° C.[b]	.86	.60	.57	.67	.41	.66	.48	1.15
Water above 100° C.[c]	1.98	2.01	1.21	2.13	1.43	2.38	1.61	4.52
Carbon dioxide [c]	30.75	34.58	34.38	29.14	36.00	25.43	32.15	2.81
Organic [c]	.36	1.64	1.72	1.78	1.48	1.19	.67	1.34
	99.99	100.07	100.18	100.11	100.20	100.25	100.21	100.20

[a] Determined by A. J. Phillips. [b] Determined by G. R. Brobst. [c] Determined by P. H. Bates.

165. Shaly limestone, one-third mile south by one-fourth mile west of northeast corner sec. 29, T. 8 N., R. 69 W., Larimer County.
167. Shaly limestone, one-tenth mile north by one-fourth mile west of southeast corner sec. 20, T. 7 N. R. 69 W., Larimer County.
168. One-third mile east of southwest corner sec. 9, T. 5 N., R. 69 W., Larimer County.
164. Shaly limestone, one-third mile west of southeast corner sec. 35, T. 4 N., R. 70 W., Larimer County.
161. Shaly limestone, one-third mile south by one-fourth mile west of northeast corner sec. 28, T. 3 N., R. 70 W., Boulder County.
159. Shaly limestone, one-half mile west by one-fourth mile north of southeast corner sec. 28, T. 3 N., R. 70 W., Boulder County.
157. Shaly limestone, one-third mile west by one-fourth mile south of northeast corner sec. 5, T. 2 N., R. 70 W., Boulder County.
158. Clay shale, one-fourth mile west by one-fourth mile south of northeast corner sec. 5, T. 2 N., R. 70 W., Boulder County.

TABLE 3.—*Analyses of waste lime from sugar factory at Longmont.*

[Material dried at 105° C.]

	New lime (170).	Old lime (171).
Silica[a]	1.73	2.26
Alumina[a]	.95	1.22
Ferric oxide[a]	.31	.40
Lime[a]	48.91	48.17
Magnesia[a]	1.91	2.26
Sulphuric anhydride[b]	1.32	2.26
Soda[a]	.44	.07
Potassa[a]	.24	.06
Water above 100° C.[c]	3.43	2.62
Carbon dioxide[a]	30.38	35.56
Organic[c]	10.13	5.46
	99.75	100.34
Moisture at 105° C.	53.12	28.76

[a] Determined by P. H. Bates.
[b] Determined by G. R. Brobst.
[c] Owing to lack of facilities the results for combined H_2O and organic matter are approximated but their total is accurate.

NOTE.—FeO can not be determined in the presence of so large an amount of soluble organic matter.

The analyses given in Table 4 represent the composition of Niobrara limestone and of an older limestone west of Denver.

TABLE 4.—*Analyses of limestones west of Denver.*

[L. G. Eakins, analyst.]

	1.	2.
Lime (CaO)	48.73	27.49
Magnesia (MgO)	2.95	18.03
Manganese (MnO)	.49	.20
Alumina (Al_2O_3)	.53	.54
Iron oxide (Fe_2O_3)	.38	.11
Phosphoric acid (P_2O_5)	.032	.029
Water (H_2O)	.11	.61
Carbonic acid (CO_2)	41.71	41.40
Insoluble	5.32	12.01
	100.252	100.419

1. "Upper Wyoming" limestone, Morrison, Colo. Mon. U. S. Geol. Survey, vol. 27, 1896, p. 55.
2. Niobrara limestone west of Denver, Colo. Mon. U. S. Geol. Survey, vol. 27, 1896, p. 67.

The following analyses, taken from a report by N. M. Fenneman,[a] show the composition of the Pierre shale near Boulder. Fenneman says:

> A partial analysis of the shale from the Austin yard, made by Prof. C. S. Palmer, is given by Mr. Austin, as follows:
>
> *Analysis of shale from Austin yard, Boulder.*

SiO_2	60.0
Al_2O_3	18.0
Fe_2O_3	4.75
MgO	2.0

---

[a] Geology of the Boulder district, Colorado: Bull. U. S. Geol. Survey No. 265, 1905, pp. 73, 74.

An analysis of a single selected lump (not a mixed sample) of the shale from Mr. Lee's yard, made by Mr. W. B. Stoddard, of Boulder, and furnished by Mr. Lee, is as follows:

Analysis of shale from Lee yard, Boulder.

SiO_2	63.309
Al_2O_3	14.380
Fe_2O_3	6.270
FeO	.859
CaO	1.810
MgO	2.570
Na_2O	2.190
K_2O	1.280
Loss by drying	2.053
Loss by ignition	5.223
	99.944

CONCLUSIONS.

It can readily be seen that the analyses in Tables 1 and 2 represent beds eminently suitable for cement manufacture, most of them being especially low in magnesia and some individually approaching the theoretical composition of a correct cement mixture. There consequently seems to be little doubt that at many points along the outcrop of the Niobrara within the area shown on the map materials suitable in composition for cement manufacture can be obtained.

The possible utilization of these materials does not, however, depend entirely on the composition of the local beds. Other factors of at least equal importance are the problem of procuring quarry sites where large quantities of rock of uniform composition can be cheaply quarried, the local cost of manufacture, the extent of the available market, and the freight rates to and the competition with other cement materials in that market.

CEMENT MATERIAL NEAR HAVRE, MONT.

By Leon J. Pepperberg.

INTRODUCTION.

In the vicinity of Havre, Mont., there are deposits of limestone and shale which contain the constituent materials of Portland cement. The occurrence of rock suitable for the manufacture of such cement is of considerable local importance owing to the fact that other building materials, such as stone and timber, are scarce in this region. During the summer of 1908, while engaged in an investigation of the Milk River coal field, the writer found opportunity to examine these rocks. Previous examination has been made by engineers and chemists, but no detailed statement concerning their character or extent has been published.

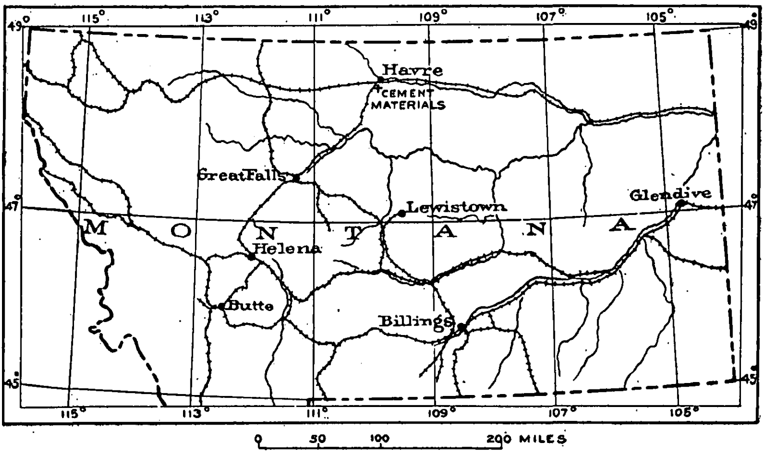

Figure 27.—Sketch map of Montana, showing location of cement materials near Havre.

The writer is indebted to Mr. S. S. Voorhees, of the United States Geological Survey, for valuable suggestions in connection with the preparation of this paper; to Mr. F. H. Newell, Director of the United States Reclamation Service, who furnished a number of chemical analyses; and to Mr. E. C. Eckel, whose friendly interest and suggestions have been of great value and assistance.

LOCATION AND EXTENT.

The cement materials described in this paper are located in the NW. ¼ sec. 31, T. 32 N., R. 16 E., and the NE. ¼ sec. 36, T. 32 N., R. 15 E. of the principal meridian, Montana, about 5 miles south and a little west of Havre, a division point on the Great Northern Railway.

(See fig. 27.) The outcrop occurs in a group of low hills, composed largely of igneous rock, which stand out prominently in comparison with the surrounding flat, treeless plains. The area underlain by the cement-making materials is about 80 acres.

GEOLOGY.

The sedimentary rocks exposed in this district belong to the Montana group of Upper Cretaceous age (with the exception of the cement material which will be discussed later), and consist of the Judith River formation and the overlying Bearpaw shale.

JUDITH RIVER FORMATION.

The Judith River formation, which is composed mainly of alternating layers of light-colored sandstone and shale, is coal bearing in this district, and on account of the relation of fuel to the manufacture of cement deserves brief mention. It outcrops extensively along Milk River north and west of Havre, where it weathers into typical badland forms. It is also exposed along the coulées close to the limestone deposit. Subbituminous ("black lignite") coal beds of workable thickness occur within the upper 150 feet of this formation.

BEARPAW SHALE.

The Bearpaw shale overlies the Judith River conformably, and consists of dark leaden-gray argillaceous shale containing large concretions, many of which are highly fossiliferous, and intercalated thin beds of sandstone. Selenite (gypsum) crystals or flakes are scattered throughout the formation. The Bearpaw shale outcrops about 1 mile east of the limestone described below, near a coal prospect, and along Milk River north and west of Havre. This shale could be used as a source of alumina and silica in the manufacture of Portland cement if future development should show that the limestone is too high in lime to be used as a natural cement material.

LIMESTONE, SHALE, AND IGNEOUS ROCK.

The principal cement materials of the district are highly metamorphosed limestone and shale. These are surrounded by igneous rock and as they are closely associated they will be treated together. The igneous rock is unimportant economically save for the effect it has had on the limestone and shale. It was found by Albert Johannsen, on examination of a thin section from the rock in contact with the limestone, to be a monzonite porphyry.

The limestone and shale are inclosed in the intruded igneous rock. As no fossils were found in these beds their geologic age is unknown. The writer is of the opinion that they were broken off the original mass at great depth and floated to their present position by the intrusive rocks with which they are associated. Several openings that have been made along the outcrop of the limestone afforded good opportunity to measure its thickness and to collect fresh samples. These openings are insufficient, however, to determine the amount of shale present, although it is probably large. The amount could be ascertained by crosscutting and drilling.

The limestone bed has a thickness of 15 to 20 feet and the dip of the strata at the outcrop is about 30° S. 10° W. There are two distinct varieties. One is a hard, compact, highly crystalline, heavy white limestone, having a greenish tinge. Its original joint and bedding planes have been almost destroyed by metamorphism. This variety will be referred to later as the white limestone. The other variety, a minutely banded, grayish limestone, although highly crystalline, is less compact than the white limestone and shows some leaching by water. The dark bands which follow the original bedding planes of this rock are due to impurities that probably consist largely of carbonaceous matter, for when highly heated the dark color disappears. In dilute hydrochloric acid the rock effervesces freely, and after the carbonate of lime is completely dissolved a dark sediment of carbonaceous matter and clay remains. This variety will be referred to later as gray limestone. Thin sections of both varieties were examined by Mr. Johannsen, who reported as follows:

> The two thin sections of limestone examined consist largely of calcite. There is a very small amount of opal and opacite, which fills cracks and forms the isotropic material. Throughout the rock occur extremely minute crystals of an indeterminable mineral, which may be a calcium pyroxene or amphibole. In a few places there are radial bunches of crystals; also too small to determine microscopically, which may likewise be a calcium pyroxene or amphibole. Some garnet occurs.

COMPOSITION OF CEMENT MATERIALS.

The following ten analyses represent samples of cement materials collected from the deposits described above.

Analyses of cement materials near Havre, Mont.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	12.83	20.60	18.86	14.50	16.00	67.78
Alumina (Al_2O_3)	3.10	10.67	3.68	2.74	9.80	18.95
Ferric oxide (Fe_2O_3)			3.18	7.22		2.67
Manganese oxide (MnO)						.50
Lime (CaO)	50.65	44.66	49.38	44.83	45.96	.73
Magnesia (MgO)	.93	2.22	.73	2.02	2.08	1.24
Sulphuric anhydride (SO_3)			.25			.06
Alkalies Soda (Na_2O)						2.23
Alkalies Potassa (K_2O)						.43
Water at 100° C						1.30
Carbon dioxide (CO_2)	28.60	22.27	22.05	27.35		
Ignition loss			1.45		25.00	1.92
	96.11	100.42	99.58	98.66	98.84	99.81

Analyses of cement materials near Havre, Mont.—Continued.

	7.	8.	9.	10.
Silica (SiO_2)	13.98	19.80	10.70	18.20
Alumina (Al_2O_3)	4.21	6.20	4.70	8.60
Ferric oxide (Fe_2O_3)	1.35	.90	.30	1.30
Manganese oxide (MnO)	....	.10	Trace.	Trace.
Calcium carbonate ($CaCO_3$)	73.93	69.70	80.90	67.75
Magnesium carbonate ($MgCO_3$)	.65	.80	1.20	1.50
Potassa and soda (K_2O, Na_2O)	....	1.70	1.10	2.10
Sulphuric anhydride (SO_3)	....	.30	.80	....
Barium oxide (BaO)	....	Trace.	Trace.	Trace.
Moisture	....	.50	.20	.30
	94.12	100.00	99.90	99.75

1. Gray limestone, analyzed by R. G. Brobst, United States Geological Survey, structural-materials laboratories. Carbon dioxide determined by J. D. Davis, United States Geological Survey, technologic branch.
2. White limestone, analyzed by R. G. Brobst, United States Geological Survey, structural-materials laboratories. Carbon dioxide determined by Chase Palmer, United States Geological Survey.
3. Limestone, analyzed by Ricketts & Banks.
4. Limestone, analyzed by Prof. A. H. Phillips, Princeton University.
5. Limestone, analyzed by W. H. Andrews, chemist and superintendent Union Portland Cement Company, Rushsylvania, Ohio.
6. Shale, analyzed for United States Reclamation Service at United States Geological Survey structural-materials laboratories.
7. Limestone, analyzed by H. J. Detweiler, Allentown, Pa.

8, 9, 10. Limestone, analyzed by Paul Reisinger.

Analyses 1 and 2 represent samples collected by the writer; Nos. 3 to 10, inclusive, are taken from a report on the examination of deposits of clay and limestone in the vicinity of Havre, submitted by Charles P. Williams, of Great Falls, Mont., to H. N. Savage, supervising engineer, United States Reclamation Service, Billings, Mont. No. 6 is an analysis of shale occurring near the limestone deposit, which can be used to mix with the limestone should it be found to be too high in lime. Nos. 7 to 10 are of value only in striking an average (with the other five analyses of limestone) of the constituents other than lime and magnesia. Neither carbon dioxide nor ignition loss were determined in these four analyses and the total lime and magnesia are figured as carbonates. It will be shown below that the amount of carbon dioxide present is not sufficient to form carbonates of all the lime and magnesia in the rock. Therefore, the figures for these two constituents in analyses 7 to 10 have been disregarded in determining the average composition of the limestone.

A study of analyses 1 to 5, inclusive, with the assumption that the ignition loss in No. 5 is carbon dioxide, shows that the amount of carbon dioxide present is not sufficient to form calcium carbonate of all the lime contained in the rock. Therefore the excess lime must be combined chemically with some other elements. As stated above, Mr. Johannsen believes the rock to contain calcium pyroxene or amphibole, and on this basis two sets of calculations were made, the calcium silicate being assumed in one to be tremolite and in the other to be wollastonite. It was found from these calculations that the excess lime is probably combined with silica to form wollastonite ($CaSiO_3$), and the following table is based on this hypothesis.

Probable chemical combination of carbon dioxide, magnesium, calcium, and silica, in samples 1 to 5, the calcium silicate being assumed to be wollastonite and the other constituents not being considered.

	1.	2.	3.	4.	5.
Magnesium carbonate ($MgCO_3$)	1.93	4.64	1.52	4.22	4.35
Calcium carbonate ($CaCO_3$)	62.70	45.11	48.31	57.15	51.66
Wollastonite ($CaSiO_3$)	24.91	39.73	36.37	26.64	30.85
Lime (CaO)	3.47	.27	4.82		2.18
Alumina (Al_2O_3)	3.10	10.67	3.68	2.74	9.80
Ferric oxide (Fe_2O_3)			3.18	7.22	
Silica (SiO_2)				.69	
Sulphuric anhydride (SO_3)			.25		
Ignition loss			1.45		
	96.11	100.42	99.58	98.66	98.84

In the above table all of the magnesia (MgO) is figured as magnesium carbonate ($MgCO_3$). The remaining carbon dioxide (CO_2) is combined with lime (CaO) to form calcium carbonate ($CaCO_3$) and the remaining lime is combined with the available silica (SiO_2) to form wollastonite ($CaSiO_3$). In Nos. 1, 2, 3, and 5 a small percentage of the lime is uncombined with either carbon dioxide or silica. The excess lime may be combined with other elements present, or there may be inaccuracies in the chemical analyses. The presence of a calcium silicate was not suspected when the analyses were requested. Consequently the analyses were made simply to determine the fitness of the limestone for cement manufacture, and preliminary examinations of this kind do not require the exactness necessary for accurate chemical computations.

In the analyses, as calculated above, from 25.26 to 35.1 per cent of the lime is combined with carbon dioxide to form calcium carbonate, and from 12.13 to 19.13 per cent of the lime is combined with silica to form wollastonite.

The following table shows the average of nine analyses of limestone from the Havre district:

Average of nine analyses of limestone collected near Havre, Mont.

Silica (SiO_2)	16.16
Alumina (Al_2O_3)	7.55
Ferric oxide (Fe_2O_3)	
Manganese oxide (MnO)	.10
Lime (CaO)	47.09
Magnesia (MgO)	1.59
Sulphuric anhydride (SO_3)	.45
Alkalies: Soda (Na_2O) and potassa (K_2O)	1.63
Carbon dioxide (CO_2)	25.05
Moisture	.61
	100.23

The following table shows the chemical combination of carbon dioxide, magnesia, lime, and silica, on the assumption that the calcium silicate is wollastonite, computed from the average of nine analyses given above:

Composition of wollastonite limestone calculated from the average of nine analyses of limestone collected near Havre, Mont.

Magnesium carbonate ($MgCO_3$)	3.35
Calcium carbonate ($CaCO_3$)	52.93
Wollastonite ($CaSiO_3$)	31.16
Lime (CaO)	2.45
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	7.55
Manganese oxide (MnO)	.10
Sulphuric anhydride (SO_3)	.45
Alkalies: Soda (Na_2O) and potassa (K_2O)	1.63
Moisture	.61
	100.23

CONTROL OF THE MIX.

The formulæ for determining the "cementation index" proposed by Eckel,[a] when applied to the analysis of the gray limestone (No. 1) and the white limestone (No. 2), give the following results: The gray has a cementation index of 0.73, which shows this variety to be high in lime, and the white limestone has a cementation index of 1.40, indicating that it is low in lime. From these figures it is evident that a Portland cement can be made from a mixture of the two limestones without the addition of clay or shale.

When Eckel's formula for proportioning mixture[b] is applied to the two limestones the resulting figures show that 1.29 parts of the gray limestone should be used for each part of white limestone, by weight, to give the proper percentage of silica, lime, magnesia, and alumina and iron oxide. On this basis S. S. Voorhees and the writer conducted the following experiments: Samples of both the gray and the white limestone were ground so as to pass through a 120-mesh sieve and mixed in the proportion of 1.29 to 1, as just stated. This mixture was subjected to the heat of a blast lamp, the result being a dark clinker having a bluish tinge. The clinker was ground to flour and one-half gram treated with dilute hydrochloric acid, which dissolved all but a small trace of the cement, showing that all of the free silica had been combined with the lime. Five grams of the cement were mixed into a pat with 1 cubic centimeter of water. Although the cement was imperfectly calcined the initial set took place in three hours and the final set in eight hours, showing that the material was a normal Portland cement.

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[a] Eckel, E. C., Cements, limes, and plasters, 1905, p. 391.

[b] Idem, pp. 392-393.

AMOUNT OF AVAILABLE LIMESTONE.

Eckel[a] states that—

> A Portland cement plant running on dry raw materials, such as a mixture of limestone and shale, will use approximately 20,000 tons of raw material per year per kiln. Of this about 15,000 tons are limestone and 5,000 tons shale. Assuming that the limestone weighs 160 pounds per cubic foot, which is a fair average weight, each kiln in the plant will require about 190,000 cubic feet of limestone per year. As the shale or clay may be assumed to contain considerable water, a cubic foot will probably contain not over 125 pounds of dry material, so that each kiln will also require about 80,000 cubic feet of shale or clay.
>
> A cement plant is an expensive undertaking, and it would be folly to locate one with less than twenty years' supply of raw material in sight. This would require that, to justify the erection of a cement plant on any property, for each kiln of the proposed plant there must be in sight at least 3,800,000 cubic feet of limestone and 1,600,000 cubic feet of clay or shale.

A close estimate can not be made of the total amount of limestone available near Havre because of the present meager knowledge of the extent of the beds. As previously stated, an area of about 80 acres is underlain by the limestone. This estimate is very conservative and drilling or extensive prospecting would probably disclose a greater amount of the rock. However, on the assumption that a 15-foot bed of limestone underlies 80 acres, 52,272,000 cubic feet, or, at 160 pounds to the cubic foot, about 4,181,260 tons of rock, would be available. On the further assumption that the 20,000 tons of raw material required per kiln per year will in this area consist entirely of limestone, the beds herein described contain enough raw material to run one kiln over two hundred years, or ten kilns twenty years. In addition there is undoubtedly sufficient shale in the immediate vicinity to meet the needs of a plant should it become necessary at any time to add shale to the mixture.

FUEL SUPPLY.

Almost one-half of the total cost of manufacturing cement is chargeable to the cost of fuel. On this account it is imperative that the fuel supply be close at hand if the cement is to be manufactured economically. As previously stated, the Judith River formation of this region is coal bearing. A small coal prospect is located about 1 mile east of the limestone deposit and coal is mined in large quantities north of Havre across Milk River and southeast of Havre.

The following table gives analyses of three samples of subbituminous coal that is available for the manufacture of cement in this district at a cost of about $2 per ton at the mine:

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[a] Eckel, E. C., and Crider, A. F., Geology and cement resources of the Tombigbee River district, Mississippi-Alabama: Senate Doc. No. 165, 58th Cong., 3d sess., 1905.

Analyses of coal from the Havre district.

[Made at the United States Geological Survey fuel-testing plant, Pittsburg, Pa.]

Laboratory No	6479	6473	6478
Air-drying loss	15.50	16.30	22.90
Analysis of air-dried sample:			
Moisture	7.64	7.81	8.16
Volatile matter	28.17	35.02	34.59
Fixed carbon	51.95	41.35	48.51
Ash	12.24	15.82	8.74
	100.00	100.00	100.00
Sulphur	.71	.95	.87
Calorific value determined:			
Calories	5,400	5,243	5,646
British thermal units	9,720	9,437	10,163

Pulverized coal high in volatile matter and low in ash and sulphur is most commonly used in modern rotary-kiln practice. The above analyses show the coal to be high in volatile matter and low in sulphur. The ash varies according to the increase or decrease of thin bony layers in the bed. This coal would probably make good gas, or it could be powdered and blown into the kiln in the usual manner.

WATER.

In the arid regions of the West the relation of the location of a plant requiring the use of water to the water supply and the kind of water available are factors that must be considered. The water from most of the springs in the Havre district is alkaline and unfit for boiler use. About half a mile from the limestone is a spring that was tramped in by cattle at the time the writer made the examination. By sinking wells at this place a small supply of water could be obtained, but it would probably be alkaline and insufficient to supply the needs of a mill. If a mill is erected either at the quarry or at the junction of the railroads it will probably be necessary to pipe water from Milk River in order to insure both good quality and a quantity large enough to supply a mill having one or more kilns.

TRANSPORTATION FACILITIES.

The region between the limestone and the Great Northern Railway is practically a flat prairie, and a spur about 5 miles long could be constructed from Pacific Junction to the quarry at small expense, connecting with the main line as well as with the Great Falls branch (Montana Central division of the Great Northern Railway), thus giving transportation facilities east, south, and west to the Pacific coast and into Canada. From the above statement it is evident that the cement materials are within easy reach of what may seem to be good transportation facilities into a large territory. However, it should be borne in mind that much better freight rates could be obtained if two or more competing lines were located near the cement materials. The cost of transporting the finished product from the cement plant to market is one that should be carefully considered and investigated before erecting a plant.

MARKET AND COMPETITION.

In the Cement and Engineering News for August, 1908, an article headed "Pacific coast cement prices decline" states that the cement mills in Washington and California are capable of supplying the demands for the product along the western coast. These mills—

> have reduced the prices from 60 to 75 cents per barrel for cement, and the grades made in the Middle West are suffering as a result of the slashing by the extreme western concerns. These grades are sold at $2.50 to $2.75 per barrel, depending on their standing for reliability. Owing to their distance from market and the heavy freight, amounting to nearly $1.50 per barrel, against them, these eastern cements are not able to enter into a competition that means a cut below $2.25, and even that figure loses them money on a basis of 85 cents per barrel at the factory.
>
> California cement has dropped from $3.05 per barrel, March 1, 1907, and $2.55 in March, 1906, to $2.20 at present. Eastern and foreign cements have dropped from $3.25 in March, 1907, and $3 per barrel in March, 1906, to $2.50 to $2.75 for eastern and $2.75 for foreign at present.
>
> At an estimated average drop per barrel of 60 cents for all grades, Seattle is saving, on an estimated cement consumption of 400,000 barrels per annum, a total of approximately a quarter of a million dollars for cement alone.

From the above statement it will be seen that it would be necessary at Havre to produce a cement of high quality at comparatively low cost and to obtain low freight rates in order to enter the coastal market and compete with the local product.

The cement materials herein described are located in a thinly populated section, but a number of large reclamation projects are contemplated in this general region and could use some of the cement produced. Moreover, under present conditions much of the product could be marketed in the large cities in Montana, in the Black Hills of South Dakota, and in Idaho, Wyoming, North Dakota, Nebraska, and probably Canada.

CONCLUSIONS AND SUMMARY.

In the foregoing pages it has been shown that the limestone and shale near Havre, Mont., are suitable materials for the manufacture of Portland cement. It has been shown further that a large percentage of the calcium in the limestone is combined with silica (calcium pyroxene or amphibole), probably forming wollastonite. The existence of a large part of the total amount of available lime in combination with silica, from which carbon dioxide does not have to be driven off in calcining, is in favor of this rock as a cement material, for the clinker can probably be produced with less fuel than from limestones containing the same total percentage of lime as a carbonate. So far as the writer can ascertain, this is the first time that limestone in which a large proportion of the lime exists as a silicate has been proposed for the manufacture of cement.

Before erecting a plant to utilize this material it would be well to prospect in detail to ascertain whether the composition of the limestone remains uniform throughout the area, for if after erecting the plant it is found that the rock is not of uniform composition it would be almost impossible to control the mix for the kiln charge and the plant would be one more among the cement mill failures, already too numerous. In this day of the specialized promoter too much emphasis can not be laid on the fact that although the use of cement as a building material is steadily increasing, the erection of a plant near a supply of good cement material, with fuel close at hand, will not necessarily be a financial success.

GANISTER IN BLAIR COUNTY, PENNSYLVANIA.

By Charles Butts.

INTRODUCTION.

One of the most important mineral industries of Blair County, Pa., is the exploitation of the rock known as ganister, which is used for refractory brick for various kinds of furnace linings. The name ganister is derived from the German ganster, meaning a spark, and owes its application to the fact that the rock will give a spark when struck with iron. In England the name is applied to siliceous beds underlying certain coal beds just above the Millstone grit, one bed of coal being known as the ganister bed. The name is also used for a mixture of ground quartz and clay that is used for refractory purposes and for road making.

NATURE OF THE BLAIR COUNTY GANISTER.

Chemically the ganister of Blair County and vicinity is a nearly pure silica rock, as shown by the subjoined analyses kindly furnished by Mr. J. D. Hartman, of Hollidaysburg, Pa.

Analyses of ganister from Canoe Mountain, Point View, Pa.

[Isaac Reese & Sons Company, Analyst.]

	1.	2.	3.	4.
Silica[SiO_2]	97.90	97.98	97.30	98.65
[Iron and alumina] (Fe_2O_3, Al [Al_2O_3])	.90	.95	1.20	.30
Lime [CaO]	.40	.25	.30	.25
Magnesia [MgO]	.36	.29	.30	.30
Loss on ignition	.40	.50	.85	.45
	99.96	99.97	99.95	99.95

Analyses of ganister from quarries at Point View, Pa.

	1.	2.	3.
[Silica] (SiO_2)	99.10	98.15	98.20
Fe and Al [Iron and alumina (Fe_2O_3, Al_2O_3)]	.60	1.20	1.35
Lime [CaO]	None.	None.	None.
Magnesia [MgO]	Trace.	Trace.	Trace.
Loss on ignition	.25	.20	.50

Analysis of ganister from Pattonsville, Bedford County, Pa.

[E. F. Wood, Analyst.]

[Silica] (SiO_2)	98.00
Alumina [Al_2O_3]	1.10
Oxide of iron [Fe_2O_3]	.85
Combined water	.10

Analysis of ganister from Water Street Gap, Huntingdon County, Pa.

S. A. Ford, Edgar Thompson Steel Works, Braddock, Pa., Analyst.]

[Silica] (SiO_2)	97.640
Oxide of iron [Fe_2O_3]	.652
Alumina [Al_2O_3]	.825
Lime [CaO]	.310
Magnesia [MgO]	.140
Loss on ignition	.460

The specific gravity of ganister ranges from 2.46 to 2.58. Physically ganister is to the naked eye a compact light-gray to white rock with a somewhat vitreous luster. It is more or less iron stained on the outside after exposure to the weather or to water along joint planes. Microscopic examination of a thin section shows the rock to have been made up originally of well-rounded quartz grains, 0.1 to 0.3 millimeter in diameter. These grains, however, have been enlarged by the addition of silica that is crystallographically continuous with the original grain, the boundaries of which are perfectly distinguishable. The addition of silica continued until the interstices between the original grains were filled and the rock was cemented into a compact mass. In other words, the rock, which was originally an ordinary pure quartz sandstone, has been changed to a quartzite. The difference between the quartzite, or ganister, and the sandstone is physical and not chemical.

GEOLOGIC OCCURRENCE AND RELATIONS.

The ganister rock of the region occurs as a bed or beds in the Medina formation of Silurian age. This formation extends through the mountain region of central Pennsylvania and makes the conspicuous ridges of which Tussey and Dunning mountains of Blair County are examples. It comprises two members—a lower red member, the "Red Medina," 400 to 600 feet thick, and an upper white member, the "White Medina," about 400 feet thick. The "White Medina" is overlain by the Clinton formation, which carries the red fossil iron ore of the region.

The "Red Medina" is composed of alternating layers of dark-red sandstone and shale; the "White Medina" consists, so far as exposed to view, of white sandstone and quartzite in layers 1 foot or more thick.

The "White Medina" outcrops in a nearly vertical attitude along the crests of Tussey, Lock, Loop, Dunning, and other mountains. Indeed, the presence of this hard, resistant rock has been the condition of the formation of these ridges, the softer rocks on each side having been removed by erosion, leaving the hard sandstone standing up in bold relief. The original posture of these rocks was flat, and they have been tilted into their present attitude in the general folding to which the Appalachian Mountain belt has been subjected.

The ganister rock occurs as a bed or beds in the 400 feet, more or less, of the "White Medina" sandstone. Certain layers of the original sandstone have been permeated by water carrying silica in solution, and this silica has been deposited in crystalline form about the original grains, cementing them together into a compact mass. Just what position in the formation as a whole the ganister beds occupy or what proportion of it they comprise is not known, though the occurrence of the ganister on or near the crests of the ridges indicates that the position of some of the beds at least is near the middle of the formation. At McKee Gap a bed 18 to 40 feet thick was quarried for a time, and some rock has been taken from the outcrop on the crest of the mountain on the north side of the Juniata at Point View, where the thickness of rock quarried does not exceed 20 feet. The quality of the rock at McKee Gap is said to be of the very best.

METHODS OF EXPLOITATION AND LOCATION OF WORKINGS.

Practically all the ganister used at present is obtained in the form of bowlders, which constitute a thick mantle over the slopes of the Medina sandstone ridges of the region for 200 or 300 feet below their crests. This loose material has, of course, been derived from the sandstone strata outcropping along the crests of the ridges.

The rock is procured by laying an incline to or nearly to the crest of the ridge and then running tracks from the incline along the side of the ridge at vertical intervals of 40 or 50 feet. The material is rolled down the slope to the track next below and loaded into cars after having been broken to sizes suitable for handling. The cars are then let down the incline and dumped into railroad cars for shipment.

The ganister rock has been extensively worked in this way by J. D. Hartman and P. S. Duncan at McKee Gap, and is now being worked by Mr. Hartman at Point View. The Harbison-Walker Refractories Company has extensive quarries on Tussey Mountain where it is cut by Juniata River.

The quantity of ganister that can be obtained in the way described above is very great. The mantle of rock waste along or near the crests of the ridges extends for miles and is so thick that very little vegetation can grow upon it, so that its white glistening surface is visible for great distances. The supply obtainable from the formation in place is, of course, practically inexhaustible, but on account of the great toughness of the rock quarrying is very expensive.

QUALITIES OF GANISTER.

The question naturally arises, What are the qualities of ganister that make it suitable for silica brick while ordinary sandstone of the same composition is not suitable? There seems to be a difference of opinion on these points. J. D. Hartman, jr., states that sandstone is worthless for silica brick, as the brick "volatilize" at a high temperature, allowing the walls of the furnace to fall in. His idea plainly is that brick made from ordinary sandstone are not sufficiently refractory. On the other hand, William Walker, of the Harbison-Walker Refractories Company, says that brick made from sandstone, even though of greater purity than the ganister rock, are not sufficiently strong mechanically to endure handling without breaking. His idea appears to be that the brick lack strength rather than refractoriness. The writer knows of no reason why silica derived from a more or less loosely cemented sandstone should fuse at a lower temperature than that from a compactly cemented quartzite like the ganister rock. It appears probable, therefore, that the adaptability of ganister for brick is due to the superior strength of the brick made from it, and this difference in strength is easily explainable by the difference in physical structure between the ganister and sandstone. In ganister the constituent grains, being firmly cemented together, do not separate in crushing but the whole mass breaks up into angular fragments and slivers which can be pressed together into a cohering mass in molding and so make a brick that will not break easily in handling; whereas loosely cemented sandstone pulverizes more or less completely into its constituent rounded grains, which do not interlock in molding and so have but little coherence and make a weak brick.

PROCESSES OF MANUFACTURE.

The ganister rock is crushed to the size of ordinary railroad ballast or finer, a Blake jaw crusher being found most satisfactory. It is then passed in charges of 1,200 pounds to a wet pan and ground to sizes ranging from dust to particles one-fourth inch in longer diameter. In this stage 1.5 per cent of milk of lime is added to bond the material sufficiently to permit handling in the operations between the grinding pan and the kiln. After molding, the brick are passed through drying tunnels in which they remain from sixteen to forty-eight hours, depending on the weather; then they are put into the kiln and stacked on edge so as to expose the greatest surface to the heat. The kilns are of square down-draft type. The time of burning is ten days—three days to bring the brick up to the temperature of burning, four days for burning, and three days for gradual cooling. The highest temperature reached is about 2,500° F.

CHARACTER OF BRICK.

The composition of silica brick as made from Blair County ganister by two different companies is shown below.

Composition of silica brick made from ganister in Blair County, Pa.

	1.	2.
Silica	96.06	95.06
Oxide of iron	.535	1.21
Oxide of manganese	.04	....
Alumina	.935	1.79
Lime	1.45	1.79
Magnesia	.526	Trace.
Potash	.146	....
Soda	.045	....

The lime shown in these analyses is due to that added for bonding the crushed material. The other substances, except silica, are regarded as impurities, but in the quantities shown they do not impair the quality of the brick, for such brick will have a melting point of approximately 3,500° F., which is about 200° hotter than open-hearth steel furnaces. It is even probable that the slight amount of impurities is advantageous, as if the brick were made from an absolutely pure silica rock it would be almost impossible to burn them hard enough, on a commercial scale, to be sufficiently coherent. With the exception of alumina, these substances have a fluxing effect. More than 1.25 per cent of iron oxide in the ganister practically ruins the brick, however.

The crushing strength of these brick ranges from 2,500 to 3,500 pounds to the square inch, which is far beyond any requirements in actual use.

USES OF GANISTER BRICK.

The silica brick made from this ganister are used for the sides and crowns of open-hearth steel furnaces, continuous glass furnaces, and any other furnaces which require a highly refractory brick and in which the temperature does not undergo sudden changes, and also in which the brick do not come into contact with material that would flux with the brick. The bottoms of steel furnaces, for example, are made of other material, such as magnesia brick. Blast-furnace linings are not made of silica brick because they are not able to resist the action of the molten metal pressing against the sides of the furnaces.

SURVEY PUBLICATIONS ON CEMENT AND CEMENT AND CONCRETE MATERIALS.

The following list includes the principal publications on cement materials by the United States Geological Survey, or by members of its staff. The United States publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Besides the publications cited, the Survey has in preparation numerous bulletins dealing with the results of tests on concrete beams and the constituent materials of concrete, etc.

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——— The materials and manufacture of Portland cement. In Senate Doc. No. 19, 58th Cong., 1st sess., pp. 2-11. 1903.

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——— Portland cement resources of New York. In Bulletin No. 260, pp. 522-530. 1905. 40c.

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