# Geology of the Bloomington Quadrangle.

Field Work and Report by J. W. BEEDE.

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During the past two summers the stratigraphy of the Bloomington Quadrangle was worked out, together with suggestions regarding the utilization of the waste limestone of the quarry belt.

A number of persons were associated with the writer in this work, whose names are given below.*

Many of the characters of the rocks have been described in previous reports and no effort will be made here to reprint them. The object has been to see them more in the large, and to map them in detail. Space forbids any historical treatment, which would necessarily be rather long.

It is impossible to finally correlate the formations with the type section of the Mississippi River, since that section is being critically revised and correlation at present would add confusion later.

## THE ROCKS AND THEIR ECONOMIC VALUE.

The position of the outcrop of the rocks is shown on the accompanying map, which also shows their thickness and the manner in which the different formations rest one upon another. The lowest rocks are found in the valleys on the east side of the map and the highest ones on the hills on the west side of the map, or, rather, in the southwest part. The lower layers pass under the higher ones to the west, as indicated by the colors on the map, and underlie the entire quadrangle.

The rocks dip a little south of west with an average dip of some 34 feet per mile. The dip varies somewhat from place to place, sometimes being nearly horizontal and again having a dip of as much as 70 feet to the mile for a short distance. What warping has taken place has produced monoclines, or steps, rather than arches or anticlines and sags, or synclines, and these steps are low and indistinct.

One condition in the western part of the quadrangle has caused considerable trouble in mapping. The harder rocks are located in

*Harry Warren Wood, Hal P. Bybee, C. A. Malott, Thomas F. Jackson, and G. C. Mance the valleys and bluffs while the soft shales form the tops of the hills. The result is that the highlands are rounded and the shales of the Pennslyvanian, or Coal Measure rocks, which look much like that of the Chester, have been washed or slumped down over the latter to such an extent that it is hard to form an accurate idea of the extent of the beds or the age of some of those that are occasionally exposed. This same condition is also responsible for the almost total absence of exposures save where soil wash has reached bed-rock. The soft material lies at the angle of repose of slump and creep under a cover of vegetation. Where this is removed and the ground neglected, the soil is quickly washed away.

*Riverside Sandstone.*—The "Knobstone" in the vicinity of Bloomington is, according to Newsom,* 50 feet thick. The lower part of the formation is shale and the upper part is a sandstone. The lower part of the shales were described by Borden as the New Providence shales.† (The town of New Providence is now known as Borden.) The sandstone has been called the Riverside sandstone from the outcrop where it is quarried at Riverside, Warren County.** Only the Riverside sandstone outcrops in the Bloomington Quadrangle.

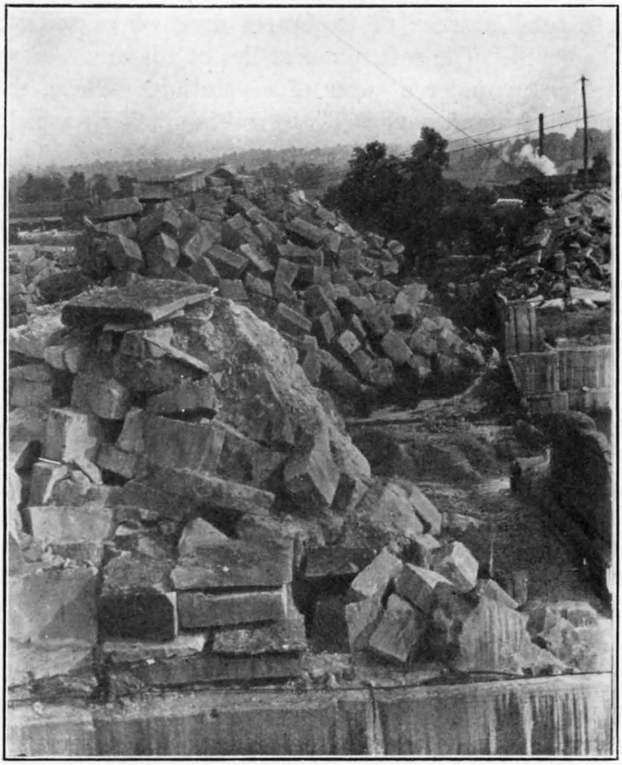
It is a fine-grained sandstone cemented with clay, an argillaceous silicilutyte. On account of its toughness and elasticity it is nearly free from joints and bedding planes, both of which are usually effectively closed on account of the clay content of the rock. The largest sand grains of specimen sectioned were from .02 to .05 mm. in the longer diameter. From this size they grade down to mere points under moderately high magnification. On account of the fineness of the sand grains and the clay cement the formation is remarkably free from water. It will absorb water but will not transmit it, and as a result, wells in the formation are usually dry, or, if deep, contain a very small amount of salty water, so that where this formation is the surface rock of a region, the inhabitants have to rely upon cisterns. There are, of course, no springs of consequence in this formation. The color of the rock is blue or bluish gray, weathering light to rusty-brown.

Locally there are rather large lenses of limestone, as at Stevens Creek, five miles east of Bloomington, where the maximum thickness is about 35 feet, and of clay shale, as found in the cuts at the Leary and Chitwood places on the Illinois Central Railroad

*Ind. Dept. Geol. Nat. Res., 26th Ann. Rept., p. 263, 1901.
†Geol. Surv. Ind., 5th Ann. Rep., p. 161, 1873.
**Hopkins, Ind. Dept. Geol. Nat. Res., 20th Ann. Rep., p. 317, 1895.

northeast of Bloomington, included in the sandstone. This clay shale bed is somewhat smaller in size than the limestone lens at Stevens Creek. Neither is on the Bloomington Quadrangle, and so far as known, only sandstone occurs upon it.

Whether this sandstone is referred to as a sandstone or a shale about Bloomington depends upon the nature of the exposure. In outcrops well exposed to the sun's rays the stone weathers to a very massive sandstone, usually with some white efflorescence upon it. Where the sun does not reach the surface of the stone effectively and the stone is continually moist, it shatters on weathering and has the appearance of shale, unless the debris is washed away as fast as formed by some stream at the base of the exposure. As is pointed out by Newsom in the article cited above, the Riverside sandstone weathers chiefly by exfoliation. One not accustomed to

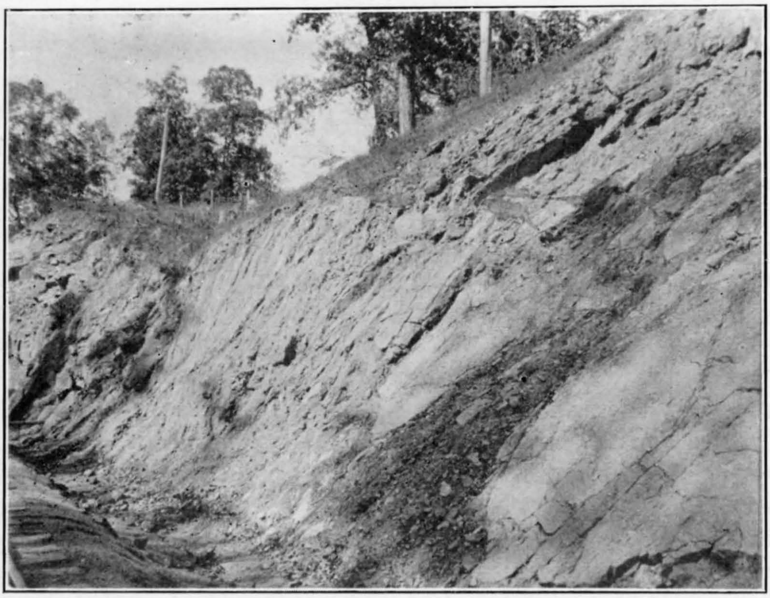


A.

A. Grout pile (discarded stone) in the Clear Creek District.

observing such things would regard many exposures as demonstrating nearly vertical bedding on account of the extent of exfoliation somewhat normal to the bedding planes; but the bedding planes are apparent to the careful observer.

An example of the peculiarities of weathering was furnished in the cut at the west end of the Unionville tunnel on the Illinois



B.

EXPLANATION OF PLATE B.

B. Sharp synclinal fold in Chester shale and sandstone. The surface of the sandstone bed forms the side of the cut. The fold is caused by the development of a sink beneath the beds. This feature renders almost useless much of the otherwise valuable shale resting on the Mitchell limestone.

Central Railroad, northeast of Bloomington. On the north side of the cut the sandstone retained its normal appearance for a few years, while the same on the south side of the cut where the sun's rays could not reach it quickly took on the appearance of shale, which it still possesses. In any excavation which penetrates the rock for a few feet the "shale" quickly changes to a very tough sandstone that is very difficult to dig or blast.

*The Outcrop.*—The main outcrop of the formation is along the east side of the Quadrangle. The greatest thickness exposed is in the northeast corner, where there are 200 feet of it to be found between the creek bed and the tops of the bluffs of Muddy Fork, and its tributary ravines. The top of the outcrop here is about 800 feet above sea level. There are high bluffs of the Riverside sandstone along Bean Blossom, Stouts and Griffys creeks, and a thin outcrop along Jacksons Creek south of Bloomington, forming a part of a large inlier of the formation. The remaining outcrops are confined to the southeast corner of the quadrangle. The highest outcrop of the Knobstone in the extreme southeast corner is 620 feet. From this it will be seen that the southwest dip makes a difference of at least 180 feet in the elevation of the Harrodsburg-Knobstone contact along the eastern edge of the quadrangle, in a distance of sixteen miles.

In the southeastern part of the region the Riverside sandstone occurs in the bluffs of Salt Creek and extends up Clear Creek nearly to Cedar Bluffs and up Little Clear Creek to within three-quarters of a mile of Smithville. From the point south of Harrodsburg east of Clear Creek to the northernmost exposure in Section 4, west of Smithville, there is a rise in elevation of the Harrodsburg-Riverside contact of 100 feet.

*Economic Value.*—The Riverside sandstone is at the present time of less economic value than any other formation on the quadrangle. It is of no value for structural purposes because the grain is so fine and the pore spaces so small that capillary attraction retains the water so tenaciously that disintegration from frost action and change of temperature is rapid. The fact that there is considerable clay between the grains, which tends to expand on becoming wet and to contract on drying, also facilitates disintegration, without acting as an effective binder. It makes a poor, acid soil, not suited to cereals, but valuable for strawberries and other small fruit and such vegetables as require an acid, sandy soil. It contains about enough clay to be used for brick and some other products, but its hardness and the difficulty of quarrying and grinding render it of little value for such purposes. Since it is not a water-bearing formation, there are no springs or wells in it, though on account of the deep valleys excavated in it and its impreviousness and the firmness of the unweathered rock, it offers ideal facilities for impounding water for any purpose, such as municipal supply, power, or irrigation.

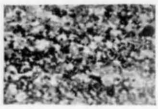
*Harrodsburg Limestone.*—The next stratum above the Riverside sandstone and outcropping along its western border is the Harrodsburg limestone described and named by Siebenthal in 1896.* The Harrodsburg limestone is from 70 to 90 feet in thickness in the quadrangle. The lower part is interstratified with shales and some soft sandstones. The lowest limestone was taken as the base of the Harrodsburg. However, since there is a tendency for these lower layers to be lenticular it is not certain that the mapping is absolutely uniform in this respect. In fact it is pretty certain that this is not the case. However, the variation is but a few feet, probably not varying beyond the limits of accuracy of mapping on the present base map.

In a general way the Harrodsburg is a very coarse crinoidal limestone in its lower part, a calcirudyte, becoming finer near the central part where the crinoids and large brachiopods and pelecypods are replaced with Bryozoa. Near the top it assumes very much the character of the Salem limestone or "Bedford oolite" above, a calcarenyte. However, so far as the rocks of this quadrangle are concerned, careful inspection with the lens will differentiate them at once. At the overhead bridge across the Monon track, between Smithville and Saunders, the two are nicely separated by a strong stylolite seam. Much of the way they are separated by a brownish bituminous marl, which locally replaces the base of the oolitic limestone. At other places it is difficult to say within two to five or six feet just where the contact is. The upper part of the Harrodsburg is composed of comminuted bryozoan remains with certain elongate particles whose nature has not yet been made out. These elongate particles seem to be peculiar to the top six to ten or fifteen feet of the rock.

Reef structures occur in the lower third of the Harrodsburg limestone. One very pronounced reef was located on Stouts Creek, almost on the quarter section line east of the center of Section 19. Extensive quarrying has now passed beyond and removed the little that was left of it. Another is found a few rods northwest of the center of Section 1, northeast of Elletsville. The creek has undercut to a considerable extent at this place, the structureless character of the reef supporting the large undercut. All around the reef the rock is very thin bedded and highly jointed. There is another reef just a half mile north of the first one on Stouts Creek. It also supports a great undercut, this time in the side of the bluff above the reach of the creek. This undercut cave has been a human habitation.

*Ind. Dept. Geol. Nat. Res., 21st Ann. Rep., p. 296, 1896.

1a



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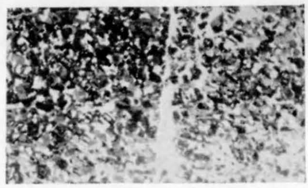

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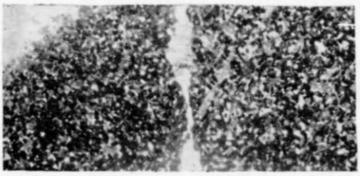

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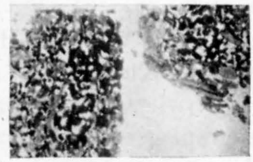
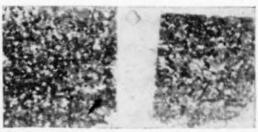


4a 4b



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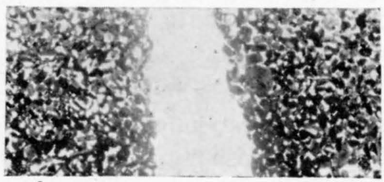

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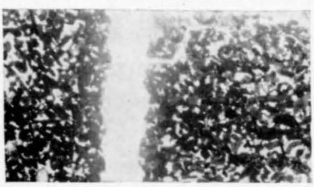

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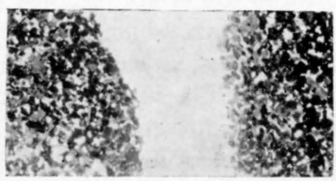

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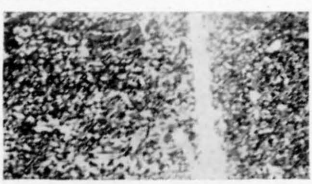

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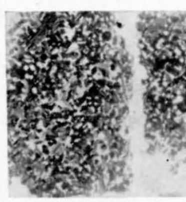


10a 10b

### Explanation of Plate D.

Figs. 1a, 1b. Horizontal and vertical sections of stone from the Bloomington Bedford Stone Co. Magnified 2½ diameters.

Figs. 2a and 2b. Horizontal and vertical sections of stone from the Crescent Stone Company's quarry. Magnified 2½ diameters. Cracks in 2b due to breaking section in grinding.

Figs. 3a, 3b. Horizontal and vertical section of stone from the Star Quarry. Magnified 2½ diameters.

Figs. 4a, 4b. Horizontal and vertical sections of stone from Hunter Bros.' Quarry. Magnified 2½ diameters. Crack in 4b due to grinding of section.

Figs. 5a, 5b. Horizontal and vertical sections of stone from Johnson's Quarry. Magnified 2½ diameters.

Figs. 6a, 6b. Horizontal and vertical sections of P. M. & B. blue stone. Magnified 2½ diameters.

Figs. 7a, 7b. Horizontal and vertical sections of P. M. & B. buff stone. Magnified 2½ diameters. Crack in 7b due to grinding.

Figs. 8a, 8b. Horizontal and vertical sections of National buff stone. Magnified 2½ diameters.

Figs. 9a, 9b. Horizontal and vertical sections of Indiana Quarries Co.'s stone. Buff. Magnified 2½ diameters.

Figs. 10a, 10b. Horizontal and vertical sections of Dark Hollow stone. Magnified 2½ diameters.

Along the base of the Harrodsburg limestone is a zone filled to a greater or less extent with geodes. This zone is frequently fifteen or more feet in thickness and extends down into the Riverside sandstone for a distance of five to ten or more feet. Those in the sandstone are usually much smaller than the ones in the limestone. Where the exposures are obscured the approximate line of contact can be made out within ten or fifteen feet by the geode deposits if sufficient judgment is used in determining the extent to which the geodes have worked down the hill.

The type section of the Harrodsburg limestone as published by Siebenthal is given below, together with a detailed section from north of Harrodsburg from which an extensive suite of fossils was collected.

THE TYPE SECTION OF THE HARRODSBURG LIMESTONE SOUTH OF HARRODSBURG, INDIANA.

C. E. Siebenthal.*

| | Ft. | In- |
|---|---|---|
| Massive fossiliferous limestone | 6 | 0 |
| Gray heavy-bedded limestone | 16 | 0 |
| Blue argillaceous shale | 2 | 0 |
| Limestone | 0 | 4 |
| Chert | 0 | 3 |
| Heavy-bedded blue to gray crystalline limestone | 6 | 0 |
| Yellow calcareous shale with geodes | 1 | 3 |
| Fine, heavy-bedded blue crystalline limestone | 11 | 0 |
| Flaggy limestone | 1 | 0 |
| Gray argillaceous limestone | 0 | 10 |
| Calcareo-argillaceous shale with bands of limestone and some goedes | 18 | 0 |
| Heavy limestone, weathering shaly | 3 | 0 |
| Calcareous shale in bed of creek | ? | ? |
| | 65 | 8 |

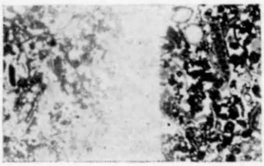
Commenting on this section, Siebenthal says: "The Harrodsburg limestone varies from 60 to 90 feet in thickness. * * *

"The 'beds of passage' from the Knobstone to the Harrodsburg limestone contain great numbers of geodes, or, as more familiarly termed, 'mutton heads', ranging from the size of a pea up to 18 or 24 inches in diameter. The geodes are confined to the lower members of the Harrodsburg, though a few are scattered through the Knobstone."

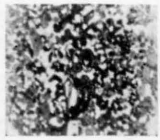
*Twenty-first Ann. Rep. Ind. Dept. Geol. Nat. Res., p. 297, 1896.

## HARRODSBURG SECTION.

| | | |
|---|---|---|
| From first ravine on railroad on west side of point north of bridge north of Harrodsburg | 1.40 | 0 |
| 27. Base of Salem limestone in the road. | | |
| 26. About fifteen feet of very irregular textured buff and blue limestone, quite fossiliferous in places | 15± | 0 |
| 25. Hard fine-grained limestone, weathering somewhat; somewhat shaly in places, cross-bedded, extending to the road, 15 or 20 feet | 20 | 0 |
| 24. Thin-bedded, hard, fine-grained limestone, upper one rough on top | 5± | 0 |
| 23. Hard blue, fine-grained crinoidal limestone (fine grained roe crinoidal limestone) weathering very rough on top | 5 | 0 |
| 22. Buff fine grained limestone | 1 | 0 |
| 21. Hard fossiliferous limestone | 0 | 6 |
| 20. Hard green limestone, shaly above, geodes | 4 | 6 |
| 19. Hard, fine-grained blue limestone in 2 layers with rounded and angular chert concretions and large geodes | 1 | 6 |
| 18. Hard blue fossiliferous limestone | 0 | 6 |
| 17. Blue cherty limestone, somewhat geodiferous | 1 | 0 |
| 16. Hard green shales | 1 | 4 |
| 15. Hard, blue, crinoidal limestone with chert | 0 | 7 |
| 14. Like number 15 | 1 | 3 |
| 13. Mostly unseen except at the top which is thin, blue limestone weathering buff | 5 | 0 |
| 12. Thin limestone like No. 11, but with large *Productus* in the upper part. Occasional geodes | 5 | 0 |
| 11. Several layers of hard blue to greenish crinoid-limestone | 5 | 0 |
| 10. Hard, slabby, greenish to gray limestone containing abundant *Spirifer*, *Derbya*, *Aviculopecten*, etc. Third fossiliferous horizon | 2± | 0 |
| 9. Limestone like No. 8, but with thin layer of chert in lower part | 7 | 0 |
| 8. Buff to blue, very fine-grained arenaceous limestone or calcareous sandstone with small goedes and occasional long crinoid stems | 2± | 0 |
| 7. Like No. 8 | 4 | 0 |
| 6. Greenish, coarse, hard, extremely fossiliferous limestone with abundant *Spirifer*, etc. Second fossil horizon | 1 | 0 |
| 5. Mostly covered up, some buff shaly limestones, no fossils | 4± | 0 |
| 4. Two layers of hard, coarse, greenish-gray, very fossiliferous limestone, *Spirifer* and *Productus* in abundance | 1 | 3 |
| 3. Hard crinoidal limestone, green to blue | 2 | 4 |
| 2. Similar to No. 3 | 2 | 2 |
| 1. Massive blue sandstone, very fine-grained | 2 | 6 |
| Total thickness of section, about | 100 | 0 |
| Total thickness of the Harrodsburg limestone, about | 95 | 3 |



11a 11b



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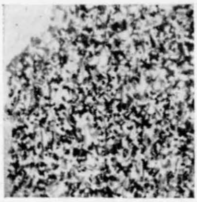

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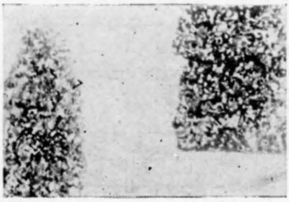
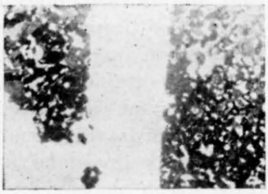
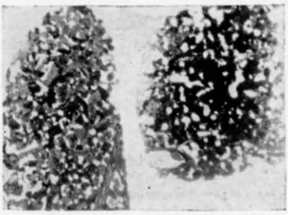


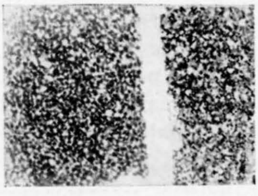
14a 14b



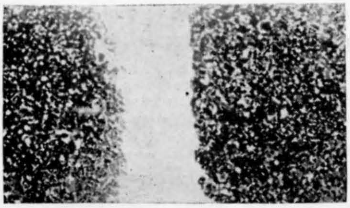
15a 15b



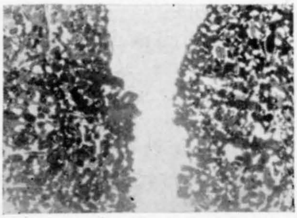
16a 16b



17a 17b



19a 19b



18a 18b

EXPLANATION OF PLATE E.

Figs. 11a, 11b. Horizontal and vertical sections of stone from the United Indiana Quarries. Magnified 2½ diameters.

Fig. 12. National buff stone. Magnified 2½ diameters.

Fig. 13. Horizontal and vertical sections of Indiana Quarries Company's No. 1 blue stone. Magnified 2½ diameters.

Figs. 14a, 14b. Horizontal and vertical sections of Indiana Quarries Company's No. 1 blue stone. Magnified 2½ diameters.

Figs. 15a, 15b. Horizontal and vertical sections of Consolidated Company's stone. Magnified 2½ diameters.

Figs. 16a, 16b. Horizontal and vertical sections of Consolidated Company's stone. Magnified 2½ diameters.

Figs. 17a, 17b. Horizontal and vertical sections of Perry Stone Company's stone. Magnified 2½ diameters.

Figs. 18a, 18b. Horizontal and vertical sections of National Stone Company's quarry run. Magnified 2½ diameters.

Figs. 19a, 19b. Horizontal and vertical sections of Perry Stone Company's stone. Magnified 2½ diameters.

There is not a specimen of limestone figured in this series that is not to be sold as A1 stone. There is some variation of the grain, as can readily be seen. However, there are other factors to be considered than mere fineness of grain. Neither the strength of the stone nor its durability are necessarily proportional to the fineness of grain. Finer or coarser, all the stone shown here is first class.

The horizontal and vertical sections shown an absence of fine beddings or lamination even in the microscopic structure.

Numbers 1 and 2 of this section belong to the Riverside sandstone, the remainder are classed with the Harrodsburg limestone.

ROCKY BRANCH SECTION.

| | | | |
|---|---|---|---|
| 19. | Covered to Salem limestone, about | ... | .. |
| 18. | Massive, buff, fine-grained limestone | 2 | 6 |
| 17. | Covered | 7 | 4 |
| 16. | Hard limestone, lower part filled with bryozoa, thin bedded.. | 17 | 6 |
| 15. | Marl filled with bryozoa | ... | 6 |
| 14. | Limestone with bryozoa | ... | 6 |
| 13. | Unexposed | 9 | 2 |
| 12. | Laminated limestone, hard, coarse, fossiliferous, in four layers | 7 | 7 |
| 11. | Unexposed | 3 | 10 |
| 10. | Laminated limestone | 3 | 4 |
| 9. | Blue shale | 2 | 0 |
| 8. | Sandstone, very fine grained, calcareous streaks | 2 | 1 |
| 7. | Unexposed | 2 | 11 |
| 6. | Coarse-grained fossiliferous limestone weathering laminated. | 1 | 2 |
| 5. | Fine grained blue sandstone | 1 | 10 |
| 4. | Unexposed | 1 | 0 |
| 3. | Coarse grained limestone with large brachiopods | 2 | 0 |
| 2. | Shale | 1 | 9 |
| 1. | Fine grained blue sandstone weathering greenish to rust-brown. Limestone streaks in the top together with geodes. | 26 | 3 |

Numbers 1 and 2 of this section belong with the Riverside sandstone and the remainder are classed with the Harrodsburg limestone. This and the previous section are twelve miles apart and show the extent of the general variations of the limestone in that distance.

If space permitted, local sections could be introduced showing the lenticular character of the three or four basal beds of the formation, and there would also be some local difference in the fauna, but nothing, at present known, would lead to a modification of the present classification or boundary of the formations.

*The Outcrop.*—The outcrop of this formation is much more extensive and irregular in form than that of the previous formation, the Riverside sandstone. This is because all the larger streams and their branches on the eastern third of the quadrangle have either cut into it or through it. All the tributaries of Salt Creek and all those of Bean Blossom Creek, except Jacks Defeat Creek, cut into the formation within the boundary of the quadrangle. The outcrop is also made more irregular by the fact that the divides between some of these streams retain irregular shaped masses of the higher formations over considerable areas.

*Economic Value.*—The Harrodsburg limestone makes a moderately good road metal if the lower half or two-thirds is used. The upper part is too soft to stand the rather heavy traffic to which many of the main roads of the region are subjected. The lower part is rather siliceous for the best grade of lime, and the stone is too coarse and thin-bedded to be of much value as a building material. However, it is available for good stone fences, and for rough work around the farm. If strong stone fences were built along the sags at the sides of fields and across small bottoms, leaving ample opportunity for flood water to get through in the latter case, they would be of great value in retaining the soil and preventing its washing away. An example of the value of this kind of treatment is to be seen on Rocky Banch, three-fourths of a mile north of the city limits of Bloomington. These walls really are terraces and are comparable, in a way, to those constructed in Europe and Asia for the purpose of retaining the soil. In this case they would also play the part of permanent fences, if properly constructed. When these fences are built across low places in the fields, the soil in a few years accumulates to a point nearly level with the top of the wall. It will not accumulate higher. This can then be put back on the steeper parts of the field from which it was washed and which are painfully evident in practically all the fields of the southern Indiana region.

The Harrodsburg limestone is of some importance as a water-bearing stratum. The rock is rather closely jointed and thin-bedded, which contributes to the ease with which water is allowed to flow through it, and furnishes holding capacity for ground water. As a result, wells of sufficient flow for domestic use are possible, and springs of small capacity, but enough for household purposes, are not rare. Seeps occur all along the contact of the Harrodsburg with the Riverside sandstone, and it is here that the springs occur. There is another line of springs near the base of the more massive part of the upper Harrodsburg limestone, where the streams have cut their valleys sufficiently deep in the rock. This water is derived from the joint and percolation flow of the overlying Salem or Bedford limestone which comes to the surface when the less porous part of the Harrodsburg is reached.

*Salem Limestone.*—(The trade names of this limestone are, Bedford Oolitic Limestone, and Indiana Oolite.) In dealing with the economic phases of this limestone, the term Bedford limestone will be used. It is the proper trade term, and Indiana Oolite is also applicable as a trade term, meaning precisely the same layer of rock as the Bedford Oolitic limestone.

Since much of the descriptive matter regarding the Bedford Oolitic limestone was published by Hopkins and Siebenthal in the Twenty-first Annual Report of this Department and copied with additional notes by R. S. Blatchley in the Thirty-second Annual Report, it will not be repeated here. Most of the changes in the quarry operations since the local maps of the Thirty-second Report were published are of minor importance, and they have not been redrawn. The method of deposition and the discussion of the grain of the stone, with photographic reproduction of thin sections, is given and the question of utilization of waste is covered by Mr. Mance.

The work on the Bedford Oolitic limestone in this vicinity has thrown considerable light on the manner in which the stone was laid down and, too, the probable quantity of the highest grade of stone available. There is frequently associated with the stone of this region a bituminous marl, usually with rank odor, often very finely sandy, and varying from a dirty brown or almost black to buff in color. The usual color is a dirty brown. It is bedded much like fine shale but behaved like an impure limestone in the creek beds, but more like a shale in dryer exposures. Sometimes this marl is found below the oolite and sometimes above it, while occasionally it is found both below and above it in the same exposure. This is the case in the northeast quarter of Section 30 and the southeast quarter of Section 19, just northwest of Harrodsburg. In the road at the crossing of the creek the oolite is pinched out and this marl, or "bastard", of the quarrymen, occupies the whole interval between the Harrodsburg limestone below and the Mitchell limestone above. There are several feet of oolite to be seen on the south side of the creek in the bluff by the side of the road, but none at all on the north side of the creek. Going up the creek, about two feet of oolite may be found on the south side in one place, but the continuous exposure in the creek bed does not reveal a bit of it. A half mile north of this there are nearly thirty-five feet of the oolite to be seen in the hill. A considerable amount of this "bastard" also continues south past Harrodsburg to the south edge of the quadrangle. A similar condition occurs at Lanesville, in Harrison County, but the fine material which replaces the oolite is more sandy than that found about here. Similar conditions are known to occur in other parts of southern Indiana. In other words, the Bedford Oolitic limestone is a series of great lenses imbedded in finer, more or less calcareous material, the interval of space between the over and undrlying rocks being maintained by the finer material. Occasionally, as northwest of Victor, parts of it are interbedded with the marl. The finer material occupying the place of the oolite where the latter is missing is very evenly and finely stratified. The oolite is highly cross-bedded and composed of fair-sized, even grains, more or less comminuted and the interspaces nearly filled with crystalline calcite. The rock flour and decaying organic matter seem to have been all removed from most of the rock by the waves and undertow and other currents and deposited in the quieter water nearby. Where this has not been complete and locally this fine rock flour has been deposited in thin layers, the thin layers are dense and firm and weather to a lighter color than the rest of the rock, and form what the quarrymen call "hard streaks" which are a detriment to the stone. The grain of the rock, its universal cross-bedding, the occurrence of the great lenses of granular rock imbedded in the finer rock flour, all seem to be in harmony with this conclusion, as well as the suggestion that the material was deposited fairly rapidly. It is to be regretted that there are no drill cores or accurately kept logs with samples from the deep wells west of the outcrop to show the condition of the rocks occupying the interval of the oolitic limestone toward the center of the basin.

From the fact that the oolitic limestone bed, as pointed out above is lenticular; from the fact that much of the stone cannot be quarried economically because of the abundance of joints or mud seams; from the fact that some of the stone locally contains hard streaks and stylolites, so frequent as to prevent its use as first-class stone; from the fact that some of the stone is too coarse or too poorly cemented, the conclusion of the observations of this region, and in fact, the whole Indiana region, is that the quantity of No. 1 stone available is limited. While there are great quantities of this grade of stone yet to be quarried, nevertheless the time has arrived when the grading of the stone should be given careful attention. The selection, through close competition, of the highest possible grades of stone as No. 1, has reached such a state of over-grading that a readjustment, and normal, uniform grading of the product is necessary. In many instances no one but an expert can tell the difference between the best No. 1 stone and the next grade, and when properly selected, the next grade is as strong, as durable, and as good as the highest No. 1 available. In this connection it should be pointed out that durability of the stone is not necessarily connected with the fineness of the grain. Indeed, frequently the reverse is the case. The durability of the stone, for many purposes, rests rather upon the size of the pores than the percentage of pore space. In very fine-grained dense rocks, the capillary attraction holds the water and prevents its escape so that the rock is much more easily damaged by frost than the stone with coarser pores, where the water has free avenues of escape, so that rarely if ever will the pores be more than nine-tenths full on freezing. Water expands about one-tenth of its volume upon freezing, and with a force sufficient to raise a column of a mile in height the distance of a tenth of the depth of water in a cylinder sufficiently strong to hold it, the column of ice being of the same diameter as the cylinder. This is why green stone, or any stone that is thoroughly saturated, is ruined by freezing through.

As is pointed out by Mance in the following discussion, the lowest course of stone in a building may be of the finest grade and the remainder of the building above the base be of a slightly lower grade, so far as size and uniformity of the individual grains is concerned, and even a stoneman could not tell the difference from the walk, and at the same time the upper courses will be quite as strong and durable as the base.

*The Outcrop.*—Except in the Clear Creek District, the outcrop of the Bedford Oolitic limestone is always found on the west side of the outcrop of the Harrodsburg limestone. In the Clear Creek District, east of the creek, the oolite is surrounded by the Harrodsburg limestone. The details of the outcrop are shown upon the map. It has not been feasible to show where the "bastard" occurs, or to indicate the grade of the stone, since this cannot be done from surface inspection.

*The Mitchell Limestone.*—Under this head authors have grouped a series of limestones of different texture, appearance, and geologic age. Difficulty has been found in separating the lithologic formation into its integral parts. One feature that adds very greatly to the difficulty is the fact that the most of the formation forms a flat plateau or plain rather deeply buried in the residual clay of its own decomposition, the surface water being carried away by subterranean drainage. Rather close study in the Bloomington Quadrangle reveals characteristics that promise to serve as guides in the accurate differentiation of these limestones. The texture of the stone varies from the exceedingly fine-grained lithographic limestone with occasional fossils and calcite crystals, Calcilutyte, through a typical oolite, to brecciated limestone with the fragments varying from a foot or more in diameter down to the finest grains, a calcirudyte, and ending up with edgewise conglomerate, sometimes 40 or 50 feet thick. There are also shale and sandstone beds in it. In spite of all these differences of faces there is a striking similarity to the hard brittle limestone usually possessing complete or partial conchoidal fracture.

The bedding planes very often are in the form of stylolites. Indeed stylolites are one of the great characteristics of the formation, as many as 25 having been observed in eight feet of rock. Most of them are very small. However some of them are of large size, single projections having been measured that were fourteen inches in length.

It seems at present that the St. Louis, St. Genevieve and Chester groups are represented in lime, the limestones that have been referred to the Mitchell. Work is under way which, it is hoped, will succeed in differentiating them.

The thickness of the formation is probably a little over 220 feet in the southern end of the quadrangle. No estimate approximating accuracy can be made within the limits of the north end of it.

Some of the details of the stratigraphy of the formation may be outlined briefly as follows: The lower 40 feet, or thereabouts, contains shale beds and marl beds usually a few inches in thickness, sometimes a foot or two. The beds are usually quite thin but some massive ones occur in this lower part. It is near this upper limit of shale beds and massive layers that some of the caves of this region and many of the large springs are found. Above this the limestone is thinner bedded again and is usually lithographic in texture. About 80 feet above the base, toward the south end of the quadrangle there is a bed of shale and marl, sometimes 5 or 10 feet thick. Associated with these are slabs of very fossiliferous limestone. Over this shale and marl bed is more lithographic limestone. Some distance above it is a chert horizon, frequently very fossiliferous, which ranges from three to four inches to a foot or more in thickness. Much of the Mitchell carries chert, but this horizon seems to be a silicious limestone becoming chert on weathering. The blocks are hard and dense on the outside but are very granular and porous within, due to the very partial silicification of the limestone. Near this horizon, perhaps just above it, is a zone varying from an inch to several feet of oolitic limestone with quartz and other sand grains. These sand grains are very perfectly rounded and some are a millimeter or more in diameter. From near this horizon upward most of the stone is oolitic, but hard and usually possessing semi-conchoidal fracture. The grains are true oolite. Near the top is a layer of marly material, sometimes shale and sandstone, from 0 to 10 or 15 feet in thickness. This bed is confined to the region south of the latitude of Whitehall. It is frequently quite fossiliferous, the marly material containing excellently preserved little brachiopods and the sandstone having a more varied fauna. At the lower contact of this layer to the Mitchell is always brecciated or even conglomeratic in a large way. This brecciation seems to be persistent throughout the quadrangle. At the east end of the abandoned tunnel, near Stanford, it is 8 or 10 feet thick and very coarse, mixed with marl or clay, though it does not possess the characteristics of an edgewise conglomerate, such as is to be seen in the gorge of McCormicks Creek, just off the north edge of the quadrangle. It appears to pinch out at the latitude of Whitehall, only the brecciated limestone remaining to mark its place. Above the layer just mentioned are from a few feet to 20 or 22 feet of whitish limestone, frequently oolitic (in the true sense), and fossiliferous, containing *Diaphragmus,* a Chester species of fossils. At Whitehall and northward this layer seems to lay upon the Mitchell limestone without any shale, marl or sandstone between them. Some detailed sections of the formation are given below:

SECTION AT THE WEST END OF THE ABANDONED TUNNEL SOUTHEAST OF OLD STANFORD.

| | *Feet.* | *Inches.* |
|---|---|---|
| 12. Shales, gray streaked with dark yellow | 7 | 0 |
| 11. Limestone, oolitic in upper part, fossils, about | 11 | 0 |
| 10. Sandstone, blue-gray, calcareous, fossiliferous, fine-grained. 1 foot to | 1 | 2 |
| 9. Shale, blue varying from sandy to marly, fossiliferous. Fossils mostly on south side of cut, more sandy on north-side | 1 | 6 |
| 8. Limestone breccia and conglomerate, fragments from microscopic size to a foot or so in diameter, 3 to 6-inch layer of pebble conglomerate on top of it, the pebbles of dark rounded fragments of lithographic limestone of the Mitchell. Sand in matrix of this conglomerate, 3 feet to | 5 | 0 |
| 7. Limestone with conchoidal fracture, apparently oolitic | 6 | 0 |
| 6. Marly streak about | .. | 3 |
| 5. Limestone, hard, oolitic | 10 | 0 |

| | Feet. | Inches. |
|---|---|---|
| 4. Limestone, lithographic to roof of tunnel, shows a few sections of fossils, 25 stylolitic bedding planes | 8 | 0 |
| 3. Limestone, sandy, thickens from about 4 inches at the west end of the cut to 3 feet near the end of the tunnel. Rocks above rest unconformably upon it | 3 | 0 |
| 2. Shale, calcareous, sandy, two inches to | 0 | 4 |
| 1. Limestone, somewhat oolitic, hard | 3 | 0 |
| Thickness of section | 56 | 3 |
| Thickness of "upper Mitchell" | 49 | 3 |

The extent to which the top of the Mitchell has been dissolved away can not be stated, but the distance to the seep representing the location of the next limestone in the Chester seems to be five to ten feet too great, and it is probable that about this amount of the limestone has been removed or is covered by the overlying shales. The layer of brecciated limestone is recognizable over nearly the whole quadrangle, though the shale layer varies in thickness and seems to disappear in the north part of the area studied.

On the east side of the hill, in the excavation there, the sandy limestone, No. 3, seems to be two or three times the thickness on the west side, and the brecciated limestone has thickened to 7 feet 6 inches. It thickens rapidly to the eastward on the west side of the hill.

APPROXIMATE SECTION OF TOP OF MITCHELL LIMESTONE IN SECTIONS 23 AND 24, SOUTH OF HENDRICKSVILLE.

| | Feet. |
|---|---|
| 9. Sandstone and shale | 10 |
| 8. Blue clay shale | 18 |
| 7. Limestone about | 1½ |
| 6. Blue clay shale | 12 |
| 5. Massive sandstone | 8 |
| 4. Blue clay shale | 8 |
| 3. Limestone, 6 feet to | 10 |
| 2. Sandstone and shales | 15 |
| 1. Mitchell limestone, brecciated on top | 65 |
| Approximate total thickness | 157½ |

## WHITEHALL SECTION, AS EXPOSED IN 1913.

The section is in an abandoned road. In 1902 the road was still in use and part of the section covered. The section as it appeared in 1902 is as follows:

| | Feet. | Inches. |
|---|---|---|
| 21. Gray massive sandstone | 3 | 0 |
| 20. Shale covered with sandstone | 10 | 0 |
| 19. Shale | 15 | 0 |
| 18. Sandstone, fine grained, fossil plants weathering mottled through red, purple and white | 2 | 4 |
| 17. Sandstone, thin bedded, fossil plants | 4 | 0 |
| 16. Blue to drab clay shales with rusty streaks, weathers reddish | 14 | 0 |
| 15. Oolitic, very fossiliferous, coarse grained | 7 | 0 |
| 14. Limestone, dense, fossiliferous, hard, diphygenic, fossils shell out easily | 5 | 0 |
| 13. Limestone, hard, fossiliferous, lithographic, little oolitic in places | 5 | 0 |
| 12. Oolite, hard, fossiliferous, brecciated in places near top | 21 | 9 |
| 11. Limestone, yellowish, weathering in fine pieces | 7 | 4 |
| 10. Limestone, conglomeratic, brecciated, pebbles composed of lithographic limestone. Matrix of dendritic limestone, hard, conchoidal fracture | 2 | 3 |
| 9. Limestone, dendritic, lithographic, thin-bedded, pale-drab to yellowish brown, weathers craggy | 5 | 0 |
| 8. Limestone, fine-grained, hard, oolitic in places | 1 | 5 |
| 7. Very cherty limestone. Chert in large and small concretions and masses. Few fossils | 2 | 6 |
| 6. Limestone, dense, oolotic, conchoidal fracture | 2 | 0 |
| 5. Limestone, hard, lithographic, fossiliferous | 1 | 0 |
| 4. Limestone, hard, fossiliferous, weathering rough and porous on the outside, oolitic, gastropods, brachiopoda, etc. | 2 | 6 |
| 3. Limestone, thin bedded, fine grained, slightly shaly | 2 | 0 |
| 2. Limestone, single layer, fine grained | 2 | 4 |
| 1. Oolitic limestone | 1 | 8 |

The brecciated limestone in No. 12 of this section represents, apparently, the horizon of the bed of shale near the top of the Mitchell farther south. It seems that the sandstone below the first limestone has thickened until it occupies most of the space between the top of the Mitchell, above the 14 feet of shale. The limestone is not seen on the east side of the Whitehall hill but is seen a little farther west on the other side of the hill.

SECTION UP THE ROAD FROM HENDRICKSVILLE TO LIBERTY CHURCH.

| | Feet. | Inches. |
|---|---|---|
| 10. Limestone, about two feet or | | 6 |
| 9. Olive clay shale | 8 | 0 |
| 8. Massive sandstone, 3 to 4 feet, quarried by road | 4 | 0 |
| 7. Covered | 10 | 0 |
| 6. Blue clay, gray sandy shale and greenish shaly sandstone | 10 | 0 |
| 5. Limestone, 15 or | 20 | 0 |
| 4. Sandstone and sandy shales about | 15 | 0 |
| 3. Mitchell limestone | 23 | 0 |
| 2. Shale | 0 | 6 |
| 1. Considerable thickness of cherty Mitchell limestone full of stylolites and fossils. | | |

No. 10 of this section is the first limestone. The thickness of No. 4 could not be accurately determined on account of poor exposure. It may not be as thick as indicated. At Whitehall this layer seems to be wanting so that No. 5 rests on No. 3.

*The Outcrop.*—The outcrop of the Mitchell limestone covers about half the area of the quadrangle. Where it rises considerably above the general drainage level it is always characterized by sinks, frequently of large dimensions. Some are a mile across and fifty feet deep. From this size they vary down to small holes. Its thickness together with the relatively low dip of the rocks makes this limestone an extensive surface formation. Another feature of the rock, which contributes quite as much to the unbroken nature of the outcrop, is its cavernous nature and the fact that the water falling on large areas of it sink into the ground and flow away as subterranean streams, instead of concentrating the energy of the water in cutting deep valleys in it and revealing the underlying formations. Aside from these reasons, the limestone is rather hard and resists stream action quite as much as any other rock in this part of the State.

*Economic Value.*—The Mitchell limestone is too hard and brittle to be of much value as a building stone in a large way. It is also thin-bedded, as a rule, and very fine grained except in the upper part, where it is oolitic. Even here, the oolite grains are bedded in a very fine rock flour cement which has the same effect, and frequently gives even the oolite a semiconchoidal fracture. The fineness of the pore space, even though the percentage of pore space is very low, unfits it for withstanding frost action, when used near the water line or in moist places. When used above foundations in superstructures it lasts well. Except for the foundations, the stone is adapted for rural dwellings and the thin beds in which it occurs and the relatively small blocks into which it is broken by the joint planes makes it rather easy to quarry. The value of stone for rural dwellings will be treated in the discussion of the following formation.

This limestone is of great value for four different purposes. They are: road metal, lime, Portland cement and as a waterbearing rock.

As road metal, the Mitchell limestone has no equal in Indiana, and probably not in the bordering States on the east and west. Its great thickness and availability make it cheap to quarry, as great faces can be carried back very economically. There is rarely any stripping to be done save of residual clay which can be removed by hydraulic stripping wherever water is available. Its value for crushed limestone, Portland cement and lime are covered in the preceding pages, the remarks about the value of the oolite for these purposes being equally applicable to the Mitchell. Many of the great "springs" (underground streams) issuing from the borders of the outcrop of this limestone have sufficient fall to permit the installation of hydraulic rams so that the owners may have modern water conveniences in their houses and frequently electric lights by proper utilization of the water and the use of storage batteries. They could also be made to furnish water for gardens.

## The Chester Shales, Sandstones and Limestones.

Resting on the Mitchell limestone are 200 feet of shales, sandstones and limestones of the Chester group of rocks. These rocks were called Huron in some of the State Reports, but the Black Shales of Ohio have long been known by that name and inasmuch as it may be necessary to use that term in Indiana for some of the black shales of the Devonian, the term Huron must be ruled out.

The Chester rocks begin, in all probability, in the uppermost part of the Mitchell limestone. The treatment under this head includes only the clastic rocks above the Mitchell, and the map shows only these rocks, since it is a lithologic map. A geologic map represents the rocks of various ages and a lithologic map represents limestones, sandstones, shales, etc. The two usually concide, but do not on the Bloomington quadrangle.

The lowermost 30 feet of these beds is largely a clay or slightly sandy shale over the most of the area of the outcrop. There is a sandstone a few feet below the top of the shales usually only three or four feet, or even less, in thickness. It occasionally seems to occupy must of the space, at the expense of the shale. This is the case at Whitehall. Much of the way this shale would apparently make good brick and shale for Portland cement. In the vicinity of McVille there is a thin streak of carbonaceous shale and a few inches of coal in places, in the lower part of these shales.

On these shales is a limestone which in the southern part of the quadrangle is from two to three feet thick and in the northern part increases in thickness to five or even ten feet. It usually weathers to a yellowish-brown color and is rather coarse, though the lower part of it is sometimes nearly white in the northern area. The limestone itself is relatively unimportant except that it is the source of many springs which supply water for families and stock. It appears to be missing over considerable areas, at least the outcrop can not be found. When it is absent the springs which accompany it are not present and the usual houses, located on account of the springs, are missing.

Resting upon this limestone, which we usually call the first limestone, is a mass of 80 to 90 feet of shales with some sandstones. The shales are frequently interstratified with thin streaks of sandstone. They may be rather clayey but frequently are quite sandy. The sandstones seem to thicken locally. This seems to be the case in the region west of Cincinnati ridge between the Cincinnati region and Beech Creek south of the Hannum School.

Over these shales and sandstones is what we have called the second limestone. It varies in thickness from 8 to 20 feet. It is sometimes oolitic and sometimes crystalline. It is frequently dissolved from beneath the thick sandstone which rests upon it and the sandstone has moved down and occupied the place of the limestone. On account of the shales below the limestone, like the other limestones of the Chester, it has moved down hill considerably by creep. For this reason in opening quarries it is well to enter the hill well above the outcrop. The limestone in places is quite fossiliferous.

Over the second limestone is a layer of 30 feet or more of sandstone, where it has not been eroded away. This sandstone is usually rather fine-grained, buffish brown or light buff, where the iron cementing material has not been concentrated in it. It is well shown in most of the cuts between Elwren (Stanford Station) and Solsberry.

Over this sandstone are some 30 feet of shales with a little sandstone upon which rests the third limestone. This third limestone is the highest formation of the Mississippian found in the area of the quadrangle. It is thin, probably not much over 30 inches in the thickness and is found near the tops of the hills in the vicinity of Cincinnati. The higher shales and the third limestone are practically confined to the Cincinnati region, having been removed from practically all the rest of the quadrangle.

*The Outcrop.*—The outcrop of the Chester is confined to the southwestern two-thirds of the quadrangle and then mostly to the hills and ridges, while the underlying Mitchell occupies the valley. Throughout the eastern margin of the outcrop in the sink region west of Bloomington, it is very difficult or impossible to map the outcrop accurately on account of the sinks developed beneath the formation in the Mitchell limestone and into which the shale limestone and sandstone have settled, sometimes as much as 40 feet or more. Except in cases where there are exposures, which are very rare, it is impossible to locate the line of contact. Indeed the contact enters each of the depressions and comes up over the rim, and in many instances is worn off from the rim. In the absence of exposures it is impossible to locate these filled sinks, since they are filled and the ground appears fairly even. In other cases the sinks are cleaned out, the material having been all washed down through it when the bottom finally closed.

The limestones of the formation appear to be wanting locally in various parts of the region. At any rate they do not appear at the surface and the springs that usually accompany them are missing. This is true of the western part of the quadrangle north of Richland Creek, the region immediately southwest of Hendricksville, the region south of the Hannum School, and the second seems to be wanting over quite an area southwest of Kirksville. The second is found all along the Indianapolis Southern R. R. from the county line to Solsberry, in the vicinity of Solsberry, Cincinnati and in some places in the northeast corner of the quadrangle.

*Economic Value.*—The economic value of this member of the Chester is much less than that of the three underlying formations. The basal shales are of value for local brick and tile works, but are too much disturbed by the development of sinks below, into which they have sunk, and been jumbled, with limestone and sandstone in such a manner that it would be expensive to separate them for such extensive use, as the manufacture of Portland Cement. Where the outcrop is steeper and the sinks are less developed there is frequently but a rather narrow margin available without very extensive stripping. The upper shales that occur sufficiently close to the railroad to be available are of rather uneven texture, and probably of composition, though locations for clay products plants may be found.

The limestones are of value as water bearing strata, and as such have had a marked influence upon the settlement of the country and the present location of homes. The second limestone is by far the most important in this connection. The large springs in the region between Elwren and Solsberry, the region of the Sanborn School, Cincinnati, and other places are examples. There is always sufficient fall to develop springs to permit the use of hydraulic rams and frequently sufficient water for the home use and usually for garden irrigation.

The second limestone is a pretty hard, tough limestone, making good road metal where available. On account of the sandstone above it and the shales below it it is seldom that much of it can be quarried without excessive stripping. It has been rather extensively used with good results in the vicinity of Cincinnati.

In many places the sandstones of the Chester have been used for foundations, and in no instance that we observed had it crumbled or given way to any noticeable extent though some of the buildings had been standing for a great many years. The sandstone is rather soft when quarried and is easily worked. The fresh stone has, usually, a dark buff color which darkens some on prolonged exposure. It is much lighter than the well known Connecticut brown stone used so extensively in the northeastern part of the country. One of the main values of this stone lies in the fact that it may be quarried at times when farm work is less pressing than others and accumulated for a series of years, if necessary, until a sufficient amount of good, well shaped blocks of sufficient dimensions are at hand to build a good modern house which will be of good appearance and which will last for generations. Barns and other larger outbuildings can be similarly constructed with very little cash outlay, while to buy the stone for such houses and buildings, which would be no better, would be an expensive operation and require much hauling from the railway stations. The main thing is to be sure of firm foundations which will not settle. This is the most important part of the operation and should be thoroughly done. The limestones of the Chester, Mitchell, and the upper part of the Harrodsburg are available for such use.

SECTION ALONG WEST SIDE OF QUADRANGLE SOUTH OF SOLSBERRY, SOUTHWEST FROM THE CENTER OF SECTION 4.

| | Feet. |
|---|---|
| 7. Covered to house northeast of middle of section | 55 |
| 6. Sandstone | 25 |
| 5. Limestone, 12 to | 16 |
| 4. Shales and thin sandstones, 80 or | 90 |
| 3. Limestone, thin | 2 |
| 2. Shales, mostly, 30 to | 35 |
| 1. Limestone, etc., to creek bottom, about | 80 |

The rocks above the sandstone northwest of the house in Section 4 represented in the 55 feet "covered" of the above section are probably largely of Pennsylvanian age.

The distance between Nos. 5 and 3 of the above section read 105 feet by barometer going down the ravine southwest from the center of the section. This is due to two causes. First it is the general direction of the dip and, second, the lower limestone has crept and slumped down some ten or fifteen feet or more. This is well shown in the road south of Solsberry where the limestone is found three times in the same grade in the hillside. The upper part of the next limestone below is also probably covered to some extent. The exposures do not show the full thickness of the sandstone and shale in the top of the Mitchell here.

# Glacial Geology.

By C. A. Malott.

## GENERAL TYPES OF TOPOGRAPHY.

The topography of the Bloomington Quadrangle is rather diversified, varying almost directly with the kind of rock structure in which the different types are formed. At the eastern edge are small, steep-sided, V-shaped ravines, heading with a steep fall of some ten or fifteen feet where the Harrodsburg-Knobstone contact occurs, and also the larger ravines or valleys with their steep, cliff-like sides and flat, widening valley floors. Succeeding to the west are gentle, undulating slopes characteristic of the Salem limestone topography. Next in turn comes the sink-hole plain of the Mitchell limestone, with its plateau-like appearance in relation to the main streams. The western half of the sheet represents the more rugged topography of the Chester sandstones and shales with the occasional thin limestones. Here occur deep, narrow valleys with sides of a steep angle, being vertical only where the limestones are a controlling feature. These various types of topography are frequently distinctly abrupt, but more often merge into each other, each gradually assuming its individual characteristics.

### The Flatwoods District.

While the above outlined types of topography are dominant as a whole, there are some features, however, which are characteristic of none of them. The northwestern part of the region represented by the sheet is especially to be noticed in this respect. Just west of Ellettsville is a wide level tract of land, only a portion of which comes within the limits of the quadrangle, which has attracted the attention and study of geologists for some time. It is a low level basin, averaging about 740 feet above sea level, about two miles wide and reaching some six miles northwest from Ellettsville towards White River near Spencer. Its peculiarities consist of low marshy tracts of land with occasional monadnocks rising island-like above a surrounding periphery of hills or higher land, and of a striking ash-colored, silty soil, usually containing shot-like concretions of ferrous and ferric oxide, which are locally known as "turkey gravel". In the lower portions, especially near the middle of the basin the ash-colored silt is covered over with a black soil containing much vegetable matter. This black soil is very fertile. This peculiar basin, locally known as Flatwoods, is drained mainly by McCormicks Creek, only the very headwaters of which are within the area of the Bloomington Quadrangle.

About three and one-half miles west of Ellettsville in S. E. $\frac{1}{4}$ Sec. 1, T. 9 N., R. 3 W., is a narrow opening leading from the Flatwoods basin into Raccoon Creek valley. South from this opening on either side of Raccoon Creek occur remnants of the same flat as observed in the above described Flatwoods basin. In places the remnants are quite extensive, as in Sec. 24, 23, 14 and 13, T. 9 N., R. 3 W. Since the drainage of Raccoon Creek is much lower than the flat-surfaced remnants of the former continuous flat, many V-shaped ravines are cut into it, making the topography rather rough. Nevertheless, the flat tracts remaining form a striking feature.

Evidence of this Raccoon Creek portion of Flatwoods having been a continuous flat, as the present Flatwoods proper, are found in the structure revealed in the steep-sided ravines and in the wells of the region. Stratified sand is very often to be seen, not only revealing the fact that distinct water currents were present, but that the region was once as rugged as regions farther south and that the valleys have been filled up to a level of the present flat-surfaced remnants. In some places the region has been filled as much as a hundred feet. How this took place will now be briefly outlined.

As a matter of history it might be mentioned that Collett in his report on the Geology of Owen County (Seventh Annual Report, Indiana Geological Survey, 1875), in attempting to explain the narrowness of White River valley above Spencer and adjacent to the northwest end of the Flatwoods basin, asserted that previous to the Illinoian glacial period, White River passed up the narrow McCormicks Creek gorge, through the Flatwoods basin, through the opening leading into Raccoon Creek valley, and thence down that valley to the present White River valley below Freedom. Siebenthal, commenting on Collett's idea, says: "The Pleistocene terraces of Bean Blossom Creek clearly prove the pre-glacial valley of that creek to have been practically as it is at present. It is impossible to imagine how it could be cut down to its present depth, while White River, into which it emptied, was running at a level

150 feet higher than now, as it is alleged to have done. Morever, the gorge of McCormicks Creek is clearly post-glacial. And further, it empties into White River at least a mile below the upper end of the 'Narrows', whose existence it was brought forward to explain''. (Twenty-first Annual Report, Ind. Geol. Surv., 1896, pp. 302.) Thus Siebenthal makes it clear that Collett's idea is not tenable. Siebenthal advances the idea that the Flatwoods basin was the site of a shallow lake during the Illinoian glacial period and for some time following.

There is no doubt that the phenomena of Flatwoods are due to the ponding of waters before the Illinoian glacial ice front. It seems that the ice advanced slightly into the area represented by the Bloomington Quadrangle. At its farthest advance it was quite likely occupying the extreme northwest sections, very probably entering the quadrangle near the middle of Sec. 33, T. 9 N., R. 3 W., and passing northward past Freeman P. O., and leaving the quadrangle near the Hardscrabble School. Near the residence of Thomas Coble in the N. W. ¼ Sec. 3, T. 9 N., R. 3 W., are remnants of an old moraine, the only direct evidence of any continued stand of the ice front upon the quadrangle. From the vicinity of the Hardscrabble School the ice front probably extended irregularly northward for over two miles and then swung eastward, crossing the headwaters of Big Creek, Jacks Defeat south of Stinesville, and then over the divide and across Bean Blossom valley. Thus, the stream draining the pre-glacial Flatwoods basin was ice-dammed, as well as the valleys of Jacks Defeat and Bean Blossom. The waters undoubtedly accumulated in Bean Blossom valley until they flowed over the divide at the old col on the farm of Jack Litten about two miles southeast of Stinesville. After coming into the valley of Jacks Defeat in this manner, they continued into the next basin west, which is the one now occupied by Flatwoods. The waters reached this basin through a low opening just west of Ellettsville. Quite an extensive lake was formed in this basin. From this basin the waters found an outlet to Raccoon Creek valley through the opening described above (hereafter this opening will be called the Raccoon Creek col), and passed down this valley, finding an outlet along the edge of the ice sheet or under it in the vicinity southwest of Freeman P. O. Ignoring the work of the post-glacial streams in the old lake-flat (which was the result of the long continued ponded waters), it can be easily seen by the contours of the quadrangle map that the general slope is about ten feet to the mile from the entrance into the Flatwoods basin just west of Ellettsville to the Freeman P. O. vicinity. This slope of the old lake-flat is in itself proof of the direction of the flow of the glacial waters.

On the withdrawal of the ice front, the portion south of the Raccoon Creek col was drained; but the region of Flatwoods proper remained a lake for a long time, with an outlet through the Raccoon col, or through the col just west of Ellettsville leading into Jacks Defeat Creek. Perhaps both of these openings or cols were outlets for a time; but the Raccoon Creek col is slightly lower, and undoubtedly persisted longer. The outlets to the Flatwoods lake were at these places because the old buried stream, or valley rather, was dammed so effectively at the lower end that it was much higher here than at the outlets above. Very probably a morainal dam was present, as evidence of such are to be seen near the head waters of Allistons Branch, which was the pre-glacial outlet of the old pre-glacial stream. The steep-sided, deep ravines and the wells of this region show that the filling here was considerably over a hundred feet. Moreover, the glacial material itself has all of the appearance of outwash from a moraine. The slope also is in the direction of the Raccoon Creek col, where the waters undoubtedly found an outlet.

The region immediately south of the Hardscrabble School (N. W. corner of the quadrangle) slopes rather rapidly to the southward, to a narrow opening in the line of hills in the middle of the southern half of section eleven. The glacial waters coming from the ice front in the upper portion of the pre-glacial McBrides Creek basin, no doubt flowed through this opening and escaped southward into the Raccoon Creek region. After the ice withdrawal, the waters continued in this direction, because McBrides Creek valley was filled by a moraine near the western edge of the quadrangle. Remnants of such a moraine have already been mentioned. Post-glacial stream action has been rapidly clearing the morainal and outwash material from the pre-glacial McBrides Creek; but there is much yet to be done. The present drainage in the region just south of the Hardscrabble School is mainly underground, which was, perhaps, already well developed in pre-Illinoian times. Much of the glacial material itself has been carried away through the underground drainage.

After the withdrawal of the glacial ice front from the Freeman P. O. vicinity, the streams went to work to clear out the material which had filled their valleys. Gradually Raccoon Creek has cut its way back into the glacial material, or old lake-flat, and at present a tributary is slowly making its way into the Raccoon Creek col, which connects with Flatwoods proper. Beautiful terraces were thus formed in the old lake flat. These are prominent features on either side of Raccoon Creek and its tributaries, and have a distinct influence upon the position of the contours. But long ago the waters of old lake Flatwood ceased to find release through the Raccoon Creek col. Underground drainage was well developed in pre-Illinoian times, and soon the old subterranean channels were cleared of glacial debris and the waters went through the subterranean pre-glacial routes. The main stream, however, was through Allistons Branch, and this stream was so thoroughly clogged that it has never been able to be much of a factor in the drainage of the Flatwoods region. The present drainage of Flatwoods is through the rocky gorge of McCormicks Creek, which is distinctly a post-glacial stream. It was initiated through underground drainage, and, having gained an early ascendancy through the peculiar suitability of its rock structure and great fall, it soon had practically the entire drainage to itself. Later, through mechanical action, and the forces of gravity, the drainage became surface, practically as it is today. The lake-flat, however, has always been imperfectly drained; even yet small depressions are either marshy or remain as small lakes; as, for instance, the Stogsdill Pond just east of the Hardscrabble School.

## The Richland Creek Terraces.

Another instance of the effect of the ice in the near vicinity of the Bloomington quadrangle is seen in the beautiful terraces on Richland Creek. These terraces begin in the vicinity of the Vernal Church, where they merge into the present alluvium. Near Whitehall they are some twenty feet above the present stream channel; at Hendricksville they are forty feet above, and at the western edge of the quadrangle they are seventy feet above. The flat represented by the connected terrace surface has a slope of about five feet to the mile down stream. These terraces were caused by the damming of Richland Creek some two miles west of the quadrangle, where the pre-glacial channel was filled deeply with glacial material and Richland Creek itself deflected to the southward over a low divide into a small stream which leads into Beech Creek. (Leverett, Mono. XXXVIII, U. S. G. S.) Thus a lake extended up Richland Creek to near the Vernal Church, and the incoming waters brought in sediment and built up a lake flat, the surface of the terraces being the surviving remnant. As the divide just off the quadrangle was cut down the lake was drained, and in turn the stream has cut down into the old lake-flat, removing much of the material; and thus the beautiful terraces on either side of Richland Creek were formed.

# Pennsylvanian or Coal Measures.

By T. F. Jackson.

The eastern outcrop of the Pennsylvanian rocks[1] in Indiana extends in a belt of varying width in an east-of-south direction from Warren County on the north to the Ohio River in Perry and Crawford counties on the south. Throughout the greater part of this area the Pennsylvanian rock consist of a series of strata which vary greatly in lithologic features both horizontally and vertically. In many places massive sandstone ranging in texture from coarse conglomerate to the fine-grained Hindostan whetrock of Orange County constitutes the bulk of the formation. Thin beds of coal, fire-clay and shale are frequently found interbedded with the sandstone. In other places a series of interbedded sandstones and shales make up the formation. Where the series is typically developed the massive sandstone is coarse-grained, more or less cross-bedded, and contains patches of quartz conglomerate and iron concretions. The color ranges from nearly white through various shades of gray, yellow and red to dark brown. It is overlain by a series of shales, sandstone and coal beds, in some places conformably, in other places unconformably. It rests uncomformably upon Mississippian limestones, shales or sandstones. In some localities shaly sandstone and shales immediately overlie the Mississippian rocks. Under such conditions, in the absence of fossils it is not always possible to determine whether these laminated strata are correlative of the Pennsylvanian or whether they belong to the Mississippian series.

The series of rocks above described correspond with the "Millstone Grit" of the early geologists. In the earlier State reports it is commonly referred to as the "conglomerate sandstone" or "conglomerate". In 1895 Hopkins[2] named the series the "Mansfield sandstone". Later Ashley[3] in his report on the Coal Deposits of Indiana placed the series in what he designated "Division I". He retained the term "Mansfield sandstone" to designate the massive bed or beds of sandstone in the formation.

[1]Hopkins, T. C. The Carboniferous Sandstones of Western Indiana. Twentieth Ann. Rep. of the Ind. Dept. of Geol. and Nat. Resources, 1895.

[2]Hopkins, T. C. Report previously cited.

[3]Ashley, G. H. Twenty-third Ann. Rept. of the Ind. Dept. of Geol. and Nat. Resources, 1898.

In stratigraphic position the formation corresponds with the Pottsville conglomerate of the Pennsylvanian system.

The general nature of the formation may be shown from the following sections from widely separated areas:

SECTION AT TROY,[1] PERRY COUNTY.

(Only the lower part of the section is given.)

| | Feet. | Inches. |
|---|---|---|
| 23. Coal II (Allegheny) | 3 | 4 |
| 24. Fire-clay | 2 | 0 |
| 25. White sandstone | 3 | 0 |
| 26. Blue sandstone | 13 | 0 |
| 27. Blue shale | 11 | 0 |
| 28. Coal Ia | 0 | 4 |
| 29. White sandstone | 9 | 0 |
| 30. Blue shale | 28 | 0 |
| 31. Coal I | 0 | 2 |
| 32. Limestone (Mississippian) | 1 | 6 |
| Total thickness of "Division I" | 66 | 6 |

GENERALIZED SECTION FOR THE ORANGE COUNTY AND MARTIN COUNTY AREA.[2]

| | Feet. | Inches. |
|---|---|---|
| 11. Coarse sandstone | 14 | 0 |
| 10. Coal | 1 | 0 |
| 9. Coarse sandstone | 35 | 0 |
| 8. Hindostan whetstone | 20 | 0 |
| 7. Coal | 1 | 2 |
| 6. Coarse sandstone and shale | 100 | 0 |
| 5. Upper Kaskaskia limestone (Miss.) | 13 | 0 |
| Total thickness of Pennsylvanian | 161 | 2 |

The lower Pennsylvanian rock in Fountain and Warren counties are principally represented by the massive Mansfield sandstone. Locally coal or shale may occur.

SECTION NEAR THE MOUTH OF SUGAR MILL CREEK,[3] WARREN COUNTY.

| | Feet. |
|---|---|
| 5. Yellow sandstone | 5 |
| 4. Black shale | 3 |
| 3. Gray and yellow striped sandstone | 12 to 15 |
| 2. Brown to black shale containing pockets of coal | 12 |
| 1. Cross bedded sandstone, shale and coal | 12 to 15 |
| Total thickness of section | 50 to 74 |

[1]See Ashley's Report previously cited, p. 1274.

[2]Kindle, E. M. The Whetstone and Grindstone Rocks of Indiana. Twentieth Ann. Rept. of the Ind. Dept. of Geol. and Nat. Resources, 1895.

[3]Hopkins, T. C. Article previously cited, p. 2[illegible]7.

The coal near the base is ten to twelve inches thick.

The Pennsylvanian rocks[1] that occur within the area included in the Bloomington Quadrangle represent in part the Lower Pennsylvania or Ashley's Division I. Geographically they occupy a position somewhat south of the center of the eastern outcrop of the Pennsylvanian in Indiana. The formation as here represented is confined to the higher parts of the hills in the western half of the quadrangle. A few isolated patches of Pennsylvanian strata occur on the higher ridges in the northern part of this area. The formation is best represented in the south and southwestern parts of the quadrangle. The formation in eastern Greene county and southeastern Owen county was indicated on Blatchley's Geologic May of Indiana.[2] The outcrops along the I. C. R. R. in Monroe county were described by Greene.[3] The Monroe county Pennsylvanian does not appear on Blatchley's map.

The formation as here represented is made up for the most part by a series of sandstones and shales, which vary greatly in lithologic features, both vertically and horizontally. Conglomerate was found at but one place. Iron ore is a very prominent constituent of the sandstones, particularly at or near the base. This iron ore layer is often of great importance in determining the Mississippian-Pennsylvanian unconformity. Thin carbonaceous layers are occasionally found and at two localities thin veins of coal outcrop. The massive Mansfield sandstone, so characteristic of a great part of the Lower Pennsylvanian elsewhere in Indiana, occurs in but few places. Where it occurs it seems to be merely a lenticular mass and rapidly changes to thin bedded sandstones and shales. Although it usually occurs near the base of the formation its outcrops are too widely separated to be of much value for stratigraphic purposes.

The formation as a whole has a maximum thickness of about sixty feet. This thickness is attained in the vicinity of the Yoho schoolhouse and about one-fourth mile southeast of Cincinnati. Owing to the heavy cover of soil it is not always possible to separate the Mississippian and Pennsylvanian rocks. The great similarity of the Mississippian sandstones and shales to the overlying Pennsylvanian sandstones and shales makes this problem a still more difficult one.

[1]For the distribution of the Pennsylvanian rocks within the Quadrangle see the Geologic map elsewhere in this Report.

[2]Blatchley, W. S., and others. Geological Map of Indiana, 1903.

[3]Greene, F. C. The Huron Group in Western Monroe and Eastern Greene Counties, Indiana. Proceedings of the Indiana Academy of Science, 1910.

The sandstones that occur interbedded with the shales are usually rather coarse and thin bedded. In many localities, however, they are rather fine grained and heavy bedded. In the latter case they may imperceptibly grade into the Mansfield sandstone. They vary in color from almost white to dark brown, depending on the iron content. They are often cross-bedded and show ripple marks and other evidences of shallow water origin. Those sandstones often undergo great lithologic changes within a short distance. Horizontally they may change from sandstones to sandy shale or clay-shale within a few feet. Vertically the same change may take place within a few inches. The cementing material is usually an oxide of iron. In a few instances the rocks seemed to be composed entirely of quartz. Iron concretions sometimes occur in those rocks, especially in those that contain a high per cent of iron.

Where those sandstones occur in beds of sufficient thickness, uniform structure, and free from iron concretions, they are suitable for building stone. They have been used for foundations, as bridge abutments, for walling cellars, and for various other structural purposes. Those sandstones are usually very readily quarried and dressed. Their durability is shown by their fine state of preservation where used as foundations for buildings erected three quarters of a century ago. The rapid advance in the cost of building material will likely cause those sandstones to come into more general use for such purposes.

The shales or clay-shales interbedded with the sandstone also vary considerably in lithologic characteristics. Usually they are grayish-white to light blue in color; frequently, however, they are of a brownish color. In a few places they are of a reddish color very similar to that of a part of the underlying Mississippian shales. They are usually of a sandy nature. Thin layers almost free from sand are occasionally found. Those thin layers are, as a rule, very plastic. About one-fourth mile south of Liberty Church is a layer of kaolin which was used for making a cheap grade of stoneware a number of years ago. As stated in the description of the sandstone, those shales frequently change into sandstone within short distances, both horizontally and vertically. Their economic value is slight. There are a few deposits that might be of local value for brick making.

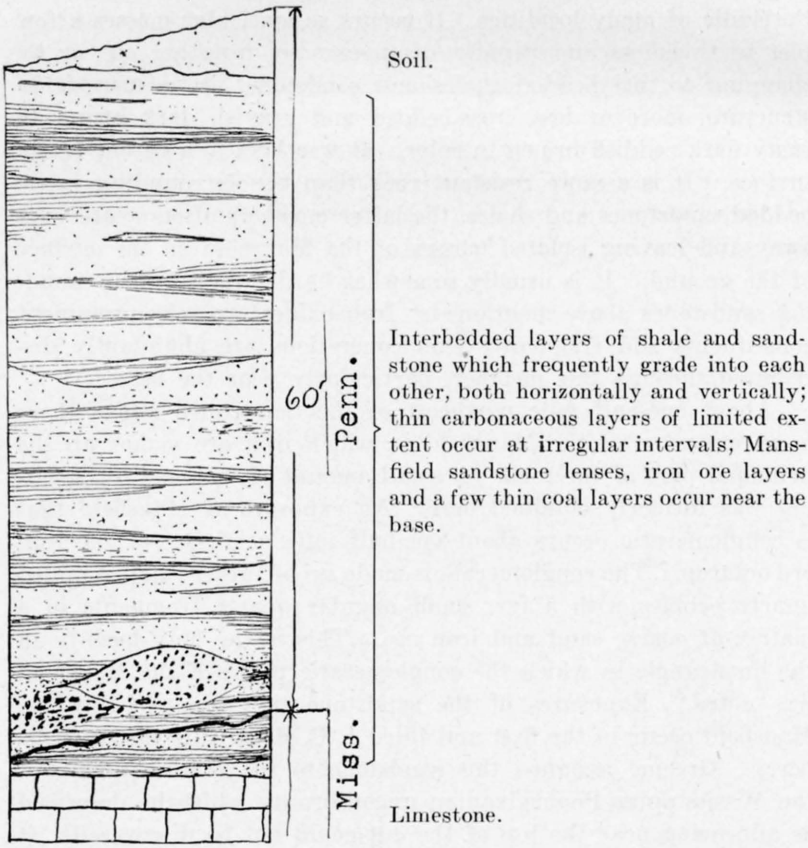
The typical Mansfield sandstone as before stated, occurs at but few localties. The conditions of deposition during Pennsylvanian time appear to have been of such a nature that a succession of interbedded sandstone and shales were laid down in most places in place of the massive sandstone member so characteristic of the Pottsville of many localities. It occurs as lenticular masses a few feet in thickness and rapidly disappears by pinching out or by changing to interbedded shales and sandstone. It is massive in structure, more or less cross-bedded and grayish dark brown to rusty dark reddish brown in color. It weathers to a rather rough surface. It is a more resistant rock than the surrounding interbedded sandstones and shales, the latter members often weathering away and leaving isolated masses of the Mansfield on the surface of the ground. It is usually somewhat harder than the surrounding sandstones above mentioned. Iron oxides are very prominent constituents and frequently iron concretions are abundantly distributed through this member, particularly near the base.

About one-half mile northeast of the Sandbourn school there is an exposure of the Mansfield in which iron ore makes up the principal part of the rock. A small amount of iron ore for smelting was formerly obtained here. An exposure of Mansfield that is conglomeratic occurs about one-half mile northeast of the iron ore outcrop. The conglomerate is made up of rather small rounded quartz pebbles with a few small angular quartz fragments in a matrix of coarse sand and iron ore. This is the only locality in the quadrangle in which the conglomeratic phase of the Mansfield was noted. Exposures of the sandstone that are probably the Mansfield occur in the first and third I. C. R. R. cuts east of Solsberry. Greene[1] assigned this sandstone to the Mississippian but the Mississippian-Pennsylvanian unconformity which he described as appearing near the top of the cut could not be discovered. It is probable that the unconformity occurs beneath the cut and is concealed. Exposures of Mansfield also occur along the west side of the road about one-half mile north of the Yoho School and along the creek bank about one-half mile east of it. At those two localities the sandstone occurs as huge blocks three to five feet in thickness, on top of the ground.

Carbonaceous layers varying in thickness from a thin streak to a few inches in thickness are found here and there in the sandstone-shale part of the formation. None of these layers appear to have a very wide horizontal distribution.

[1]Greene, F. C. Paper previously cited.

GENERALIZED SECTION OF THE PENNSYLVANIAN FORMATION FOR THE BLOOMINGTON QUADRANGLE.




From the nature of the members of the formation and their relation to each other it is inferred that they were laid down principally as a discontinuous, shallow water deposit. It is very probable that the formation was deposited principally in stream valleys in the eroded Mississippian land surface. This would account for the rapid lithologic changes in the sandstone-shale part of the formation and for the occasional occurrence of the Mansfield sandstone which could have been deposited at the mouths of the tributaries of the smaller streams. The absence of marine fossils except at Cincinnati in the extreme southwestern part of the quadrangle would seem to confirm this view. If such conditions prevailed during the deposition of the formation it is not likely that its original eastward extension was very far from that of the present outcrop.

Fossil plants of Pottsville age were found in a number of places in the southwestern part of the quadrangle. Collections were made from a shale bed about one-fourth mile south of the Yoho School and from a sandstone-iron ore layer one-fourth mile southeast of Cincinnati. An examination of those fossils has shown that the Pennsylvanian formation here represents an horizon as old or older, than the Sharon coal of northwestern Ohio, i. e., the lower part of the Upper Pottsville.

# The Utilization of the Waste Stone.

By G. C. Mance.

The largest industries of the country have all been developed by improved methods of the utilization of waste. The success of the Standard Oil Company and the meat packing industries is directly traceable to their close utilization of the waste products of their business. The stone industry has been one of the most backward of all industries in its use of the waste stone that results from the operation of quarry and mill.

During the operations of quarrying, the loss of stone will reach from 30 per cent. to 50 per cent. of the solid cut, and one operator who was working a quarry where there was no adequate covering over the building stone layer estimated that as high as 60 per cent. of the solid cut of his quarry was wasted. The quarry in which 70 per cent. of the solid cut can be put on the market is an exceptionally good quarry. The probable average of waste for the whole quarry district is 38 per cent. to 45 per cent. of the solid measure.

The causes of this great amount of waste stone are many, but the most important may be grouped under the following heads:

(1) The texture of the stone.
(2) Mud seams and joints.
(3) The character and amount of the overburden.
(4) Irregularities in the stone.
(5) Crackings in the stone due to geological causes.
(6) Carelessness in the handling of the stone in the quarry.
(7) Variations in the color of the stone.

The general texture of the stone is granular and a wide variation in the coarseness of the grading may occur even in a single quarry. This variation may appear in the different beds or even in different parts of the same bed. The stone of too coarse texture has to be discarded, as there is no demand for the coarse-grained stone in the trade, and when the graining of the stone is very fine it may be harder and more difficult to work. The medium-grained stone is consequently the most desirable and gives a larger profit to the quarryman. In many places the stone contains small crystals of calcite, and when these crystals are numerous they produce what is known as "glass seams". When these occur the stone is usually rejected. The presence of any large fossils also causes the rejection of the stone.

When the stone in the quarry has been covered by nothing but the loose material resulting from the disintegration of the upper part of the formation, the stone will be traversed by a number of deep mud seams ranging up to ten feet wide and twenty-five feet deep. These seams are the result of the action of water which enters the ground and, becoming charged with the organic acids of the soil and the carbonic acid gases of the air and soil, dissolves the limestone along the natural joints of the rock formation and the connecting material from between the grains for some distance into the blocks. These seams may be developed in either direction, depending on the direction of the surface drainage at the point. In many of the quarries where the surface drainage has been at an angle with both sets of seams it will be found that both sets are developed. Most of the quarry openings have been made along the edge of the outcrop of the overlying Mitchell limestone; and the quarry is worked back under the Mitchell stone. In such cases the seams will be less developed and the thicker the overburden the fewer will be the number of mud seams and the less open will they be. All stone formations contain joints but the stone of this district is especially free from them and large blocks can be quarried in many of the quarries.

The overburden in the quarry is usually a few feet of loose material resulting from the disintegration of the rock strata at that point, and the overlying limestone of the Mitchell formation. When this limestone layer is lacking the amount of waste due to weathering of the building stone layer is greatly increased, and in fact the amount of waste resulting from the fact that the stone has no good cover makes it unprofitable to operate such a quarry. The result of thick stripping of the underlying stone is very noticeable in such quarries as the old P. M. and B. quarry operated by the Indiana Quarries Company and the George Doyle quarry in Dark Hollow, where upwards of thirty feet of Mitchell limestone is removed. In these quarries the seams are hardly noticeable and none of the joints have been opened and filled with mud, as is the case in many quarries where little stripping is necessary.

In many of the quarries there occur structural irregularities known as stylolites, usually called "crows feet" or "toe nails". These irregularities are the only representatives of bedding planes or horizontal joints. They usually are responsible for the loss of from three to six feet of stone on either side of the seam.

In at least three of the quarries the stone shows a tendency to split up in irregular blocks as soon as quarried and this splitting results in the loss of many valuable blocks of stone. The cracks seem to be present in the stone before it is quarried, but do not open until the stone is removed from its bed. This condition probably results from geological movements within the earth and the resulting stresses set up cause the stone to crack or at least develop lines of weakness. In one quarry all these cracks were in a horizontal plane and may have been caused by a settling of the formation as a result of the removal of the underlying beds, since the trouble existed only along the edge of a hill, and the cracks decreased in extent as the operations were carried farther into the hill.

The present methods of handling stone in the quarry result in much waste that could be avoided. Most of the operations in the quarry are performed by unskilled labor, as the quarry work is less desirable than the mill work. As a result the quarry laborer is underpaid and careless. The channeler, drill and scabbling machines each causes some waste and if the work is not well done the irregular breaking of the blocks will represent another great source of waste.

The Oolitic limestone is of two shades of color, known to the trade as "buff" and "blue" stone. The difference is caused by a chemical change in the small amount of iron compounds present in the stone. The original color of all the stone was blue, but the oxidation of the iron, which was present, originally, in the form of ferrous compounds, into ferric compounds, has caused the blue shade to turn to a light grey or greyish brown, known as buff stone. When the quarry block is entirely buff or entirely blue, it can be sold at full price; but the line of separation between the buff and blue stone is usually very irregular, and consequently there are blocks in which the colors are both present, with the result that this mixed stone has to be sold at a much lower price, some of it being rejected altogether. There is a growing tendency in the stone trade to disregard the difference in color of the stone, for the stone will take on a uniform color after a longer or shorter period of exposure to the atmosphere. In fact if a block of blue stone be exposed to the sunlight and atmosphere for a month it is difficult to tell whether it was originally buff or blue without chipping into it. A building made of the mixed stone although presenting a peculiar appearance at first will soon become uniform in color and the fact that it was mixed stone will be difficult for even a stone expert to decide. A building made entirely of blue stone will slowly change to the same color as a building of buff stone, so that the grading of the stone on this basis is unnecessary if the trade were educated up to this fact.

In the mills less waste occurs, but even here the amount sometimes reaches as much as 20 per cent. of the weight of the quarry block purchased. Estimates by the different mill operators place the amount all the way from 8 per cent. to 22 per cent., but Mr. Hunter, superintendent of the Oolitic Stone Mill of Bloomington, has figures of actual weights of rough stone shipped in and the sawed stone shipped out which show that fully 20 per cent. of the quarry block is wasted at the mill. This percentage of waste increases with each additional operation that the stone undergoes and in the case of decorative work is far more than the above figure. This waste is greatest where planer and lathe work is done and where the stone is turned out as columns.

Since a conservative estimate of the quarry waste would be 40 per cent. and the same estimate at the mill could be placed at 17 per cent. the part of the stone finally reaching the building trade is about 50 per cent. of the amount of the solid cut. The 1912 report of the United States Geological Survey on Mineral Resources places the output of the Southern Indiana Quarry District at 10,442,304 cubic feet and at the rate of waste given above the waste of the district must be close to ten million cubic feet of stone per year. Of this vast waste pile at present about 18,000 cubic feet is turned out as crushed limestone and about 8,500 cubic feet is made into lime, and allowing that as much more is sold for other purposes it will be readily seen that the present utilization of the waste stone amounts to nothing as compared to the amount produced. To this vast accumulation of any year must be added the amount of waste that has been in process for the last twenty-five years of active operation of the quarries of this locality.

The present method of disposal is to dump the waste stone into the old workings or give it to the railroads for hauling it away. In fact such a large amount of waste has accumulated at some of the quarries that the disposal of the present waste is a problem, and in many cases waste heaps of other years have to be removed so that new floors may be opened. The present method is to pile the waste in large piles at the sides of the opening by means of a derrick. When the floor is to be extended to the point where the waste pile is located, the pile must be moved to make room, and is usually thrown back into the worked-out floor. Since most of the quarries are located on the hillside a better method of disposal and one which would not interfere with the later recovery of the stone would be the use of cable ways and overhead cars for running the discarded blocks to a place well removed from the quarry and to a point where there was no available stone to be covered.

The usual price of the waste stone loaded on the cars at the quarry is fifteen cents per ton, this price being paid by the limestone and lime plants of the district. The charge of the railroad for moving cars in the stone belt when the product is to be rehandled is $2 per car, so that the product at a central point would cost about 20 cents per ton, but this is not a fair estimate, as almost any of the quarries or mills would contract to give away their waste if the contracting company would promise to take care of the entire output of waste stone.

The waste stone or at least a part of it might be taken care of by some one or more of the following methods:

(1) More careful grading of the stone and the use of a large amount of the rejected blocks in rougher buildings.

(2) The production of ground limestone for fertilizer and for use in the manufacture of glass.

(3) The production of lime.

(4) The production of Portland cement.

(5) The production of crushed stone for road metal and flux in the steel industry and for crushed rock concrete.

In the case of the last four uses mentioned the Mitchell limestone of the stripping would be just as useful as the waste oolite stone, and in the case of road metal and crushed rock concrete it would on account of its greater hardness be better than the softer oolite stone. The cost of stripping could be entirely offset by the use of the stone in any of the last four ways mentioned.

The amount of waste that could be utilized for these purposes would be increased by the amount of Mitchell limestone taken off as stripping and the ultilization of this stone would make profitable the operation of quarries which have been abandoned on account of the high cost of stripping this stone.

*Stone Grading.*—The present methods of grading stone are very unsatisfactory as there are no hard and fast rules to follow and the selection of the different grades of stone is left to each individual quarryman. This allows a wide variation in what is called "A1" stone, for what one quarryman having a good quarry will call second grade stone will be the same grade of stone that another operator will be putting on the market as "A1".

If a selection is to be made on the basis of graining or color alone there will be about as many grades of stone as there are quarries in the district. The result is that bids are made on the basis of a single sample, and since the quarrymen are in the habit of sending out as samples selected stone they are in most cases unable to furnish any large amount of stone that is truly up to the sample submitted. This causes a tendency on the part of the builders to be altogether too stringent in their specifications and much dissatisfaction results. The stone trade would be much benefited if every operator would exercise more care in the selection of his samples. It would be a benefit if the present method could be done away with and a single grade of stone be made.

In other words if all the stone could be sold for a single grade, it could be put out at a higher price than is now charged for the lower grades and the larger output would give a greater profit. The following table gives in general the grades recognized and the average prices paid for each grade.

QUARRY BLOCKS.

| | |
|---|---|
| "A1" Buff | $0 25 per cubic foot. |
| "A1" Blue, fine grained | 25 per cubic foot. |
| Trade Buff | 20 per cubic foot. |
| Trade Blue | 20 per cubic foot. |
| Mixed stone, part buff and part blue | 13 per cubic foot. |

To these prices must be added five cents per cubic foot if the blocks are scabbled. The higher grades of stone are the ones sent to long distances, the New York market especially demanding the best grade.

Every mill operation the stone undergoes increases its price. The cost of some of the simpler operations is as follows:

| | |
|---|---|
| Sawing on two sides | $0 15 per cubic foot. |
| Sawing on four sides | 30 per cubic foot. |
| Sawing on six sides | 45 per cubic foot. |

Planing: Charge made according to the surface area planed and the shape and weight of the stone.

The above figures were kindly submitted by Mr. Johnson of the Chicago and Bloomington Stone Co., and Mr. Freese of the National Stone Co.

During the earlier years of the stone industry in the Southern

Indiana Stone Belt only the finer grades of stone were made use of and large quantities of quarry blocks were discarded as waste. At the present time these are utilized more and more but there is still a large amount of stone piled on the waste heaps that could be used if the selection of the stone were carried on more carefully.

It has been suggested that a large amount of the waste quarry blocks and even a large amount of the waste of the mills could be utilized if a machine for cutting the stone in small sizes say brick size or cement block size could be perfected. It seems possible that an arrangement of small circular saws could be made that would turn out this stone in small rectangular blocks, and a demand be created for their use in cheaper buildings. In fact a very cheap product could be put on the market in this way and its development would assist materially in the solution of the waste stone problem.

Another way in which much of the rougher block stone could be utilized is by the use of the poorer grades of stone in the upper parts of buildings. The wearing and lasting qualities of this stone are equal to that of the better grades and the only reason for its rejection is the fact that its appearance is not as attractive as that of the better grades. If the lower parts of the building were finished in the fine grades of stone and the higher stories were made of the poorer grades the cost of the building would be materially lessened without a lowering of durability, or any impairment of appearance. No person at the street level can distinguish the grade of stone used in the second story of a building.

In the following paper I will attempt to show the economic value of the waste stone as a means of fertilizing acid soils and as a flux in the manufacture of glass. These two industries are growing rapidly and should offer a broad field for the disposal of much of the accumulating waste heaps.

# Utilization of By-Products of Oolitic Limestone.

By G. C. MANCE.

## GROUND LIMESTONE.

This paper was written as a part of a larger paper which will appear later. The present paper is put out as an advance chapter of the same and the proper acknowledgments will be found accompanying the larger paper. The subject of the paper from which this is taken is: "The Utilization of the Waste Products in the Quarry Industry of Southern Indiana." The report of the United States Geological Survey on Mineral Resources for the year 1912 placed the output of building stone in the Southern Indiana Quarry District as 10,442,304 cubic feet, and since a conservative estimate of the percentage of waste in quarrying would be 40 per cent. at the quarry and at least 10 per cent. more at the mill it would leave almost ten million cubic feet of stone in the form of waste which should be utilized before the industry could be called economically handled.

At the present time about 18,000 cubic feet is turned out as crushed limestone and about 8,500 cubic feet is made into lime. If this quantity is doubled to cover the amount disposed of in other ways the amount of waste disposed of at the present time does not exceed 55,000 cubic feet. From the above figures it will be readily seen that the present utilization of the waste stone amounts to nothing as compared to the amount to be used. To this vast accumulation of any year must be added the amount of waste that has been in process of accumulation for the last twenty-five years of active operation of the quarries of this locality.

In addition to showing a method of waste stone utilization I have attempted to show the farmers of the State the value of the stone as a means of soil betterment and thus create a market for the product as soon as an effort is made to place the product on sale.

### GROUND LIMESTONE.

Trace the history of agriculture back as far as possible and you will find that man has been familiar with the use of calcium compounds in the treatment of certain soils which had failed to produce their usual crops. The Roman farmer dug marl to treat his fields with before he planted them, and whether he originated the practice or whether the idea was handed down to him by some earlier agricultural people is still a matter of doubt. Nor were the Romans the only people of that early date that practiced the liming of their land when the soil failed to produce. The custom has been followed in China for long ages, only here it was muck dressing that was in practice, but since the beneficial part of the muck was its calcium carbonate content, the process was the same.

We have records to show that the farmers of England have made the practice of spreading chalk or marl on their soils for nearly two centuries and we are also in possession of the observations made on the results produced. Dr. C. G. Hopkins in his work "Soil Fertility and Permanent Agriculture", says: "An English record of 1795 mentions the prevailing practice of sinking pits for the purpose of chalking the surrounding land. At the famous Rothansted Experiment Station it has been found that the fields that had received a liberal application of this natural limestone a century ago are still moderately productive while certain fiields remote from the chalk pits which show no evidence of such application are extremely unproductive." There is no early record that the easily pulverized limestones and marls were burned to improve their fertilizing value. The burning of limestone to quick lime was probably first practiced with the idea of finding an easy method of pulverizing the resistant rocks so that they could be successfully applied to the soil. The treatment of soils with ashes may also have been in part responsible for the idea of burning the limestone before using it.

The early farmers of England as might be expected, appear to be the first to make use of the chalk on the soil to increase its productivity. This is easily explained by the great deposits of chalk outcropping in the southern counties. That the generous applications of calcium carbonate bearing compounds were of value to the lands and were concerned in their increased productivity is shown by the fact that the limed fields are still distinguishable.

Following a rather extended use of lime and calcium bearing compound on the soil there was a long period during which time the use of lime fell into disrepute. The cause of this disfavor was that the use of quicklime had become more general than the use of chalk or limestone and this dressing had been used in too large quantities. In fact we are only now coming back to the use of this helpful form of soil dressing. Some works on agriculture written as late as the early eighties are inclined to treat the use of lime on the land as an unnecessary waste of time and money. This attitude resulted from the fact that the chemical actions connected with the transfer of nitrogen from the atmosphere to the soil was not thoroughly understood. F. H. Storer, Professor of Chemistry in Harvard University, writing on agriculture in the late eighties says, "Many of the landlords of the present day absolutely forbid the use of lime on their lands." An old German proverb is quoted as follows by Professor Hopkins: "Kalk macht die Vater reich, aber die Sohne arm." (Lime makes the father rich, but the son poor.)

Probably no field of endeavor in scientific research did more to show the value of lime on land than the study leading up to the discovery of the bacteria which have the power of changing the nitrogen of the air to nitrates or as commonly spoken of as the fixation of nitrogen.

The average composition of the air by volume is often given as follows:

| | |
|---|---|
| Oxygen | 20.61 |
| Nitrogen | 77.94 |
| Carbon dioxide | .05 |
| Aqueous vapor and other gases | 1.40 |

Of these constituents, plants need all for their proper growth and development. But one of the strange phenomena of nature is the fact that while plants can appropriate the oxygen and carbon dioxide direct from the air, the nitrogen is not directly available although it constitutes over three-fourths of the whole atmosphere. It has long been known that in some peculiar way the nitrogen of the air was, on some kinds of soils and with some crops, finally transformed to an available form, but the process was a closed book. Later science has shown that certain soils and the roots of certain plants formed the home of small bacteria or organisms which had the power to take up the nitrogen of the air and give it up in the form of nitrates to the soil. In this form it is known to be one of the most needed plant foods. Along with these discoveries it became known that these organisms thrived better in normal or slightly alkaline soils, and when a soil became markedly "sour" or when acid was present their development was arrested, and in fact a point was quickly reached where they failed to live. The scientists developed the fact that these microscopic organisms commonly lived in tubercles upon the roots of members of the family of plants commonly known as legumes (clover, peas, soy-beans, cow-peas, etc.). These tubercles can be easily seen on the roots of these plants, varying in size with the different kinds of plants, but the organisms are far too small to be visible to the naked eye. As the nitrates are formed they are drawn upon by the plant for its own food, but when the crops are harvested and the roots remain behind, or when the crop is ploughed over, the nitrates remain in the soil and increase its fertility. The reason for the use of lime or limestone upon the land is for the purpose of neutralizing the acids that may be present in the soil. These acids are always present to a greater or less degree as they result from the decay of any form of organic matter. The most common form of acid present in soils includes carbonic acid, nitric acid, as well as the various organic acds as lactic acid, acetic acid, etc. The reaction between these acids and a base or basic salt gives a salt and leaves the soil free of acid. To supply this base, quicklime is often used, but it is now known that ground limestone will do as well in reducing the acidity of the soil and is far less destructive to the organic matter contained in the soil.

The burning of limestone into lime is a process of driving off the carbon dioxide contained in the calcium carbonate of which the limestone is formed and takes place according to the following reaction:

$$CaCO_3 = CaO + CO_2$$

In other words the calcium carbonate is broken up into calcium oxide which is the quicklime and carbon dioxide which is driven off as a gas. The calcium oxide thus formed reacts with the waters of the soil when it is applied and slacked lime of calcium hydroxide is formed according to the following reaction:

$$CaO + H_2O = Ca(OH)_2$$

when this water slacked lime comes in contact with the air it tends to take up carbon dioxide from the air and changes back to calcium carbonate of which the limestone was originally composed. The reaction takes place as follows:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

In addition to the fact that the crushed limestone is as effective as lime on soil, since both do the same work through the same chemical reactions, the lime is far more destructive to the organic matter that might be present in the soil. The use of crushed limestone is accompanied by less inconvenience than the use of lime, as the latter is injurious to the skin and must be handled with care. The burned lime in addition to being a powerful chemical agent in the destruction of organic matter tends to increase the solubility of the phosphorus and potassium in the soil. Although this may give larger crops at the time of dressing the soil it tends to cause a rapid improverishment of the field. Since the main object in the use of lime or limestone on land is to correct the acidity of the soil and thereby increase the amount of nitrates present, the use of ground limestone is just as effective as lime dressing and less expensive. Where the soil is especially rich in organic matter, as in the case of peaty and other swamp soils, the lime is probably the better dressing as the soil can spare a large amount of organic matter without becoming impoverished. There are types of soil also that contain large amounts of phosphorus and potassium which become available very slowly and in such cases the lime will hasten the liberation of these necessary plant foods. Professor Hopkins says, "Of course the landowner must be governed somewhat by the cost of material. As a rule fine-ground limestone will be both the best and most economical form of lime to use, wherever it can be easily obtained. If caustic lime is used we should make special provision to maintain the humus in the soil by making even larger use of farm manure, legume crops and green manures. It might be expected that burned lime would produce a greater increase in the crops for the first year or two than would be produced by ground limestone, more especially where the mineral elements, phosphorus and potassium, are not applied; for ground limestone produces only the milder action, chiefly of correcting the acidity of the soil and thus encouraging the multiplication and activity of the nitrogen-gathering and nitrifying bacteria; whereas the burned lime not only produces this same effect, but it also acts as powerful soil stimulant, or soil destroyer, attacking and destroying the organic matter and thus liberating plant food from the soil, usually resulting in more or less waste of valuable nitrogen and humus."

There are at least ten chemical elements to the life and growth of plants that are essential: (1) Oxygen, (2) carbon, (3) hydrogen, (4) potassium, (5) magnesium, (6) calcium, (7) iron, (8) sulphur, (9) phosphorus, (10) nitrogen. The subject of soil fertility in fact can be narrowed down to only two, as all the others can be obtained from the air and almost any soil that can be called in any way normal. These two are the phosphorus and nitrogen. In some cases potassium must be added, but this is the exception. Since the air contains an inexhaustible supply of nitrogen, and by properly controlling the acidity of the soil this vast supply of nitrogen becomes available through the action of the nitrifying bacteria, the problem can be termed one of securing lime or limestone and phosphorus bearing compounds. In the few cases where the element potassium is necessary it can usually be obtained by treating the soil with gypsum, as most all soils contain more or less clay or waste from feldspathic rocks and this contains the necessary potassium, and the calcium of the gypsum will slowly replace the potassium in the clay, giving potassium sulphate which is an available form of this element.

The farmer of Indiana should no longer waste his earnings on prepared fertilizers, as it is time that he learned what was necessary in a fertilizer and prepared it himself for the soil on which it is to be used. Prepared fertilizers must contain the necessary elements for a number of different soils and thus the farmer who purchases them must purchase a large amount of material which can not possibly be of use on his soils. An attempt should be made to educate the farmer to a point where he will be able to determine what fertilizers his soils need and from this knowledge buy the raw materials and mix his own fertilizer. The State of New York maintains a bureau of soils for the testing of soils of the State, and any farmer who cares to submit a sample of his soil can have it tested free of charge and with the analysis he receives advice as to the kind and amount of fertilizer to use in the treatment of his land. This State could find no more efficient means of helping her agricultural population than to maintain a bureau where free analysis and advice could be obtained. This idea has lately been taken up by a number of States, and in the future every large commonwealth will furnish free of charge all the scientific aid possible. The physical effects of the use of ground limestone on different soils are very peculiar. When the ground limestone is added to a clay soil it makes the soil more mellow. In fact the richer a soil is in limestone the more readily the soil crumbles and the more readily the rain can percolate through it. The cause of the compactness of a clay soil is that such soils are composed of very small particles which fit very closely together and water passes between these particles with difficulty, but when the limestone is added the lime cements a number of these small particles together to form a much larger granule, and as these granules increase in size the spaces between the granules increase also in size. When once thoroughly dressed with crushed limestone a clay soil will remain in a friable condition for a number of years and the effects pass away very slowly. On the other hand when a sandy soil is dressed with ground limestone the soil becomes more compact and has a greater ability to retain moisture. The particles of the sand on being cemented together by the limestone as it dissolves, causes the soil to become more compact and the soil is thus given an increased ability to hold water. This effect of ground limestone is readily shown by the appearance of the soil after a long drought. On fields that have been treated with the limestone the soil is markedly more moist than the fields not treated. This is well shown by a series of experiments which have been carried on by Mr. Perry Blackburn on his farm near Oolitic, Indiana, during the last two years. The writer visited the farm early in June after that section of country had undergone a severe drought and examined a field which had received a partial dressing of rather coarse limestone early in the spring. The line of division between the dressed part of the field and the portion which had received no limestone was marked, as the accompanying picture will show. The clover on the part of the field that received the limestone dressing was on an average six inches taller, the roots were on an average four inches longer and the soil markedly more moist than on the portion which had been left without the dressing. In the picture it will be seen that the part of the field on the right which received no limestone is hardly covered by the crop and the clover present is short and undeveloped, while on the left where the limestone dressing was applied the clover is much thicker, taller and more advanced in its growth.

The statements of those interested in commercial fertilizers that lime and limestone are not fertilizers have tended to keep many farmers from the use of these soil correctives. In the direct use of the word, limestone is not a fertilizer as it does not contain any one of the three essential plant foods, phosphorus, nitrogen or potassium. Such materials which act in a secondary sense have been called by Professor Vivian, in his work "The fundamentals of soil fertility", soil amendments. The chief value of these amendments lies in their ability to correct conditions in the soil that keep plant foods from becoming available. The condition most easily observed and the most widespread is soil acidity which causes the death of the nitrifying bacteria. Probably no one man has done more toward the development of the theory of raw fertilizers than Professor C. G. Hopkins, and the result of his experiments in the use of ground limestone and ground rock phosphate leave no doubt that the grinding of limestone and rock phosphate will soon be a great economic industry. The results of these experiments are published in pamphlet form and can be obtained from the Illinois Experiment Station. The results of these experiments will be outlined in this connection for the benefit of those who would be unable to obtain these circulars:

"In November, 1903, a farm of about 300 acres was purchased at less than $20 per acre. It was abandoned prairie land which was thought to be almost worthless, but by the scientific employment of a small quantity of farm manure and ground rock fertilizers, it was brought to a point where the yield of wheat on a 40 acre field was 35½ bushels. During the ten years that the experiment was in progress a six-year rotation system was used, one year each of corn, oats, and wheat, and three years of meadow and pasture with clover and timothy. During the ten years two applications of two tons per acre of ground limestone and two applications of one ton each of ground rock phosphate were made. These applications of fertilizer occupied twelve years and cost $18 per acre or a cost of $1.50 per acre per year and this outlay resulted in an increase of 24 bushels per acre more than the amount that was raised on an adjoining strip of land with liberal applications of farm manure. The differences in the clover were even more marked than the differences in the wheat crops. The following is given as the best directions for the southern counties of Illinois, and most of the southern part of Indiana closely resembles Illinois in the condition of the soils. The directions are as follows: First apply two to five tons per acre of ground limestone. Second, grow clover or cow-peas. Third, apply from 1,000 to 2,000 pounds per acre of very finely ground natural rock phosphate, to be plowed under with the clover or cow-peas. During late 318 tests to determine the effect of lime or ground limestone on crop yields in southern Illinois were made. These included 79 tests on legumes (clover, cow-peas, and soy-beans), 122 tests on corn, 55 tests on oats and 62 tests on wheat, these crops being grown in the rotations practiced. As an average of all tests the yield per acre was increased by one-half ton of hay, 5 bushels of corn, by 6.6 bushels of oats, by four bushels of wheat. The data at hand and here reported are amply sufficient to justify the conclusion that, in practice economy systems of farming on the common prairie and timber soils of southern Illinois, limestone at less than $1.00 per acre per year, will produce twelve tons more of clover or cowpea hay, five bushels more corn, six bushels more of oats and four bushels more wheat than would otherwise be obtained. The only reason that the same statistics are not available for the soils of Indiana is the fact that the farmer has been too much inclined to let well enough alone and practice the system of farming followed by his father before him. He must realize that economic conditions have changed and what would bring success on the virgin forest soils of a century ago will lead to disaster at the present time."

Probably no better and more convincing data can be furnished at the present time than the following taken from the work of Prof. Hopkins in Circular No. 157 on Soil Fertility. He says:

"As an average of the first two years' work on two different experiment fields (Ewing and Raleigh) where the initial application was five tons per acre, the average increases were one-fourth ton of hay, nine and one-fourth bushels of corn, eight and nine-tenths bushels of oats and three and one-half bushels of wheat; and, as the increased farm manure or increased crop resources from these larger crops are returned to the land, the effect becomes more marked in subsequent years. On the Vienna experiment field in Johnson County about nine tons per acre of ground limestone were applied ten years ago. At a cost of $1.25 a ton, this amounted to $11.25 and the returns for this investment have thus far amounted to 90.3 bushels of corn, or to 42.2 bushels of wheat, or to three and one-third tons of clover hay. Any one of these will pay for the limestone three times over; and, in addition, two-thirds of the legume crops have been plowed under as green manure, and at the end of nine years, with no farther application, the land treated with limestone is producing five bushels more wheat, nine and three-tenths bushels more of corn and one and four-tenths tons more hay per acre than the land not so treated. Indeed, as an average of the last two years, this old worn hill land has produced larger crops where limestone had been applied than the average yield for the State for each of the crops, corn, wheat and hay."

As this paper is not supposed to go deeply into the agricultural phases of the limestone as a fertilizer, except to show what a broad market could be opened up by a proper process of education for the farmer, an outline of the kinds of soil that need this dressing with their distribution will be all that will be attempted in this connection but the work is ready and the field for experiment is broad and must be covered before we can say we know the possibilities of raw fertilizers and the principles that govern the use of them.

## What Soils Need Limestone Dressing.

The idea that, since the soils of much of Monroe and Lawrence counties are on the limestones and in fact are residual soils from decomposition of limestones, they do not need limestone dressing, is responsible for the fact that the farmers of these counties have allowed these vast deposits to go untouched. In fact the operator of the only crushing plant in the district says he has sold less than a car load of crushed stone in these two counties since opening his plant over a year ago. No idea could be farther from the truth. Limestone while only slightly soluble in pure water is dissolved very rapidly in water containing only a small part of some acids, and even carbon dioxide in solution (carbonic acid gas) will dissolve it to a great extent. Through the long ages that these soils have been exposed to the leaching action of the rain waters, together with the acids formed by the organic remains present, there has been a steady loss of the calcium carbonate present and an increase of the amount of acids in the soils. The fact remains that there are no soils in the entire State that are any more acid than many of the hillsides of the southern Indiana driftless area. Probably the best indication of the effect of crushed limestone upon these soils can be seen in the condition of the fields which lie along the roads which have received a surface of limestone. The dust from the roads has been blown over the nearer parts of the fields while but little of it reached the more remote portions. The stand of grass or crops is always better on this portion that has received even this small amount of limestone. Another sample of the effect of limestone on this land can be seen along the stream beds which receive drainage from the hillsides that are underlain by the limestone above the level of the stream as compared to the stream beds farther east where no limestone is close to the surface in the adjacent hillsides.

The amount of acid soils in the entire State represents more than three-fourths of its area. Practically all soils west and south of a line passing along the boundaries of the following counties are strongly acid: the southern boundary of Newton and Jasper counties, the western and southern boundaries of White and Carrol counties, the southern boundary of Howard and Grant counties, the western and southern boundaries of Delaware and Randolph counties. In addition to this area there is a smaller area in the northwestern part of the State including most of Porter, Laporte, Starke, Pulaski, Marshall, St. Joseph and Elkhart counties that are in the same condition as far as soil acidity is concerned.

In addition to these larger areas, there are many smaller areas in the northern and eastern sections of the State that are acid soils. The larger area includes what is known as the driftless area of the southern portion of the State and the Wisconsin glacial lobe. The entire southeastern section of Illinois south of Danville also is acid and might provide a market for crushed limestone from this section if it were not for the fact that this industry has been developed to so high a level in that State and the cost of the product is kept very low by regulation of freight rates and convict labor.

### Test for Soil Acidity.

Every farmer can easily make his own tests and satisfy himself as to the acidity of his soil, without skilled advice. One of the best and easiest methods of testing the acidity of a soil is by what is known as the litmus paper test. The test is carried on in the following manner: Take a fair sample of the soil to be tested (to make an average sample, take a small portion from several points of the field to be tested, mix carefully and reject one-half the pile cut through the middle, mix the remaining half carefully again and repeat the process until only a small portion remains), moisten with pure water and press together upon a small piece of neutral litmus paper. The presence of the acid will cause litmus paper to turn a reddish pink color. Allow a little time for the action to take place. Be careful not to touch the paper with the fingers after it has been moistened as perspiration is acid in reaction and will affect the paper. Another method of applying the test is to scrape away a little surface soil and press the paper to the moist earth revealed. Cover the paper and leave a few minutes. To obtain good results only the best grade of neutral litmus paper must be used. People are often misled in making this test by the direction to use "blue litmus paper which can be bought at a low price at almost any drug store." In fact the ordinary blue litmus paper is not sensitive enough to detect a quantity of acid which would entirely prevent the growth of clovers. Any druggist can procure the best grade of neutral litmus paper at only a slight additional cost. This small extra cost represents the difference between success and failure of the tests. A good crop of clover which stands well and continues its growth throughout the season is a pretty good indication that enough lime is present in the soil for present purposes, but where the clover fails to grow or where it only makes growth part of the season, limestone can be applied with good results.

### Lime or Crushed Limestone.

When a soil is "sour", the acidity may be corrected by either caustic lime or crushed limestone, as both react with the acid of the soil to form salts. The reactions are as follows:

$$CaO\ 2HNO_3 = H_2O\ Ca(NO_3)_2.$$

In other words calcium oxide (quicklime) plus nitric acid equals water and calcium nitrate.

$$CaCO_3\ 2HNO_3 = H_2O + CO_2 + Ca(NO_3)_2.$$

Which means that calcium carbonate (crushed limestone) plus nitric acid equals water, carbondioxide and calcium nitrate the same compound that came from the caustic lime. The function of soil conditioning already mentioned is performed equally well by both, but where they differ is in their effect upon the organic matter present in the soil. Caustic lime is better than ground limestone only when the soil contains an abundance of organic matter or some form of phosphorus which is not readily available. It should always be borne in mind that caustic lime, although giving good results for a year or two, tends in the end to impoverish the soil.

Probably no more convincing experiments have been carried on along the line of the relative values of burned lime and crushed limestone than those of the Pennsylvania and Maryland Experiment Stations. The results of these experiments are summarized in Circular 110 of the University of Illinois as follows: "Four plots were treated with burned lime at the rate of two tons per acre every four years. Four other plots were treated with ground limestone at the rate of two tons per acre every two years. A four year rotation was practiced consisting of corn, oats, wheat, and hay, being mixed timothy and clover, seeded on the wheat land in the spring. Seven products were obtained and weighed each year; namely, corn, corn stover, oats, oats straw, and hay.

After twenty years results had been obtained showing that with every product a greater total yield had been obtained from the plots treated with limestone than from those treated with burned lime. Furthermore, with every product whose total yield for the last eight years was greater than the first eight years limestone produced greater increase than the burned lime, and with every product whose total yield for the last eight years was less than the total yield for the first eight years the decrease was less with the limestone. This demonstrates the tendency of burned lime to exhaust the soil."

The actual figures of the above experiments are, to say the least, startling, and the effect upon the soil shown by careful chemical analysis bears out the statements already made. The nitrogen present in the soil treated with crushed limestone was greater than the amount present in the soil treated with burned lime by an amount equivalent to the amount of nitrogen present in 37½ tons of farm manure. Or represents an equivalent of more than two tons per acre per year of the farm manure. The analysis also showed that the amount present in the second case was in about the same ratio as the amount of nitrogen. This alone should demonstrate that the ground limestone is the proper form of neutralizer as well as being the form provided in nature.

### The Amount of Limestone to Use.

The amount of crushed limestone to use on the soil to correct its acidity depends on a number of things, among them the location of the field (whether hillside or flat land), the amount of acidity, and the fineness of the limestone used. Hillsides lose their lime faster than flat land, but the accumulation of acid is slower than on the flat land. If a rather coarse limestone is used the hillsides will need most limestone. The amount of acidity determines the amount of the limestone that is used up soon after its application and thus determines the amount that will be left in the soil to correct acidity that will occur later. The finer the limestone is ground the quicker will be its action and the quicker it will be used up and dissolved. Thus a ground limestone that contained both coarse and fine ground stone is the best. The larger lumps present may remain several years before entirely dissolved and used on the soil. The best average quantity to use is about two tons per acre every four years unless the soil shows acid tests in the meantime, then increase the number of applications in preference to increasing the amount used. This amount should keep almost any soil "sweet". A large amount of the acidity of the soil comes from the capillarity of the soil, which causes the waters of the soil to rise bringing with them the acids of the subsoil. If the subsoil is very acid the amount of limestone should be increased to destroy it. The time of year for spreading limestone makes little difference but the suggestion of the spring before the spring rains is probably the best.

## Cost of Crushing Limestone.

Cost data on the cost of crushing stone is very difficult to obtain with any degree of accuracy on account of the numbers of factors to be reckoned with, but where a plant is already in operation in the kind of stone to be crushed, the data is more available. Such a plant operating in the Oolitic stone belt is located at Oolitic, Indiana, and the operating company is the Stone Products Company of Bedford, Ind. The superintendent, Mr. E. W. King, kindly furnished the following data on his work.

The plant has been in operation a little over one year and in that time the business has made a steady increase. The demand for the crushed product is growing till the operators are thinking seriously of the feasibility of enlarging the plant to increase its output. The present plant represents an investment of approximately $7,000 and the following figures represent fairly the cost of turning out this product in a mill of this size.

| | |
|---|---|
| Labor at the mill | $0 08 per ton. |
| Total labor charge, including sales | 31 per ton. |
| Power | 06 per ton. |
| Upkeep | 05 per ton. |
| Stone | 15 per ton. |
| General expense | 05 per ton. |
| Total cost per ton for present output | $0 63 per ton. |

With an additional 10 cents per ton added to cover depreciation of machinery the total cost will be 73 cents per ton. And the price charged for the product free on board the cars at Oolitic, Indiana, at present is $1.18 per ton. The present equipment could be made to put out 75 tons per day if the demand was large enough, but at present the output is quite considerably below this figure, as the market has not been worked up to its greatest development as yet. The plant is only equipped with storage bins for ten tons and this hampers the output, but the company has already made plans to enlarge this part of their plant and by so doing a larger amount of the crushed product can be handled. Any increase in the output will not be accompanied by a corresponding increase in the cost of production as the fixed charges on the equipment which represents a large part of the cost of production will not be increased, so the cost of production will decrease with increase of the output. The product is at present sold for agricultural purposes during the summer months and for use in fluxing in the glass industry during the winter.

The machinery in use at the plant consists of a Forster type crusher put out by the McLanahan Machine Company of Hollidaysbury, Pennsylvania. This reduces the stone to inch and onhalf size when it is carried by belt conveyor to a pulverizer where it is reduced to 20 mesh. The crusher according to the statement of the superintendent is not giving satisfaction on account of the high cost of the upkeep and the owners are thinking seriously of installing a gyratory crusher of the Gates type. Power for the machinery is purchased from the Southern Indiana Power Company and the investment mentioned included the cost of wiring and motors.

The stone for the plant is purchased from the mill and is of the smaller sizes so that the crusher can handle them without further breaking. The quarry company furnishes this material free on board the cars at the fifteen cents per ton quoted. The company has a large belt conveyor to carry the waste from a nearby scabbler into the crusher. The preparation of the limestone for fertilizing purposes simply consists of pulverizing the stone until it will pass a certain mesh screen. The size of the largest lumps that will be of value upon land is still an open question, but the general idea is that the larger the lumps the slower the sweetening process takes place and the longer its results can be seen. The stone is usually fed to a large crusher called a breaker and this reduces it to a certain size. The largest piece that will pass a certain ring is the size by which the product is called. It is then fine crushed in some form of pulverizer and screened, the fine product stored while the material too coarse to pass the screen is returned to the pulverizer to be worked over again.

Rock breakers are of three general types depending on the form of their motion.

(1) Jaw breakers, in which the motion of the crushing parts is reciprocating.

(2) Gyratory crushers, in which the motion of the crushing parts is rotary and spiral.

(3) Roll crushers, in which the motion of the crushing parts is rolling.

The jaw breakers are of two types according to whether the greatest movement comes on the smaller lumps fed or on the larger. The first kind are known as the Blake type of crusher and those of the latter kind are known as the Dodge type. Very complete descriptions with sectional drawings of all types can be found in the work of Prof. R. H. Richards of the Massachusetts Institute of Technology, entitled "Ore Dressing."

Gyratory crushers are classified on the same principles as the jaw breakers. The type most widely used and the type that will give the best results in the crushing of limestone for fertilizing material are those known as the Gates or the McCully type of breaker.

The type of rolling crushers is known as the Forster crushers. The jaw crushers are usually selected where the output of the plant is small on account of their small first cost and the fact that the cost of the up-keep depends to a large extent upon the output. The cost of crushing a small quantity per unit of output is in favor of the jaw crusher. In the selection of a jaw crusher great care is necessary on account of the great strain that is necessary to withstand. Some of the following things should be kept in mind when a selection is to be made. Frame should be heavy and cast in as few pieces as possible, foundations should be low and very massive as jar is great. Machine should be low and size of jaws ample for the amount of rock fed. Larger jaws will accommodate larger lumps and the power expended per ton crushed is the same regardless of the size of the crusher. Larger crushers also cost less for up-keep than smaller ones. The average rate of crushing with a crusher of this type working in hard limestone is about eight tons per horse-power per hour of power used, with the output reduced to one inch size. This amout increases rapidly as the output is turned out in larger sizes. Prof. Richards gives the following amounts per horse-power per hour:

Thirteen tons to one and one-half inch size.

Sixteen tons to two inch size.

Nineteen tons to two and one-half inch size.

Twenty-one and one-half tons to three inch size.

Twenty-eight and one-half tons to three and one-half inch size

The cost of preliminary breaking with jaw crushers can be best obtained from the following table taken from Richard's "Ore Dressing."

ESTIMATED COST OF BREAKING WITH A BLAKE TYPE BREAKER.

| | | | | | |
|---|---|---|---|---|---|
| Size of mouth | 10x4 | 10x7 | 15x9 | 20x10 | 30x13 |
| Tons per 24 hours, 2-inch size | 92 | 120 | 192 | 360 | 600 |
| Horse-power | 5 | 8 | 12 | 20 | 40 |
| Cost of breaker | $275 | $500 | $750 | $1,050 | $2,250 |
| Cost in cents per ton for oil | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| Interest and depreciation | 0.097 | 0.135 | 0.127 | 0.095 | 0.122 |
| Power | 0.705 | 0.865 | 0.811 | 0.721 | 0.865 |
| Labor | 4.348 | 3.333 | 2.083 | 1.111 | 0.667 |
| Wear | 0.815 | 0.815 | 0.815 | 0.815 | 0.815 |
| Repairs | 0.462 | 0.462 | 0.463 | 0.462 | 0.462 |
| Total cost per ton crushed | 6.447 | 5.630 | 4.318 | 3.224 | 2.951 |

Machines of this type are more widely used for crushing stone for road metal than in regular crushing plants as they produce less fines than is given by the gyratory crushers of the larger sizes. A jaw breaker uses more power per unit of output than the gyratory crusher on account of the large weight of the reciprocating parts and the fact that they are in the act of crushing only half the time while the action is continuous in the gyratory crusher. The cost list given in the above table was calculated as follows by Prof. Richards:

"Sizes, capacities, power and original costs were taken from the catalog figures of the different companies putting out these machines.

"Oil, costing 35 cents per gallon is estimated to be used at the rate of one quart per 24 hours, on a 30 by 13 inch breaker, breaking 600 tons in 24 hours to a maximum size of 2 inches. The cost per ton is $35 \times \frac{1}{4} \div 600 = 0.015$ cents. The cost per ton for a 10 by 4 inch breaker estimated to use one half pint per 24 hours, breaking 92 tons to 2 inch size is $35 \times 1/16 \div 92 = 0.024$ cents. The average of these two figures is about 0.020 cents.

"Interest and depreciation at 10 per cent. per annum: For a 10 by 4 inch crusher would be $27.50 per year. On a basis of 308 operating days per year and 92 tons being crushed per day, the cost would be $\$27.50 \div (308 \times 92) = 0.097$ cents. Other sizes can be calculated in the same way.

Power is estimated to cost $40.00 per horse-power per year of 308 days or $0.1298 per day. For a 10 by 4 inch breaker using five horse power and breaking 92 tons per day, the cost per ton would be $0.1298 x 5 ÷ 92 = 0.705 cents.

"Labor.—It is assumed that the breaker is fed by a sloping chute and can therefore be fed by one man at a cost of two dollars per 12 hour shift or four dollars per 24 hours. The cost per ton for the 10 by 4 inch machine would be $4.00 ÷ 92 = 4.348 cents. Other sizes to be calculated in like manner.

"Wear is estimated at 0.815 cents per ton, which is the average of the gross cost per ton at 18 mills.

"Repairs other than wearing parts. The maximum figure recalled was $155 per year. These repairs were required by a machine breaking 109 tons per day of 33,572 tons per year of 308 days, making the cost per ton $155.00 ÷ 33,572 or 0.463 cents per ton."

Although this table is taken from average conditions and average hardness of rock, it can be taken as a conservative set of figures for the conditions that exist in the limestone belt of Southern Indiana, and any estimates based on these will be sure to be high enough.

Jaw crushers are on the market in all sizes up to the giant Farrel which is for very coarse breaking to eliminate the necessity of sledging. This machine will handle 350 tons per hour crushed to 16 inch size. Another late improvement in jaw crushers to reduce the rock more in a single machine is the machine known as the "Sturtevant Roll Jaw Crushers". This machine has a grinding as well as crushing effect on the rock and its output is much finer than that of the ordinary crusher.

Gyratory breakers are the standard type for work such as grinding of rock fertilizer where a considerable output is to be handled and the mill is to be kept in continuous action. This type of crusher will be found in all the larger crushing plants such as those operated at cement mills and ore plants. The following table taken from Richard's "Ore Dressing" and recommended as correct by the leading manufacturers of today will give a fair idea of the cost of crushing with crushers of this type. The figures are calculated by the same method as that used in the case of the jaw crushers as shown on an earlier page.

ESTIMATED COST OF BREAKING WITH GYRATORY BREAKERS.

| | | | | |
|---|---|---|---|---|
| Breaker No. | 0 | 2 | 4 | 6 |
| Size of mouth in inches | 4x30 | 6x50 | 8x68 | 12x88 |
| Tons broken in 24 hours | 72 | 228 | 720 | 1,500 |

| | | | | |
|---|---|---|---|---|
| Horse-power | 3 | 8 | 16 | 32.5 |
| Cost of breaker | $375 | $760 | $1,800 | $3,300 |
| Cost in cents per ton for oil | 0.020 | 0.020 | 0.020 | 0.020 |
| Interest and depreciation | 0.169 | 0.108 | 0.081 | 0.071 |
| Power | 0.541 | 0.456 | 0.288 | 0.281 |
| Labor | 5.556 | 1.754 | 0.556 | 0.267 |
| Wear | 0.971 | 0.971 | 0.971 | 0.971 |
| Repairs | 0.308 | 0.308 | 0.308 | 0.308 |
| Total cost per ton | 7.565 | 3.617 | 2.224 | 1.918 |

It will be seen by a comparison of the two tables that as soon as the output passes the 200 ton per day mark it is cheaper to use a gyratory crusher and with the 10 by 4 inch crusher, it is only slightly cheaper than the crusher of the gyratory type of the same output. It must also be remembered that the higher cost has been included in the calculations or at least interest on the larger outlay has been accounted for.

Sturtevant Mill Company of Boston and Farrel and Bacon of New York deal in the jaw breakers, while the Power and Mining Machine Company of Milwaukee, Wisconsin, handle the McCully type of the gyratory crushers. All these companies have furnished figures on the cost of crushing with their especial type of machinery.

Following the coarse crushing the product is fed to some sort of pulverizer. The most common forms in use are what is known as rolls. These are heavy metal cylinders held together by powerful springs or gravity arrangements and are rotated at such high speed that their centrifugal force tends to hold them together and at the time impart a heavy blow to the stone as it passes between them. The closeness of approach of the roll is regulated by shims or compression bolts. The larger the roll the great its capacity since with the same speed of rotation its peripheral velocity is far greater. The cost of rolling 100 tons per 24 hours would be as follows, ten horse-power required: Power, $1.30 cents per ton; attendance, $1.50 cents per ton; wear on rolls, 0.02 to 4.00 cents per ton; repairs, oil, etc., 0.37 to 0.60 cents per ton. Total cost $3.19 to $7.40 per ton would be a good estimate. The above calculation can be found in Richards.

Several special types of machinery are in use for the final reduction of the product after it has passed through the crusher, and probably better results can be obtained from a hammer bar pulverizer or a set of ring rolls than can be secured from the common type of rolls. The hammer bar pulverizer depends upon a blow struck in space to the effect of crushing, the harder the impact the finer will be the product. The mill works on the principle that a weight placed to swing freely on a revolving shaft will stand at right angles to the shaft when the shaft rotates rapidly, and that the faster the rotations of the shaft the harder the blow that can be struck by the weight before it will be forced back. The stone is fed into this machine and struck by the first set of weights and thrown against the retaining case of the machine from which it rebounds in the way of the next set of weights to receive a greater impact due to its own motion as well as the motion of the swinging weight. These mills are rotated at speeds from seven hundred to fifteen hundred revolutions per minute. The lower walls of the mills may be made of cast iron screens so that the pulverized material may escape while the uncrushed stone is carried around again till it is reduced to the size that will pass the screen. The advantage of these mills is that the screening and pulverizing can be done in one machine. One drawback to their use is the large amount of power used to drive them. The cost of pulverizing the output is about 10 cents per ton for 200 tons per day. This figure will be increased for smaller output and decreased for increased output. The high speed of rotation of the machine tends to drive out the crushed product by air pressure, the swinging parts acting as a fan. Many of these machines are coming into use for this work and seem to be giving satisfaction.

The ring roll mill is a mill in which the rollers are placed inside of a ring or cylindrical case and the crushing force comes between these rolls and the inside surface of the mill. The rotation of the ring imparts a motion in the same direction to the rollers, and since they are held firmly to the inside of the ring the material in passing between the ring wall and the roller is brought under great pressure. Much force is applied, due to the centrifugal force of the rotating parts. And this force also keeps the material fed to the outside of the ring and tends to draw it under the rolls. Its great advantage lies in the fact that there are few wearing parts. The mill is very accessible and the speed is slow enough so that there is little vibration and the parts can be so well balanced that elaborate foundations are not necessary. Another advantage is the fact that the consumption of power per unit of output is comparatively small. These machines will handle about one ton per horse-power per hour in limestone crushing. These machines for the larger units are built duplex, that is, two like machines on a single shaft. This has the advantage of less cumbersome parts and less vibration with less cost of repair, as the smaller parts of the two mills cost less than large parts for a large single mill would.

The cost of handling limestone through such a machine from 2 inch size or finer down to pass a 20-mesh screen can be calculated with all investment charges, including interest, depreciation, wear and tear and repairs, to be about 8.455 cents per ton in a plant handling 200 tons per day, and this figure will be decreased with an increase of output and increased with a decrease of the output. The Sturtevant Mill Company are putting these mills on the market and the above figures were taken from their catalogues.

The cost of screening and elevating the crushed stone is a more difficult proposition to calculate, as conditions differ so much in every separate plant that it is almost impossible to give anything but the most approximate calculations. Screens are named from the motion they have as shaking screens or riddles, gyrating, rotating screens or trommels and inclined separators. These do not need defining as the name is self-explanatory. Of these the trommel is the type most used in fertilizing plants, although the Newaygo Separator of the Sturtevant Mill Company which is an inclined separator, is coming rapidly into use. Their chief advantage lies in the small amount of power consumed in vibrating them, the largest sizes taking less than one horse-power. The vibration in this type of screen is imparted to the wire cloth by a number of small hammers while it is held taut. The inclination of the screen allows a coarse wire to be used even when a fine product is desired. In the trommel the material is fed in at one end and the coarse particles pass out of the other end while the fine material passes through the sides. These screens are rotated and slightly inclined, the greater the inclination the finer screening can be done. They use but little power and are rotated from 16 to 20 times per minute. Screening is improved by faster rotation and greater slope, but the decrease in the output of screened material under these conditions is very rapid and the limit is soon reached. Plates with slits are often recommended in place of wire cloth and are more lasting, but the percentage of openings is necessarily less and the screening is slower. The cost of screening will, when all charges are taken into account, be about one cent per ton when the output handled is as before quoted 200 tons per day of limestone to 20 mesh. Another thing to be taken into account when deciding which type of screen to purchase is the size of the machine necessary to do the work. The trommel must necessarily have a larger screening surface than a vibrating screen for only a small portion of its screening area is in use at once while the entire surface of the vibrating can be in operation at one time. The other types of screen can, for this connection, be considered simply as modifications of those already mentioned and need no detailed description.

Elevating the product is necessary in practically every plant unless the location selected was so placed in respect to the slope of a hill that every movement of the product from the machine to the next could be controlled by gravity. Plants where this condition prevails are very few, as such a favorable location would in most cases make the switching of the stone to the plant and its removal from the bins to cars a problem. The most common types of apparatus used in carrying crushed stone material from one point to another is the belt conveyor. In this piece of apparatus a belt is run over wheels arranged to cause the upper surface of the belt to be concave and thus the product will remain on the belt. Rough belts or cleats are sometimes used. The capacity of a belt conveyor is determined by its velocity and width. They are in operation up to 40 inches wide with a speed of 650 feet per minute. Such a belt will handle about 1,220 tons per hour. As the elevation increases an elevator becomes necessary and the bucket elevator is the only one giving satisfaction in this kind of work. They consist of an endless belt running over two pulleys, one above and one below. The buckets are riveted to the belt and act as scoops as they pass through the material and carry a quantity along the belt in each bucket. These are run at speeds up to 400 feet per minute but the slower they are run the longer life they will have and less repairs they will need.

Bins are the one problem that needs to be figured on closely by any company about to start a plant as the capacity of the storage bins limits the running time in case of dull market. Bins are at the best expensive, and if extra large ones are put up, the first cost of the plant is so high as to seriously interfere with the profit of the young venture.

Bins are usually of wood construction and elevated so that the material may be delivered by chutes. They must be roofed and must not be leaky.

To show that even the large manufacturing companies which put out crushing machinery will not give any but approximate figures, we publish the following letter received from one of the leading firms which handles crushing machinery in reply to a letter asking the cost of crushing in certain size plants.

"Dear Sir—The necessary equipment of your plant would include a crusher, set of rolls, screens, elevator, transmission machinery and power, but we can give no figures as to cost till a stated project is laid before us and our engineering department has gone into the matter. If you care to fill out the inclosed blank we will gladly make an estimate."

The blanks returned, the following data was submitted including a plan of a ten ton per hour plant.

"Dear Sir—The machinery required will be as follows together with weights and prices:

| | | |
|---|---|---|
| One crusher, No. 4 | 23,000 lbs. | $1,134 00 |
| One fine crusher | 4,000 lbs. | 1,000 00 |
| One 10x6-inch bucket elevator, 38 feet, 6 inches | 1,700 lbs. | 201 00 |
| One No. 3 screen | 1,600 lbs. | 350 00 |
| Pulleys, five in all | | 90 00 |
| Shaft, boxes and set collars | | 23 00 |
| Belts, four in all | | 55 00 |
| Total cost of plant without buildings and bins | | $2,853 00 |

This figure lacks the freight, cost of installation, and the work of building plant and bins. If the above figures were taken and to them were added the following:

| | |
|---|---|
| Freight | $205 00 |
| Building | 850 00 |
| Installation | 300 00 |
| Bins | 250 00 |
| Total | $4,458 00 |

This would be a fair estimate of a small plant that would handle about 100 tons per day. The power necessary to drive such a plant would be about 40 to 45 horse-power. The cost of crushing in such a plant should not exceed the following figures:

| | |
|---|---|
| Interest and depreciation, 6 and 9 per cent | $668 70 |
| Taxes and insurance, 2 per cent | 89 16 |
| Labor | 2,230 00 |
| Power, at 2 cents per kilowatt hour | 1,848 00 |
| Wear and repairs | 420 00 |
| Oil and waste | 35 00 |
| Total year's operating expense | $5,290 86 |

With a total year's output of 30,800 tons, the cost per ton of the product turned out of the mill will be about 17.5 cents. To this must be added the cost of advertising, and the office and sales force. With these put at thirty cents per ton it still brings the cost of the product well under fifty cents per ton. The accompanying plan of a plant of this size was submitted by the Power Mining and Machine Company of Milwaukee, Wisconsin.

Another firm suggested the use of a jaw crusher and a swing hammer pulverizer, but the cost of the pulverizer made the entire investment a little higher than this estimate.

The following figures on a large plant turning out from 20 to 25 tons per hour would be about as follows: These prices are subject to the discounts given by the firm and are for the material free on board the cars at the manufacturing plant.

| | | |
|---|---|---|
| One steel breaker for heavy duty, set to crush to two-inch size and handling 25 tons per hour: | | |
| Size 10x20 in. Horse-power 18, speed 150 r. p. m., wt. | 12,500 lbs. | $1,407 |
| One No. 2 ring roll mill, horse-power 75, speed 325 r. p. m., wt. | 45,000 lbs. | 8,857 |
| Four separators, each 0479, horse-power 5, wt. | 7,200 lbs. | 1,916 |
| One elevator, horse-power 10, wt. | 2,200 lbs. | 395 |
| Pulleys, belts and supports | | 325 |
| Building and bins, including labor | | 2,000 |
| Freight, foundations and cartage | | 950 |
| Total outlay | | $15,850 |

Fixed charges on this investment would be as follows:

| | |
|---|---|
| Interest at 6 per cent | $951 00 |
| Depreciation at 9 per cent | 1,426 50 |
| Taxes and insurance at 2 per cent | 317 00 |
| Total fixed charges | $2,694 00 |

Operating charges about such a plant would be approximately as follows:

| | |
|---|---|
| Labor, at $2.00 per day | $5,544 00 |
| Power at $40.00 per horse-power per year | 4,320 00 |
| Wear and repairs | 810 00 |
| Oil and waste | 98 00 |
| Total operation expense for one year, 308 days of 10 hours. | $10,772 00 |
| Total yearly output, 77,000 tons. | |

Cost per ton slightly under fourteen cents per ton. To this must be added the fixed charge of about three cents per ton, which brings the cost up to approximately seventeen cents per ton. This figure is plenty high, as the liberal discounts and the fact that the estimates on the other costs are very conservative would tend to reduce the cost in case of a plant being actually built.

The breakers of the type included above are made in capacities from six to forty tons per hour and the prices range from $715 to $2,572. In cases of large output, roll-jaw fine crushers are often used following the breakers before the product is fed to the ring-roll mill. This increases the output of the equipment materially. They range in sizes from one to twelve tons in capacity per hour and cost from $429 up to $2,858. These machines can be used on large size rock without previous crushing. They are slower in action than a breaker.

Ring-roll mills are made to handle output of 40 tons per hour and cost up to $8,857.

Vibrating screens cost from $400 up to $600 according to the fineness of the product desired. Their capacity ranges around six tons per hour for limestone grinding to 20 mesh.

The estimate of one of the leading firms on the cost of wear and up-keep on the machinery of a limestone crushing plant is one-fourth of a cent per ton for the material turned out. This cost is divided up as follows:

| | | |
|---|---|---|
| Total, including belts, etc. | 1/5 | cents per ton. |
| Ring roll mill | 8/100 | cents per ton. |
| Elevator | 7/1000 | cents per ton. |
| Screens | 5/100 | cents per ton. |
| Total, including belts, etc. | 1/5 | cents per ton. |

Since the average farmer would rather purchase a ready mixed fertilizer than to trouble to mix it himself it should be an economic project to construct a mixing plant in connection with a crushed limestone plant in this district, and to that end the proposition of getting the raw rock phosphate was taken up with several of the phosphate dealers in the phosphate belt of Tennessee, which is the nearest available deposit of this raw material. The owners of these deposits quoted prices averaging $6.00 to $6.50 per ton laid down in Bloomington in small lots and these prices would probably be reduced to at least $5.00 per ton on a large contract with a plant which was handling a large part of their output. These figures are on a phosphate rock that carries from 11 per cent. to 14 per cent. of phosphorus, or in other words, represents about 25 per cent. phosphoric acid.

The amounts usually recommended for treatment of ordinary soils is two parts of limestone to one of ground phosphate. At this rate the mixture could be turned out ready for use at about $2.25 per ton and allowing a fair profit to the operator it could be sold F. O. B. Bloomington at about $3.50 per ton. This would bring it to almost any part of the State at less than $5.00 per ton. The Indiana Railroad Commission has fixed the rates on natural fertilizers such as crushed limestone at a very low rate, in most cases ranging not over seventy to eighty cents per ton.

If lands were known to be lacking in potassium, gypsum could be mixed with the fertilizer. The average cost of gypsum in this country last year was according to the report of the Bureau of Mineral Resources about $2.00 per ton and the amount used on land as fertilizer was about 55,000 tons. The three could be mixed as follows for land deficient in potassium salts: Four parts of crushed limestone, two parts of phosphate rock, one part gypsum. This mixture could be put on the market at the same price as the former one mentioned. Deposits of gypsum occur in northern Ohio and the cost at this point in large quantities would undoubtedly be markedly lower than the $2.00 per ton mentioned.

The total output of phosphate rock from the fields of Tennessee was approximately 450,000 tons last year which represents about 14.5 per cent. of the total output of the country. The deposits are very large and this valuable mineral fertilizer should have a much broader use in the treatment of worn out soils than it has at the present time. The use of crushed limestone in the treatment of acid soils has increased so rapidly that the figures given for any one year are far below what they are the next year. The last available figures are 200,000 tons for the year of 1912.

## Waste Limestone in the Manufacture of Lime.

The generally accepted theory with regard to the origin of limestones is that most of them are of organic origin, although some geologists still hold that the massive beds of limestone deposited in the earliest geological periods were chemical precipitates. Limestone, or at least the chemical compound, calcium carbonate, which constitutes the main part of limestone may occur in a great number of forms in nature. Common limestone, marble, aragonite, calcite, and travertine are composed almost entirely of calcium carbonate, while dolomite is composed of calcium and magnesium carbonate.

Pure calcium carbonate is composed of 44 per cent. carbon dioxide and 56 per cent. of calcium oxide. These two chemical compounds can be separated by means of heat and this is the chemical reaction carried out in the manufacture of lime. The carbon dioxide, being a gas, is driven off by heat and the calcium oxide, a white solid, known as quicklime, remains in the kiln.

Calcium the metallic constituent of limestone is very abundant in nature; in fact only oxygen, silicon, aluminum and iron are more abundant. An estimate of the amount of limestone in the earth's crust by T. Mellard Reade placed it as equivalent to a layer around the earth with a thickness of 528 feet. Van Hise estimates the amount of calcium carbonate in solution in the waters of the ocean as one hundred and sixty trillion metric tons. Calcium can not exist in nature as the metal or the oxide on account of its great affinity for water. Water changes it immediately to the form known as slacked lime or calcium hydroxide. The hydroxide in turn is acted upon by carbon dioxide to form carbonate. The formation of quick lime takes place according to the following reaction:

$$CaCO_3 + heat = CaO + CO_2.$$

which means that when calcium carbonate of limestone is heated it gives up carbon dioxide and becomes calcium oxide or quick lime. Quicklime when acted upon by water in the process commonly known as slacking gives the following reaction:

$$CaO + H_2O = Ca(OH)_2.$$

$Ca(OH)_2$ is the substance commonly known as slacked lime or the milk of lime. This slacked lime on exposure to the air when wet takes up carbon dioxide from the air and again forms calcium carbonate as shown by the following reaction:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

Although the chemical explanation of the above changes has been known but a few decades, nevertheless the fact that the changes themselves took place was known even in the early ages where the Egyptians were engaged in building their great works. In fact some of their mortars are still to be seen and they are known to be very similar to our present common lime mortars. All the great structures built before the time of the Roman Empire were constructed with lime mortars, but the Romans used a cement made from volcanic ash in many of the great structures built under the Empire. The use of this cement was soon abandoned, and the mighty castles of the middle ages are constructed with lime mortars.

Limestones are widely distributed and they differ materially from one locality to another. They are found interbedded with other sedimentary rocks and often grade into them insensibly. Their purity may vary from rocks containing but 45 per cent. calcium carbonate to limestones with as high as 99 per cent. calcium carbonate. The limes of commerce are produced by calcining almost any of these limestones, the resulting lime varying in its uses with its varying purity. The impurity most often found is magnesium carbonate and when the percentage of this runs above 20 per cent. the rock is called dolomite. Following magnesium carbonate the most common impurities found are silica or sand, alumina or clay, and iron.

A limestone composed of nearly pure calcium carbonate will furnish a high grade of quicklime. This product is known as white lime, hot lime, or fat lime while the product from a limestone containing magnesium is called cool lime, brown lime or lean lime. In scientific language the former is called a high calcium lime while the latter is known as dolomitic or magnesium lime.

The limestones of both the Mitchell and the Salem formations are very free from magnesium carbonate and in fact are among the purest limestones of this country, so that any lime burned in this district would be classed as a high calcium lime. In other words it would be composed of almost pure calcium oxide.

The West Virginia Geological Survey, Volume III, in discussing lime describes lime oxide as follows: "Lime oxide when pure is a white solid, without crystal form, infusible and non volatile at temperatures below 3,000 degrees Centigrade. The commercial oxide is more or less tinged with color due to the impurities present. The metallic lime (calcium) free from oxygen may be made by electrolysis of fused lime chloride, or more readily by heating seven parts of the iodide of calcium with one part of sodium in a crucible. The metal is yellow in color, soft, with a specific gravity of 1.578. It is both malleable and ductile and does not tarnish in dry air. If heated in a stream of air or oxygen the metal burns into lime oxide with a very brilliant light. Lime oxide can be obtained in a very pure form by heating the nitrate of lime $Ca(NO_3)_2$".

White lime slacks readily, and rapidly with the evolution of much heat and becomes a perfectly white paste. Any impurities present tend to retard this chemical action. The presence of magnesium makes the process much slower, and less heat is evolved. Limes containing less than ten per cent. of MgO show no effect but as soon as the amount goes above this figure the slowing up of the reaction is noticeable.

The presence of aluminum and silicon oxides in a limestone tends to color the lime produced to a gray color but when present in small quantities they only make the action of the lime less vigorous; that is, these impurities do not ordinarily exert any chemical influence or in any way change its physical properties. They have a dilutent action the same as sand when mixed with lime to produce mortar. If this alumina or silica be present in finely divided particles it will be susceptible of chemical combination with the lime if the temperature employed in burning the lime be high enough. As these constituents increase the limestone is called argillaceous or arenaceous, and from this grades into shales or sandstones according to whether the dilutent is clay or sand. The presence of these impurities in small proportion produces on higher heating a hydraulic lime; that is, it gives the lime the property of setting under water. When the quantity of clayey impurity in a limestone reaches 6 per cent. it begins to produce hydraulicity but below this percentage its only noticeable effect is a retardation of slacking. In fact many limestones containing between six and twelve per cent. of clayey impurities make good, cool, slow slacking limes, but the risk of over-burning them is very great. This is not true of white limes. When earthy limestones are over-burned they form a hydraulic cement and must be finely ground to be of use. From the above discussion it will be seen that the limit between common lime and hydraulic cement is only in the amount of clayey material or alumina present and the percentage of alumina present is the only difference between the hydraulic cement and a true Portland cement. In fact these products form a series with the hot or white limes at one end and true Portland cement at the other. The dividing lines are more or less arbitrary and depend upon chemical composition. The following divisions are commonly made:

(1) Common or fat lime.
(2) Hydraulic limes.
(3) Hydraulic or Roman cement.
(4) Portland cement.

The main difference between limes on the one hand and cements on the other is that cements are burned at a much higher temperature, contain a much higher percentage of alumina and silica, and must be thoroughly pulverized before water will have any great effect upon them.

The presence of iron or sulphur in a limestone in any amount spoils it for the manufacture of lime. The iron in addition to coloring the lime dark has a fluxing effect. The sulphur darkens the lime and forms sulphates of calcium or magnesium. Organic matter when present in a limestone does not interfere with its lime making properties since it is completely removed by the calcining process which the limestone undergoes.

Mortars made from hot limes harden more quickly than those made from magnesium limes, and tests made at the end of 30 or 60 days show the mortars made from hot limes to be harder and more resistant than those made from lean limes. This superiority does not appear to persist, for tests made on mortars after they have been set a year or more show their resistance to be about equal.

When water is added to lime, calcium oxide hydrates and changes to calcium hydroxide. On exposure to the air the excess of water is given up. It has been generally held that the set of the lime was complete when all the water disappeared from the lime but it has been determined by Chatelier that the slacking of lime takes place in four stages.

(1) Simple absorption of water.

(2) The mixture is warmed by contact and by the heat of the chemical action taking place, and a portion of the added water is evaporated.

(3) The mass cools and moisture is fixed by the silicates, although some of the free lime remains unslaked.

(4) The unslaked lime removes this water from the silicates and becomes completely hydrated.

The above is quoted from Volume III of the West Virginia Survey.

The time taken for a lime to set depends on a number of factors; among them the amount of impurities present, the amount of water used, the air temperature, and the thickness of the lime layer. Fat, or hot limes, set much more rapidly than lean ones, and when a mason has been taught to use one it is difficult for him to handle the other. After the set has started, any movement of the plaster tends to weaken the bend and injure the work. After the first set the lime hydrate takes up carbon dioxide from the air and forms carbonate of lime, as shown earlier in this paper. This process is a slow one and in the case of some limes it may be years before the lime has finally returned to the state of a carbonate. The rapidity with which this change takes place depends on the amount of exposed surface of the mortar, the thickness of the layer and the porosity of the mortar. As this action goes on a crust of the carbonate forms over the surface of any considerable mass of mortar and protects the soluble hydrate within from being dissolved or changed and therefore this final carbonate condition may never be reached throughout the mass.

In regard to the final reaction of the lime with the sand in a mortar, S. W. Beyer says in his paper on "The Physical Tests of Iowa Limes" in volume seventeen of the Iowa report:

"Long contact of lime hydrate with finely divided silica is known to cause a reaction by which the silica combines with the lime forming stable silicates of lime. The extent to which this reaction progresses depends on the physical and chemical qualities of the siliceous impurities in the lime or of the sand used with it. If these are very fine, chemical action is favored. Silicates, such as clay or feldspar, for example, are more susceptible to attack by the lime than is quartz sand. Hydraulic limes are apt, therefore, other things being equal, to give a more durable final product than the purer limes. In the same way, muddy or clayey sand used with lime, although less desirable at the start, will likely contribute to the durability of the mixture in time because of the development of these stable compounds by the caustic action of the lime. In the case of silicates, it is probable that other elements, especially alumina, also enter into combination."

Lime has many uses in the various industries but by far the most important use is in the production of lime mortars for structural work, interior walls and plastering. In these uses the lime can not be employed alone on account of the great shrinkage of the lime paste in setting and its own lack of inherent strength when set. It is also cheaper to add some foreign substance, which material will always be cheaper than the lime itself. The most common material used for filler in mortars is sand. Any type of sand grain is superior in hardness to the set lime and when the lime mortar cements these hard grains together the resulting mortar is hard and durable. In the production of mortars any inert substance which does not shrink nor deteriorate may be used. Ground or rough crushed limestone may be used and will give equally good results. In fact crushed stone being rough edged gives the lime more chance to adhere and thus the resulting mortar is very durable. Dolomitic limes are more durable and show less shrinkage than high calcium limes.

A long series of tests of the proper percentages of lime and foreign material for the strongest mortar, and the type of lime best adapted to the manufacture of mortars have been conducted by the Geological Survey of the State of Iowa and the results of these tests can be found in the annual report of that State for the year 1906, Volume 17, pp. 106 to 146.

The reaction by which limestone or carbonate of lime is broken up into lime oxide or quicklime and carbon dioxide takes place above the temperature of 850 Centigrade or 1,562 Fahrenheit. This reaction will go on to completion only in a current of heated air, which carries away the carbon dioxide as fast as formed. Dr. Thorp in his Industrial Chemistry says: "Calcium carbonate begins to decompose below a red heat into calcium oxide and carbon dioxide, but the decomposition is not complete until a bright red heat (800 to 900 C.) is reached. The temperature should not rise above 1,000 to 1,200 C., as there is danger of overheating the lime. For successful burning, it is essential that the gases escape freely from the kiln, the draught usually being sufficient to remove them as they form. This escape may be accelerated by blowing steam or air into the kiln during the burning, or even by wetting the carbonate as it is introduced."

The amount of heat required to produce this change of limestone to quicklime is 3,735 calories for one kilogram of calcium carbonate changed. This amount of heat is equivalent to 747 B. T. U. These are the figures given by Gruner, while Eckel gives the heat requirement as 784 B. T. U. The above figures are quoted from Volume III of the West Virginia Geological Survey.

Limekilns are of two general classes, periodic and continuous. After a charge has been calcined, the periodic kiln is allowed to cool before it is emptied and recharged. With the continuous kiln this delay is not necessary. The calcined material can be withdrawn and fresh material can be added without loss of time or the great waste of heat, which we have with the periodic kilns. Kilns are fired by two general methods. In the first case with what is known as "short flame burning", the material to be calcined is charged in alternate layers with the fuel. In this method the limestone is in close contact with the fuel, and is, of course, more or less contaminated with ashes after burning. In what is known as the long flame method of burning, the fuel is burned on a separate grate and only the flames and hot gases pass into the shaft of the kiln. With this method no ashes are left in the product and a purer lime is produced. With the long flame method there is a materially greater loss of heat, but the purity of the product more than counterbalances the loss. With any of the various forms of kilns other fuels than coal can be used as, for example, natural gas. producer gas, or oil. Any one of these fuels has the advantage over coal of cleanliness and regularity. The fact is becoming generally recognized that producer gas as a fuel for lime burning is the ideal fuel, because the heat can be applied more closely to the charge than in the case of any other fuel, and because the product will be more even and cleaner than with any other fuel.

Continuous kilns are preferred where fuel is expensive, and where a regular output is desired. In fact where close figures are necessary on the cost of fuel the periodic kiln is out of the question. The continuous kiln is a tall, narrow furnace or shaft, built of brick or iron plates, and may vary considerably in size. Such kilns are usually thirty-five to forty-five feet high by six to eight feet in diameter. The limestone is fed in at the top and is calcined as it passes down through the kiln, the lime being taken out at the bottom. The burning goes on without interruption even during the process of charging or removing the lime. In this country many long flame periodic kilns are now in use, the main reason for their installation being their cheapness and simplicity of construction, but they are very expensive in their use of fuel. With these kilns an arch of large blocks of limestone is built about three feet from the bottom of the kiln, openings being left for the flames to pass through. On top of this arch small lumps varying in size from a cocoanut to an orange are piled till the kiln is full. The fire is then built and the temperature of the whole mass is slowly raised during six or eight hours till a full red heat is obtained. This heating must be slow in order to prevent the arch from crumbling. The high temperature is maintained for about two days after which the fire is allowed to burn out and the kiln is allowed to cool. The material is removed and the kiln recharged, much time being lost by the process.

The first method of burning lime, and one occasionally used at the present time for fertilizing lime, was to pile together heaps of logs on which blocks of limestone were laid. The whole mass was fired and the over-burned or under-burned blocks were thrown aside, the remaining material being used. This method was followed by the heap or ditch method in which the limestone was piled in long heaps on a bed of wood and long openings for draught channels were left through the piles. These huge heaps were fired as the smaller heaps had been fired before, but the burning took a much longer time. These ditches were modified into trenches upon hillsides where the material to be burned slid down through the trench much as it does in the limekilns of today; the burned product came out at the lowest level. This type of kiln required four times as much wood fuel as the amount of lime burned, but the small cost of wood in the earlier days made the method practicable. Next came the stone pot kilns which were square chambers of stone about eighteen to twenty feet high and about twelve feet square. These would produce as much as eight hundred cubic feet in 24 hours. They were the forerunner of the modern type of intermittent kiln, and many of them are still in use. The modern lime plant has three floors. The top one is for charging the kilns, the middle one for charging the fires, and the bottom one for removing the burned product. The upper floor is connected by inclines to the quarry, up which the limestone is drawn in cars to be dumped in the top of the kiln. The second floor is on a level with the coal bins and is usually also level with the ash dump. The lowest floor is at the ground level so that the product can be loaded in cars.

Under present conditions one ton of coal will burn from three to five tons of lime. The problem is to keep the fires at their greatest efficiency and to force or draw the hot gases up into the kilns. These things can be best accomplished by means of forced or induced draught. There are four methods of securing better draught on lime kilns at present and they are as follows:

(1) Air jets.
(2) Steam jets.
(3) The Eldred process.
(4) The Suction process.

In the first process jets of air are forced under the grates and the fire boxes are kept tight, on the same principle as forced draught under a boiler.

In the second method steam jets are introduced through the grate bars to give the necessary force to the upward gaseous currents.

The fourth method is to apply suction fans at the top of the kiln to draw off the waste gases as fast as they are formed.

The Eldred process is a combination of the two methods in which steam and air jets are forced into the kiln and suction fans take away the waste gases.

There is no question as to the fuel economy with any of these methods for increasing the draught, but as to their relative value expert engineers are not at all agreed. Of course, the use of reinforced draught in the manuacture of lime is a source of danger if not properly handled because careless handling is sure to give an inferior product, and the danger of over-burning is much greater. A carelessly burned product in addition to being inferior for use is also inferior in its keeping properties. These difficulties would be lessened if the lime were hydrated before being put on the market.

One hundred pounds of good limestone will yield from fifty-six to fifty-eight pounds of lime, but the shrinkage in volume does not exceed fifteen per cent. and is usually much less. There is little difference in the hardness of lime and limestone, but the lime is much more porous and when acted upon by water it falls into powder.

Pure lime is infusible at the temperature of the oxyhydrogen flame and is therefore used in the production of the calcium light. For light pencils the lime must be very pure, as any impurities cause it to fuse and form a glass slag. Lime is a powerful base and reacts with acids to form salts of calcium.

With the development of the use of gas producers and producer gas in all lines of industry the increased use of gas in the manufacture of lime is only a matter of time. Several types of gas producers are in use at the present time. The Morgan system is one of the oldest of these. It consists of a cylindrical steel shell which extends into a water filled ashpan. The fuel is automatically fed in at the top of the producer and scattered over the entire fuel bed. A jet of air and steam is introduced through a central tuyere in the bottom of the producer. All the operations are continuous and automatic and the ashes are removed under water. This producer is capable of a very steady and uniform flow of gas and is admirably adapted to the manufacture of lime. At a lime plant in New Milford, Connecticut, a two weeks' run showed a saving over old methods of forty per cent. in fuel, and an increase of twenty per cent. in the capacity of the kilns. The cost was lowered from twenty-five cents to seventeen and one-half cents per barrel of 300 pounds, and the capacity of the two kilns equipped with this apparatus increased from 65 to 80 barrels per kiln per day. The above is quoted from Rock Products, Volume IV, and from Volume III, of the West Virginia Survey.

Professor G. P. Grimsley in his comprehensive work on lime and cement in the third volume of the West Virginia Geological Survey Reports, describes five general kilns at present in use in the industry in that State as follows: "The Shoop kiln, manufactured by S. W. Shoop and Company of Altoona, Pennsylvania, is what is known as a center draught kiln and rests on a foundation of common brick or stone. The stack is made of 3/16 inch steel, twelve feet in diameter and and about 25 to 30 feet high. The inner cylinder is made of fire brick supported by a back wall of red brick. The inner diameter of the cupola is 5½ feet near the fire boxes and eight feet near the top. This leaves a space about 18 inches below, between the brick cylinder and the steel cylinder, which is filled with ashes or earth packed solidly. The shape of the interior of the cupola is conical to about the middle and then becomes a cylinder. The barrel below the furnace to the cooling pot which is made of one-fourth inch steel and about four feet long, is bolted to a base five feet square so that it may be easily repaired. The opening of this pot is closed by shears readily operated into the car below. Fire brick pillars at the furnace opening into the cupola prevent the lime dropping into the fire boxes and choking the draught."

The following explanation and claims are made by the designer of this kiln (S. W. Shoop) for the natural draught:

"The kiln is constructed with two chambers or ashpits to each side under the firing doors. One is located centrally underneath the other, with foundation on the floor line connected with flumes around the cooling formation of the lime chamber, which gather the heat and hot air from the cooling lime and distribute it underneath the grate bars. The velocity that this heat gathers passing through these flumes is almost equal to forced draught, making it the strongest natural draught kiln constructed. Not only are there advantages derived through draught, but a large saving in fuel is effected by the utilization of this hot air.

"Taking into consideration that it requires about twelve pounds of air, or fifty cubic feet, to consume one pound of coal, and that this air flowing under the grate bars in the ordinary style of kiln at an average temperature of 70 degrees Fahrenheit has to be raised to a temperature of nearly 2,000 degrees Fahrenheit, there is economy in collecting the waste heat from the cooling lime. By the introduction of a small jet of steam underneath the grate bars in connection with the hot air, there is an excellent forced draught for coal."

The Broomell kiln, known as the Keystone limekiln, made by the Broomell, Schmidt and Steacy Company of York, Pennsylvania, is a steel clad kiln built on a somewhat different plan than the Shoop kiln. The supporting base of the kiln is heavy steel reinforced by vertical double angle iron posts. The steel cooling cone within the supporting basal cylinder is made of heavy boiler plate suspended from a heavy cast iron bed plate and can be readily removed for repairs. At the bottom of the cooling cone are patented draw gates opened and closed by hand wheels which project outside the supporting base so that the workman can turn the gates without coming in direct contact with the hot lime and dust. The heat of the kiln is generated in four independent furnaces, each twenty-four inches wide, thirty inches high and about four feet long. The furnaces can be used with forced draught under the grate bars by forcing a mixture of steam and air through an inserted steam pipe. Induced draught is obtained by using an iron cover with a door and attaching a suction fan to the top of the kiln. The shell of the kiln is composed of heavy steel plates bolted together, and the interior is lined with fire brick supported by common brick. Near the top of the kiln is placed a heavy steel cone to protect the brick and above this cone is a large storage space, the full diameter of the kiln. The rock is heated in this space by the heat passing through the kiln and its temperature is gradually raised as the rock passes down to the burning zone. These kilns are usually placed in batteries with three feet of space between them, and any kind of fuel may be used. The most popular sized kiln is the Number 3 which is described as follows by the company:

| | |
|---|---|
| Diameter of shell outside | 11½ feet. |
| Diameter of brick lining inside | 6½ feet. |
| Diameter of cooling cone at the top | 7 feet. |
| Diameter of cooling cone at the bottom | 2 feet. |
| Height of cooling cone | 7 feet. |
| Total height of kiln | 48 feet. |
| Shipping weight of kiln | 44,000 pounds. |
| Weight of special brick | 14,800 pounds. |
| Fire brick required | 8,463 pounds. |
| Common red brick | 15,700 pounds. |

Capacity, 90 to 140 barrels of 200 pounds each per 24 hours.

The O'Connell kiln patented in 1899 has boilers set in the arches of the furnace openings into the body of the kiln. These boilers supply the necessary heat for the kiln and also provide a means whereby steam generated in the boilers may be used to aid combustion. By this means the fuel used for burning the lime produces steam to run the blowers and conveyors to elevate the stone, and operate quarry pumps and other necessary machinery. It is claimed to save twenty per cent. of the fuel ordinarily required for burning the lime.

The Hoffman kiln, a horizontal circular kiln, invented in Europe for the manufacture of brick, is also extensively used for lime burning. It consists of an arched circular room divided by movable partitions into sections (usually twelve in number). The limestone is placed in these sections and fired through openings in the roof into the first section, and when the lime is burned the fire is added to the next section and so on around the circle. The air enters the section in which the lime is being removed and cools the burned lime, becomes heated in the section where the full fire is being maintained, and then reaches the sections charged but not burned, giving off its heat, and finally passes from the last section out through a chimney at the center of the kiln. Dampers serve to regulate the air current, and sections not in use can be shut off, since all are connected with the central chimney by openings which can be readily closed. In England, according to Frasch, the Hoffman kiln produces daily 1,200 to 1,500 cubic feet of lime with a consumption of only five pounds of slack coal per cubic foot. In Germany the saving of fuel in the Hoffman kiln is almost 75 per cent. over the old methods. The lime is said to slack more easily and cannot be stored so long a time as that made in other kilns. The saving in fuel in the Hoffman kiln over the best drawn kiln is said to be 40 per cent. This form of kiln is well adapted to use where the lime is to be hydrated before it is placed on the market.

Rotary kilns are in use in a few instances but not enough data is available to determine their economic value. The following figures indicate the cost of lime burning with oil fuel and a rotary kiln:

Average output, twenty-five tons per day.
Fuel consumption, forty barrels (52 gallons per barrel).
Stone, 98.5% $CaCO_3$.
Labor cost, $22.00 per day.
Oil consumption per 100 pounds of lime, 26.2 pounds.

This represents a total cost of about nine cents per bushel.

The cost of lime manufacture differs markedly in different sections of the country. Some of the most important factors in the cost of lime or the factors which cause variations in cost of production are different labor costs, variations in fuel cost, and the cost of quarrying the rock.

The following figures are given as the average cost of a two-kiln plant with a daily capacity of 500 bushels. The expenses run as follows:

| | |
|---|---|
| Interest on plant and land | $1 60 |
| Repairs, taxes, etc | 1 30 |
| Cost of quarrying 30 tons of rock | 7 00 |
| Fuel cost (Coal $1.25 per ton) | 5 00 |
| Additional labor cost | 12 00 |
| Total cost of 500 bushels | $26 90 |
| Cost per bushel, 5.4 cents. | |

These costs for the Southern Indiana district would be, with up-to-date plants:

| | |
|---|---|
| Interest on plant and depreciation | $2 00 |
| Repairs, taxes, etc | 1 30 |
| Quarry cost or cost of waste stone (15 cents per ton) | 4 50 |
| Fuel cost (coal $1.50 per ton) | 6 00 |
| Labor cost | 10 00 |
| Total | $23 80 |
| Cost per bushel, 4.8 cents. | |

There are approximately twenty-seven bushels to the ton of quicklime. A fair estimate of the cost of lime burning in the quarry district of Southern Indiana with the cheap waste limestone as a raw material would not exceed $1.50 per ton after all expenses are counted in.

In slacking a high calcium lime there is an increase of about forty pounds to the bushel. Quicklime weighs about seventy-five pounds per bushel.

## Uses of Lime.

Lime probably has the greatest number of uses of any mineral product. Approximately one-half of the lime burned in this country is used for structural material and the remaining half is used for chemical purposes. Different grades of lime have different uses and in fact most grades of the product have some special use to which they are best adapted. Some purposes require a high calcium lime and some require a slow slacking lime such as results from the burning of dolomitic limestones. The principal uses of lime as a structural material are in lime mortars, and plasters in gaging Portland cement mortars, concrete, and gypsum plasters, and as a whitewash. Both quicklime and hydrated lime can be used for these structural purposes. The chemical uses of lime are given in the government reports on the industry as follows:

*Agricultural industry*---

As a soil amendment (either calcium or magnesium lime can be used).

As an insecticide (either).

As a fungicide (either).

*Bleaching industry*—

Manufacture of bleaching powder, "chloride of lime" (calcium).

Bleaching and renovating rags, jute, ramie, and various paper stock (either).

*Caustic alkali industry*—

Manufacture of soda, potash, and ammonia (calcium).

*Chemical industries*—

Manufacture of ammonia (calcium).

Manufacture of calcium carbide, calcium cyanamide, and calcium nitrate (calcium).

Manufacture of potassium and sodium dichromate (calcium).

Manufacture of fertilizers (either).

Manufacture of magnesia (magnesium).

Manufacture of acetate of lime (calcium).

Manuacture of wood alcohol (calcium).

Manufacture of bone ash (either).

Manufacture of calcium carbides (calcium).

Manufacture of calcium light pencils (calcium).

In refining mercury (calcium).

In dehydrating alcohol (calcium).

In the distillation of wood (calcium).

*Gas manufacture*—

Purification of coal and water gas (either).

*Glass manufacture*—

Most varieties of glass and glasses (calcium).

*Milling industry*—

Clarifying grains (either).

Manufacture of rubber, glue, pottery, and porcelain (either).

Dyeing fabrics and polishing material (either).

*Oil, fat and soap manufacture—*

Manufacture of soap, glycerine, candles (calcium).
Renovating fats, greases, tallow, butter, etc. (calcium).
Removing the acidity of oils and petroleum (either).
Lubricating greases (either).

*Paint and varnish manufacture—*

Refining linseed oil (either)
Cold-water paints (either).
Manufacture of varnish and linoleum (either).

*Paper industry—*

Soda method (calcium).
Sulphite method (magnesium).
For strawboard (either).
As a filler (either).

*Preserving industry—*

Preserving eggs (calcium).

*Sanitation—*

As a disinfectant and deodorizer (calcium).
Purification of water for cities (calcium).
Purification of sewage (calcium).
Water softening and purifying (calcium).

*Smelting industry—*

Reduction of iron ores (either).

*Sugar manufacture—*

Beet root (calcium).
Molasses (calcium).

*Tanning industry—*

Tanning cowhides (calcium).
Tanning goat and kid hides (either).

The uses of lime in the agricultural industry are many, but by far the largest part used is as a soil amendment, and this use is thoroughly treated in the portion of this paper dealing with crushed limestone as a fertilizer. It is there shown that crushed limestone will do the same work as lime and at a much smaller cost than with lime. The only case in which lime is better adapted to soil treatment is in the case of a soil very high in organic matter, as in the case of drained lands where the soil is of a peaty nature and a part of the organic matter in the soil can be sacrificed for quicker returns.

Lime is used in the preparation of nearly all of the insecticides and fungicides used for protecting plants. Lime and iron sulphate commonly known as copperas and water is much used as a spray under the name of Bordeaux mixture. This mixture is used to kill fungous growths on vines and trees. A mixture of about 20 pounds of sulphur, 15 pounds of common salt, 35 pounds of lime, and 50 gallons of water will make, when boiled, a spray that will destroy scale and other insects, without hurting the trees, at any time of year. Many other mixtures of this type are known.

Slacked lime when treated with an excess of chlorine gas forms calcium oxy-chloride $Ca(OCl)_2$, commonly known as "bleaching powder", much used in bleaching vegetable fibers for the textile and paper industries.

Quicklime is used in the manfacture of the alkaline hydroxides, such as sodium, potassium and ammonium hydroxides. The carbonate of the substance when treated with quicklime and water gives calcium carbonate and the hydroxide of the substance, as for example:

$$CaO+Na_2CO_3+H_2O=CaCO_3+2Na(OH).$$

That is, quicklime plus sodium carbonate plus water equals calcium carbonate plus sodium hydroxide.

Calcium carbide, much used in the production of acetylene gas, is made from a mixture of 100 parts of lime and 70 parts of coke. This mixture must be heated at the temperature of the electric arc for some time, so that plants for its manufacture must have cheap sources of power. The carbide breaks up slowly in the air but rapidly when treated with water according to the following reaction:

$$CaC_2+2H_2O=C_2H_2+Ca(OH)_2.$$

The manufacture of acetate of lime from which pure acetic acid is prepared, and the purification of wood alcohol and acetone, are carried on along the same line. Milk of lime is used to take up the acid from the impure wood spirits while the alcohol and acetone are carried over and condensed. Much lime is used in these reactions. The only method of obtaining wood alcohol of high purity is by distillation over lime.

In the manufacture of soaps the lime is used to obtain the alkaline hydroxides from the carbonates as described earlier in this paper. The action of the lime on tallow or grease is to form organic salts or calcium. The calcium is easily replaced by sodium or potassium from some of their compounds, to form the soluble soaps of commerce. Saponification with lime is a necessary step in the manufacture of candles, glycerine and the explosives derived from glycerine. The milk of lime is used also to remove any trace of acid that might be present in the pure products.

Lime plays a very important part in the manufacture of paper. The first use of lime in this industry is in the cleansing of the materials and the removal of foreign substances. This method is employed in the case of rags, straw, etc., that are to be used in paper manufacture. If wood pulp from soft woods is to be used, the pulp is boiled in a solution of sodium carbonate which has been rendered alkaline by the addition of pure lime oxide. In the sulphite process the wood of spruce, hemlock, etc., is boiled with sulphurous acid and milk of lime till the tars and oils are removed and the pulp softened. The paper pulp is usually bleached with chloride of lime before rolling. It will thus be seen that it plays one of the most important parts in this industry.

The uses of lime in sanitation are so numerous and so well known that space will not be given here to discuss them.

Lime is used in sugar manufacture in the process known as "Defecatio." The lime here removes the excess of organic acids and coagulates the albumen and mucus. Lime, although slightly soluble in water, is more soluble in sugar water and the lime unites with the sugar to form an insoluble compound, in which form it can be washed with alcohol and water. The calcium from this sugar of lime compound can be removed by passing carbon dioxide through the solution.

Lime is used in tanning hides where a strong solution of milk of lime is used to remove the hair from the hides. The lime also dissolves the fatty matter and dissolves the corium, loosening the fibres, which swell the hides. The length of time that the hides undergo this liming process determines the pliability of the leather formed. The addition of sodium sulphite to the lime gives a paste that will remove the hair in a few hours if spread on the hair side and rolled in.

I have only attempted to outline a few of the more important chemical uses for lime. A discussion of these industries can be obtained from any of the later texts on Industrial Chemistry.

It will be seen from the table above that high calcium limes are far more important and have a much larger use in the manufacturing industries of the country than the magnesium limes and those burned from dolomite.

The demand for these manufactured products is sure to increase very rapidly in this country during the next few years, and the demand for lime will increase accordingly. The price of high grade high calcium limes is sure to increase with the increased demand for them in the new manufacturing projects that are sure to spring up in the next decade.

The vast diversity of the uses of lime is sure to keep the demand constant even if the different industries make varying demands for it. The ability of lime to correct soil acidity has been thoroughly treated in the part of this paper treating the use of lime and limestone and their relative effects on acid soils.

## The Hydration of Lime.

When a magnesium lime is packed for shipment its slow slacking action and little heat given off in slacking makes it possible to keep it a long time and to ship it in paper sacks without fear of its destruction, or danger to property near it. This is not true of the hot, high calcium limes. Their great affinity for water has always made them dangerous to property as well as causing them to spoil in storage or transit. In most industries the hydrate of lime is as useful as the pure quicklime and much easier to handle, being also less liable to spoil. This demand for an easily handled and shipped compound led to the placing of lime hydrate on the market. By whatever process quicklime and water are brought together the same chemical reaction results, namely:

$$CaO+H_2O=Ca(OH)_2.$$

When the oxide leaves the kiln it is in lumps about one-fourth larger than the lumps of limestone from which it was burned. These lumps on slacking fall into a fine white powder known as the hydrate of lime. The reaction is accompanied by the generation of a large amount of heat that under certain conditions may cause combustion. If this reaction is carried on directly after the quicklime is cool, and the resulting product is dried, it can be stored or shipped without any danger to property or to itself. The lime hydrate contains about 25 per cent. of water and has a specific gravity of about 2.08 while the specific gravity of limestone is about 2.8. The specific gravity of pure lime oxide may be as high as 3.1.

The burning of the lime has much to do with the rapidity with which it slakes. Lime burned at temperatures under 1,000 degrees Centigrade will slake quickly, while limes burned at higher temperatures are liable to take hours to slake thoroughly. When a hot lime and water are mixed temperatures as high as 310 degrees Fahrenheit may be reached; this temperature will under appropriate conditions cause combustion.

To slake the lime properly the water must be added slowly. About one-third the amount of water necessary to slake the lime should be added first, and after the heat is generated the rest of the water can be added. If the lime is mixed with a large amount of cold water the product will be very granular. The weight of high calcium limes is increased about one-third on slaking. One bushel of good lime will make about two and one-half bushels of slaked lime, with a weight about one-half as great per bushel.

The old method of lime hydration practiced by masons and plasterers consisted in pouring the necessary amount of water over the lime in a water-tight box lined with sand and lime paste. The lime was spread over the bottom of the box in a layer about eight inches thick and enough water added to make a thick paste. A layer of sand is spread over the lime to keep in the heat. This method when properly carried out by an experienced man, will give a good product, but careless work usually injures the lime and makes it inferior as a building material. The new method of lime hydration at hydrating plants and the marketing of the product already slaked, does away with the danger of careless slaking, and the resulting material gives much better satisfaction as a building material.

Many processes are now in use for slaking lime and several of them are operated under patents and the product is sold under various names, such as lime hydrate, limoid, cream of lime, etc. The process consists essentially of the following operations: First the lime lumps are crushed with some type of crusher to give a uniform size of lump so that the water will act rapidly. Second, the hydrating is accomplished as follows: A weighed portion of lime is placed in the hydrating pan, which is a pan holding 1,000 to 2,000 pounds. Scrapers in the pan level the lime down to a depth of about eight inches. The pan rotates under a number of stationary ploughs which are so arranged that the lime is thoroughly turned over and mixed every half revolution. An automatic sprayer which contains a predetermined amount of water is located over the pan and sprinkles the water evenly over the surface of the lime. As soon as the water and lime are thoroughly mixed the pan is emptied and a new charge is placed in it. The process of hydrating a high calcium lime does not require over half a minute per charge. Following the process of hydration the product is screened to remove particles of limestone, underburned lime and unslaked lumps. The product screened to about 40 mesh is stored in bins ready for bagging and shipment.

The equipment of a small hydrating plant should include two elevators, one to take the lime from crusher to bin and one to take the slaked lime from the hydrator to the storage bin; a hydrator, a crusher, and screens.

The above process is known as the batch process. Other methods use machinery which is continuous in operation, the most common being the rotating cylinder containing screens for discharging the product as fast as it is hydrated. Water is sprayed into the cylinder as well as jets of steam, which accelerates the process. The lime is fed in at the higher end of the cylinder and travels slowly toward the lower or discharge end. The usual capacity of these cylinders is about eight tons of hydrated lime per hour. They require about five horse-power to operate them.

The lime hydrating industry is one that is sure to grow in this country as the product has many advantages over quicklime for every use in which the caustic properties of the lime are not a necessity. The main advantages are as follows:

1. Hydrated lime will keep better than quicklime.
2. It can be shipped in paper bags instead of barrels.
3. The impurities have been removed in the hydrating plants.
4. It is ready for immediate use. No slaking or seasoning is necessary.
5. Less is needed to produce an equally strong mortar.
6. It can be mixed dry with sand or cement, thus requiring less labor.
7. Less danger in packing and in handling.

With these advantages favoring it the use of hydrate can not but develop very rapidly and plants for hydrating lime will be a paying venture. Mixtures of lime hydrates and Portland cement are already much used in making concrete walls. This is also recommended in the production of concrete building blocks, where it is claimed that it improves the water resisting qualities and gives a lighter shade to the blocks.

Lime hydrate is used with kerosene and copper sulphate or Paris green as a spray, and as such it is recommended as a very good insecticide.

The manufacture of building bricks from mixtures of sand and lime has been carried on for a number of years in regions where the soils were sands, and clays were lacking, but these mortar bricks proved very unsatisfactory and the industry never reached large proportions. The patent of Dr. W. Michaelis for hardening sand lime brick by high pressure steam has given the industry making sand lime bricks a great impetus. The patent, taken out in 1881, lapsed before any great use was made of it, but since 1900 a large number of plants for the manufacture of sand lime brick by this method have begun operations in Germany. The first plant to operate in this country was started at Michigan City, Indiana, in 1901, and at the present time about 100 plants are in operation in the United States.

Sand lime brick, or "Kalksandstein" as it is called by the Germans, is a mass of sand grains cemented together by hydrated calcium silicate. The union, instead of depending on the lime as a cement, depends upon the formation of the silicate by the high temperature to which the brick is subjected in the process of manufacture. This industry is sure to grow and with it the demand for lime.

The reasons why the lime industry has not been developed in the stone belt of Southern Indiana are many. In this connection I will quote from the paper on the Lime Industry of Indiana by W. S. Blatchley in the twenty-eighth annual Report of the Indiana Department of Geology and Natural Resources, as follows: "The average of eight analyses of specimens from eight of the leading quarries of Bedford stone showed the following percentage composition: Calcium carbonate, 97.62; magnesium carbonate, .61; iron oxide and alumina, .36; insoluble residue, .91. These analyses show the fitness of the Bedford oolitic stone for making a very pure quicklime; and the practical burning of the lime at Salem, Bedford and other points proves this fitness. For some reason, however, the lime industry in the oolitic stone district is not as flourishing as it should be. Abandoned kilns are found in a number of localities in the area, notably in Monroe County, near the old University building at Bloomington, and at Ellettsville, in Lawrence County; two southeast of Bedford, and three south of the same place along the Monon Railway, and in Owen County at Romona." Professor T. C. Hopkins in his report on the oolitic stone industry in the twenty-first Annual Report of the State Geologist, says in substance: "Seeing the great quantity of waste rock on the dump piles about the quarries one wonders why more of it is not burned into lime, and no satisfactory answer could be obtained to that query when put to the quarrymen. One said it did not make good lime. Another that the lime was too hot, and some had not thought of it, did not know that it had ever been tried, or would make lime at all. One need only to look at the average analysis quoted above to see that it would, as remarked earlier in this paper, make a rich fat lime." Quoting from the same source: "The reason that more of it has not been burned into lime may be due to a number of causes, as follows:

"(1) Freight rates, the cost of bringing in the coal and shipping the lime.

"(2) A prejudice in the local markets against rich lime.

"(3) Want of a large market, as they are situated in the midst of the Mississippi Valley, with large deposits of limestone on all sides.

"(4) The lack of some enterprising person to push the business into prominence, as all the stone dealers are interested in the sale of building stone and not lime."

With regard to these reasons for the lack of development of the industry in this district it will be seen that at the time of writing this report not all of them are effective. In the first place more railroads have penetrated the stone belt and are competing for the business, and this has had a tendency to lower freight rates. The quarry operators and the railroad managers have come to a realization that their interests were mutual and so they are better acquainted with conditions and will co-operate more fully to make rates that will allow the industry to develop. In the second place the development of the process of hydrating lime at the manufacturing plants has done away with the objections to hot limes by making them easy and safe to handle. With this objection removed the rich lime will be more popular in the market than the lean limes now used. In the third place the markets of the Central West are being supplied with limes from Ohio which must cross Indiana in transit, thus placing on them higher freight rates than would be placed on Indiana limes. In fact Ohio limes are being used at the present time in the stone belt of Indiana. This is the more to be lamented when it is known that most of the Ohio limes are dolomitic limes and that the Indiana limes are superior for most uses if put on the market in the form of lime hydrate.

The last reason urged is probably still the most effective in holding back the industry, but this can not long stand in the way, for the stone industry is filling up with a younger generation of progressive business men who find the profits of the industry not large enough to satisfy them, and realizing that a more careful utilization of the waste heap can add to their profits, they will develop any collateral industry as soon as convinced that the returns are proportionate to the capital invested.

The 1913 output of lime in Indiana was 96,359 short tons, valued at $323,905, while her neighboring State, Ohio, put out 497,693 tons valued at $1,976,316. To make up the difference of 401,000 short tons of output so Indiana would take rank with her neighbor it would be necessary to burn in the State eight million cubic feet of limestone more than is burned at the present time. It will be seen from these figures that if waste limestone that accumulates in the quarry district every year were used in the manufacture of lime, Indiana would take rank as one of the greatest lime producing States in the Union.

Approximately eighteen million cubic feet of limestone is burned per year in the State of Pennsylvania in order to produce their lime output of about 852,000 short tons. The price of lime in Indiana averages around $3.50 per ton and calculated on this basis the waste from the quarries in a single year would be worth nearly $1,250,000, if the product were in the form of lime. Of course, these figures are only approximations for the reason that any such an increase in the output of the State would probably cause a drop in the price paid per ton, but with the increase in the demand for a high calcium lime in the chemical industries of the country, due to the changed conditions of manufacture in Europe, the producer of this kind of lime can look for a strong demand and good prices for a long time to come. In Ohio the price of lime remains about $4.00 even with her large production.

At the present time there is only one lime plant in operation in the Southern Indiana quarry district. This plant was the property of the Ohio and Western Lime Company of Bedford, Indiana, until the latter part of 1914, when it was purchased by the Indiana Quarries Company. The plant is located on the site of the Old Perry Matthews and Buskirk quarry of the Indiana Quarries Company on Buff Ridge; and the limestone burned comes from this quarry. While the plant was operated by the first company the operators were furnishing derrick and switch connections for the lime company. Since the same company is now operating both quarry and lime plant the industry will be sure to develop. In reply to a request for information concerning the plant under its new owners, the following information was promptly furnished. The equipment of the plant consists of four kilns, two of stone and two of steel construction. The plant will furnish employment for 15 men at an average wage of 22½ cents per hour. The yearly output of the plant is about 225,000 bushels of lime and the coal consumption is about 5,200 tons. The cost of production of the lime is figured at about ten cents per bushel. The plant represents an investment of approximately $25,000.00.

## Portland Cement.

The cement used by the ancient Egyptian builders was a type similar to our present lime mortars. There is no reason to believe that they were familiar with any form of hydraulic cement. The first use of this type of cement is attributed to the Roman builders who used it in the great engineering works of the early empire. This cement was made by burning a volcanic ash found abundantly in the vicinity of Naples and called puzzuolana. The product was called Puzzuolan cement. This type of cement differed very much from our modern Portland cement both in composition and method of production. A very similar cement is produced at the present time from blast-furnace slag. Following the fall of the Empire even this type of cement was forgotten and the great buildings of the middle ages were put up with plain lime mortars.

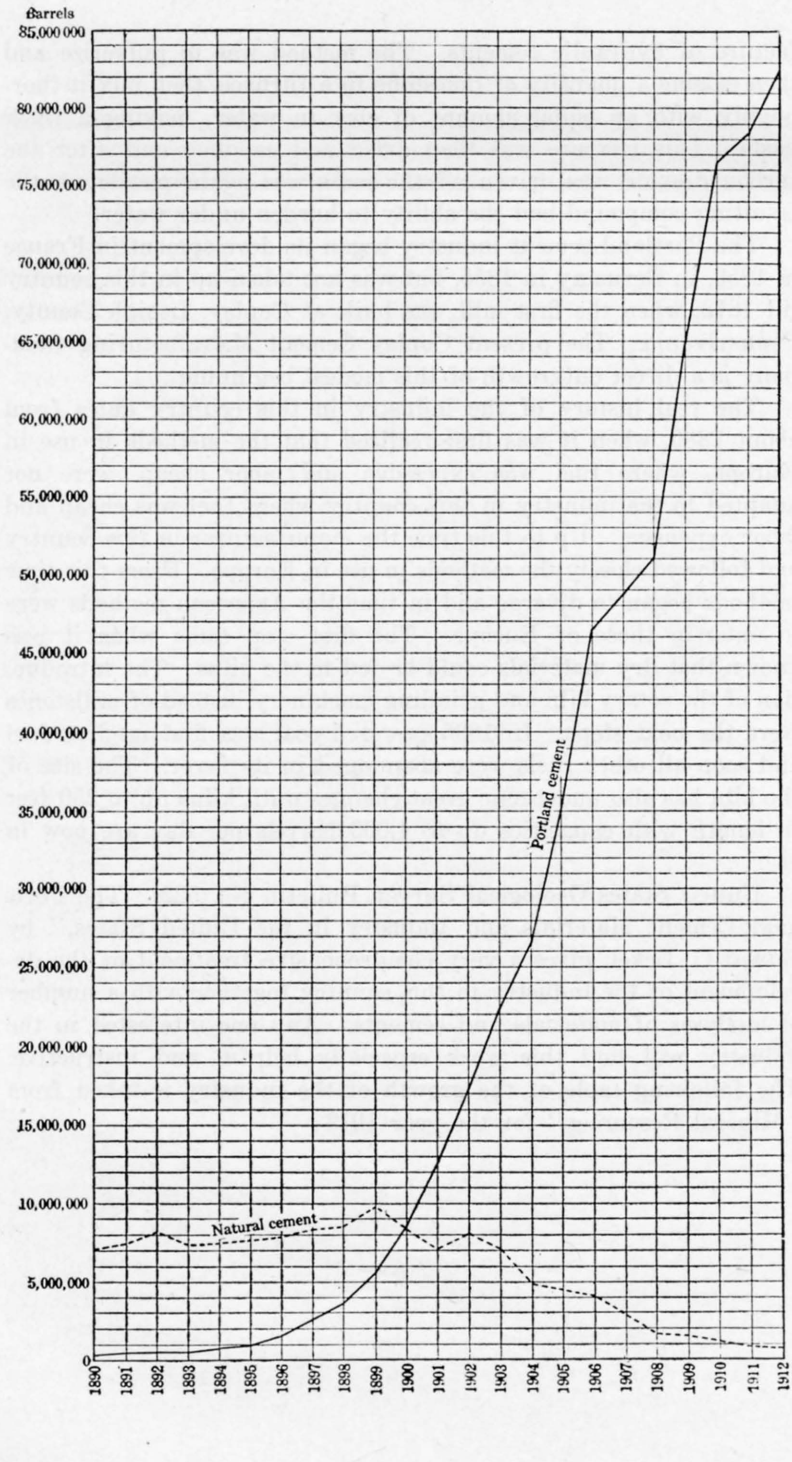
In 1756 John Smeaton, an English engineer, began a series of experiments with hydraulic cements for use in the construction of the Eddystone lighthouse. When the results of these experiments were made public in 1791 a number of other men began experiments and in 1796 a patent was given in England to a man by the name of Parker. The product was also patented in France about the same time, and both products were very similar to our present Rosendale cement.

The first compound approximating the composition of our present Portland cement was manufactured in England under a patent granted to Joseph Aspdin of Leeds, England, in 1824. No formula was given with the application for the patent, and consequently the exact composition of this cement is unknown, but to it was given the name of Portland cement on account of its close resemblance to the oolitic limestone of Portland, a well known building stone. Aspdin's cement was made from a mixture of chalk and clay and was burned at a higher temperature than is necessary in the manufacture of hydraulic cements. The method was to pulverize and then calcine a quantity of limestone in a furnace, then mix it thoroughly with an equal amount of clay in water, making a thick paste. This mixture was then dried and calcined and after the carbon dioxide was driven off the mass was again powdered, the resulting compound had the ability to harden under water.

The Portland cement industry began its development in France in 1850, in Germany in 1855, but was not taken up in this country till 1872, when the first mill was built at Coplay, Lehigh County, Pennsylvania. The present Coplay Cement Manufacturing Company is a direct outgrowth of this modest beginning.

The real history of the industry in this country dates from about 1880, when it was first realized that the methods in use in Europe, where fuel was expensive and labor cheap, were not adapted to the industry in this country where fuel was cheap and labor expensive. Up to this time the manufacturer in this country had followed closely the methods in use in Europe. From this time methods began to diverge and in time the American methods were to outstrip those of Europe. The first step came when it was known that dry materials could be fed to the kilns. The introduction of the rotary kiln and grinding machinery instead of millstones were the next steps. In 1895 powered coal was first used as fuel and soon all other fuels were abandoned in its favor. The size of the kiln has also undergone great changes until kilns up to 250 feet in length with capacities up to 1,000 barrels per day are now in use.

United States Geological Survey Bulletin No. 522, "The Portland Cement Materials and Industry in the United States," by Edwin C. Eckel, gives a very comprehensive treatment of the development of the industry in this country together with a number of analyses of materials and cements. Any one interested in the industry will find this work especially helpful and instructive. The following table of the growth of the industry is taken from "Mineral Resources" for the year 1912:


Barrels
85,000,000
80,000,000
75,000,000
70,000,000
65,000,000
60,000,000
55,000,000
50,000,000
45,000,000
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Portland cement
Natural cement
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912

The total amount of cement of all kinds produced in this country during the year 1912 was 83,351,191 barrels valued at $67,461,-513. The output for 1911 was 79,547,958 barrels valued at $66,-705,136. This represents an increase of 4.78 per cent. in quantity and 1.13 per cent. in value over the previous year. Of this amount over 98.5 per cent. was Portland cement. This quantity of cement, which is given in barrels, represents a total weight of 13,985,034 long tons and a value of about $4.79 per ton.

Indiana with five producing plants put out (in 1812) 9,924,124 barrels with a value of $7,453,017. The average price per barrel for cement in Indiana for the year was 75 cents. Of this amount 9,634,582 barrels was shipped.

The five plants at present operating in Indiana are located at the following points:

Mitchell, Indiana. This plant uses limestone and shale.

Speed, Indiana. This plant uses limestone and shale.

Buffington, Indiana. This plant uses blast-furnace slag and crushed limestone.

Syracuse, Indiana. This plant uses marl and clay.

Stroh, Indiana. This plant uses marl and clay.

Indiana ranks second only to Pennsylvania as a producer of Portland cement, although only five plants are operated in the State.

The deposits of stone in Indiana, with which this paper is concerned, are included in the Mississippian rocks of the State and are described in an earlier chapter of this report.

The following analyses are taken from Eckel's work on "Cement Materials and Industry in the United States," and are quoted by him from reports on the limestones of Indiana:

ANALYSES OF MISSISSIPPIAN LIMESTONES FROM INDIANA.

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$) | 0.50 | 0.70 | 1.74 | 1.60 | 0.65 | 0.90 | 1.13 | 0.31 | 0.48 |
| Alumina ($Al_3O_2$) and iron oxide ($Fe_2O_3$) | .98 | .91 | .29 | .18 | 1.00 | 3.00 | 1.06 | .32 | .15 |
| Lime carbonate ($CaCO_3$) | 96.60 | 96.79 | 95.62 | 95.55 | 95.54 | 95.00 | 96.04 | 98.09 | 98.91 |
| Magnesium carbonate ($MgCO_3$) | .27 | .23 | .89 | .93 | .40 | .22 | .72 | ...... | .63 |

| | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. |
|---|---|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$) | 0.84 | 0.86 | 0.64 | 0.76 | 1.26 | 1.69 | 0.63 | 0.15 | 0.50 |
| Alumina ($Al_2O_3$) and iron oxide ($Fe_2O_3$) | .13 | .16 | .15 | .15 | .18 | .49 | .39 | .64 | .71 |
| Lime carbonate ($CaCO^3$) | 97.39 | 98.11 | 98.27 | 98.16 | 97.90 | 97.26 | 98.20 | 93.80 | 93.07 |
| Magnesium carbonate ($MgCO_3$) | .78 | .92 | .84 | .97 | .65 | .77 | .81 | 4.01 | 4.22 |

1. Chicago & Bedford Stone Co., Bedford, Lawrence County. Eighth, Ninth, and Tenth Ann. Repts. Indiana Geol. Survey, 1879, p. 95.
2. Simpson & Archer quarry, near Spencer. Idem, p. 94.
3, 4, 5. Dunn & Co., Bloomington. Twenty-first Rept. Indiana Dept. Geology, 1897, p. 320.
6. Monroe Marble Co., Stinesville. Report of a geologic reconnaissance of Indiana, 1862, p. 137.
7. Salem. Idem, 1886, p. 144.
8. Stockslager quarry, Harrison County. Idem, 1878, p. 96.
9. Milltown. W. A. Noyes, analyst. Twenty-seventh Rept. Indiana Dept. Geology, 1902, p. 98.
10. Acme Bedford Stone Co., Clear Creek, Monroe County. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1899, p. 381.
11. Hunter Bros. quarry, Hunter Valley. W. A. Noyes, analyst. Twenty-first Rept. Indiana Dept. Geology, 1897, p. 320.
12. Indiana Stone Co., Bedford, Lawrence County. W. A. Noyes, analyst. Idem.
13. Twin Creek Stone Co., Salem, Washington County. W. A. Noyes, analyst. Idem.
14. Romona Oolitic Stone Co., Romona, Owen County. W. A. Noyes, analyst. Idem.
15-16. Hoosier Stone Co., Bedford, Lawrence County. F. W. Clarke, analyst. Bull. U. S. Geol. Survey No. 42, 1887, p. 140.
17-18. Indiana Steam Stone Works, Big Creek. L. H. Streaker, analyst. Twenty-first Rept. Indiana Dept. Geology, 1897, p. 320.

"Cement consists of certain anhydrous double silicates of calcium and aluminum, which are capable of combining chemically with water to form a hard mass." The above definition is given in most texts on industrial chemistry, but from an industrial standpoint it is an intimate mixture of limestone and shale or marl and clay that has been calcined and ground till it will harden under water. Cements differ from lime mortars in that they do not require carbon dioxide from the air in hardening and are very insoluble in water. The hardening of the cement takes place throughout the whole mass simultaneously and thus makes them very useful as a building material.

Cements are of three classes, as follows:

(1) Those cements formed from volcanic tufas or materials resembling them, such as Puzzuolan, blast furnace slags, etc. These cements require the addition of lime before showing their hydraulic properties.

(2) Those cements which contain large quantities of free lime such as Roman cement and "hydraulic" limes. These cements have been formed by burning a natural argillaceous limestone at a temperature that has driven off all the carbon dioxide present in the limestone without being sufficiently high to fuse the product.

(3) True Portland cements or those which have been prepared by burning, at a high temperature, an intimate mixture of clay or shale with a calcium carbonate rock.

The chemical composition of Portland cement has not been definitely determined, but the most exhaustive work on the subject has been done by a French chemist, Le Chatelier. After careful synthetic determination he gave the following formula for its composition:

$$x(3CaO, SiO_2)\ y(CaO, Al_2O_3)$$

in which x and y are variable quantities depending on the relative properties of silica and alumina in the clay used.

The essential ingredients of Portland cement may vary slightly in their chemical composition but the limits of variation are reasonably well marked. The average composition of the raw materials are shown in the following table. (Thorp):

| | *Clay.* | *Marl.* | *Limestone.* | *Shale.* |
|---|---|---|---|---|
| $SiO_2$ | 42.20 | 0.50 | 3.00 | 15.00 |
| $Al_2O_3$ | 12.30 | 0.20 | 1.50 | 7.00 |
| $Fe_2O_3$ | 4.60 | 0.10 | ..... | 7.00 |
| $CaCO_3$ | 23.90 | 94.50 | 96.50 | 71.00 |
| $MgCO_3$ | 16.05 | 2.25 | 3.00 | 4.00 |
| Alkalies—Moisture, etc. | 0.95 | 2.45 | ..... | ..... |

It will be accurate enough to state that the mixture from which Portland cement is made must contain approximately 75 per cent. of calcium carbonate, 20 per cent. of silica, alumina, and iron taken together while the remaining 5 per cent. includes the magnesia, sulphur and other substances that are present as impurities in the raw materials.

It is seldom possible in nature to find a rock deposit approaching the composition necessary for the making of Portland cement, so that the materials have to be derived from different deposits and mixed as used. The usual ingredients for the manufacture of Portland cement are obtained from deposits of limestone, which furnish the calcium carbonate, and deposits of shale, which furnish the silica, alumina, and iron.

The determining factors in the value of a deposit of limestone for the manufacture of Portland cement are as follows:

(1) Chemical composition of material.
(2) Physical character of the material.
(3) Amount if the material available.
(4) Location of the deposits with respect to accessibility of the different ingredients.
(5) Location of the deposits with reference to transportation routes.
(6) Location of the deposits with regard to location of fuel supply.
(7) Location of the markets to be supplied.

With regard to the possibilities of turning the waste rock of the Southern Indiana quarry districts into Portland cement, it would be well to look at the deposits in the light of the above requirements. In chemical composition the Mitchell and Oolitic stone are both very well fitted for the manufacture of cement. In fact the Lehigh Portland Cement Company is operating a plant at Mitchell, Indiana, in which the Mitchell limestone is used altogether. The United States Cement Company plant at Bedford, Indiana, operated for some time with Oolitic stone and pronounced it of first-class quality. Both deposits are very high in their percentage of calcium carbonate and contain very little other material which could be considered as an impurity in the manufacture of cement. It is generally conceded that, other things being equal, no better stone deposits for the manufacture of Portland cement can be found anywhere.

In its physical characters the stone is well adapted to cement manufacture, as it is easily crushed and carries a low percentage of moisture.

The question of the available supply of material for the manufacture of Portland cement from the waste limestone of the quarry district introduces a number of problems that are rather difficult of solution. The amount of material necessary for a paying plant is large, and the problem of getting the waste to a centrally located plant raises difficulties of transportation which will be taken up late in this paper. In so far as the amount of material necessary for the manufacture of cement is concerned, the supply is practically unlimited, but the problem of its delivery at a central plant is difficult of solution.

The relation of the deposits of the limestone to the deposits of shale is favorable for economic operation. The shale used by the Lehigh Cement Company is brought from the Knobstone formation (near Brownstown and Sparksville, Indiana). These shale deposits are available for any plant operating in the southern part of the district, as several roads enter the stone belt from the east. This formation outcrops east of Bloomington along the Illinois Central railroad and would be available for a plant located at Bloomington. There are deposits of shale in the Chester formation which outcrops west of the city, but it is not known how extensive the deposits are or whether they are adapted in composition to cement manufacture. This feature is discussed in another part of the present report.

A cement plant located at either Bedford or Bloomington would be in a favorable position with regard to fuel supply, markets, and transportation routes generally. The belt is penetrated by at least five east and west roads and by the Monon running from the north to the south.

"Run of mine" and slack coal can be laid down in either town very cheaply, as the coal fields are less than forty miles from either place.

There are two general methods of cement manufacture known as the wet and dry method respectively. The process adopted in any locality depends upon the deposits to be worked and the economic conditions under which the work is to be carried on.

In the wet process the clay and chalk or marl are ground fine in edge runners with heavy rolls. This material is then mixed with about half its weight of water. This slime, or as it is called "slurry", is pumped into buhrstone or tube mills where it is given a thorough grinding. After this wet paste is dried, it is sent to the kilns where it is calcined. The burned clinker is then ground fine to produce the finished product. The Hoffman's ring furnace which has been described in the part of this paper treating of lime, is often used in calcining the cement. Another type of furnace much used is the Dietsch two-storied kiln. This is a continuous kiln the material being fed in at the top and discharged at the bottom. Tests made on this type of furnace with regard to the fuel consumption give about seven tons of clinker per ton of coal burned. The Hoffman furnace uses about the same amount of coal per ton of clinker.

In the dry process the materials, shale and limestone, are ground separately to a good degree of fineness; then they are carefully mixed in predetermined amounts by large mixing machines and this mixed material is charged into the upper end of a long rotary kiln. The fuel (powdered coal) is driven into the lower end of the kiln by compressed air and burns as it enters. The hot gases and flame are driven up the kiln and meet the mixture as it rolls down, on account of the rotating of the kiln. The burned clinker drops from the lower end of the kiln where it is picked up by a bucket conveyor, carried to the top of a high tower, and allowed to fall through space to cool. The fuel charged into this kiln is powdered coal, which gives a very high temperature, on account of the powerful draught produced by the compressed air.

The cooled clinker is charged into a mill where it is finely ground and the product is then ready for the storage bins.

The shale and the limestone are first ground by large crushers for coarse crushing and following these the material is fed to fine crushers and rolls in succession before mixing. The crushers most commonly used are crushers of the Gate gyratory type which reduce the material to about two-inch size. Fine crushers follow these and are usually of the Gates and Gardiner types. The material usually needs drying before it is mixed, and this is accomplished by conducting it through a smaller kiln into which the waste gases from the calcining kilns are conducted. The tube mills used consist of horizontal iron tubes about 16 feet long by four to six feet in diameter, which rotate on a shaft, making about twenty-five revolutions per minute. The tube is about half full of flint pebbles, about the size of a hen's egg and these produce a grinding action as the tube rotates. These pebbles are retained in the tube by the screens at the outlet end through which the ground rock passes. The rock is fed to the mill by means of belt conveyors and a new supply of pebbles is charged into the tube as fast as the old ones wear out. The rapidity of rotation and the rate of the feed determine the fineness of the product.

This fine grinding of the clinker is often done by Griffin mills which consist of a heavy steel roll revolving on a vertical shaft with a gyratory motion, and pressing by centrifugal force against a steel inclosing ring. These mills have a great capacity and will grind very fine, but the cost of upkeep is much greater than with the tube mill. After leaving the Griffin mill the ground clinker is in some modern plants passed through tube mills, which grind it finer than is possible in the Griffin mills.

The power required in the manufacture of cement is given by Professor Bleininger of the Illinois Survey as 1.5 horsepower per barrel of output—that is a 1,000 barrel plant would require 1,500 horsepower. This is rather high for the larger plants where one horsepower per barrel of output has been realized. One 5,000 barrel plant is now operating on 4,500 horsepower.

The fact that the deposits of material for the manufacture of cement are located near coal mines does not always insure a cheap supply of fuel under present conditions where powdered coal is to be used as a fuel in the kilns. Many coals are not suited for the burning of cement, as the ash from the coal mixes with the cement in the kiln; and in the case of a coal of high sulphur content or high percentage of ash these impurities may spoil the cement. Coal must have a high heating value, as the temperature of the kiln should be kept up to about 2,500 degrees Fahrenheit. To insure even heating throughout the entire length of the kiln, the coal should contain a large amount of volatile matter. These considerations are so important that the location and supply of fuel becomes more important than the location of the deposits of cement material. As mentioned above, the cement deposits are located near the Indiana coal fields, but at the present time the Indiana plants are using Pittsburg coals. This difficulty could be remedied by the use of producer gas in the kilns. In fact the use of gas is increasing even in the coal districts of West Virginia and Pennsylvania. The advantages of the use of producer gas as a fuel for the manufacture of lime or cement are many and the use of gas as a fuel in both industries is sure to grow rapidly. Producer gas is better than coal for the following reasons:

(1) The absence of ash in the burned product. In the producer gas the ash remains behind in the producer and only the combustible gases are passed into the kilns to burn, thus insuring a purer product.

(2) The presence of a great amount of water as the gas burns. A large percentage of the gas consists of hydrocarbons and hydrogen, and the combustion of these gives water. This is of especial advantage in the manufacture of lime.

(3) The high heating value of the gas.

(4) The ready control of the point of burning and the temperature.

(5) The fact that any coal can be utilized in the manufacture of gas.

## Cost of Cement Manufacture.

The cost of the raw materials varies greatly in the different districts. Estimates on the loss of weight due to burning the raw material to cement clinker are: for dry, hard limestone and shale about thirty-three and one-third per cent., that is, 1,000 pounds of the mixture of limestone and shale will give about 665 pounds of cement clinker. A barrel of Portland cement weighs about 380 pounds, and Eckel states that if the losses of manufacture are included, it is safe to say that 600 pounds of raw material will produce a barrel of cement. The cost of excavation and delivery is given as from eight to fifteen cents per barrel. That represents a cost of from 27 to 50 cents per ton of raw material at the mill. Since it takes from four to five carloads of limestone per carload of shale and the price of limestone delivered in the quarry district is very low, the shale could be brought quite a distance without exceeding the above figure.

The fuel cost, as has been already stated, is a more important consideration than the cost of raw materials. In the use of powdered coal the coal must be dried, then crushed. The average moisture content of coals is about 8 per cent. and under favorable conditions it takes about a pound of fuel per hundred pounds of coal to dry it. The best type of dryer now in use is the rotary dryer. At the above figures the cost of drying fuel will be about three to four cents per ton of dried product. Coal, to give the best results, when powdered, for cement burning, must be very fine, and the usual practice is to reduce it to such a size that from 85 to 95 per cent. will pass a hundred-mesh sieve. The poorer the grade of coal used the finer it must be powdered. The coal is usually powdered by two operations. It is first reduced to about 30-mesh by means of ball mills and then fed through a tube mill. This process may be varied to fit the conditions in any mill, although the price will total about the same.

The total cost of crushing (provided fine slack is not obtainable), drying, and pulverizing the coal, together with the cost of elevating and conveying the coal to the kilns, will amount to as much as thirty cents per ton, which is equivalent to from one to two cents per barrel on the cost of the cement.

Power cost in a cement plant is also a large item. The power consumption is estimated as one horsepower per barrel of output per day, while a cost of one cent per horsepower is low except in the very large plants. Of course many plants are saving a part of the heat from the kiln and using it in the form of power, but even with this saving it will be seen that the cost of power is bound to be fairly heavy.

The cost of labor varies so in different localities that any figures will be only approximations. Professor Grimsley gives the relative cost of production as follows: fuel 35 per cent. of total cost, labor 45 per cent. and other expenses 20 per cent.

In Bulletin 3 of the Ohio Geological Survey the following figures are given for the cost of production per barrel of cement:

| | | |
|---|---|---|
| *Labor.* | | |
| Quarrying | $0.050 | |
| Crushing and drying | .005 | |
| Grinding | .015 | |
| Burning | .015 | |
| Power generation | .011 | |
| Coal grinding | .010 | |
| Yard work | .015 | |
| Machine shop | .0225 | |
| Miscellaneous | .0025 | |
| | | $0.15 |
| *Raw Materials.* | | |
| Coal | $0.225 | |
| Gypsum | .0125 | |
| | | $0.2375 |
| *Accessory Expenses.* | | |
| Repairs | $0.04 | |
| Oil | .02 | |
| Miscellaneous | .03 | |
| | | $0.09 |
| Packing and loading | $0.04 | |
| Works and management | .02 | |
| | | $0.06 |
| Interest on investment ($700,000) | $0.07 | |
| Sinking fund and deterioration | .10 | |
| Management and selling expenses | .065 | |
| | | $0.235 |
| Total per barrel of output | | $0.7725 |

The total cost of production in Michigan is figured as follows in Volume 8 of the Geological Survey of that State::

| | |
|---|---|
| Total cost of materials and labor of manufacture | $0.4785 |
| Overhead and selling cost | .2015 |
| Total | $0.68 |

The figures given above are on a plant with an output of 1,200 barrels per day. The cost of production would fall below this figure in a larger plant for the reason that several of the items quoted above will not increase in the same ratio as the increase of output.

No reliable figures are at hand on the cost of production in Indiana; but as the two States from which I have quoted prices are bordering states and operate under the same conditions, the figures for Indiana will be somewhere near those quoted above.

The cement industry has reached a point where cost of production and selling price are so close together that cement can only be manufactured economically in large plants. In fact with the selling price where it is the profits are very small in any plant with an output below 3,000 barrels per day.

Since it requires over 400 pounds of limestone to the barrel of cement, on account of the losses from ignition, a 3,000 barrel plant would require at least 600 tons of waste limestone per day. This would be equivalent to approximately 7,000 cubic feet of stone per day, or over two millions cubic feet per year for a steady run. Figuring on the same basis, a 5,000 barrel plant would require nearly three and a half million cubic feet of limestone per year. The superintendent of the plant at Mitchell gives 30 carloads per day, which very closely approximates the above figures.

Although the waste of the quarry district is probably considerably more than this amount during an active year, the collecting of this amount at a central plant with any degree of regularity would be impossible. It will thus be seen that a cement plant could not be constructed to use the waste of the quarry district economically, at least unless a special quarry were run to carry the plant over slack times. Another thing that would make it uneconomical, is the fact that most of the waste is in the form of large blocks which would need blasting and sledging before they would be in a condition in which they could be fed to the crushing machines. In fact this cost would be almost as much as the cost of blasting the material off the "solid" ledge with high explosives, with which also a large percentage of fine material would be produced.

Transportation charges to a central plant would be at least five cents per ton. (The price now paid for moving cars in the district if the product is to be hauled again.)

If the cost of material and the charges for loading it on the cars be added to this, the total figure will exceed twenty cents per ton at the mill. Practically every estimate of engineers as to the cost of mining the raw material and delivering it at the mill is as low or lower than this, where the deposits can be worked by quarrying with high explosives. It will thus be seen that this method of waste utilization does not commend itself as a means of solving the problem in hand.

There are a number of old quarries or openings that have been worked out or have proved poor building stone, that could be optioned at a very low figure, and many of these contain almost unlimited supplies of limestone that, while it will not make good building stone, would make a high grade of cement. In many cases the railroad tracks are still in position and where removed the grade still remains. Feeling that these might be utilized, I asked several companies interested in stone quarrying with explosives to give estimates of the cost of blasting the material of the solid ledge and delivering it to the crusher for a cement plant located near these quarries.

Among the answers received, the data furnished by the E. I. duPont de Nemours Company as to the cost of blasting with high explosives were very full and helpful.

Much work has been done by the United States Bureau of Mines on the production of explosives especially fitted for different grades of work and as a result much information is at hand as to the explosive best suited to the work in hand and the uses to which it can be put. These bulletins are for free distribution by the Director of the Bureau of Mines and can be had for the asking.

The following letter received from H. S. Gunsolus, Manager of the Technical Division of the duPont company will be of interest in this connection to any company interested in blasting out limestone for cement:

### Quarry Blasting.

"Your letter of December 30th, in reference to the cost of explosives per cubic yard for blasting limestone to be used for fertilizing material is at hand.

"We have not replied earlier, due to our wishing to get some information together which might be of assistance to you. We are going to list below a number of shots which have either been supervised or witnessed by some of our own technical men and feel sure that the figures given are approximately correct. You understand, of course, that the variation in cost is due to local conditions, stratification, mud seams, etc., as well as the size crusher to be used, which of course will regulate the size of the broken stone.

"In limestone, used for railroad ballast, we had eight holes, spaced eighteen feet apart. Average face burden nineteen feet; average depth forty-eight feet, approximately 4,900 cubic yards.

There was used 3,300 pounds 40 per cent. dynamite, making a cost per cubic yard of about .084 per cent.

"A blast in cement rock, nine holes, spaced 22 feet apart: Average face burden 32 feet; average depth of hole 62 feet; approximately 13,000 cubic yards. For this there was used 2,500 pounds 60 per cent. dynamite and 1,800 pounds 40 per cent., making a cost of about .046 cents per cubic yard.

Another blast in cement rock of seven holes, spaced 15 feet apart: Average face burden 23 feet; depth 60 feet; about 5,400 cubic yards. For this there was used 500 pounds 60 per cent. and 2,900 pounds 40 per cent. dynamite, making cost of about 8 cents per cubic yard.

"Blast in hard, massive limestone, eight holes: Average space between about 28 feet; average face burden 33 feet; depth of holes about 95 feet; approximately 26,000 cubic yards. For this there was used 2,200 pounds blasting gelatin, 3,350 pounds 60 per cent. and 1,250 pounds 40 per cent. dynamite, making cost per cubic yard of about .046 cents.

"Blast in limestone for lime manufacturing, of three holes, spaced about 17 feet apart: Average face burden 24 feet; average depth of holes 100 feet; approximately 4,600 cubic yards. The dynamite used amounted to 1,200 pounds 60 per cent. and 1,600 pounds 40 per cent., making an average cost of .032 cents.

"Another blast in limestone for cement manufacture, nine holes, spaced about 20 feet apart: Average face burden 36 feet, and about 53 feet in depth; approximately 12,700 cubic yards. For this there was used 1,720 pounds 60 per cent. and 2,500 pounds 40 per cent., making cost of .045 cents per cubic yard.

"Another blast consisting of four holes 18 feet apart with about 25 feet face burden and 100 feet deep; approximately 6,700 cubic yards, for which there was used 2,200 pounds 60 per cent. and 1,600 pounds 40 per cent., making average cost of .056 cents per cubic yard.

"Eight holes blast spaced 15 feet apart, with a face burden of approximately 25 feet, holes 115 feet deep; about 12,800 cubic yards, for which was used 3,950 pounds 40 per cent. and 2,000 pounds 50 per cent. Cost per cubic yard being about .038 cents.

"Sixteen 70-foot holes, face burden of 25 feet, spaced about 15 feet apart; approximately 15,000 cubic yards, for which was used 3,750 pounds 60 per cent., 4,050 pounds 40 per cent., making cost per cubic yard of about .068 cents.

"Another, nine 50-foot hole blast, spaced 18 feet apart, with 25-foot face burden; approximately 7,500 cubic yards, for which there was used 3,350 pounds 40 per cent., making cost of .055 cents per cubic yard.

"Seven 60-foot holes spaced 15 feet apart, with about 20 feet face burden, approximately 4,600 cubic yards. For this was used 500 pounds 60 per cent., 2,900 pounds 40 per cent.; making cost of .095 cents per cubic yard.

"Eight holes which ran from 80 to 108 feet in depth spaced 27 feet apart, with 30-foot face. There was about 22,000 cubic yards in this shot, for which there was used 2,200 pounds blasting gelatin, 3,350 pounds 60 per cent. and 1,200 pounds 40 per cent., making cost of about .055 cents per cubic yard.

"Another eight 48-foot hole blast, spaced 18 feet apart, with 20-foot face burden, approximately 4,500 cubic yards, for which there was used 3,300 pounds of 50 per cent., making average cost of about 10 cents per cubic yard.

"A nine 62-foot hole blast, with a 32-foot face burden, spaced about 20 feet apart, approximately 13,300 cubic yards, used 2,500 pounds 60 per cent and 1,800 pounds 40 per cent., making average cost of about .045 cents per cubic yard.

"Had a 14-86-foot hole, spaced 18 feet apart, with a 30-foot face burden, making approximately 24,000 cubic yards. Used 850 pounds 50 per cent., 3,250 pounds 40 per cent. and 4,000 pounds 60 per cent., making cost of about .046 cents per cubic yard.

"Another shot was five 85-foot holes, spaced 18 feet apart, with about 25-foot face burden, about 5,000 cubic yards, for which there was used 1,300 pounds 60 per cent. and 1,000 pounds 35 per cent. This cost about .06 cents per cubic yard.

"These figures are taken from various sections of the country, not being confined to any particular locality, and we have figured the explosives on basis of 12½ cents for the 40 per cent., 13.7 cents for the 50 per cent., and 14.9 cents for the 60 per cent., and 25 cents for the blasting gelatin. These are about the average figures, and of course vary according to the location.

"Thinking perhaps you might be interested in the comparative cost between the steam or air drill and the well drill system:

"One of our technical men made a close study of this and found that the cost of drilling with an ordinary tripod drill varies from 10 cents to 25 cents per foot, this wide variation depending on the nature of the rock, cost of labor, fuel, oil, the number of drills in operation and the accessibility to source of power—water, etc. The fewer the drills in operation, if run from a central power plant, the higher the cost per foot.

"In rock of medium hardness, such as limestone, a man working industriously should average about 50 or 60 feet of hole per 10-hour day. The cost of drilling such rock seldom falls below 15 cents per foot in a quarry operating several drills.

"The cost of drilling a 5-5/8-inch hole with a well drill varies from 20 cents to 50 cents per foot, the general average being somewhere around 30 cents. A good operator and helper in ordinary limestone can make from 15 to 40 feet per day of 10 hours.

"A 25-foot headway is a very good average. Room for comparison—180 feet of drilling with each type of drill. Relative cost, 15 cents per foot for steam drilling, and 30 cents per foot for well drilling. Steam drilling 180 feet at 15 cents is $27.00. At a 7x7 spacing nine 20-foot holes will break about 325 cubic yards. About 140 pounds of 40 per cent. dynamite would be required, which would amount to $17.50, this, plus the cost of drilling, making $44.50. Breaking of 325 cubic yards would mean cost of about 13.6 cents. Working this by well drill system, take three 60-foot holes, drilling 180 feet at 30 cents equals $54.00. At 20x20 spacing thirty 60-foot holes will break approximately 2,600 cubic yards. About 1,300 pounds of 40 per cent. explosive would be needed, which would cost $168.75, making total of $222.75 to get out 2,600 cubic yards, or about .085 cents per cubic yard.

"We trust that this information will be of some interest and benefit to you, and that we have not delayed so long that you cannot use it in your paper, which we understand you are preparing for report of the State Geologist.

"Yours very truly,

(Signed) MANAGER TECHNICAL DIVISION.

Practically all the data furnished by other companies, although not given in detail, agreed with the above figures as to cost when the conditions under which the blasting was done were the same.

It will be seen that the cost of blasting out material in large amounts in localities such as this district would approximate eight cents per cubic yard. Figures on the cost of transporting this material to the crushers in a form in which they can use it (that is, including the cost of extra blasting and sledging where necessary) would be about the same figure, while labor and capital charges on the machinery would be about 26 cents per cubic yard, giving a total of about 44 cents per cubic yard for the limestone. This is about 19 cents per ton. Calculating along the same line, the cost of shale winning is about 11 cents per ton under favorable conditions. This makes the raw material cost on an average 17½ cents per ton or about 5¼ cents per barrel of output. (These figures are made on four parts of limestone to one part of shale and 600 pounds of raw material per barrel of cement burned.) It will be seen that this figure is rather low as compared with the figures given by engineers on the subject, but when it is taken into account that the deposits of limestone are in a very favorable location for quarrying in this district and no calculations have been made on the cost of bringing the materials together at a central plant the figure can be taken as a close approximation of the cost.

The demand for cement is growing rapidly in this country and as soon as cheaper methods of power production and cheaper fuels are utilized the industry is sure to be a good paying venture. The fact that the difference between cost of production and selling price is so small is an added incentive to the development of better methods and machinery of production.

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# CRUSHED LIMESTONE FOR ROAD MATERIAL, RAILROAD BALLAST AND CRUSHED ROCK CONCRETE.

The value of the output of crushed limestone for road making, railroad ballast and crushed rock concrete is greater than that of any other limestone product. In 1913 this output was 35,169,528 short tons, or approximately 470,000,000 cubic feet of limestone, with a value of $19,072,224. The output was divided up as follows:

Road making, 13,296,377 short tones, value $7,353,665.

Railroad ballast, 11,774,121 short tones value $5,551,415.

Concrete, 10,000,030 short tons, value $6,167,144.

The average price of this material was 54 cents per ton. In road making Indiana ranked third, with an output of $956,234, being outranked by Ohio and New York. In the production of railroad ballast Indiana was tenth with an output of $203,431. In the use of limestone for concrete Indiana ranked sixteenth with an output of $103,855.

The two properties of limestone which are of importance in its use as a road making material, are its wearing qualities and its cementing properties. The subject of good roads has attracted wide atention in a number of States, and while there are a great variety of rocks which can be used as a road metal none are better adapted to the work than a good hard grade of limestone.

The limestone of the Mitchell, which must be removed as stripping in many of the quarries, is admirably adapted to road construction, for it is a very hard limestone with good wearing qualities. The stone, although hard, is easily crushed because it is not tough but brittle, and it works up easily.

The stone of the oolitic formation is a softer stone and will not wear long on roads which are subject to heavy traffic. When a road receives a thick covering of this stone the surface of the stone coating tends to run together and becomes firmly cemented. If the travel is not too heavy during the time the material is setting the road will harden down in good shape. But if the traffic is heavy the stone is ground fine before it becomes cemented together. The roads of Monroe and Lawrence counties are to a great extent built of limestone, most of the material being taken from the Harrodsburg and Mitchell limestones which outcrop in those vounties. Most of these roads are in good condition, although some of them have been in use for a long time without any especial care.

The waste limestone resulting from the removal of the overlying Mitchell limetsone in many of the quarries is an ideal road metal, and if transportation charges were reasonable its use through the State would give Indiana far better roads than exist at the present time in many parts of the State.

The Office of Public Roads of the United States Department of Agriculture maintains a testing plant for the testing of road materials and many specimens have been tested, including eight samples of limestone from Lawrence County and five samples of limestone from Monroe County. All of these samples, although showing a low value for toughness, were high in their cementing value and good in hardness and percentage of wear. The data on these tests can be found in Bulletin No. 44 of the Office of Public Roads. Indiana has reached a period of active road improvement; and it would be a good thing for the quarrymen who are puzzling over methods of waste disposal to see that the limestone of Monroe and Lawrence are sufficiently advertised and brought to the notice of the officers in charge of road construction in the State.

The railroads that have tried to use the oolitic limestone for railroad ballast have been inclined to report unfavorably on it. The roads that have used the Mitchell ballast report that it is very satisfactory, but the softer oolitic stone will not give a firm enough bed. Where this latter stone has been used it has usually been over harder ballast which has previously been used. The softer stone held by the hard particles is under such conditions ground as in a ball mill by the jar of the passing trains. It is likely that if the entire bed of the road could be made of the soft stone, it would tend to cement into a solid mass and become in a way monolithic. If the material were ground reasonably fine before being placed in position, then wet down and allowed to settle, the jarring action of the passing trains would not tend to grind it fine as happened in the experiments mentioned above. Much of the waste from some of the quarries has been removed for ballast, but in most cases it was given to the railroad for removing it. In most cases the operator loaded the material free of charge.

In concrete work much crushed stone is used. The strength of the concrete is measured by the strength of the cement and so concrete made from crushed limestone is practically as strong as that produced from any other stone. In the manufacture of concrete the crushed rock should be angular, as the resulting aggregate is stronger than when made with worn particles.

In any of the above uses the material need only be crushed to, say, two-inch size, so that a single coarse crusher is all that is needed. The most common type used in this work is a Blake jaw crusher.

Extensive tables on the cost of coarse crushing are given in the part of this paper treating of crushed limestone as a fertilizer, and these cost figures will apply equally well to the work on road material, as the same machinery is used for rough crushing in both cases.

The cost of crushing with a Blake type crusher ranges from three to six and one-half cents per ton, depending on the output of the crusher. The power consumed per ton crushed to two-inch size is about one-sixteenth of a horsepower per hour.

### Waste Limestone as a Slag for Blast Furnaces.

In the treatment of iron ore in the production of pig iron it is necessary to add some fusible material of low specific gravity as a means of removing the impurities present in the ore. The present method of ore treatment in use in this country is to feed the ore together with coke and limestone into the blast furnace by means of a pair of hoppers closed by means of bells. The object of the double valve is to avoid the escape of the furnace gases. Large quantities of air heated to 600 or 800 degrees Centigrade are forced into the lower part of the furnace at a pressure of from twelve to fifteen pounds per square inch. This air burns the coke and the heat thus generated melts the charge and as the materials settle to the bottom of the furnace the ore and the slag separate on account of their different specific gravities. The limestone is decomposed by the high temperature, giving up carbon dioxide and changing to calcium oxide or common lime.

The large amount of silica and clay or alumina which is contained in the ore unites with the lime from the limestone to form what is called the slag. This slag is the waste product in the manufacture of iron and usually has the following general composition: From 30 to 35 per cent. $SiO_2$, 10 to 15 per cent. $Al_2O_3$ and 50 to 55 per cent. CaO. The amount of limestone to be used with any given ore is determined by the amount necessary to produce an easily fusible slag.

If the slag is not to be made use of it is drawn off into large tilting ladle cars and dumped away. In most cases this slag has the proper composition for a good grade of cement, if properly handled. When the slag is to be used as material for the manufacture of cement it is drawn off into water, where it takes on a coarse granular form which makes it easy to handle. Great efforts are made to keep the slag of proper quality, and if a uniform grade of iron is to result the composition of the slag must be carefully watched.

Both limestone and dolomite are extensively used for fluxes throughout the country. Both these fluxes have their advantages, but as the manufacture of cement from blast furnace slags becomes more widespread, the demand for a high calcium limestone will increase, for the reason that the slags from dolomite flux are not suitable for cement manufacture.

The slag obtained from high calcium fluxes develops hydraulic properties when cooled quickly. This is accomplished by running the molten slag into water. The resulting granular product is dried and ground very fine, and mixed with a certain percentage of slaked lime. This mixture is again ground fine enough to pass a two hundred mesh sieve. The resulting powder will have the properties of a good hydraulic cement. This form of cement works best in places where it is constantly wet, since drying tends to disintegrate it.

Dolomite flux is favored in the Birmingham iron district, as shown by the following from the work of Burchard and Butts on Iron Ores, Fuels and Fluxes of the Birmingham District: "The fluxing power of dolomite is greater than that of limestone; an equivalent of carbonate of magnesia weighs eighty four while an equivalent of carbonate of calcium weighs one hundred; in fluxing power these equivalents are equal because the power of a base to combine with an acid does not depend upon its atomic weight but upon its chemical affinity. So the fluxing power of the two carbonates are to each other as 84 is to 100.

"The dolomite of this district is a great deal purer than the limestone. The foreign matter of the former does not exceed 2 per cent. while of the latter an average is at least 4 per cent. To determine the value of a stone as a flux we must deduct the impurities it contains, plus as much of the base as is necessary to flux these impurities. Taking the limestone as a 96 per cent. lime carbonate, and deducting 8 per cent. to take care of its own impurities we have left 88 per cent. of lime carbonate as available flux. Taking the dolomite to contain 2 per cent. of impurities and 43 per cent. of carbonate of magnesia, with 55 per cent. of carbonate of lime, we have left, after deducting 4 per cent. of the carbonate of lime to take care of the impurities, 43 per cent. of magnesia carbonate and 51 per cent. lime carbonate. The fluxing powers of the two carbonates are to each other as 84 is to 100, so reducing the magnesia carbonate to its equivalent in fluxing power of lime carbonate we have

$$\frac{43 \times 100}{84} + 51 = 102.19.$$

"Therefore the relative values of the two fluxing materials of this district are to each other as 88 is to 102.19."

In other words the dolomite flux is preferred because of its greater purity; but this objection to limestone will not apply to the waste limestones of the Southern Indiana quarry district, as none of the dolomites used for flux are any more free from impurities than the Oolitic limestones which often carries as high as 98.5 per cent. calcium carbonate. The overlying Mitchell limestone is, if anything, purer than the Oolite stone.

Another argument in favor of dolomite fluxing stone is that it gives a more liquid slag than a limestone.

In this regard I would say that very liquid slags are only necessary where the ore used contains a large amount of impurities. The only blast furnaces that could use our waste stone, on account of the high freight rates, are located around Gary and Chicago and use much higher grade ores than those needing very liquid slags.

Dolomite can not be used as a slag when the ores run high in sulphur. The lime carbonate is better than magnesium carbonate because the calcium has a greater affinity for sulphur than magnesium.

Since most of the ores now used from the ore fields of Michigan and Minnesota are high grade ores and carry some sulphur the demand for limestone slag is sure to increase even if the tendency to produce blast furnace cement does not increase, which it seems sure to do. This industry is developing rapidly in many foreign countries and seems almost sure to increase here, as the cost of such manufacture is very small and also offers an opportunity for the removal of a large amount of waste material.

Waste stone has been sent out of the Southern Indiana quarry district for use as flux in the steel mills of Gary and Chicago for a long time; but the amount has been small and the profit from this source to the quarrymen has amounted to little more than a method of getting the waste piles out of the way. This condition results from the excessive rates charged on such shipments by the railroads, or, at least, the conditions under which such shipments must be made. As soon as the railroad officials realize the amount of this material that could be carried if more favorable rates were made there will be a tendency to make better terms and provide better conditions.

One thing that has held back the development of this outlet for the waste stone of the district is the fact that in the past many quarry operators have adopted the practice of giving the waste stone to the railroads if they would remove it, even going so far as to load the material free of cost. Under such circumstances the profit, if any, has gone to the railroads and it has consequently been to their interest to charge relatively high rates on shipments of this material by individuals.

The total amount of limestone used for fluxes in the United States in 1913 represented a value of $11,103,989, of which Indiana produced $199,995, ranking ninth in the industry. This represented a production of 22,620,961 long tons at an average price of forty-nine cents per ton.

The production in 1912 was 20,190,554 long tons with a value of $9,937,772.00 with an average price of 49 cents per ton.

# LIMESTONE AND LIME IN THE MANUFACTURE OF GLASS.

"Glass is an amorphous, transparent or translucent mixture of silicates, one of which is always that of an alkali." The above definition of glass is taken from a work on industrial chemistry. The present paper is concerned only with the glass that contains calcium as the alkali metal. In the technical discussion of glass two general classes are recognized: lead glass and lime glass. The lime glass is most widely used, harder, cheaper, less fusible and has greater brilliancy than the lead glass. The essential materials for the manufacture of lime glass are silica; an aklali such as soda or potash; and lime or limestone. In the manufacture of glass materials free from iron or iron compounds must be used. The alkalies most commonly used are the carbonates or sulphate of sodium or potassium. The carbonates fuse more easily but the sulphates being cheaper are more commonly used. With the sulphate powdered carbon must be used as a reducing agent, the reaction being as follows:

$$2Na_2SO_4 + 6SiO_2 + C = 2(Na_2O, 3SiO_2) + 2SO_2 + CO_2.$$
$$2Na_2SO_4 + 2SiO_2 + C = 2Na_2SiO_3 + 2SO_2 + CO_2.$$

Common salt as a source of sodium in the manufacture of glass has not yet reached any extended use, but some method whereby it can be used economically is sure to be perfected. Lime, or more properly calcium, is obtained from limes or finely ground limestone. The lime has been used much longer than the limestone but has always given more or less trouble on account of the fact that it changes in volume, as it takes up carbon dioxide from the air. And this makes it difficult to mix the constituents of the glass in the correct proportions. The fact that the only form in which the limestone can be used is as a finely ground powder makes this a very good way for the plants turning out ground limestone for fertilizing purposes to dispose of their product during the dull season. The one plant already turning out ground limestone in the quarry district disposes of a large amount of its surplus product in this way.

The ground limestone can be used at the same mesh for glass manufacture as it is turned out for fertilizer, thus doing away with the necessity of installing extra screens. The manufacture of glass in this country has greatly increased during the last year or so and is sure to grow to a great industry in the next few years.

The chemical composition of the limestones of the Southern Indiana quarry district makes them very well adapted to the manufacture of glass, as they are very high in calcium carbonate and contain only traces of iron and aluminum. The demand for the ground limestone of this district is sure to grow when it becomes generally known that the chemical composition of the stone is so well adapted to this industry.

The final reactions in the manufacture of lime glass are as follows:

$$Na_2CO_3 + CaCO_3 + 2SiO_2 = Na_2Ca(SiO_3)_2 - 2CO_2.$$

Or,

$$Na_2Sio_3 + CaCO_3 + SiO_2 = Na_2Ca(SiO_3)_2 + CO_2.$$

Data on the amount of stone used for the purpose of glass manufacture in this country are not at present available, since the government reports on the amount of stone used give the stone used in glass factories, paper mills, carbonic acid plants, and for fertilizing purposes in one group, and it is impossible at present to get separate data on the subject.

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# MINOR USES OF WASTE LIMESTONE.

## LIMESTONE IN THE LeBLANC PROCESS OF SODA MANUFACTURE.

As a result of chemical experiments stimulated by the offer of a large prize by the French Academy of Science in 1775, Nicholas LeBlanc patented the process of soda manufacture which remains in use to the present time. The only other process at present in competition with it is the Solvay process, which will be mentioned later The LeBlanc Process consists of treating common salt with sulphuric acid to produce hydrochloric acid and acid sodium sulphate, or at higher temperature the normal sodium sulphate. The first reaction is as follows:

$$2NaCl + H_2SO_4 + 2HCl + Na_2SO_4.$$

The sodium sulphate is mixed with limestone and coal or charcoal and calcined in a reducing flame, forming a mixture of calcium sulphide and carbonate of soda. This reaction takes place as follows:

$$Na_2SO_4 + 2C + CaCO_3 = Na_2CO_3 + CaS + 2CO_2.$$

The sodium carbonate and calcium sulphide can be readily separated by leaching with moderately warm water as the sulphide is practically insoluble while the carbonate is easily soluble. This industry has been able to hold its own with the newer processes on account of the fact that hydrochloric acid and bleaching powder are produced as by-products of the process. At least one-half the world's supply of carbonate of soda is produced by the LeBlanc Process at the present time.

The manufacture of lime chloride, or muriate of lime, can be carried on along with the process of soda manufacture, as the only chemicals needed are limestone and weak solutions of hydrochloric acid. When limestone is treated with a dilute solution of hydrochloric acid and the solution concentrated by evaporation and allowed to cool, crystals of lime chloride will be deposited. These crystals will have the composition ($CaCl_2$, $6H_2O$), but when they are heated they will lose two-thirds of the water, leaving a porous lime chloride which has a wide use as a drying and dehydrating agent in chemical laboratories. At the present time, a large supply of this compound is produced as a by-product of the Solvay Process of soda manufacture.

## THE SOLVAY PROCESS OF SODA MANUFACTURE.

The reactions of the ammonia process, later known as the Solvay Process, were first discovered by Dyar and Hemming in 1838, but no use was made of them till Solvay, a Belgian, constructed an apparatus for their use in 1863. Its advantage over the LeBlanc Process lies in the fact that there are no troublesome by-products, such as "tank waste", formed. No hydrochloric acid or chlorine is formed in the process, as these all pass into the form of calcium chloride. The process depends on the fact that sodium bicarbonate is but slightly soluble in cold ammoniacal solutions of common salt. The most important part of the process depends upon a careful regulation of temperature. The chemical reactions involved in the process are as follows:

$$NaCl + NH_3 + H_2O + CO_2 = NaHCO_3 + NH_4Cl,$$

which is salt, plus ammonia, plus gas, plus water, plus carbon dioxide, equals sodium bicarbonate plus ammonium chloride.

The carbon dioxide is obtained by burning limestone in a specially constructed kiln so arranged as to save the carbon dioxide. This gas is forced upward through a tower in which a concentrate brine of common salt charged with ammonia is flowing down. The temperature of the whole is kept at 35 degrees Centigrade. The sodium bicarbonate, being less soluble than the other constituents, is separated from them on filters. The bicarbonate is readily changed to carbonate by heating. The liquor which passes the filters is treated with the lime formed in the production of the carbon dioxide gas used in the tower, and the following reaction takes place:

$$2NH_4Cl + CaO = 2NH_3 + CaCl_2 + H_2O.$$

The liquor will contain calcium chloride and some sodium chloride. These are separated by crystallization, since the salt is more soluble and remains in solution. The ammonia and salt solution can be used again, so there is no waste. The limestone used in either this or the LeBlanc Process must be very pure, as the presence of iron, silica or magnesia interfere with the reactions and the purity of the product.

### Carbon Dioxide Recovery.

In the manufacture of lime there are large quantities of carbon dioxide driven off. This gas is now used extensively for charging mineral waters and in the manufacture of paints. It is usually made for these industries by the action of weak acids on lime carbonate, using marble or a limestone in the operation. Since this gas can be condensed to a colorless liquid under a pressure of 50 atmospheres and easily handled it seems like an unnecessary loss to allow it to escape in the manufacture of lime, and then produce it as it is needed in other industries.

This recovery of $CO_2$ is already in operation in England, and the more progressive lime plants of this country are sure to install it in the near future.

### Limestone in Lead Smelting.

The Savelsburg process of lead smelting consists of heating an intimate mixture of galena or (lead sulphide) with limestone and water, in a reverberatory furnace in a strongly oxidizing atmosphere. The resulting mass contains the lead in the form of an oxide and calcium sulphate, from which the lead can be removed by any of the ordinary methods of shaft furnace purifying. This process is often carried on with lime instead of limestone. These methods are giving way to direct blast furnace oxidation as this can be accomplished if the temperatures are carefully regulated.