Ivory Plaster of the English Mill.

	Per cent.
Silica and insoluble material	2.13
Lime oxide (CaO)	36.89
Sulphuric anhydride (SO_3)	52.19
Oxide of iron (Fe_2O_3)	0.36
Water	8.55
	100.12

By calculation the analysis would give:

	Per cent.
Silica	2.13
Lime sulphate	88.71
Lime carbonate	0.67
Water	8.55
Iron oxide	0.30
	100.36

Granite Plaster of the English Mill.

	Per cent.
Silica and insoluble material	1.50
Lime oxide (CaO)	37.23
Sulphuric anhydride	52.10
Oxide of iron	trace
Water	8.81
	99.64

By calculation:

	Per cent.
Silica	1.50
Lime sulphate	88.55
Lime carbonate	1.43
Water	8.81
Iron oxide	trace
	100.29

Plasticon Plaster of the Alabastine Mill.

	Per cent.
Silica and insoluble material	1.60
Lime oxide	38.29
Sulphuric anhydride	50.11
Loss, moisture, etc.	9.20
	99.20

By calculation:

	Per cent.
Silica	1.60
Lime sulphate	85.14
Lime carbonate	5.84
Water	6.63
	99.21

This sample showed traces of iron oxide and magnesia oxide.

Alabastine Plaster of the Alabastine Mill.

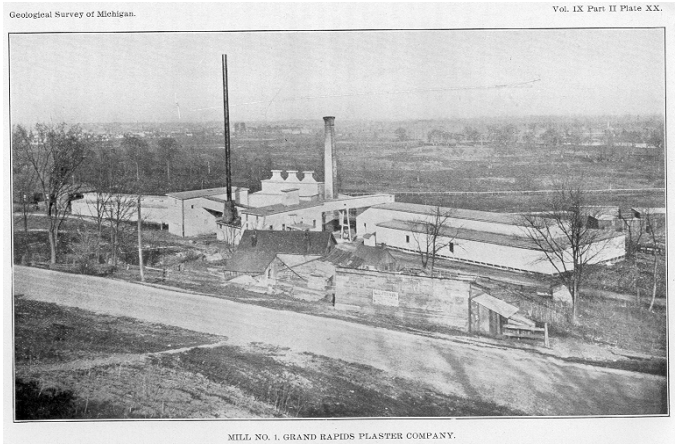
	Per cent.
Silica	1.38
Lime sulphate	85.91
Lime carbonate	4.48
Water	7.48
Iron and alumina	0.75
	100.00

Granite Plaster of the Powers' Mill.

	Per cent.
Silica	8.64
Lime sulphate	72.45
Lime carbonate	7.96
Water	4.94
Iron and alumina	1.03
Magnesium carbonate	4.98
	100.00

An examination of these analyses shows that the lime sulphate varies from 72.45 per cent in the Power's mill plaster to 92.95 per cent in the Alabaster plaster. The impurities vary from 22.6 to 2.06 per cent. The water percentage varies from 4.94 to 8.81 per cent. The loss of water in the calcining of these plasters is 74, 60, 55 per cent.

These analyses compare favorably with those given of the French plasters and with those from other districts in this country.



[XX. Mill (No. 1.) of the Grand Rapids Plaster Co.]

CHAPTER X.

PHYSICAL EXAMINATION OF GYPSUM WALL PLASTER.

§ 1. Introduction.

The physical examination of a Portland cement is regarded as of much more practical value than the chemical analysis. Contracts are made on the basis of such examination and all cements are carefully tested before being accepted for construction work, and the tests are carried along as the work progresses. There has grown out of this demand, a system of testing,[1] which is used with certain variations throughout the world, and is even a subject of legislative and governmental control.

In the case of gypsum cement wall plasters such tests are seldom asked for by the trade, and they are not often made except by the manufacturing companies themselves to secure a control over their product, so they may send out a uniform plaster. Such tests for scientific purposes have been made in this country by the University of Wyoming and by the Iowa Geological Survey. Before the results of either of these departments were published, the writer began work on the same lines and while the results have been partially outlined in the meetings of the Kansas Academy of Science, this is the first published account of the work.

The growing use of plaster in construction, as "staff" etc., will probably lend importance to these tests in the future.

Uniformity in results from cement tests and from gypsum plaster tests are difficult to secure and the personal error as well as the errors of manipulation are leading features in all such tests. Not only do tests on the same material by different persons vary, but even those made on the same material by the same person show variations in results often impossible to explain.

In testing hydraulic cements attempts have been made to establish standards for comparative purposes. This is seen in the work of the German Association of Cement Manufacturers, the French Government Commission in 1891, and in the conferences of the International Association for Testing Materials. In this country there have been no government commissions appointed for this purpose, but in 1885 a committee appointed by the American Society of Civil Engineers reported on a set of rules for cement testing which have served as a standard for the work of testing cements in the U. S. In 1899 another committee was appointed by this society to revise these rules and bring them up to date.

In my own work I have taken the rules of testing Portland cements and adapted them to use with the gypsum plasters.

[1]In the description of the methods of testing cements, the author wishes to give due credit to the articles of R. L. Humphrey in the Journal of Franklin Institute, as well as the various articles in the Proceedings of the American Society of Civil Engineers. See also Mr. Humphrey's paper at the end of Volume VIII of these reports.

§ 2. Fineness.

The fineness of grinding of cement is measured by the percentage of residue on No. 50, No. 100, No. 200, sieves having approximately 2,500, 10,000, and 40,000 meshes per square inch. A good cement leaves practically no residue on the No. 50 sieve. According to Humphrey, the sample should be thoroughly dried at a temperature of about 130° F. and the operation can be considered complete when not over 1-10 of 1 per cent passes through after five minutes of continual shaking1:

While in Portland cements the fineness of grinding is one of the essential parts of the manufacture, in gypsum plasters for ordinary uses, exceptional fine grinding is not required and the extra cost of such grinding would not justify the work. Taking two plasters which are sold in the Kansas market, and they show the following variation in fineness:

	Per cent.
Not passing through 20 mesh sieve	0.59
Not passing through 40 mesh sieve	8.7
Not passing through 60 mesh sieve	8.1
Not passing through 80 mesh sieve	8.9
Not passing through 100 mesh sieve	15.1
Through 100 mesh sieve	57.4
Lost in sieves	1.21
	100.00

	Per cent.
Not passing through 20 mesh sieve	0.48
Not passing through 40 mesh sieve	5.35
Not passing through 60 mesh sieve	2.21
Not passing through 80 mesh sieve	2.83
Not passing through 100 mesh sieve	3.41
Through 100 mesh sieve	84.56
Lost in sieves	1.16
	100.00

§ 3. Weight.

According to Michaelis a good Portland cement should not weigh over 75 pounds per cubic foot. The specific gravity runs from 2.72 to 3.05. The gypsum rock runs about 2.3 and the calcined plaster has a specific gravity of 1.81. A cubic foot of plaster of Paris weighs 54.76 pounds determined on Grand Rapids plaster. When set it weighs 103.3 pounds, and with two parts sand to one part plaster a cubic foot weighed 126.2 pounds.

§ 4. Gauging of Plaster.

The preceding tests are applied to the dry material, other tests usually looked upon as more important are applied to the cement or plaster mixed with water. The amount of water used in the mixtures is important in all comparative examinations.

Briquettes made from different proportions of water are found to vary in the tests made. It is then important to determine the percentage of water necessary to make the pats and briquettes of plaster of just the proper

consistency for manipulation. The proper mixture has been termed the “normal consistency” of a cement. In many laboratories great care is taken to determine this amount of water.

"At the Charlottenburg testing laboratory in Germany it is the practice to determine the percentage of water to be used, by mixing the cement to a syrupy paste so that it will run from a knife (6 by 1½ inches) in long thin threads without forming lumps. Representing the quantity of the water for this condition by N, then the percentage of water (W) required to produce a normal consistency is obtained from the formula $W = \frac{N+1}{2}$ for neat tests and $W = \frac{N+3}{4}$ for sand tests (1 to 3)” (Humphrey.)

A simple method is also given by Humphrey which he states gives results closely agreeing with the preceding. This consisted of moulding the plaster in a ball and dropping it from a height of one foot. The ball is of the proper consistency when it does not flatten materially or crack in this experiment.

In the present work on gypsum plasters different proportions of water were used until a normal consistency was determined, which would thoroughly moisten the plaster and, on striking with a trowel, would show a moist surface but not bring water to the surface. Different brands of plaster required slightly different percentages of water. In the earth plasters 30 per cent of water represented the average amount to be used, while in the plasters made from the rock, 40 per cent was required. For sand mixtures of earth plaster, 13.4 per cent of water was used.

§ 5. Time of Setting.

The time of the beginning of set and the time of final set in cement and plaster give a classification into rapid and slow setting. Ordinary plaster of Paris sets in a few minutes but by the addition of a retarder the set may be delayed two hours or even twenty-four hours.

The fact that some gypsum plasters run uneven in the time of set is considered by the practical plasterers as an argument against them. The workman uses one day a plaster of certain make which sets as a fairly slow plaster and if the next lot of plaster has a quicker set, he has trouble with the wall unless he uses considerable caution. Certain brands run remarkably uniform in time of setting and stand in high favor with the trade. The cause of this variation is not usually sought for by the manufacturer. The careful chemical examination employed in all Portland cement mills, is seldom made in gypsum mills. The material is placed in the kettles, burned so long, and a certain amount of retarder added, and the finished product is ready for the market. In gypsum rock quarries the quality is usually uniform, but in many of the earth deposits the variations are marked, and careful manipulation is necessary to send out uniform plasters.

The setting time of gypsum plaster may be determined in the same way as in cements. The Vicat needle which carries a given constant weight is brought against the surface of the properly gauged pat of cement or plaster. When this needle under a load of 50 grams failed to sink half way into the pat, the initial set is said to have commenced. When under a load of 300 grams, it fails to sink into the mass the final set is said to have taken place. This method of determination is in common use in the cement laboratories of England and also in this country.

This apparatus, illustrated in Fig. 42, consists of a frame K, bearing the movable rod L, having the cap A at one end, and the piston B, having a circular cross-section of 1 centimeter diameter at the other. The screw F holds the needle in any desired position. The rod carries an indicator which moves over a scale (graduated to centimeters) attached to the frame K. The rod with the piston and cap weighs 300 grams; the paste is held by a conical hard rubber ring, I, 7 centimeters in diameter at base, 4 centimeters high, resting on the glass plate J. 15 centimeters square.

A convenient method with apparatus readily made in any laboratory is by the Gilmore wires. A wire with a flat area of one-twelfth inch and loaded with one-fourth pound is used to determine the initial set. This needle fails to penetrate the plaster when the set has commenced. A second wire with one-twenty-fourth inch area and loaded with one pound will not penetrate the mass when the final set has taken place. These wires were prepared as described and placed in a wooden frame so as to keep them vertical and give a direct pressure on the pat of plaster.

The tests were made on neat cement plaster and carefully timed, the wires were kept clean of all adhering plaster. The time of initial set was determined within a range of very small variation, but the final set was not so readily determined as it is difficult to determine the exact time of the needle making no impression. In the mixing of gypsum plaster with water it is very difficult to get it thoroughly mixed especially in quick setting plasters, and as a result portions of the pat will be set while other portions are still soft. This result may possibly be explained by inequality in the distribution of the retarder or by some portions of the plaster being more highly calcined than other parts.

In the results of these tests average times of set were selected from a series of tests.

	Initial set.	Final set.
Pure plaster of Paris	7 min.	20 min.
Roman plaster	25 “	3½ hours (retarded.)
O. K. plaster	50 “	4 “ “

§ 6. Tensile Strength.

The most popular series of tests on cements are those determining the tensile strength as these are regarded as easy to make and not requiring very expensive apparatus.

Appliances.

In the early days of cement testing, two machines were used, one known as the Grant machine now represented by the Riehle and Olsen machines which are long simple lever machines. The other type smaller and more compact, the Michaelis testing machine, is now found in a modified form in the Fairbanks testing machine. The later machine is perhaps the more popular in this country on account of the ease of handling and compactness, and was used in all the experiments in our laboratory.[1]

The briquettes of cement or plaster are moulded in single or gangue moulds which are held together by clamps in the middle or at the ends of the moulds. They are usually made of brass. The shape of the mould has been modified from time to time, and slightly different forms are now used in different parts of the world. The original square mould of the Grant machine had a one and one-half inch section, but was modified later by Grant so as to have angular ends and this form is still used in England. In the Michaelis machine the briquettes were rounded at the ends and at the center were slight indentations or cunettes to insure the briquette breaking at the center. This form is the standard in Germany and France and has a cross section at the center of five square centimeters.

In the United States the briquettes have slightly angular ends and taper toward the center where the cross section is one inch. Unless the briquettes are carefully adjusted, cross strains are set up and the briquettes tend to break in other places than the center. In the earlier machines the clips of the machine closed tightly on the briquette, allowing no room for adjustment. Modern clips are larger and touch the briquette along four lines only, and so are more readily adjusted to remove any cross strains.

Mixing.

The cement or plaster is thoroughly mixed or gauged with the proper amount of water, on a non-absorbing surface like plate glass or marble. The German method is to mix a slow setting cement three minutes and a quick setting cement one minute. Plaster being usually quick setting should be mixed as quickly as possible. Mechanical mixing machines like the Russell jig and Faija mixer are not used in very many American laboratories. The work is carried on in a room of uniform temperature if possible.

When the plaster is thoroughly mixed it is pressed into the mould by hand and gently forced into place. The surface is then struck off smooth with the trowel and mould turned over and the other side smoothed off if necessary. After a few hours the briquettes can be removed and after being carefully numbered are laid aside for the breaking tests.

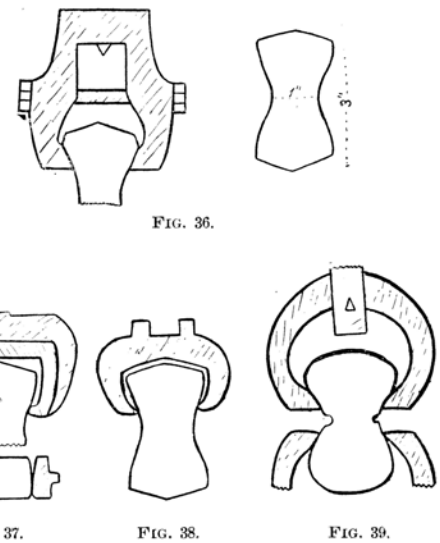


FIG. 36. Cement Briquette and Clip, used in England.
FIG. 37. Cement Briquette and Clip, used in United States.
FIG. 38. Cement Briquette and Clip, used in United States.
FIG. 39. Cement Briquette and Clip, used in Germany and France.

[36, 37, 38, 39. Various Forms of Cement Briquette and Clip]

[1]See Vol. VIII, Part 3, of these reports for figures of the different testing machines, also Fig. 40.

In the experiments of the Washburn College laboratory, with quick setting plasters, one briquette was moulded at a time, using 3½ ounces (99.2 grams) and 40 cc. of water representing the 40 per cent mixture. In the slow setting plasters 19 ounces (538.46 grams) are used with about 165 cc, of water and five briquettes are made, a 30 per cent mixture. The proportion of water varied somewhat with the plaster used in the experiments. In the Kansas plasters for a stiff mixture, the water percentage varied from 26.3 per cent to 40 per cent for neat briquettes (without sand); and in sand mixtures (2 to 1) the water percentage varied from 12 to 14, and proportions were about the same in the Michigan plasters. Nearly 600 briquettes were made and broken at intervals of 24 hours, 7 days, 30 days, 6 months, and 1 year.

The briquettes for the long time test were set on edge on glass and kept in a room of fairly uniform temperature until broken. The sand used was ordinary Kansas river sand screened through a sieve (No. 20) of 400 meshes and held by a screen (No. 40) of 1,600 mesh, and carefully dried. The sand mixtures were two parts of sand to one of plaster. The quick setting plasters required the higher water percentage in mixing and the slow setting, the lower percentage.

Breaking.

The briquettes were broken in a Fairbanks machine. In this portion of the work care must be taken to properly center the briquettes and avoid cross strains with resulting cross breaks away from the center. The presence of air bubbles and incipient cracks will sometimes cause the diagonal breaks even in the most

careful manipulation. In the briquettes of high strength the bucket was always loaded with a light weight and the shot allowed to flow in a small and uniform stream.

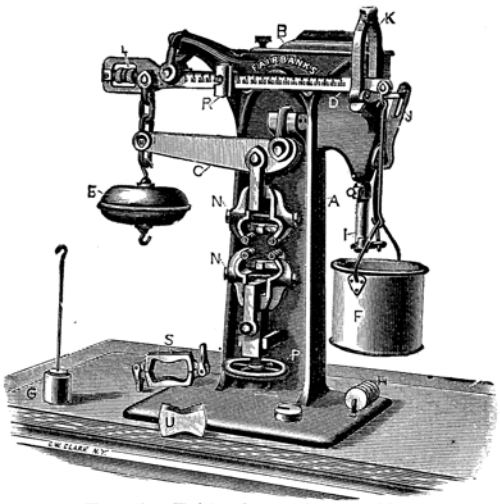
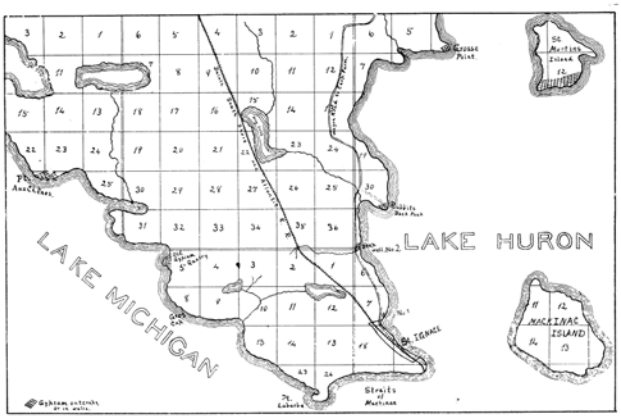


FIG. 40. Fairbanks testing machine.

[40. Fairbanks Cement Testing Maching]

Geological Survey of Michigan. Vol. IX Part II Plate XXI.



SKETCH MAP OF ST. IGNACE AREA.

[XXI. Sketch Map of the St. Ignace Area]

Tables.

The tests of the Michigan plasters were made in the laboratory under my supervision by two advanced students, Mr. Elmer Schultz and Mr. John Worsley, and their results were accepted as thesis work for their degrees, by Washburn College.

TENSILE STRENGTH OF GYPSUM WALL PLASTER.

Kind of plaster.	24 hours.		One week.		One month.		Six months.		One year.	
	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.
Roman (Kansas). Neat	215 280 282 298 210	255	380 390 380 395	386	550 543 567 492	553	402 458 poor poor	430	466 305 340	370
Roman (Kansas). Two parts sand	130 112 111	117	370 340 382 312	351	398 365 360 375	375	328 310 425	364	281 292 268 270	278
O. K. (Oklahoma). Neat	202 270 215	229	545 555 376 365	460	594 465 476 563	525	515 505 543 610	543	421 390 494 469	441
O. K. (Oklahoma). Two parts sand	100 90 92 82	91	372 340 280 280	318	410 410 435 365	410	378 358 397 322	366	288 289 284 278 324	293
Keene's Cement (Kansas). Neat	240 243 235 159	220	430 403 402 472	426	368 440 517 368	423	356 440 490 500	447	493 337 515 497	461
Keene's Cement (Kansas). Two parts sand	40 47 39 44	43	180 202 178 195	189	223 190 126 92	180	236 228 248	237	230 263 244 214 249 204	234
Satin Spar (Kansas). Plaster of Paris. Neat	297 270 270 254	273	526 325 326 483	415	585 534 667	595	553 515 635 786	622	495 407 407 poor	436
Crystal Rock (Kansas). Two parts sand	140 144 148	144	480 525 510 491	502	450 512 533	498	423 423 444 340	408	380 362 405 399	387

TENSILE STRENGTH OF MICHIGAN GYPSUM WALL PLASTERS.

Kind of plaster.	24 hours.		One week		One month.		Six months.	
	Pounds.	Average.	Pounds.	Average.	Pounds	Average.	Pounds.	Average.
A. Made at Grand Rapids. Neat	215 215 200 238	217	404 385 447 467	422	....	....	405 445 390 403	411
A. Same plaster. Two parts sand	106 91 100	99	372 340 360	324	242 269 222 218	210	302 295 288 347	308
B. Made at Grand Rapids. Neat	....	....	468 508 453 430	465	562 477 500 462	500	495 454 496 319	441
C. Made at Grand Rapids	228 273 278 238	254	658 618	638	650 617 540 524	575	*555 *736 *731 *696	680
C. Same plaster. Two parts sand	....	....	400 420 452 454	431	257 266 252 266	260	..... *353 *311 *321	328
D. Made at Grand Rapids. Neat	349 345 311 342	336	498 510 387 320	429	538 549 407 350	461	†503 †410 †478 †312	426
D. Same plaster. Two parts sand	117 116 143	125	387 398 473 391	412	207 370 317 314	302	410 261 359 347	344

* Three months.
† Two months.

TENSILE STRENGTH OF OLD GYPSUM WALL PLASTER.

Kind of plaster.	One month.		Five months.		Two months.	
	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.
O. K. (Oklahoma). One year old plaster. Neat	.....	.....	372	458	324	277
	.....	.....	543		220	
	.....	.....	458		242	
	.....	.....	478		340	
	.....	.....	440		294	
	.....	.....	.....		245	
Roman (Kansas). One year old plaster. Neat	252	337	129	150	383	359
	400		147		410	
	359		168		342	
	.....		158		300	
Plaster of Paris. (Kansas). One year old plaster. Neat	528	536	.....	.....	.....	.....
	607		.....	.....	.....	.....
	494		.....	.....	.....	.....
	507		.....	.....	.....	.....
	583		.....	.....	.....	.....
	500		.....	.....	.....	.....
Roman (Kansas). One year old plaster. Two parts sand	.....	.....	195	186	263	298
	.....	.....	100		262	
	.....	.....	240		352	
	.....	.....	210		316	

Discussion of Results.

In the gypsum earth plasters of Kansas the maximum strength appears to be reached in one month and then they decline in six months and one year. This decline is more marked in the neat plaster than in the sanded plaster. These plasters are represented in table I by the Roman and O. K.

The rock plasters represented by Keenes and Satin Spar show their greatest strength in six months. The Crystal Rock also a rock plaster gave its greatest strength in one week. The greatest strength recorded was of plaster of Paris in six months when one briquette broke at 786 pounds. In sanded mixtures the rock plaster stood higher tests than the earth plasters.

Even a hasty examination of these tables shows the variation in results of the same plaster tested in the same length of time by the same person who endeavored to secure as uniform manipulation as possible. It has been urged by some of the practical operators that only the highest tests should be used in judging plaster or cement, because the plaster will have a certain highest strength which cannot be increased by the person making the test, but which can be lowered, and in the mixing of the plaster the workman is more apt to lower the strength than to increase it. The results, however, as given will probably agree more closely with the average results of the plasterer in his work, who will not always if ever secure this greatest strength of the plaster.

It must be clearly kept in mind that the lowest of these tensile strengths is far greater than any strain that will ever be applied to a wall. So in practical work these are all good plasters, and the ease of working, and the uniform results of different ton lots will be of more value in determining the superiority of one brand over another. Such tests as are given in these tables are valuable for comparative purposes.

Why the strength should fall after one or six months is an unsettled problem. The amount of retarder added is so small that we can hardly look to that for an explanation, though it may have some effect on the crystal network and changes in the retarder in time may effect the strength of this network. The real explanation lies hidden in the adjustment of crystals in the network and belongs to the obscure subject of crystallization, its causes and steps in its progress. It is evident that in some of these plasters the early changes in crystal formation are slower than in others as a marked variation is seen in 24 hours which disappears later. This is especially true of the sanded plasters.

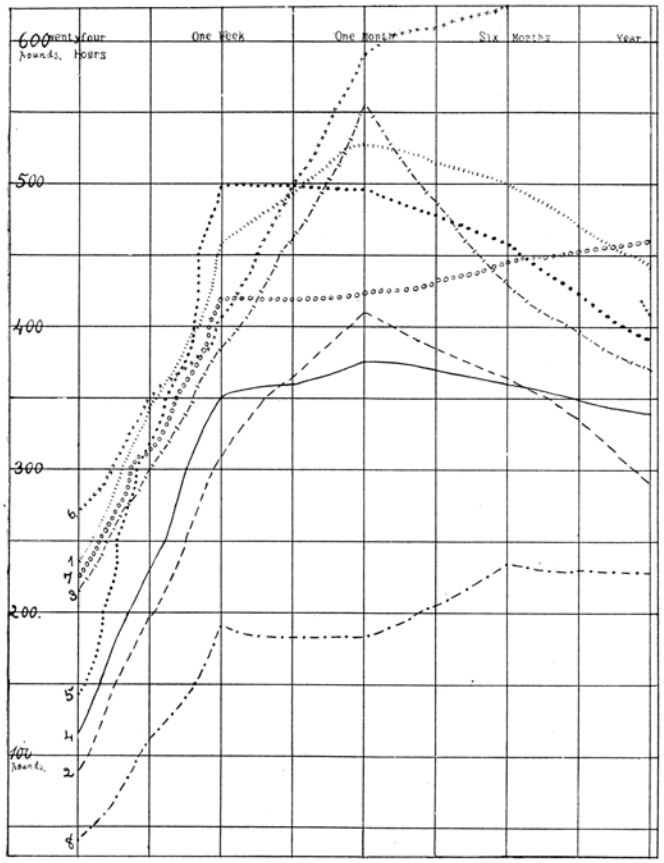


FIG. 41. Chart of tensile strength of gypsum plasters, one day, one week, one month, six months and a year, after setting.

1. O. K. Cement Wall Plaster (neat).
2. O. K. Cement Wall Plaster (2 parts sand).
3. Roman Cement Wall Plaster (neat).
4. Roman Cement Wall Plaster (2 parts sand).
5. Crystal rock Cement Wall Plaster (2 parts sand).
6. Satin spar Cement Wall Plaster (neat).
7. Keenes Cement Plaster (neat).
8. Keenes Cement Plaster (2 parts sand).

[41. Chart of Tensile Strengths of Gypsum Plasters]

The Michigan plasters are all made from rock, as no gypsum earth deposits are known in the state. The greatest increase in strength of these plasters from 24 hours to one month as is also true of the Kansas plasters, shows that the final set as determined by the needles does not represent the complete setting of the plaster. The changes of crystallization which we call the set are going along rapidly at first then more slowly for one month and in some cases six months, and the readjustment of the network of crystals would seem in some of these plasters to be going on for a year after they are mixed with the water.

A number of the Michigan plasters seem to reach their maximum strength in one week and decline in strengthen one month. The greatest strength recorded was of a briquette broken at 736 pounds after three months. These results of tests do not show any great variations from the same kinds of Kansas plasters.

Tests on Old Plasters.

The statement is often made that gypsum plasters cannot be kept long without losing their strength and that in a few months they are of low strength or even worthless. Several sacks of plaster were left in a room near the laboratory for over a year. These sacks were open and the room was damp in the spring, and not heated in the winter, so the plasters were exposed to a varying temperature from the hot summer to the cold winter. Briquettes were made from these samples and broken giving the results shown in table III. These plasters were from the same sacks which furnished the material used for the briquettes shown in table I.

Comparing the results of the two tables, of fresh plaster and plaster exposed one year, it is found that the O. K. plaster in 5 months has decreased in strength from near 543 pounds to 458. The plaster of Paris in one month from 595 to 536 pounds. The Roman in one month from 553 to 337, and in five months from near 430 to 150 pounds. This last brand is the only one which shows any serious effect of the exposure. These plasters under as bad conditions of exposure as would ordinarily be found show decrease of strength, but they are still after one year's exposure good plasters.

To test frost effects on these gypsum plasters, a number of briquettes were made and as soon as set were placed out of doors in the open air for one week with the temperature below freezing, and the briquettes broke from 352 to 793 pounds with an average of 500 pounds, showing practically no effect on the strength for that time.

Some Low Tests.

At some of the mills there is a tendency to draw the plaster from the kettles before the second boiling, and some of the operators have claimed that such plaster is just as good as any other. If this claim was true it would give the advantage of calcining plaster with less fuel and save much time so adding to the capacity of the plant. Among the various sacks of plaster brought from Michigan, two sacks were tested, one of which showed by chemical analysis a high percentage of water and evidently it had been drawn from the kettle too soon. The plaster when set would break when taking it from the mould and would not test as high as 100 pounds when the greatest care was taken with the briquettes.

The other brand showed too low a water percentage and the tests showed it had a very low tensile strength. It was tested neat and after 60 days gave the following results:

91 pounds	
156 pounds	
101 pounds	
232 pounds	Average 150 pounds.
186 pounds	
145 pounds	
139 pounds	

Another sack of good plaster from the same mill made at another time gave, when tested in the same way and after the same length of time:

503 pounds	
410 pounds	Average 426 pounds.
478 pounds	
312 pounds	

These results seem to show that of the two evils, under-burning and over-burning, the former is the greater. These plasters should reach in 60 days at least 500 pounds tensile strength, as they are made from good rock and with good appliances for calcining. These tests are useful in showing that poor plaster can be made from the best material by faulty manipulation. It may be due to cheap and inexperienced calciners or to careless ones. This trouble is found in all plaster fields and I have found similar poor plasters in other districts. The tests were carried out with plasters from nearly all the Michigan mills, and these two sacks were the only poor plasters found, and further, the mills that made these poor plasters are sending out some of the finest grades of Michigan plaster.

§ 7. Comparison of Physical Tests with Chemical Analyses.

It was thought that a careful comparison of physical tests with the chemical analysis might throw some light on the effects of certain ingredients in the rock on the strength of the plaster made from the rock. When the results of these tests are compared, a variation is found in the tests on plasters at different mills made from rock of practically the same chemical composition. The time of calcining and the amount of heat used as well as many other factors vary and so produce variations in results which obscure the effects of the rock impurities.

The earth plasters with their impurities of clay, silica, and lime, set slower than the rock plasters and usually show a little lower tensile strength, especially when mixed with sand.

Another method was used to determine the effects of these impurities. Pure plaster of Paris was tested and then varying proportions of powdered limestone were added, also different proportions of powdered clay. Briquettes were made from these mixtures and broken after 30 days.

Per cent of lime.	Carbonate of lime mixture. Lbs.	Average.	Per cent of clay.	Clay mixture. Lbs.	Average.	Pure plaster of Paris. Lbs.	Average.
1.	390 392 275	352				585 534 667	595
2.	360 248 323	310	2.	poor 248 328	288		
3.	286 348 494		4.	262 350 293	302		
6.	331 321 332	328					
8.	375 389 379	381	8.	357 340 287	328		
10.	345 285 244	291	10.	342 217 290	283		

The addition of the lime and clay had a tendency to cause the briquettes to swell and so make them difficult to place in the clips of the machine. This binding of the briquettes causes them to break away from the center in a number of cases. The addition of these impurities lowered the strength, but the different proportions did not change the results materially until the 10 per cent mixture was reached. The setting time was but little altered.

Another line of experimental work was tried by mixing the ground clay with ground gypsum rock and calcining the mixture as follows: One pound of ground clay was mixed with seven pounds of gypsum flour and placed in a kettle heated to 250° F. (120° C.) and heated for a half hour to a temperature of 266° F. (130° C.) when the boiling ceased. The mixture was heated 15 minutes longer and the temperature reached 386° F. (196° C.) and then the whole mixture was withdrawn having been heated about one hour. The color of the finished plaster was reddish. It set in one hour and the briquettes in one week had a tensile strength of 500 to 585 pounds. A one-fourth mixture gave a reddish plaster which set in one and one-half hours.

The adding of the clay impurity before calcining the rock increased the tensile strength and formed a slow setting plaster. In sand mixtures, however, the plaster showed a very low tensile strength similar to the Keene's cement tests as given in table I in an earlier part of this chapter. Such cements are used neat or if mixed with sand have lime added to them. The specifications with the use of Keene's cement state as imperative that for sand mixtures three bushels of slaked lime must be added for each 100 square yards of surface. The tests given were on the cement without any addition of lime.

The analysis of the mixture of one part of clay to seven parts of gypsum after calcining is given below with analysis of plaster made from gypsum rock and gypsum earth.

	Mixture 7 to 1.	Earth Plaster.	Rock Plaster.
Silica and insoluble material	12 30	12.02	1.20
Iron and alumina	0.78	0.44	0.20
Lime carbonate	0.07	14.39	1.68
Lime sulphate	83.48	68.36	89.42
Water	2.80	4.98	6.82
	99.43	100.19	99.32

The mixture agrees closely with the earth plaster in its percentage of silica, but is lower in lime carbonate. In percentage of lime sulphate the mixture stands between the earth and rock plasters. It was evidently burned at a higher temperature than the other plasters as shown in the water percentage, but the high strength of the plaster would argue against this percentage of water being a defect in the plaster. The clay when added to the calcined plaster has little effect, but when added before calcining it has the effect of a retarder without lowering the strength of the plaster. The experiments would suggest that the clay in the earth plaster acts as a retarder, but that the full effect of this impurity is only seen when the plaster is heated to a high temperature.

§ 8. Compression Tests.

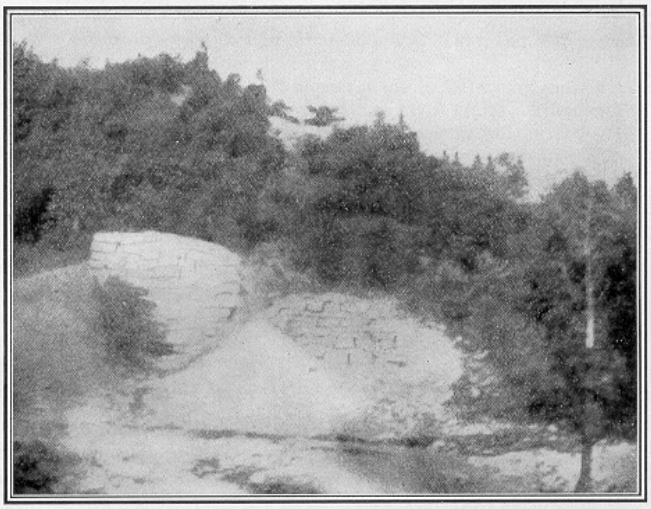
Compression tests on cement are also held in high favor by many experts. On account of the expense of the machinery for this work and the difficulties in making the tests, the compression tests are not often made. They are usually made on two inch cubes. Such tests have been made on gypsum plasters by the Wyoming Geological Survey.

A series of compression tests were made with the same mixtures and the same time of exposure as in the tensile tests. The plasters used were mainly Kansas products and they were moulded in prisms of the size 2 by 2 by 4 inches, and the pressure was applied to the ends of the prisms in a hydraulic compression machine at the Sante Fé shops at Topeka. The results are given below:

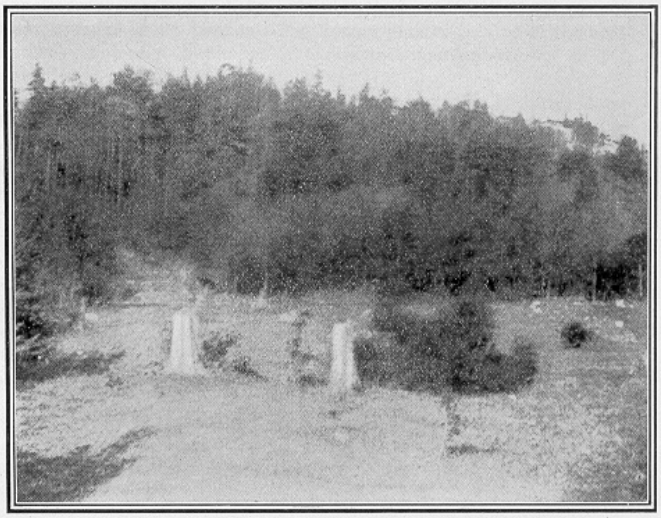
Plaster.	One week. Lbs.	Av.	One month. Lbs.	Av.	Six months. Lbs.	Av.
Roman Neat	7600 7850 7300	7583	7250 7400 8000	7550	11050 9450 7820	9440
Roman Two parts sand	5200 5000 4000	4733	4100 4100 6300	4833	4950 4720 5760	5143
O. K. Neat	5600 7300 8800 7500	7300	14250 12475 11175	12966	10000 11830 10950	10926
O. K. Two parts sand	6250 7125 7125 7125	7125	8000 8200 7550	7916	4700 6500 6050	5750
Crystal Rock Neat	8000 6000	7000	7830 5350	6590		

The next table shows the relation of the compression tests per square inch to the tensile strength per square inch, being as many times the tensile strength as is indicated by the figures.

Plaster.	One week.	One month.	Six months.
Roman, neat	4.8	3.2	5.5
Roman, two parts sand	3.3	3.2	3.5
O. K., neat	7.9	6.1	5.0
O. K., two parts sand	19.5	4.1	3.1



A. OLD LIME KILNS ON SLOPE OF RABBIT'S BACK.



B. RABBIT'S BACK RIDGE, NEAR ST. IGNACE.

[XXII. A. Old Lime Kilns on slope of Rabbit's Back
B. Rabbit's Back Ridge, St. Ignace]

§ 9. Absorption Tests and Effect on Strength.

Briquettes of gypsum plaster were made in the moulds and after drying were placed in water, then in air and allowed to dry, and then placed again in the water, and after drying were broken.

Three briquettes of neat O. K. plaster made in Oklahoma showed an average weight after 24 hours in the air of 118.6 grams. These were placed in water for 72 hours and gained 4.8 grams in weight or a gain of 4 per cent. This does not represent the real gain of water by absorption, as part of the material of the briquette went into solution, as shown by their weight after exposure in the air of the same room for a week, when they showed an average weight of 112.6 grams, which compared with their weight when removed from the water (123.39 grams) shows a gain through absorbed water of 10.79 grams or 9.5 per cent. These briquettes were again placed in water for 60 hours, then left in the air for 12 days. They were broken 32 days from the time of mixing and showed a maximum tensile strength of 522 pounds and an average of 466 pounds. The same cement tested in the ordinary way in 30 days gave a maximum strength of 594 pounds with an average of 525 pounds.

Roman cement plaster made in Kansas was tried in the same way. The neat briquettes had an average weight of 111.14 grams and after three days in the water showed an average weight of 118.1 grams, or a gain of 6.96 grams or 6.2 per cent. These were then exposed in air for five days and placed in water six and one-half days and left in the open air again fourteen days. Thirty days after the first mixing the briquettes were broken and showed a maximum strength of 587 pounds and an average of 496 pounds. The Roman plaster treated in the ordinary way showed a maximum of 567 pounds and an average of 553 pounds.

Keene's cement plaster made as a special preparation of hard plaster with an average weight of briquettes of 123 grams, after three days in water weighed 129.6 grams, or a gain of 6.6 grams or 5.1 per cent, and treated in the same way as the Roman gave a maximum test of 465 pounds and an average of 445 pounds. Tested in the ordinary way the maximum tensile strength was 517 pounds and average was 423 pounds.

The loss in strength shown in O. K. plaster in this treatment was 59 pounds; in Roman, 57 pounds; while in the special brand of Keene's cement, an increase was shown, probably due to some error in manipulation of the tests. These water tests show that standard gypsum plasters are not injured to any great extent by such soaking. This accords with practical experience for often gypsum plaster walls wet from leaking roofs dry but and appear to be as strong as ever.

§ 10. Tensile Strength of Gypsum Plasters and Lime Plasters.

An effort was made to secure the tensile strength of ordinary lime plaster moulded in Fairbanks moulds and broken in the testing machine. The lime was carefully slaked and mixed with two parts of sand. The briquettes so made showed a tendency to crack and many of the experiments were failures on this account.

	One week.		One month.		Six months.	
Mixture.	Lbs.	Av.	Lbs.	Av.	Lbs.	Av.
Lime plaster Two parts sand.	24 16 18	19	23 25 32	27	38 42 53 68	50

These results show a very low tensile strength for the lime when used in these small masses. The addition of hair to the lime as is done in the ordinary use of lime plaster and the larger quantities give better results, than would be indicated by these tests. Lime plaster has a good tensile strength on the wall, but cannot equal the hard gypsum plasters. The effect of dampness, jars, fire, etc., are much more destructive to lime walls than to gypsum plaster walls. The durability of the gypsum plaster wall is certainly much greater than is the case of

the lime wall. The tensile strength of gypsum plaster walls can be increased by the addition of fibre and especially by the use of wood fibre. It was the intention to make a series of tests of such fibred plasters, but it is difficult to secure uniform results with ordinary fibred plasters when used in small space of a briquette mould as the fibres are long enough to get in the way and leave air bubbles in the plaster. I was unable at the time these tests were made to secure samples of wood fibred plaster. In these plasters the wood fibre is small and would not cause the same trouble in the work that the longer fibre did.

§ 11. Adhesion Tests.

Adhesion tests have been made at times on Portland cements, but they are not common. It is found that such cement will adhere to ground glass better than to brick or stone and adheres but poorly to a wood surface. A convenient method of applying the test is to cement two stones or bricks crosswise at right angles and determine the weight necessary to pull them apart.[1]

In tests of gypsum plasters made by the Iowa Survey, pieces of paving brick were ground on an emery wheel so as to give approximately one inch cubes. One face of the cube was carefully ground to give a cross section on one square inch. These pieces were placed in cement moulds with the true one inch surface at the center of the mould. The other half of the mould was filled with plaster and the vacant place around the piece of brick was filled with neat Portland cement mortar. When these briquettes were broken they showed the adhesive strength of the plaster to be only a fraction of the tensile strength.

In the present work a considerable number of adhesion tests were made by selecting briquettes which had been broken at the center and were fairly smooth in section. These were thoroughly wet with water and placed in the moulds and the remaining half was filled with plaster. The results of these tests while perhaps not valuable for scientific comparisons with tests made in other laboratories by different methods, yet throw, light on the adhesive character of gypsum plasters when spread over walls with another coat partially dry, or in repair work on old walls. When the old plaster in these experiments was not wet, there was scarcely any trace of adhesion, which shows that in such repair work the wall should be thoroughly wet before the new plaster is added.

This method used on the Iowa Survey gave adhesion tests which seldom reached 100 pounds in four weeks and most of the tests showed less than 50 pounds. The method used in the present work showed higher results, and results that were in the main no more variable than in tensile tests.

Plaster.	One day. Lbs.	One day. Av.	One week. Lbs.	One week. Av.	One month. Lbs.	One month. Av.	Two months. Lbs.	Two months. Av.	Three months. Lbs.	Three months. Av.
Granite. Neat.	54, 49, 20, 69	48	96, 142, 212	150	116, 36, 98	83			159, 217, 295, 382, 275, 291, 321, 247	273
Granite. Two parts sand.	50, 37, 45, 67	50	94, 62, 49	68	133, 116, 166	138	328, 232, 110, 287, 106, 167, 230, 146, 318	214	237, 110, 195	181

The relation of the adhesive strength to the tensile is shown in the following table, the tensile strength being as many the adhesive as is indicated by the figures. The three months adhesive tests are compared with the six months tensile tests.

Plaster.	One day.	Oae week.	One month.	Three months to six months tensile.
Granite. Neat.....	4.5	2.8	Not determined.	1.5
Granite. Two parts sand	2.0	4.7	1.5	7.1

[1]See article on cement tests, Vol. IX, Part III, of these reports.

§ 12. Specific Gravity.

No tests were made for the determination of the specific gravity of these plasters. Experiments could be made along this line which would without doubt produce interesting results. It was hoped earlier in the work that opportunity would be found to make these determinations. According to Humphrey, LeChatelier's method is the most convenient to use in determining the specific gravity of cements, and it could well be used with the gypsum plasters, and his description is here given.

The apparatus consists of a flask D of 120 cc. capacity (see Fig. 42), the neck of which is about 20 centimeters long. In the middle of this neck is a bulb C, above and below which are two marks engraved on the neck, the volume between these marks E and F being exactly 20 cc. Above the bulb the neck is graduated into one-tenth cc. The neck has a diameter of nine mm. Benzine free from water and being neither very volatile nor hygroscopic is used in making the determinations.

The specific gravity can be determined in two ways:

1. The flask is filled with benzine to the lower mark E, and 64 grams of powder are weighed out and carefully introduced into the flask by the aid of the funnel B. The stem of this funnel descends into the neck of the flask to a point a short distance below the upper mark. The cement cannot stick to the sides of the neck and obstruct the passage. As the level of the benzine approaches the upper mark, the powder is introduced carefully and in small quantities at a time, until the upper mark is reached. The differences between the weight of the cement remaining and the weight of the original quantity (64 grams) is the volume which has displaced 20 cc. of the liquid.

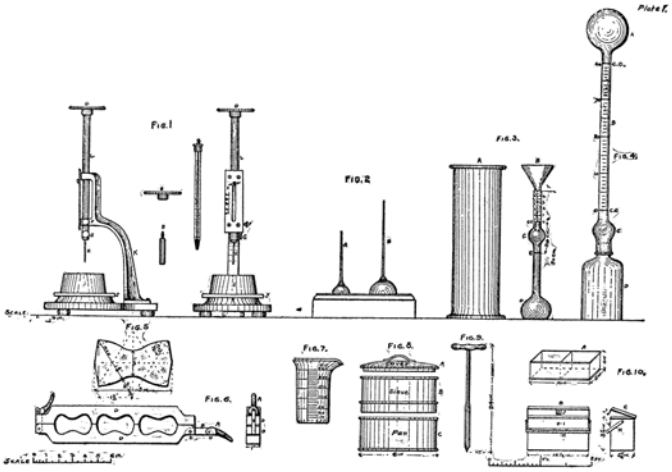


FIG. 42. Modern form of Vicat needle and other testing apparatus for Portland Cement. Upper row left to right, Vicat needles, Gilmore wires, specific gravity apparatus. Lower row, moulds, graduate, sieves.

[42. Testing Apparatus]

2. The whole quantity of the cement is introduced and the level of the benzine rises to some division of the graduated neck. The reading plus 20 cc. is the volume displaced by 64 grams of cement.

The specific gravity is then obtained from the formula:

$$\text{Specific gravity} = \frac{\text{weight in air}}{\text{displaced weight}}$$

or

loss of weight in liquid.

During the operation the flask is kept immersed in water in a jar A, in order to avoid any possible error due to variation in the temperature of the benzine. The cement in falling through the long neck completely frees itself from all air bubbles. The results are said to agree within .02.

§ 13. Influence of Sand on Plaster.

The addition of sand lowers the tensile strength of the plaster as is shown in the tables of the tests already given. In ordinary lime plasters sand is necessary to increase the adhesive properties of the plaster, and sand is said to increase the adhesion of Portland cements. In the gypsum plasters, the tests of adhesion given show that the addition of sand decreases the adhesion of plaster as well as the tensile strength. These results would indicate that sand is not needed in gypsum plasters to give them tensile or adhesive strength. The addition of sand to these plasters makes them cheaper as a sack of plaster with the addition of the proper amount of sand will cover a greater surface, and without injuring the strength in any practical degree.

Another important influence on the addition of the sand is in making the plaster easier to work. Pure gypsum plaster mixed with water is more or less sticky and tends to roll up into lumps. The addition of sand overcomes this trouble. The advantages of sand mixtures are not in the strength and probably not in the duration of the wall, but rather in convenience to the workman, and therefore in the better character of the wall for this same reason, and in the reduction of the cost. This latter reason sometimes tempts the workman to add an excess of sand and so to make a weaker wall. Crumbling gypsum plaster walls that are sometimes reported are either due to improper burning, or to too much sand added, or again to use of old partially set plaster left in the mortar boxes.

CHAPTER XI.

ORIGIN OF GYPSUM.

§ 1. Deposition by Action of Sulphur Springs and Volcanic Agencies.

Various theories have been advanced to explain the origin of gypsum in various parts of the world. In order to arrive at a satisfactory explanation of the origin of the gypsum deposits of Michigan, a brief resumè of these theories will be given in this chapter.[1]

Gypsum is deposited directly by some thermal springs as in Iceland[1], where it is formed by the decomposition of volcanic tufa by acids dissolved in water. The sulphurous acids become oxidized to sulphuric, and thus convert the carbonates, especially of the lime and magnesia, into sulphates. Through evaporation the sulphate of lime is deposited, forming layers of fibrous and selenitic gypsum.

Small gypsum deposits are found around the fumaroles[2] of the craters and lava streams in Hawaii where sulphurous acid is converted into sulphuric, and attacks rocks which contain lime. Gypsum is found in the form of acicular crystals associated with sulphur in the craters in New South Wales.[3] The gypsum concretions of the Hartz are regarded as due to the action of sulphur vapors on lime rock. According to Lapparent[4] the large deposits of gypsum and anhydrite at Montiers, Bourg-Saint-Maurice, in the western Alps and Switzerland are due to the transformation of lime through sulphur reaction.

Dana[5] explains the origin of a portion of the New York gypsum as a secondary mineral due to the alteration of the limestone by action of sulphuric acid. The acid comes from sulphur springs by the oxidation of the sulphuretted hydrogen. Such springs are found in New York especially near Salina, and Syracuse, also at Byron in Genesee County. The layers of shale sometimes pass through the gypsum, and the gypsum is connected with the overlying waterlime beds as shown in Figure 43 after Hall taken from Dana's text book.

[1]See also Vol. V, of these reports, the introduction to Part 2.

[1]Bunsen in Annalen der Chem. 1847.

[2]Iowa Geol. Survey, Vol. XII, p. 116; 1902.

[3]Minerals of New South Wales, p. 164; 1888.

[4]Lapparent Geologic, p. 1026.

[5]Dana Manual of Geology, pp. 554-555; 1895.

See also report No. 64, U. S. Depart, of Agriculture. Division of soils, p. 54, gypsum formed from limestone in Texas.

Personally I am inclined to think that in most cases the genesis is inverse, the sulphuretted hydrogen being the product of carbonated water, organic matter and gypsum. L.

According to Lyell[1], the thermal waters of Aix in Savoy in passing through the strata of Jurassic limestone turn them into gypsum, also the springs of Baden near Vienna deposit a fine powder composed of a mixture of gypsum, sulphur, and "muriate of lime." In the Andes at the Puenta del Inca, a thermal spring contains a large proportion of gypsum and carbonate of lime.

Mr. R. S. Sherwin[2] who has studied the gypsum deposits of Oklahoma regards the massive gypsum of this section as due to the alteration of limestone by the water of sulphur springs.

Dawson[3], following Lyell, explained the origin of the gypsum of Nova Scotia as follows:—First, there was an accumulation of numerous thin layers of limestone, either so rapidly or at so great a depth that organic remains were not included in any but the upper layers. Second, there was an introduction of sulphuric acid, in solution or in vapor, which was a product of volcanic action. Then for a long time the acid waters acted upon the calcareous material without any interruption from mechanical detritus. The limestone and calcareous matter are changed to the sulphate, and gypsum of good quality accumulates in considerable thickness.

[1]Lyell Principles of Geology, p. 245.

[2]Transactions Kans. Acad. Science, Vol. XVIII, p. 85

[3]"Origin of Gypsum at Plaister Cove, Nova Scotia," Quarterly Journal Geological Society, Vol. V, p. 339, 1849.

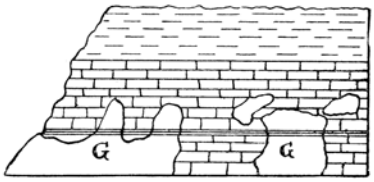


FIG. 43. Limestone altered in part to gypsum, after Dana.

[43. Lime Stone Altered in Part to Gypsum. (From Dana)]

§ 2. Hunt's Chemical Theory of Gypsum Formation.

Hunt's[2] chemical theory of the formation of gypsum is somewhat complex, but he believed it applied, to a large part of the gypsum deposits of marine and fresh-water origin. In his own words the theory is as follows:—

"1. The action of solutions of bicarbonate of soda upon sea water separates, in the first place, the whole of the lime in the form of carbonate, and then gives rise to a solution of bicarbonate of magnesia, which, by evaporation, deposits hydrous magnesian carbonate.

"2. The addition of solutions of bicarbonate of lime to sulphate of soda or sulphate of magnesia gives rise to bicarbonates of these bases, together with sulphate of lime, which later may be thrown down by alcohol. By the evaporation of a solution containing bicarbonate of magnesia and sulphate of lime, either with or without sea salt, gypsum and hydrous carbonate of magnesia are successively deposited.

"3. When the hydrous carbonate of magnesia is heated alone, under pressure, it is converted into magnesite; but if carbonate of lime be present, a double salt is formed, which is dolomite.

"4. Solutions of bicarbonate of magnesia decompose chloride of calcium, and, when deprived of their excess of carbonic acid by evaporation, even solutions of gypsum, with separation of carbonate of lime.

"5. Dolomites, magnesites, and magnesian marls have had their origin in sediments of magnesian carbonate formed by the evaporation of solutions of bicarbonate of magnesia. These solutions have been produced either by the action of bicarbonate of lime upon solutions of sulphate of magnesia, in which case gypsum is a subsidiary product, or by the decomposition of solutions of sulphate or chloride of magnesium by the waters of the rivers or springs containing bicarbonate of soda. The subsequent action of heat upon such magnesian sediments, either alone or mingled with carbonate of lime, has changed them into magnesite or dolomite."

[2]Quarterly Jour. Geol. Soc. Vol. 16, p. 154, 1859. Chem. and Geol. Essays, pp. 80-92. 1878.

§ 3. Deposition of Gypsum Through Action of Pyrites Upon Carbonate of Lime.

Pyrites or iron sulphide decomposing in clays may change the carbonate of lime into sulphate of lime, and so form gypsum, usually in small amounts and scattered through the clay.

These crystals are found in the coal measure clays of Kansas (see Vol. V, Kans. Survey, p. 73) near the surface, and in size varying from microscopic crystals up to an inch in diameter. The neighboring shales are heavily charged with pyrite, which decomposes forming iron sulphate, which is carried in solution and acts on the limestone and shales. Gypsum produced in this way often forms very perfect crystals, but it is not of economic importance.

§ 4. Gypsum Deposited in Rivers.

Rivers may in some instances carry high percentage of sulphate of lime and so deposit gypsum at their mouths or in the basins into which they empty. Lyell in his Principles of Geology (p. 247) cites the river in Sicily known as La Fiume Salso, as an example of this method of origin.

§ 5. Secretion of Gypsum by Animals.

In the cruise of the Challenger[1], M. Buchanan found the Bathybius forming a sulphate of lime deposit. This unicellular animal belongs to the lowest group of animal life and forms slimy masses on the bottom of the sea. Many believe it is not an animal, but merely a deposition of lime salts in the water.

[1]Lapparent Geologic, p. 135.

§ 6. Gypsum Formed from Anhydrite.

Anhydrite ($CaSO_4$) on taking up two molecules of water forms gypsum, and causes an increase in volume of 33%. According to Lapparent the force exerted by this change is four times as great as that of water freezing. This change on a small scale is found in many places, but in the Hartz mountains, according to Gary, the gypsum is formed from anhydrite through the entrance of water. Near Ellrich the change has formed mounds of gypsum in concentric shells one and one-third meters (52 feet) high, often hollow in the interior. The force of the expansion has been sufficient to break crystals of quartz and dolomite in the layers above.[2]

[2]Possibly much of the Michigan gypsum has been anhydrite. The specific gravity of gypsum being from 2.314 to 2.328 according to Dana and that of anhydrite from 2.899 to 2.985, the substance of gypsum in the shape of anhydrite and water (20.9% H_2O plus 79.1% $CaSO_4$) would have a specific gravity of between

$$\left(\frac{20.9 \times 1 + 79.1 \times 2.8999 \text{ to } 2.985}{100}\right) = 2.401 \text{ to } 2.569.$$

Therefore the substance of gypsum in the form of anhydrite and water is more condensed than in the shape of gypsum; therefore pressure would tend to aid its formation or change into the former shape. This may be the reason of the occurrence of anhydrite in the deep well samples, as well as its formation in boilers and similar places under pressure. L.

§ 7. Gypsum Deposited from Sea Water.

The most generally accepted theory of origin of large deposits of gypsum and salt has been that they are evaporated from salt water lakes or arms of bays and seas cut off from the main ocean. This theory has been given for the Iowa, New York, Virginia, and Kansas fields in the reports on salt and gypsum in those states. In the Kansas report, the writer endeavored to picture the history of the changes resulting in the evaporation of gypsum and salt laden water in a bay whose water retreated to the southwest in Permian time.

Examples of these changes can be found in the salt lakes and ocean gulfs and bordering seas at the present day. In southern Europe are excellent examples of the results of the evaporation of salt lakes, and in this country the best examples are seen in the Great Salt Lake and in the neighboring salt lakes of Utah and Nevada, Lake Bonneville in the Quaternary period of geological time covered an area of 19,570 square miles with a depth of 1,050 feet, and its waters were fresh. Through evaporation, its level was lowered below the place of outlet at the north, and its waters in the course of time became more and more saline. This evaporation has continued until the present remnant, Salt Lake, has less than 2,400 square miles of area with an extreme depth of 50 feet, with its waters almost a concentrated brine with specific gravity of 1.1. The total amount of salts in this lake water is 15%, of which 11.8% is common salt (NaCl).

The waters of the Dead Sea afford another example of concentrated brine due to evaporation. In this water there is 26% of salts, but differing in composition from the American lake. There is only 3.6% of the common salt and 15% of the magnesium chloride as compared with 1.5% of this salt in the Great Salt Lake. The amount of gypsum in the waters of the two basins is nearly the same, 0.086%. The composition is given in the following table:—[1]

	Great Salt Lake.	Dead Sea.
Chloride of sodium	11.8628	3.6372
Chloride of magnesium	1.4908	15.9774
Chloride of calcium	.....	4.7197
Chloride of potassium	0.0862	0.8379
Bromide of magnesium	.....	0.8157
Sulphate of calcium	0.0858	0.0889
Sulphate of potassium	0.5363	.....
Sulphate of sodium	0.9321	.....
Water	85.0060	73.9232
	100.0000	100.0000

Ocean water according to the analyses of the Challenger Reports contains 3.5% of mineral salts of which three-fourths is common salt, sodium chloride. The waters of the Atlantic show the following varieties and proportions of salts:—

	Per cent.
Chloride of sodium (common salt)	77.758
Chloride of magnesium	10.878
Sulphate of magnesium	4.737
Sulphate of lime (gypsum)	3.600
Sulphate of potassium	2.465
Carbonate of lime	0.345
Bromide of magnesium	0.217
	100.000

When such a body of water is cut off and evaporated, the gypsum is deposited after 37% of the water is removed, and common salt only after the removal of 93%. The normal order would be a deposit of gypsum and then a much heavier deposit of salt. But as 93% of the water must be evaporated before the salt would be thrown down, the evaporation might go far enough for the deposition of gypsum, but not far enough for the salt, or the salt might be deposited and subsequently removed by solution. The first condition apparently took place in the Kansas gypsum area, and both in Michigan. Gypsum deposits are more widespread in nature than salt, but they usually occur in thinner beds.

[1]Geikie Text Book of Geology, p. 383; 1885.

In most areas the amount of gypsum found is far greater than the amount found in ocean water that would cover the area at reasonable depths. The present condition in the Mediterranean sea seems to aid in the explanation of the formation of such deposits and has been cited for

this purpose in the discussion of the Kansas[1], Iowa[2], and former accounts of the Michigan areas.[3]

[1]University Geol. Survey of Kan., Vol. V. p. 138.

[2]Iowa Geol. Survey, Vol. 12, p. 123.

[3]Geol. Survey of Michigan, Vol. V, Part 2, p. 15.

§ 8. Mediterranean Sea.

The most complete study of the composition and the currents of the Mediterranean sea have been made by Capt. Nares and Dr. Carpenter of H. M. S. Shearwater in 1871.[1] They found the basin of this sea to be 6?000 feet deep, separated from the ocean at the straits of Gibraltar by a ridge 1,200 feet high. The water of the Atlantic outside the ridge had a specific gravity of 1.026. In the western part of the sea the gravity is 1.027, and at the eastern part of the sea it is 1.03. The proportion of salts in the ocean was 3.6%, and in the Mediterranean is 3.9%. Passing over the dividing ridge were two currents, one over the other. The upper was inflowing and the lower outflowing. The water of the basin is not concentrated enough to deposit salt and gypsum, but it is gaining in quantity of salt held in solution.

So it is thought that the water in the old seas or gulfs of Kansas and Iowa received additions of salt and gypsum by inflowing water and thus increased the thickness of the deposits. This theory is thought to explain the great thickness of the salt deposits at Stassfurt (1,000 feet), and at Sperenberg (3,000 feet) in Germany, which could hardly have been deposited except from a continuous supply of salt water.

[1]Published in Proc. Roy. Soc. Vol. XX, p. 97, 414; 1872, cited in Enc. Brittanica, Vol. XV, p. 821.

§ 9. The Michigan Carboniferous Salt Sea.

The area of rocks in Michigan formed after the deposition of the Marshall and Kinderhook series is approximately circular in outline with a radius of 85 miles, giving an area of 22,686 square miles. As will be later shown, the sea covering this area in Osage time was 700 feet in depth, and assuming the average depth to be 326 feet, based on well records, there would have been about 1,280,000 billion gallons of water.

The analyses of the Atlantic ocean water show 93.3 grains of gypsum to the gallon. If this Michigan sea had that proportion it would have yielded nearly nine billion tons of gypsum.

The thickness of gypsum at Grand Rapids is 18 feet and at Alabaster is 20 feet. The approximate area at Grand Rapids is 24 square miles and at Alabaster, 10 square miles, and while the gypsum does not by any means keep this thickness given over these areas and is even absent in parts of the area, it has probably been removed by solution since its deposition. These conditions would give 1,237,764,000 tons of gypsum.

If the assumption is made, that the gypsum covered all the area with a thickness of 20 feet[1], then it would require 917 billion tons or 90 times the amount of water in this original sea, and one would need to look for the ridge or barrier over which the ocean waters flowed to supply the water for the gypsum, unless the same was supplied as in the Great Salt Lake by land drainage.

[1]That a large part was covered is indicated by the occurrence of $CaSO_4$ also in the Alma, Midland, Mt. Pleasant, and Bay City wells.

§ 10. Caspian Sea.

For a modern illustration of the conditions in this Michigan sea, the Caspian[2] sea might be cited. Into the northern part of this sea empty the Volga, Ural, and Terek, rivers bringing in a large quantity of the fresh water, so that the sea water is nearly pure, with a specific gravity of 1.009. This small amount of salt, according to Von Baer, is partially due to the fresh water brought in and also to the number of shallow lagoons surrounding the basin, each being a sort of natural salt pan. At Novo Petrovsk a former bay of the main sea is now divided into a number of basins showing all degrees of saline concentration. One of these has deposited on its banks only a thin layer of salt, a second has the bottom covered with a thick crust of crystals, a third is a compact mass of salt, and a fourth has lost all the water and is a mass of salt covered with sand. On the other side of the sea in the peninsula of Apsheron are ten salt lakes from one of which 10,000 tons of salt are annually produced.

The concentration is seen on the greatest scale in the Karaboghay (Black Gulf) of the Caspian, whose nearly circular shallow basin is about 90 miles across, and almost entirely cut off by a long narrow spit of land communicating with it by a channel not over 150 yards broad and five feet deep. Through this passes a current with an average velocity of three miles an hour, accelerated by the western winds.

This current is due to the indraught produced by excessive evaporation due to the heat and winds from the surface, of the basin, which at the same time receives but little return from streams. The small depth of the bar prevents a counter current of highly saline water into the sea. The current carries into the Black Gulf, according to Von Baer, 350,000 tons of salt daily. If the bar should be elevated and cut off the basin from the sea, the gulf would quickly diminish and become a salt marsh, later drying up and leaving a heavy salt deposit. North of this gulf over the Russian steppes are sands and marls intermingled with salt, representing former salt lakes now dried up.

[2]Von Baer, Bull. Acad. St. Petersbourg, 1855-6, quoted in Enc. Brittanica, Vol. V, p. 176.

§ 11. The Michigan Caspian Sea.

The Kinderhook sea of the American continent was an interior sea with a bay extending north-east into Michigan. In this bay were laid down the Marshall sandstones. The close of the period was marked by an uplift in this area and a retreat of the sea southwestward, finally exposing a wide area of land in southern Michigan and northern Indiana. At Lafayette, Ind., the floor of this sea rose at least 563 feet above sea level.[1] North of this land barrier was a large interior sea with a floor near Grand Rapids 375 feet above sea level lower by nearly 200 feet than the ocean to the southwest, but surrounded by the Marshall series, at this time dry land 777 (Kalamazoo), 983 (Coldwater), to 1000 feet (Hillsdale) above sea level on the south; 700 feet (Huron County) on the east; and 755 feet (Grayling) at the north; a sea like the Caspian, with a depth at first of probably 700 feet or more, and an area of 22,686 square miles.

In this sea were elevations and depressions, the ridge at Lansing 500 feet above sea level, and a depression east of Saginaw 380 feet below sea level separated by a ridge 187 feet above the sea floor.

This sea probably had its tributary streams coming from the highland at the north and northeast flowing down across the recently emerged flats of the Waverly and Marshall land, bringing in a supply of sediment and doubtless salt and gypsum from the Salina beds at the north.

The lake basins of Michigan and Huron were not in existence at this time but belong to a much later chapter in the geological history of our continent. The irregular clay seams and the clay bedding planes in the gypsum represent an influx of sediment, wind blown material, or the result of tidal currents, or material brought in by streams.

As the evaporation of these waters-went on, the first deposit would be carbonate of lime thrown down when the specific gravity was raised to between 1.0506 and 1.1304. By further concentration, when the specific gravity was between 1.1304 and 1.22, gypsum would be deposited. At this time 37% of the water must have been evaporated. If the sea was originally 700 feet in depth, it would now be 440 feet deep, still covering the Saginaw ridge but exposing the Lansing ridge. Thus would be formed smaller basins in which evaporation would go on rapidly. Further well records might give a clue to the other basins separated by ridges the sea would gradually become like the modern Caspian with smaller basins around the main sea, in which all degrees of concentration would be found.

In the deep basins near Saginaw, the dividing ridge would be exposed before the concentration produced the deposition of salt. In the evaporating basin the deposit of gypsum would occur especially around the borders of the basin, and by the influx at first of water across the Saginaw ridge the contracting basin of water was probably renewed, resulting in the 20 or 25 feet of gypsum in the area south.

[1]The references are to present sea level. It is assumed that there has been no post carboniferous folding.

The normal order should be a dolomite limestone floor on which would be a deposit of gypsum covered by layers of salt. In the present developed area the gypsum rests on the limestone or dolomite floor but with no salt beds over it. The rock salt deposits are below the gypsum series in the Monroe or Salina series. Further, in the Marshall and Grand Rapids series at Saginaw, Grand Rapids, etc., the salt wells secure their salt wholly from natural brines. Rock salt occurs only occasionally in veins in the gypsum.

If the Michigan inferior sea evaporated completely then there would have been, on the assumption that the waters were like the present Atlantic ocean, 17.9 times as much salt as gypsum. This would have been deposited over the gypsum and especially in the lower part of the basins towards the interior where the waters deprived of their gypsum had retreated on evaporation, but in the same geological series. The salt might later have been removed by solution through downward circulating waters dissolving out the more soluble salt. The gypsum now remaining shows marked effects of solution and these effects would have been much greater in the salt. The salt laden waters would flow downward along the slope of the rock and percolating through would work up under the hydrostatic pressure, as it approaches the center of the basin, into the overlying Parma sandstone, which is more gypsiferous than the underlying Marshall.[1]

Another possible explanation of the final history of this sea is found in the great extension of the sea in the next epoch resulting in the formation of the St. Louis limestone. The sea at this time extended its borders north and south and passed across the Michigan interior basin to Grand Rapids on the west, and on the east into Huron county. Possibly this took place before the Michigan sea had disappeared by concentration. From the sandstones and shales of the Michigan series found in the well borings of the interior it would seem that the ocean flowed over the southern barrier into the interior sea a number of times before the greater or culminating St. Louis inundation, and thereby deposited these sediments in which no gypsum or salt are found, as the water was diluted and the specific gravity was not high enough to cause precipitation. These overflows, local in their occurrence, cannot be correlated with other sections unless with those of the Logan series of Ohio whose origin may be similar.

In the deeper Michigan borings gypsum seems to be replaced by anhydrite, but it is stated that where the depth of water is 325 feet, thus giving a pressure of ten atmospheres, anhydrite is formed instead of gypsum.[2]

The theory as outlined for Michigan is based on the study of comparatively few well borings, and on a comparative study of the present conditions in the

Caspian sea and those of the Michigan area as far as they can be determined. There is a wide range of probability involved and while the theory is advanced as a theory resting on limited data, it seems probable that it represents approximately the conditions of the origin of these deposits.

[1]See analyses in U. S. G. S. Water Supply, Paper No. 31.

[2]New York State Museum Report, Vol. III, No. 11, p. 11, 1893. See previous foot note, page 185.

§ 12. Vein Deposition.

Gypsum is of course readily precipitated from waters which hold it in solution. It gave much trouble by coating the casing of salt wells. It is not infrequently found in little isolated crystals in shales. I have also seen it coating the cleat or vertical joints of coal. It has been found in the copper country. Large clear selenite was found at the National mine.

All these occurrences are, however, of course only mineralogical curiosities. L.

CHAPTER XII.

GYPSUM AS A FERTILIZER.

§ 1. Early Experiments.

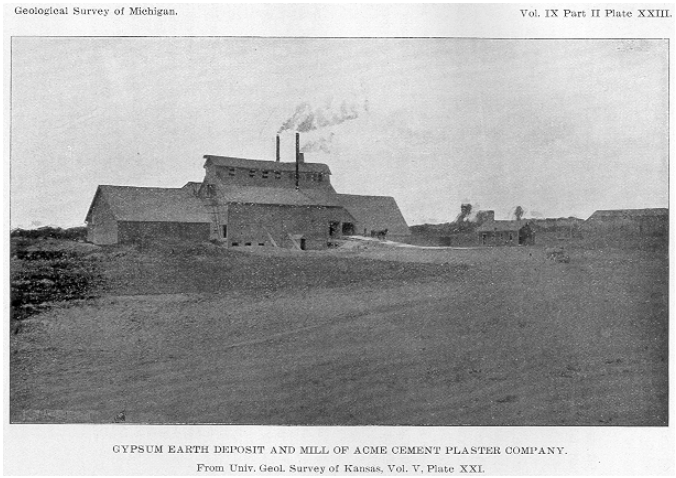
Ground uncalcined gypsum stone or land plaster, as a soil fertilizer, has at times been endowed, by writers on this subject, with the most wonderful and mysterious life-giving power. Other examples have been cited to show that it had no effect whatever, but such examples are rarely given in the earlier writings. From some of the accounts given it would seem as though land plaster used with certain crops would give a three years' yield in one. The good effects of land plaster have been assigned to its influence on the air, on water, and on the soil itself.

Among the earliest accounts of gypsum as land plaster are those of Virgil who writes of the value of impure gypsum on cultivated fields, and the early farmers of Britain and of Lombardy had great faith in its use.

In this country, down to the year 1889 nearly two-thirds of the quarried gypsum was ground into land plaster. In the early 70's in Michigan, the mills could not supply the demand, though they were run night and day, and the material sold at a high price of $4.50 a ton. In 1890 the uses of gypsum in this country were reversed in ratio, and nearly twice as much rock was calcined as was used for fertilizer. By 1893 the proportion was three to one, and in 1898 the amount of gypsum calcined was six times that ground into land plaster.

There were several causes for this change. One was the growing doubt with regard to the wonderful properties of land plaster. Fields which had given greater yields by its application year after year, now failed to respond to the treatment. As it was sometimes expressed, the soil had grown tired of this form of food. Prof. F. S. Kedzie says that:—"Land plaster consists of elements which are rarely found deficient in soils.[1] Hence it seems reasonable to suppose that the beneficial action of $CaSO_4$ is certainly not direct but through secondary action. Its benefits are practically confined to the leguminous family, and the lessened use is due to a greater knowledge of what the crops remove from the soil, as well as to the discovery of phosphatic deposits and increased use of phosphatic manures. Since the fertilizer law passed in 1885, the exact percentage of different constituents in commonly used fertilizers is known.

[1]CaO is always present, and SO_3 very commonly in lower Michigan waters. See U. S. G. G. Water Supply, paper No. 31, and annual report for 1902.



[XXIII. Cement Plaster Mill and Gypsum Earth Deposit of Acme Cement Plaster Co., Kansas]

Then, also, commercial fertilizers composed of various ingredients became popular. Large companies were organized over the country, who by the use of large capital, careful preparation of materials aided often by judicious advertising were able to sell at a reasonable price patent phosphate fertilizers embodying the good points of gypsum and giving other valuable qualities in addition.

New uses for calcined plasters were devised especially in its use for hard wall plaster, Alabastine, Anti-Kalsomine, etc., which enlarged the demand and opened a line of manufacture which proved more profitable than the grinding of the crude material.

The opinions of agricultural chemists do not always agree and often opposite views are expressed in standard books of reference. The reports of agricultural societies down to about 1870 nearly always contained reports from farmers describing their experiments with gypsum on various crops. No agricultural treatise was complete without a discourse on this subject. At the present time it is rare to find gypsum discussed in such society meetings and modern books of agriculture devote but a paragraph to the subject of land plaster.

The following is a list of references to the subject in the reports of the Michigan State Board of Agriculture:

Gypsum Deposits in Michigan.

Year.	Page.
1853	337
1856	585
1871	199
1886	150

Plaster.	Year.	Page.
Action of, on land	1875	257
	1879	91
Amount per acre to use	1875	264
	1886	72
Apple trees dusted with	1879	280
Article on agricultural value of, by Dr. R. C. Kedzie	1875	256
Clover and	1877	149
Compared with other fertilizers	1875	265
Corn and	1878	162
experiments	1877	78
Curculio, fought by	1888	224
Discussed	1850	294
	1864	85
	1879	81, 91
	1883	100
	1886	74
Drainage carrying out, of soils	1875	262
Dust for insects	1879	280
	1888	224
Experiments with	1865	236
	1866	56
	1877	78
	1878	215

Plaster.	Year.	Page.
Grass top dressed with	1865	236
	1866	56
How much to sow	1875	264
	1886	72
Light soils and	1864	19
Lost by drainage	1875	262
Manurial value	1850	294
	1864	85
	1879	81, 91
	1883	100
	1886	74
Mixed with other things, effect of	1879	91
Of Paris, manurial use of	1855	183
Sowers	1878	373
Used at Grayling	1888	209
Wheat treated with	1875	265
Plaster.		
Ashes and salt, experiments with	1888	215
Dust and carbolic acid for curculio	1888	224
Used at Grayling	1888	209
Plaster.		
Effect on potatoes	1889	226
rutabaga	1889	230
Used on Grayling farm	1889	79

The history of gypsum as a fertilizer[1] dates back a little over a hundred years. A century has seen its rise in the estimation of agriculturists and its decline. The land plaster industry started probably in Wurtemberg but was first brought to the attention of the world by the Economic Society of Berne, Switzerland. The first account that can be found of this use of gypsum is in the Memoires de la Societé économique de Berne in 1768. This society had submitted the following theme for public discussion, "Description of the different kinds of earth and methods for mixing them, to render the soil fertile."

Among the papers submitted to the society was one by a clergyman, J. F. Mayer of Kupferzell in Würtemberg, which was given first rank by the jury of the society of Berne. In the main paper there is no reference to gypsum, but in an appendix was a brief note on gypsum as a fertilizer, which according to Prof. Chuard brought about almost a revolution in agricultural methods of fertilizing soils. The society requested Mr. Mayer to give them further knowledge on this subject, which he did in the following words:—

(Translated from the French.)

"It is only two years since one has entertained the thought that a stone of which little account was taken, was nevertheless well suited to attract to itself the oil and salt of the air, and consequently suitable to be placed on the meadows and to enrich them. When it is found crude, it is reduced to powder, and after it is crushed it is spread on the meadows or upon sterile soils of whatever nature they may be. Over one acre one scatters eight fri (a measure 13 inches in diameter and 8 inches high) and this fertilizer furnishes the best forage and the best clover one can imagine. It has greater effect if calcined, but the best effect is obtained by adding to it two fri of wood ashes and eight handsful of salt, and the whole soaked in a half pail of manure water. Let these materials be well mixed, then let them lie eight days, after which having stirred them, one may spread them on the soils to be fertilized. Our people profit by it continually and the experience for two years has justified the first trials. As soon as one is quite convinced, and one cannot conceive it otherwise, that all plants are composed of salt, oil, and earth, one will be as easily persuaded that gypsum flour scattered over wheat, oats, barley, and vegetables, ought to produce the same effect. The experiment has already been tried."

The society of Berne realizing the importance of this communication, decided to have the experiments at Kupferzell repeated at a number of places, and these results were published in the Memoir for 1771, especially in two communications, one by N. H. Kirchbergner, and the other by M. Tschiffeli.

The paper by Kirchbergner is an account of a series of experiments on clover, lucerne, and radishes, and the author expresses his admiration over the marvelous results obtained from the use of this gypsum fertilizer. On an acre (arpent) twelve measures of gypsum, costing three francs and twelve pence produced more forage than 12 cars of manure costing not less than 72 francs. He preferred calcined gypsum to raw, not for the effect but because it was more readily pulverized. The gypsum produced a greater effect the first year but also gave an increase in crops the second year. It had more effect on dry earth than on wet, was better on heavy soil than light. Sowed in the spring on natural forage it produced its best effects on the second cutting.

The memoir of Tschiffeli proved at the start that gypsum was excellent material for the soil and not injurious. The conclusions of the experiments were the same as in the first memoir. On wheat becoming weak in its growth at the first of June, gypsum applied in double portion at a dry time, brought about at the first rain an almost miraculous growth and made a good harvest. Both of these men observed that no culture profited with gypsum like trefle, luzerne and the plants of this same family.

These experiments were repeated by others and the use of gypsum fertilizer spread over France, then over Germany and England, and became especially

prominent in the United States where the gypsum was imported from the Monte Martre quarries near Paris.

[1]For the account of this early history, the writer is indebted to Prof. Chuard of Laussanne Switzerland, who has kindly placed at hand a number of his papers on this subject.

§ 2. Early Use in America.

The early farmers in Maryland, according to Bees, used gypsum fertilizer with great success, and this writer states that:

"It was most beneficial on high and sandy soils and had good effect on wheat, rye, barley, peas, potatoes, cabbage, clover and all natural grass crops. The invariable result of the several experiments incontestibly proves that there is a most powerful and subtle principle in this tasteless stone, but by what peculiar agency or combination it is capable of forcing vegetation in such an instantaneous and astounding manner is a mystery which time reserves for others to unfold."

Benjamin Franklin called attention to the value of gypsum as a fertilizer for grass, by sowing the land plaster in a clover field near one of the main roads in Pennsylvania so as to form the sentence, "This has been plastered with gypsum," and the letters it is said could be detected readily by the height and color of the clover where the gypsum had been sown.

Grece's American Observations.

Mr. Chas. F. Grece[1] writing of his observations in the United States and Canada in 1819 in the Quarterly Review, says:

"This valuable manure, almost unknown though very easy to obtain, merits the attention of every farmer. There is scarcely a farm in the provinces but it might be applied to with advantage. The practice of nine years on the following soils and crops may suffice to prove its quality. On a piece of poor yellow loam I tried three grain crops without success, with the last which followed a hoe crop I laid it clown with barley and the return was little more than the seed. The grass seed took very well. In the month of May of the following year I strewed powder of plaster at the rate of one minot and one peck to the arpent (acre). In July the piece of land being mowed the quantity of the grass was so great that it was not possible to find room to dry it on the land where it grew. The product was five large loads of hay to the arpent. It continued good for five years. . . . I tried plaster on cabbages and turnips, but did not perceive any good effects. From the frequent trials of this manure on various soils it is evident that it is applicable to both light and strong soils for top dressing of succulent plants."

[1]Vol. XXIII, pp. 147-150; 1820.

Ruffin's Experiments.

Ruffin, in his book on Calcareous Manures,[2] written in 1832, states that,

"There is no operation of nature heretofore less understood or of which the cause or agent seems to be so totally disproportionate to the effect as the enormous increase of vegetable growth from a very small quantity of gypsum in circumstances favorable to its action. All other manures, whatever may be the nature of their action, require to be applied in quantities very far exceeding any bulk of crop expected from their use. But one bushel of gypsum spread over an acre of land fit for its action may add more than 20 times its own weight to a single crop of clover hay."

[2]Page 151.

Mr. Harbe[1] in the German Land-Owners meeting in 1841, stated that he had found gypsum of most value on clover and peas. If applied to peas, and oats were planted the next year, there was a greater yield, but the plaster applied directly to an oat field produced no effect. The discussion at this meeting brought forth contradictory remarks with regard to the use of gypsum on meadows. In the Gardener's Chronicle for 1841 (p. 785), gypsum was stated to be of little use on corn, but useful for clover, grass, potatoes, and turnips, and was especially good on light or chalky land and should be sown broadcast in proportion of about five bushels to the acre.

[1]Agricultural Society of England, Vol. 333. p. 224; 1812.

Harris' Experiments.

Mr. Harris,[2] in 1878, gave an account of his experiment on oats at the Moreton farm near Rochester, N, Y., in the following table:—

	Bushels to acre.	Weight per bushel.	Pounds of straw.
On field No. 1, without manure	36	22	1958
On field No. 2, with 600 lbs. of gypsum	47	26	2475

There was an increase of 11 bushels to the acre, and nearly one-half ton more straw.

	Bushels to the acre.
On potatoes with no manure	95
" " " 100 pounds of plaster to the acre	101
" " " 150 pounds of ammonia sulphate	140

He did not find gypsum valuable as a direct fertilizer for wheat, but quotes an old adage that, "clover is good for wheat, plaster is good for clover."

[2]Talks on Manures, pp. 126, 254: 1878.

§ 3. Theory of De Candolle and Chaptal.

The early theory to explain the action of gypsum on soils, very attractive and popular in its day, was that of De Candolle,[3] who looked upon gypsum as a stimulant to the leaves of plants. This theory, which became prevalent, stated that "sulphate of lime acts as an irritant in favoring respiration and exhalation of plants."

Chaptal modified this theory somewhat, and regarded the stimulation as due to the saline character given to the sap by the presence of gypsum, and as this mineral dissolved very slowly, it would gently stimulate and hot irritate.

[3]Annales de Chimie, 55, p. 312.

§ 4. Gypsum as Direct Plant Food.

The examination of the ash of plants was made long ago, and formed the basis for a number of theories concerning the action of plaster on plants, especially for those theories which regarded gypsum as a direct element of plant food.

Analyses of Plants.

	Water.	Nitrogen.	Ash.	Potash.	Soda.	*Lime.*	Magnesia.	Phosphoric acid.	*Sulphuric acid.*	Silica.	Chlorine.
Pasture grass	782	7.2	21.2	8.1	0.3	2.6	1.2	1.9	0.7	4.1	2.1
Red clover, young	860	6.0	14.0	5.1	0.3	3.9	1.3	1.7	0.3	0.4	0.6
" " in bud	820	5.2	14.7	5.5	0.3	4.5	1.6	1.5	0.4	0.4	0.5
" " in flower	800	4.8	13.7	4.4	0.3	4.8	1.5	1.3	0.4	0.4	0.5
Alfalfa, (early flower)	740	7.2	19.2	4.5	0.3	8.5	0.9	1.6	1.1	1.8	0.6
White clover, in flower	805	5.6	14.3	3.1	1.0	4.3	1.4	1.8	1.1	0.6	0.7
Potato plant	750	3.4	9.5	5.8	0.3	0.3	0.5	1.6	0.6	0.2	0.3
Oats (grain)	143	17.6	26.7	4.8	0.4	1.0	1.9	6.8	0.5	10.5	0.3
Maize (grain)	144	16.0	12.4	3.7	0.1	0.3	1.9	5.7	0.1	0.3	0.2
Spring wheat (grain)	143	20.5	18.3	5.6	0.3	0.5	2.2	9.0	0.2	0.3	0.1
Winter wheat (grain)	144	20.8	16.8	5.2	0.3	0.5	2.0	7.9	0.1	0.3	0.1
Garden beans (seed)	150	39.0	27.4	12.1	0.4	1.5	2.1	9.7	1.1	0.2	0.3

The translation of the German work by Prof. Sprengel, published in the Agricultural Gazette in 1844 (p. 858), states that gypsum suffers no decomposition in the soil but passes in its entire state into the substance of the plant.

According to Johnston,[1] in 1849, the benefit of gypsum to clover is due to its decomposition in the soil; thereby furnishing lime and sulphur to the plants. This author believed the gypsum did not fix ammonia, and further absorbed very little moisture from the air. According to his experiments,

1000 parts of soot gained from moist air 36 parts by weight.
" " " coal ashes gained 14 parts by weight.
" " " burnt clay " 29 " " "
" " " chalk " 4 " " "
" " " gypsum " 9 " " "

[1]Manures, pp. 454-481; 1844.
Use of lime in Agriculture, p. 204; 1849.

§ 5. Retention of Ammonia by Gypsum.

Moist gypsum in contact with ammonium carbonate has been supposed to form ammonium sulphate according to the formula,[2]

$$(NH_4)_2\ CO_3+CaSO_4=(NH_4)_2\ SO_4+CaCO_3$$

[2]U. S Dept. of Agric. No. 64, Division of Soils, 1899, Cameron, p. 155.

If used in stables and other places it serves to retain to some extent the ammonia which otherwise might escape into the air. This use of land plaster is recommended by Snyder[1] and also by Wiley.[2]

It was early discovered that the atmosphere contained carbonate of ammonia which was carried down to the earth in rain water, and there it was thought to be held or fixed by gypsum. A good statement of this theory is given in Browne's American Muck Book,[3] written in 1851. The carbonate of ammonia acted on the sulphate of lime so as to form sulphate of ammonia and carbonate of lime. This prevented the escape of the volatile carbonate of ammonia back into the air. A computation was made which showed that 100 pounds of common unburned gypsum would fix 20 pounds of ammonia containing 16½ pounds of nitrogen. This would furnish a very large amount of valuable food to plants for their use; but now it is known that the amount of ammonia in the air is so small that it is very doubtful whether the amount so fixed by gypsum is even appreciable to the plants.

This theory was held and much elaborated by the chemist Liebig, who calculated that if 40 pounds of gypsum were placed on a field, and only one-tenth of it entered plants as ammonia sulphate, theoretically there would be nitrogen enough for 100 pounds of hay, 50 pounds of wheat, or 60 pounds of clover.

[1]The Chemistry of Soils and Fertilizers, p. 161, 1899.

[2]Principles and Practice of Agricultural Analysis, Vol.2, pp. 307-308; 1895

[3]Pages 68 to 75.

Stockhard's Theory.

Some have held that the gypsum fixed the ammonia formed within the soil by decaying vegetable matter; and further, that the gypsum hastened this decay. Davy tried a number of experiments to disprove this latter statement and he found that meat mixed with gypsum and allowed to stand a considerable period of time showed not the slightest difference in time of putrefaction, from meat not so treated. The former part of the theory is given in a brief summary by S. Stockhardt:[4]

"Gypsum acts chiefly through its sulphuric acid", which on the one side procures soluble ammonia from the humous constituent of the soil and furnishes this to the plant at the period when it is especially inclined to the production of leaves and stems; and on the other side, strengthens and increases the power of plants to absorb ammonia from the atmosphere, and this in greater proportion as they are more abundantly endowed with delicate and juicy leaves and are thus already fitted by nature to make a more abundant use of the atmosphere."

[4]A Familiar Exposition of the Chemistry of Agriculture, p. 226; 1855.

§ 6. Van Wormer's Experiments.

Experiments by Lewis H. Van Wormer on the fixation of ammonia by land plaster conducted under the direction of F. S. Kedzie for a senior agricultural thesis in the Michigan Agricultural College in 1895, seem however, to show that dry plaster has but little power to absorb and affix ammonia. Dampened plaster absorbed ammonia but lost most of it on drying out. This led Mr. Van Wormer to conclude that the power of absorption depended more upon the water than upon the plaster. It seems, however, to be possible that the water acted as a necessary medium for reaction and that then the reaction above stated may have gone on. Mr. Van Wormer experimented under conditions both abnormal and normal. In one set of experiments he placed under bell jars a watch glass of ammonia and a watch glass of plaster or some other substance under each. Five grams of dry plaster under the jars with five c.c. of ammonia left for more than ten days contained only from 0.1 to 0.2 c.c. of ammonia less than would be absorbed by 3. c.c. of water. In only 48 hours it contained 2.5 respectively 3.3 of ammonia.

Another line of experiments was to place water, plaster and sulphuric acid in crystallizing dishes under the floor of a stable reeking with ammonia. After four days 15 grams of plaster moistened with 15 c.c. of water, 15 c.c. of water straight and 15 c.c. of sulphuric acid had absorbed relatively 25.8, 10.8, and 199.4 c.c. of standard decinormal solution of ammonia containing 1-7 grams of ammonia per liter of water.

A similar experiment with 5 grams of plaster and 5 grains of sand each added to 5 c.c. of water, gave for the plaster 7.4 and 4.3 c.c. of the ammonia solution in four days, and in another case 3.5 to 1.3 c.c.

In testing plaster in comparison with muck (peat) in a similar way 5 grams of each with excess of water absorbed in three days 10.2 c.c., and 32.1 c.c. respectively and in 24 hours 7.5 and 34.3 c.c., and in three days under the stable floor 6.6 to 31.5 c.c. In an experiment under bell jars with barely enough water to wet the two that ratio was 1.7 c.c. to 37 c.c. again in favor of the muck. Further experiments show that muck or peat was a much more effective fixing agent than plaster.

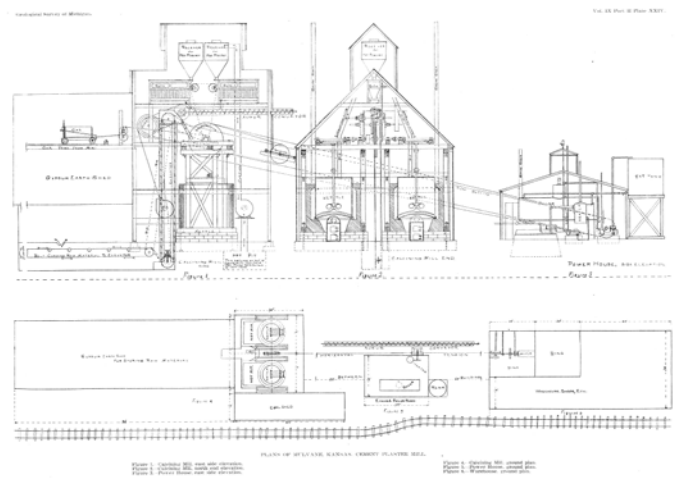
§ 7. Boussingault's Experiments.

Boussingault,[1] in 1841 spread gypsum over a clover field, and then analyzed the clover from the land where gypsum was spread and where it had not been spread. He found a great increase in amount of ash, which represented an increase in all the mineral constituents, but especially in lime, magnesia, and potash. These experiments, carried on for two years on the same land, are given in the following table:—

	Land with gypsum.	No gypsum.	Land with gypsum.	No gypsum.
Ashes free from CO_2	270.0	113.0	280.0	97.0
Silica	28.1	22.7	10.4	12.7
Oxides (iron, manganese, alumina)	2.7	1.4	?	0.6
Lime	79.4	32.2	102.8	32.2
Magnesia	18.1	8.6	28.5	7.1
Potash	95.6	26.7	97.2	28.6
Soda	2.4	1.4	0.8	2.8
Sulphuric acid	9.2	4.4	9.0	3.0
Phosphoric acid	24.2	11.0	22.9	7.0
Chlorine	10.3	4.6	8.4	3.0

This table gives the number of kilograms of the elements in clover from a hectare of ground, and it certainly shows that gypsum has had considerable effect on the clover. The great increase of potash shown by these analyses was explained as due to the direct action of the gypsum on the soil or was left out of account altogether. It is explained in another way by more modern theories as will be described in another section.

[1]Rural Economy, 1887.



[XXIV. Plan of Modern Gypsum Mill erected in Kansas]

§ 8. Davy's Theory.

Sir Humphrey, and others before and after his time, have regarded gypsum as a direct source of plant food. Davy found that clover contained about two hundred weight per acre of sulphate of lime, and that this was the amount of gypsum which produced the greatest benefit on the soil, so he argued the gypsum entered the plant as sulphate of lime.

An examination of the table of plant composition given above shows that lime and sulphuric acid are present in the plants benefited by the gypsum. Other tables give sulphur as an element in plant ash rather than sulphuric acid. So sulphur was supposed to come from the gypsum which did not enter directly as plant food, but was first broken up into its parts. This action was supposed to depend on the presence of humous acids, whereby the gypsum was broken up into humate of lime and sulphuric acid. If too little humus was present this action would not take place, and on such soils gypsum would be of no value; if too much humus, the action would be rapid, setting free so much sulphuric acid that it would corrode the roots of the plants and so prove injurious. The lime shown in the table of plant analyses

was supposed by many to result from the decomposition of the gypsum.

The sulphur of plants probably comes from other sulphates more easily decomposed than gypsum, though a small portion may result from this mineral. Most of the lime is certainly derived from other compounds, especially the carbonate of lime, which is readily soluble.

§ 9. Recent Theory of Storer.

Gypsum is now[1] thought to act as a fertilizer of soils in three ways, one mechanical and two chemical.

First, lime is known to flocculate loose soils; that is, collects together the loose particles and so makes the soil more granular. This may be illustrated by placing lime in a muddy liquid, and the mud will flocculate and settle to the bottom. Lime has also an opposite effect on tough clay soils, where it granulates them, breaking the soil up into finer particles. Gypsum as a lime salt, appears to act to a small extent in these ways and so improve the mechanical condition of the soils; but in this respect other lime compounds act more powerfully and more rapidly, and so would be better.

Second. Storer has pointed out that gypsum has nearly one-half its weight in oxygen and gives this up to many substances, and so may act upon nitrogenous and carbonaceous substances in the soil.

Third, and most important, it has been shown that gypsum decomposes the double silicates in the earth, setting free potash as a double sulphate. According to Storer the action is as follows:

$$\left.\begin{matrix} Al_2O_3 \\ CaO \\ K_2O \\ H_2O \end{matrix}\right\} x\ SiO_2 + CaOSO_3 = \left\{\begin{matrix} Al_2O_3 \\ CaO \\ CaO \\ H_2O \end{matrix}\right\} x\ SiO_2 + K_2\ OSO_3$$

By this means the potash in solution reaches the roots of the plants. This method of supply is of special advantage to the deep rooted plants, as in the order Leguminosae—the clovers, beans, etc., which contain a considerable percentage of potash in their tissues.

Soils with abundant potash would not need gypsum, and soils with no potash compounds would not be benefited in this respect by gypsum.

The gypsum is then to be looked upon as an excitant rather than as a form of plant food. Land plaster according to this theory uses the potash of the soils more readily than it is used naturally and so after a few years the soil fails to respond to the gypsum dressing, and the soil is said to have grown tired of this treatment. The experience of many farmers is that gypsum is very beneficial for a few years and after that it fails to produce any effect. This is expressed in the old English adage, "Lime enriches the father, but impoverishes the son."

[1]Chemistry of Agriculture, Vol. 1, pp. 206-216; 1887.

§ 10. Experiments in Kansas.

Recent experiments made in Kansas[1] on prairie and tame grasses appear to show that on the soils in the Manhattan region, plaster has but little effect.

On prairie grass the average yield on non-plastered plats was 1.248 tons to the acre. On plastered plats the yield was 1.256 tons.

The experiments on tame grass are shown in the table:

	1st cutting. Pounds.	2d cutting. Pounds.	Total yield per acre. Tons.
Plaster, 800 pounds per acre	1,076⅔	676⅔	3.506
Plaster, 400 pounds to the acre	1.012½	690	3.404
Nothing	1.008	690	3.396

The experiment gave an increase on the plastered land of 165 pounds of hay on one and one-fourth acres, and the fertilizer cost of this land was $1.80.

On corn the yield on non-plastered acre plats was 71.3 bushels to the acre; on plastered plats the yield was 70.6 bushels, and in another experiment the increase through the use of plaster was one-tenth of a bushel.

[1]Bull. 32 Kansas State Agricultural College Experiment Station, pp. 239, 240; 1891.
Bull. 30, p. 201, 202: 1891.

CHAPTER XIII.

MISCELLANEOUS USES OF GYPSUM.

§ 1. Uncalcined Gypsum.

Gypsum in its ground uncalcined state is used as land plaster for fertilizer on various soils. Its value in this connection is much disputed and doubted, and the subject is discussed in the previous chapter. Commercial patent fertilizers have displaced this form to a very considerable extent. Many of these, however, have a base of gypsum to which are added the various other ingredients.

Terra Alba.

The white, finely ground, crude gypsum is sometimes sold under the name of terra alba for adulteration purposes. This substance is sometimes mixed with white lead paints, making a cheap substitute for the lead. It has been detected in flour, sugar, candy, baking powders, and other compounds. The pure food laws in a number of states have been instrumental in detecting a wide range of such illegitimate uses.

In India, powdered gypsum is kept in the bazaars as a drug. It is supposed to have cooling properties, and a gruel made from it is given in fevers. It is also used by the Chinese in a similar way. In India it is also calcined and used for chewing with betel, though sometimes carbonate of lime is used instead.

Gypsum is sometimes added to the water used in brewing. Soft water,[1] free from saline matter is not good for brewing purposes, so sodium chloride and gypsum are added. The English laws allow this to be added up to 50 grains per imperial gallon. Soft water gives higher extracts as it dissolves the albuminous matter in the malt more effectually than in hard water, but the impurities are powerful agents of change. Lower Michigan waters will rarely need gypsum added to them.[2]

The famous Burton ales in England are made with water from wells which pass through the gypseous deposits in the Keuper marls of the district. This water is considered especially desirable for brewing. Its composition is as follows, in an imperial gallon of 10 lbs.=70,000 grains:

	Grains.
Chloride of sodium	10.12
Sulphate of potassium	7.65
Sulphate of lime	18.96
Sulphate of magnesia	9.95
Carbonate of lime	15.51
Carbonate of magnesia	1.70
Carbonate of iron	0.60
Silicic acid	0.79
	65.28

In another large brewery at Burton, analysis shows the water to contain 54.5 grains of sulphates and 9.93 of carbonate of lime.

Gypsum flour or terra alba is mixed with poorer grades of wheat flour and used for dusting the moulds in metal casting. The mixture is sold under the name of Corine flour.

The crude gypsum is used in the preparation of some pharmaceutical preparations. It is also used in some methods of decomposing ammonia in the manufacture of sal-ammoniac.

Thin plates of selenite are sometimes used in optical work to determine the positive and negative character of minerals, and as it does not transmit heat well it is used to protect the lenses of optical lanterns.

Garnierite or the hydrous silicate of nickel, is mined in New Caledonia, and it is one of the important sources of nickel. The ore is smelted in a low blast furnace with coke and gypsum.

In Michigan, a special branch of manufacture is that of bug plaster, which is a land plaster mixed with Paris-green or other poison and used on potatoes and vines to destroy the insects. As a base of insecticides it is widely used.

[1]Encyclopedia Brittanica, Vol. IV, p. 275.

[2]See U. S. G. S. Water Supply, Paper No. 31.

Manufacture of Crayons.

Chalk crayons for blackboard and carpenter's use, are now commonly made from gypsum. The ground uncalcined gypsum is mixed with other ingredients according to a secret formula, pressed and dried and packed in boxes. One of the largest companies engaged in this work is the American Crayon Co., of Sandusky, Ohio, established in 1835. Their new works, completed in the fall of 1902, is the largest factory of this kind in the United States. They manufacture a variety of products besides crayons. The company sells annually about 18,000 cases of crayons, requiring 80 pounds of gypsum to the case, or 720 tons a year. The gypsum is obtained from the Marsh quarry at Port Clinton.

Hardening of Gypsum Blocks.

Various methods have been devised to harden blocks of gypsum to imitate marble. A Canadian company a few years ago quarried large blocks out of the Alabaster quarry with a channeling machine. These blocks were shipped to near Toronto and hardened, but for some reason the work was abandoned. Some of the Michigan gypsum has been hardened at Chicago, but the work has been on a small scale. A Chicago company a few years ago established a factory for making this artificial marble at Canyon City, Colorado.

A number of patents have been issued for this work. Patent number 549,151 (1894) by Mr. Geo. W. Parker, formerly of San Francisco, is entitled "Process of Treating Gypsum Rock to Imitate Chalcedony." The claim is as follows:

“The process of treating gypsum rock to represent chalcedony consits in first completely dehydrating the

rock by the action of hot air, next allowing the now porous rock to absorb a solution of sulphate of iron, nitric acid, and potassium sulpho-cyanide, after which immersing in a solution of aluminum sulphate [$Al_2(SO_4)_3$] for fifteen hours, next expose to air and then polish as set forth."

Patent number 588,287 (1897) by Geo. W. Parker of Grand Rapids, (filed October, 1895; renewed, July, 1897), is entitled "Gypsum Rock to Imitate Marble." The claim is:

"The process of treating gypsum rock which consists of eliminating the moisture from the rock by the action of hot air, then removing the then hot calcium sulphate into a closed compartment charged with the fumes of ammonia and then immediately immersing the cool rock in a warm solution of aluminum sulphate until the pores are filled, as set forth."

Hardened gypsum treated with stearic acid or with paraffine and polished, resembles meerschaum, and it is used for cheap pipes. Sometimes coloring solutions of gamboge are added to complete the resemblance.[1]

[1]Wagner, Chemical Technology, p. 333, 1889.

Use of Uncalcined Gypsum in Portland Cement.

A small amount of gypsum added to Portland cement, retards its set and apparently does not injure its tensile strength. Large amounts will retard the set of the cement and also give it a greater tensile strength, but after a time the set cement will begin to check.

In one briquette tested which had been mixed with a high percentage of gypsum, the tensile strength in 24 days was 1,100 pounds, with no trace of cracks or checks. This broken briquette is now over a year old, and it is badly checked and cracks extend nearly half way through the block.

According to Michaelis,[1] gypsum may be added to cement in amount up to four per cent by weight to increase the hardness, though the German regulations and those of the London Chamber of Commerce permit but one-half of this amount.

This writer states that the gypsum in the cement takes the form of calcic aluminate, $Ca_3Al_2O_6$+3 $CaSO_4$+n H_2O, the n probably equalling 30. This substance crystalizes in needle shaped rods of one-half millimeter in length. Most Portland cements have seven to nine per cent of alumina and can take up 28 to 30 per cent of calcic sulphate and water. If in larger quantities these crystals forming and expanding will break the cement.

The experiments of Candlot[2] show the following influence of gypsum on the cement. 100 grams of cement are used and the amounts of gypsum added as shown in the first column.

Grams of gypsum.	Initial set. Hours.	Initial set. Minutes.	Final set. Hours.	Final set. Minutes.
0.0	0	7	0	22
0.5	0	50	2	40
1.0	2	40	4	50
1.5	2	57	5	17
2.0	3	00	5	20
3.0	3	00	6	40
4.0	3	30	7	00

According to Candlot, the time after the mixture is made has its effect on the setting of the cement. A mixture of cement with three per cent of gypsum showed the following variation with time:

	Initial set. Hours.	Initial set. Minutes.	Final set. Hours.	Final set. Minutes.
On day of mixture	1	00	7	00
4 days after mixture	0	5	2	15
7 " " "	0	5	0	20
11 " " "	0	8	0	30
15 " " "	0	5	0	30
32 " " "	0	10	0	30
41 " " "	0	45	5	30

His explanation of the influence of the gypsum on the cement is that the gypsum combines with the aluminate of lime and loses all its water at 300° and forms a sulpho-aluminate of lime with the formula (Al_2O_3 3CaO) 2½ SO_3CaO). He states that in Portland cement there is always some free lime and very little alumina. As this free lime dissolves rapidly, it hinders the hydration of the alumina. The sulphate of lime added to the cement is not able to combine with the alumina and adds its action to that of the lime to hinder the hydration of the aluminate. The set is ascribed to the aluminate, and the gypsum hinders its hydration.

[1]The Cement Bacillus by Dr. Wilhelm Michaelis, The Eng. Record, Volume 26, p. 110, 1902.

[2]Candlot, Ciments et Chaux Hydrauliques (Paris), p 325; 1898.

According to Dibdin[1] the gypsum is first dissolved and then precipitated in very fine particles on the grains of cement, so the chemical incorporation of the water in the cement is delayed. By some simultaneous occurrence of some chemical action the cement has greater strength.

The influence of gypsum on the strength of the cement is shown in the following table from Dibdin:

Breaking weight in pounds of briquettes of one square inch section after 28 days.

	No. 1.	No. 2.
With no gypsum	618	800
0.1 per cent gypsum	587	693
0.3 " " "	630	750
0.5 " " "	623	777
0.7 " " "	590	813
1.0 " " "	690	823
1.5 " " "	657	890
2.0 " " "	613	860

[1]Lime, Mortar and Cement, by Dibdin (London), p. 128; 1868.

§ 2. Calcined Gypsum.

When gypsum is calcined it is known as plaster of Paris. The finer grades are sold as dental plaster and as plaster of Paris for the manufacture of casts and moulds. It is also used for white finish on the walls of buildings. Dental plaster is usually reground and carefully sifted so as to give a superfine plaster free from grit. Our museums of art show the large use of plaster for moulds and casts of ancient works of art and architecture.

Plaster was prepared at the old Phoenix Plaster Mill of New York city for glazing porcelain, a use which has apparently disappeared with time, other forms of glaze being regarded as better adapted to this work.

It has also been recommended by Prof. Moses of Columbia University, for use in place of charcoal in blow pipe tests.

§ 3. Wall Plaster.

In this country, gypsum wall plasters known under the names of rock wall plaster, hard plaster, cement plaster, adamant, etc., are either mixtures of plaster of Paris and retarder, or of plaster of Paris, retarder and sand. Such plasters set slowly and are applied to the walls in the same way as lime plasters.

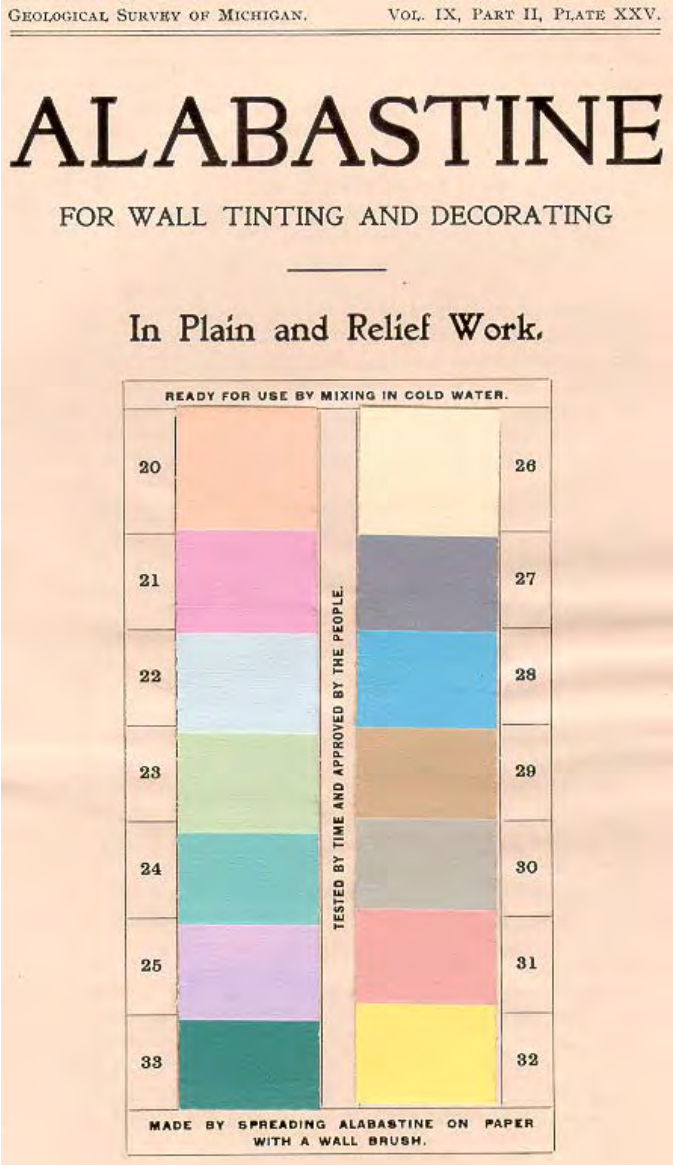
Strength of Wall Plasters.

In determining the hardness and strength of wall plaster the French workmen are accustomed to ascribe the strength of the plaster to the hardness of the original gypsum rock. So that other conditions being equal, according to the French rule, the harder the gypsum rock, the stronger the plaster made from it.

The Paris gypsum contains a high percentage of lime carbonate (12%), and it makes a plaster of high strength, but Gay Lussac pointed out that this was not due to the lime carbonate directly, as the lime carbonate was not altered at the temperature used in burning gypsum, but the lime still might add to the more equal distribution of the heat and help to avoid the danger of everburning.

The amount of water used in guaging the plaster is also important in determining the strength of the resulting product. To obtain all the strength of the plaster it is stiff gauged (gache serré) by adding very little water. In making the finish plaster more water is added than before the plaster is guaged thin (gache clair).

In the use of ordinary lime plaster three coats are usually applied to the wall. The first rough or scratch coat, composed of lime and sand, is applied to the wall or lath and dried in ten days to two weeks. It is common to scratch or furrow this coat with a trowel so that the second coat will adhere more firmly. The rough coat must be thoroughly dry before the second or brown coat is applied. In composition the second coat is practically the same as the first and dried in about the same time or a little longer.



[XXV. Alabastine Wall Tints]

The last or finish coat is applied after the second is thoroughly dry. It is made from slaked lime putty made two or three weeks before it is used, mixed with plaster of Paris, and pure white, fine sand, or from a mixture of plaster of Paris and lime putty. The workmen must then wait until the wall is thoroughly dry before the wood work can be nailed on the walls.

In working with gypsum plasters, the first or rough coat is applied and before it is set the second or brown coat is applied and thoroughly pressed into place with the first one. This makes practically one coat of plaster, three-fourths of an inch thick. The cement plaster for this work is mixed with two parts of sand. In 24 hours the last or finish coat, about one-eighth of an inch thick, is put on. It is composed of pure plaster of Paris and lime putty. In order to give a white smooth marble like surface, the brown coat is brought to a smooth surface, and the white coat is worked down with a flat wooden trowel called hand float, and a water brush to dampen the wall. When the walls are to be painted a sand finish is often used

where sand is mixed with the final white coat so as to give a rough finish.

On account of the hard plasters setting more rapidly than the lime plasters, it is difficult for a workman familiar with lime work to float a hard plaster wall until he has become accustomed to its use. As a result lime plaster men with little experience with gypsum plasters nearly always condemn them.

The plaster is applied directly to the brick or stone wall, or it is spread over laths made of split white or yellow pine, three to four feet long, one and one-half inches wide, and one-fourth inch thick. One-quarter inch space is left between the lath for the clinch of the plaster.

In fire proof buildings metallic lath are used, made of woven wire, or perforated metal, either plain or galvanized. Expanded metal lath has also become very popular and is regarded by many as superior to the other kinds. About 18,000,000 square yards of expanded metal lath are used each year in this country. Nearly 10,000,000 square yards were used in the construction of the buildings of the Paris Exposition, and most of this was furnished from the United States.

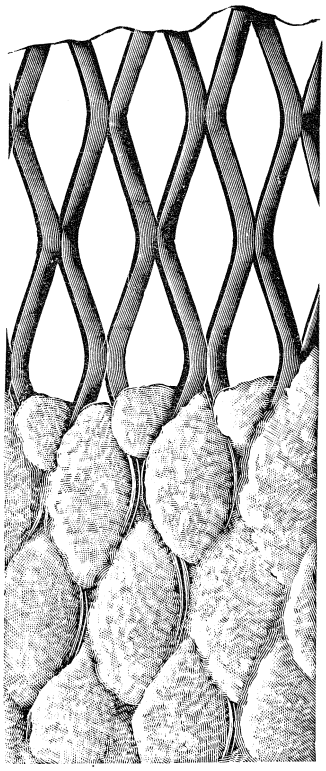


FIG. 44.

[44. Metal Lath Used in Plaster Work]

In making the expanded lath a strip of metal seven inches or more wide and eight feet long is placed upon a table and a cutter operates on it longitudinally cutting and expanding one row of webs at a time. The best types of these machines will make 400 to 600 yards a day. In a recent method invented by Mr. G. A. Turnbull of Chicago, a sheet of metal seven and one-half inches wide and of the desired length is fed into the rolls and cut in a number of short longitudinal overlapping slits. The sheet then passes over the expanding rolls, and the metal is stretched out in width, enlarging the openings. The machine used in this method will make 4,000 to 5,000 yards a day.

The metal lath is fastened to the studding by iron staples, and the clinches formed in the numerous openings give increased firmness to the wall. There are numerous patent metal laths now placed on the market. Different builders refer different makes and each thinks he has chosen the best. Where the plaster passes through the perforations it spreads out and forms a coat on the inside as well as on the outside of the metal, protecting it from rust, making strong clinches, almost impossible to break, and gives an almost perfect fire proof wall.

In Michigan most of the calcined gypsum is used for wall plaster, and its advantages as set forth in the advertising circulars of the companies and supported by the testimonials of prominent architects and builders are as follows:

Its superior tensile strength and hardness. It dries out much more rapidly than lime plaster, so that the carpenters can soon follow the plasterers; the painter and paper hangers can follow the carpenters in a day or two. The entire building can be delivered and occupied from five to six weeks sooner than with lime mortar. Coloring compounds can be mixed with the material in its preparation for mortar to produce any tint desired. Ceiling and walls thoroughly soaked from leaking and unprotected roofs have not been injured. It attains a high polish and may be used for wainscoting as a substitute for marble. It is fire proof and a non-conductor of heat and cold, so that changes of temperature do not affect the walls which therefore do not chip or crack. The walls being dense and hard are vermin proof, making the plaster valuable for hospital walls.

That these hard plasters are appreciated by the trade is seen from the following extract from the American Architect:

"In this age of improvement it seems strange that men should so long have been confined to the use of lime, sand; and hair, for making interior walls and ceilings, especially since walls so made have proved very weak and unsatisfactory, and many know from sad experience what destruction, annoyance and loss ensue, when, from some slight cause, its own weight or rottenness, down come ceilings about their ears with the inevitable result of damage, dust, and confusion."

The great objection to the use of cement plaster has been the greater expense. It has cost about one-fourth more than the ordinary lime plasters, but the greater advantages more than compensate the first expense. It is also said to be noisier, i. e., does not deaden the sound so well.

In some localities the careless methods of mixing the materials have caused bad results in the work and have

caused hard wall plaster to be looked upon with disfavor. Too much sand will make the sack of plaster cover more area, but it weakens it and the same result follows the mixing of the old set plasters in the boxes with the new material.

The directions for the use of these hard plasters are given as follows:

Use clean, sharp sand and mix thoroughly with the plaster before adding the water and do not mix more than can be used in one hour. The materials should be mixed in a water-tight box and should never be remixed after its set has commenced. The box and tools should be cleaned after each batch. Brick walls and porous substances should be thoroughly wet before applying the mortar, in order to reach the full strength of the materials. Floating should be done with the least possible amount of water, as soon as the material begins to stiffen and before it sets. In troweling the finish work use as little water as possible to prevent joinings and water streak showing. Use by measure two parts sand to one part of fibred plaster. Dry lath should be sprinkled one hour before plastering. For the hard white finish, mix one-half lime putty with one-half of fibred plaster. One ton of gypsum plaster will cover 225 to 250 yards of surface on wood lath set one-quarter of an inch apart, or will cover 225 yards on metal lath, or will float 400 yard.

The brands of these gypsum plasters made in Michigan are, Plasticon, Eagle, Acorn, Hudson River Mills, Green A, Eclipse, Granite, Ivory, Adamant, Diamond, Alabaster.

In many parts of the United States, especially east of the Mississippi river, the demand is for a plaster mixed with sand, ready to be mixed with water and applied to the walls. In Lower Michigan the two brands manufactured are the Adamant and Granite Wall Plaster. The sand is thoroughly dried in revolving cylinders or over specially constructed stoves, and mixed in Broughton mixers with retarder and plaster of Paris, and fiber.

Gypstone.

A high grade hard plaster is now made in Houghton for use in Upper Peninsula. The makers, the M. Van Orden Co., claim for it that the constituents are very carefully weighed, not measured, very thoroughly mixed, and are very uniform, and as a local sand is used in mixing, the freight on it is saved. A fat Ohio, so called fire clay, i. e., white clay, is used as spreader, and it will be seen by Sec. 6, of Chapter VIII, also affects the set.

Many Michigan coal underclays might be used for this purpose.

In order to show the fire-proof properties of hard wall plasters, the Rock Wall Plaster Co. of Columbus, Ohio, performed the following experiment in the presence of a party of city and state officials:—

Four frames were made out of two by four studding, 12 by 18 feet square, two of these were wood lathed, one steel lathed, and one covered with sheet steel. All but the last were plastered, common lime plaster on one, rock wall plaster on the other two. These were laid on the fires in the boiler furnaces in the Board of Trade building.

In less than one and one-half minutes the steel covered frame was burning. In seven minutes the lime plastered lath were burning. In 29 minutes there was evidence that the heat had penetratd the rock plaster on the wood lath but it had not effected the wood covered with the steel lath. At the end of 40 minutes the rock plastered samples were removed and found to be charred but not in flames, while the other two samples were practically destroyed.

The testimony of fire marshals and owners of buildings plastered with gypsum plaster, seems to be practically unanimous as the protection of such plasters against the spread of fires in such buildings.

An objection to the use of hard plaster in residences has been that the density of the wall makes it a good conductor of sound from one room to another, where the partitions are made of the plaster. In order to correct this fault various forms of fibred plaster have been invented, known as wood fiber, fire pulp, etc. A common material for this purpose is wood fiber made on specially constructed machines, and the wood fiber is mixed with retarded plaster. One of the very popular pulp plasters is made by the Napoleon Pulp Plaster Co., of Napoleon, Ohio. It is a mixture of marl, gypsum, fire clay, wood pulp, and fiber, retarder, and lime carbonate: Machinery for this fiber is manufactured by the Wood Fiber Machinery Co. of Sandusky, Ohio.

The gypsum plasters are sometimes mixed with materials to add to the fire-proof qualities. Mixed with asbestos it has been used for plastering the inside of stove bowls. Calcined gypsum is mixed with finely ground cinders and poured between the iron joists in fireproof buildings. Temporary plates are placed above and below the joists giving a smooth under surface for the finishing coat of the ceiling of the lower stories, and a smooth upper surface on which the tile floor may be laid. The material is claimed to be thirty-five per cent lighter, of twenty-five per cent greater strength, and sixty per cent cheaper than tiling which has long been used for this purpose.

Plaster mixed with asbestos is said to give double strength. This mix-tare has been found valuable around steel beams in fireproof buildings. In such buildings a small fire doing but little apparent damage, will sometimes warp these beams and so twist the structure as to greatly injure its strength.

§ 4. Manufacture of Hardened Gypsum Plasters.

When gypsum stone is heated and thrown into a ten per cent solution of alum for a few minutes, and then heated again, the resulting plaster on setting is very much harder than the ordinary plaster.

Payen, as stated in the chapter on Technology, in his sixth principle, thought the hardening was due to the formation of a double sulphate of potash and lime. Landrin analyzed so called alum plasters with the following results:

LANDRIN'S ANALYSES OF ALUM PLASTERS.

Elements.	French cements.	English cements.		Stucco.
Carbonate of lime.....	1.05	0.41	0.37	0.36
Silica	0.72	.....	0.42	0.51
Water	1.48	1.45	1.19	1.08
Sulphate of lime.....	96.75	98.19	98.02	98.55

An examination of these figures shows that the alum cements are of great purity, and there is no trace of alumina and potash. Landrin explains the hardening of alum plasters as due to the reaction of sulphate of alumina and potash on the plaster stone, converting nearly all the carbonate of lime into the sulphate, or gypsum. This seems to indicate that the French preference for lime plasters is prejudice.

Landrin placed the crude gypsum in a ten per cent solution of sulphuric acid for fifteen minutes and then calcined it, and obtained a plaster of good set and hardness. Heat must be applied in sufficient amount to drive out all the sulphuric acid and the best temperature was found to be between 600° and 700° F. Hydrochloric acid was also tried but with poor results.

By the Greenwood hardening process, the gypsum stone is burned in the usual way, then steeped in an 8% to 10% alum solution for some minutes, drained and dried in the air, and again burned at a uniform and constant temperature carried to dull redness but not beyond.

The earlier patents of Keene and later of Keating called for a mixture of plaster of Paris with one part borax, one part cream of tartar, and eighteen parts of water. This mixture was burned at a low red heat for six hours.

Borax alone produced good results. One volume of saturated solution of borax and twelve parts of water made a plaster which set in one-fourth hour; with eight volumes of water, it set in one hour; and with four volumes of water, the set was delayed several hours. This cement is known under the name of Parian cement. These cements were liable to effloresce, throwing off paint, and this is remedied by neutralizing the acids.

Keaur and Knop made silicated plaster used for sponging plaster casts, giving them increased hardness. To a potash lye made by adding one part potash to five parts water, some milk whey is added as free as possible of fatty matter. Four parts of this lye are mixed with a syrupy solution of potassium silicate. Sulphur in the whey may make dark stains which will disappear when dry.

A German method of making a hard plaster is to add to plaster of Paris, two to four per cent of pulverized eibisch roots and mix with 40% water. This will harden in an hour. Eight per cent solution will make a still harder solution.

Martins' cement is a mixture of plaster of Paris and (commercial K_2CO_3) pearl ash, instead of borax, and produces a fatter cement. Kuhlman's method was to harden the plaster with a solution of water glass, but it is not always satisfactory. Blashfield used lime water to which some zinc sulphate is added.

Heinemann, in Hanover, under patent issued July, 1883, heated the crude gypsum rock and placed it in a lime chloride solution, then immersed it in a magnesia sulphate solution, and finally treated with lime and tannin solution, and dried the product. The finer varieties of white plaster are sometimes called Marezzo marble or white Portland cement.

Magaud's cement is made by treating the gypsum with a solution of sulphate of zinc, sulphate of iron, or sulphate of copper.

M. Julke communicated to the French Academy of Sciences in 1885 a new method for hardening plaster. By this method six parts of the best quality of gypsum plaster and one part of fat lime recently slaked and finely sifted are mixed. This is used in ordinary plaster. When it is dry the mass is soaked in a solution of some sulphate whose base may be precipitated by lime forming in insoluble precipitate. Among the most convenient sulphates are iron and zinc. The lime in the pores of the plaster decomposes the sulphate producing two insoluble bodies, sulphate of lime and oxide of lime which fill the pores giving the dense hard plaster. With zinc sulphate the object remains white, while with, iron it is at first greenish and on drying it takes a reddish color. The iron surfaced casts have a strength twenty times greater than in the ordinary plaster casts. Landrin found that lime had great influence in gypsum plasters. By mixing lime with the plasters in different proportions he obtained plaster which set regularly, became hard and took a high polish. He states that it is better not to use over ten per cent of lime. Landrin's explanation for this change is that the lime in contact with water sets free heat, which evaporates the quantity of water not needed to bring the hydrated plaster back to its original gypsum state. The carbonic acid of the air then carbonates, little by little, the excess of lime in the plaster, giving increased solidity and hardness to the plaster.

General Scott invented a mixture sold under the name of selenitic mortar which consists of Portland cement, with plaster of Paris or green copperas (ferrous sulphate). This hastened the set, and the invention attracted much attention some years ago, but modern experience is against this addition where great strength is required.

Seagliolia is a mixture of plaster of Paris, retarder, and coloring substances and is used to imitate various kinds of marble and ornamental stones. The original mixture contained numerous splinters (scagliole) of marble which has given the name.

In the Pantheon of Paris[1] the surface of the dome was dried by large braziers to remove all moisture. A mixture of one part yellow wax, three parts oil, in which one-tenth of the whole weight of litharge had been mixed before melting, was then applied at a temperature of 212° F. It was laid on with a brush until the stone would absorb no more. The paintings of M. Gros were then put on and have stood 20 years without trace of cracking or change on this plastered wall. A mixture of one part oil with one-tenth of its weight of litharge and two or three parts of resin is sometimes used in this way.

Roman cement, sometimes cited as a variety of gypsum cement was according to Parker's original English patents a hydraulic lime made from lime carbonate nodules found in clay.

[1]Burnett, Limes, Cements, Mortars, London, pp. 97-112; 1892.

§ 5. Gypsum Paints.

The finely ground gypsum is calcined and carefully bolted, then set with water in the form of oblong prisms. These after thoroughly drying in the open air, are reground and the resulting powder is sold as Michigan whiting, and used in a variety of ways. The true whiting used with linseed oil in the manufacture of putty is carbonate of lime, and the Michigan whiting has been tried as a substitute but does not work satisfactorily.

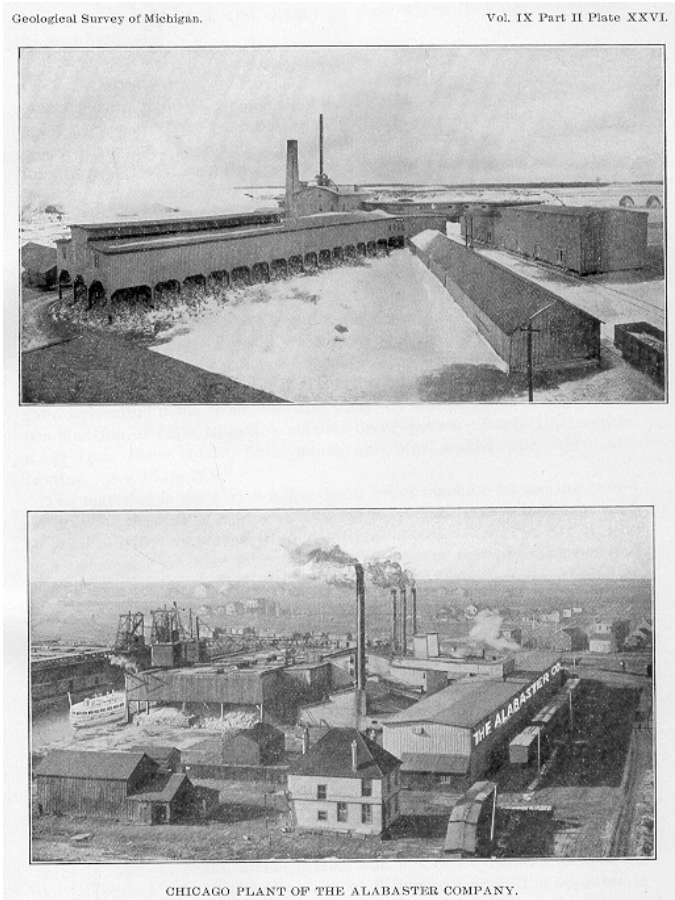
The Michigan whiting is used as paper filler. The bleached pulp in the manufacture of paper is drawn out in fine fibers on the beater rolls and is then loaded with some mineral material consisting usually of china clay or fine gypsum. When this is added in moderate quantity it closes up the pores of the fibers and enables the paper to take a better finish. It is used especially in writing and printing papers.

§ 6. Selenitic Lime.

Selenitic lime[2] or cement is an artificial mixture of gray chalk or other similar lime and a proportion of plaster of Paris. In one method lightly calcined gray chalk lime is reheated to bright redness in shallow kilns having perforated floors, under which are placed pots of sulphur. The heat igniting the sulphur produced fumes of sulphurous acid which rise and form a coating probably of sulphate.

In another the sulphuric acid is sprinkled on the calcined lime, or plaster of Paris is mixed with the ground lime. In one method four pounds of plaster of Paris is mixed in one half pail of water, to be added to one bushel lime in a mortar mixing mill, with sufficient water to make a creamy paste. These limes set rapidly and soon become hard but they are not commonly used, and cannot be used where they are exposed to the weather.

[2]Heath, A Manual of Lime and Cement, London, pp. 29, 30.



[XXVI. Chicago Plant of the Alabaster Company]

§ 7. Alabastine.

Alabastine, made at Grand Rapids, is often called cold water paint. In its preparation the pure blocks of gypsum rock are selected, ground, calcined, and then reground to the finest powder. This superfine gypsum flour is mixed with metallic colors and sold in packages to be used for tinting and frescoing interior walls. Five pounds of the material will cover fifty square yards of plain tinting on a smooth non-porus wall. It can be used over any solid surface, such as plaster, wood ceiling, brick, or canvass, and is applied with an ordinary wall brush. It does not flake or scale off, and hardens like the wall on which it is placed and so can be applied coat over coat.

In mixing the material two and one-half measures of Alabastine are added to one measure of cold water and stirred thoroughly and should be used within five hours. It is flowed on the wall heavily and brushed out to the proper thinness. It is claimed to cover 50 to 100% more surface than kalsomine made from lime and glue. It can be made in any tint or combination of tints to match carpets or draperies. Forty tints can be made from three colors, red, yellow, and blue, mixed with white alabastine. See Plate XXV.

The material is used with a free hand relief machine in making raised designs for borders of rooms in any variety of patterns. It can be used to imitate ivory, embossed leather, antique metal, tiling, etc. It is used in a pneumatic machine for whitening the interior walls of factories and warehouses.

§ 8. Lieno.

Another preparation of fine ground gypsum and metallic colors is made by the United States Gypsum Co., and sold under the name of Lieno, a word formed by reversing the letters of the inventor's name, Mr. O'Neil. This material is made in shades somewhat like Alabastine, and it is used in the same way for tinting walls. The company make a special feature of the use of Lieno for relief work. For this purpose two parts of the material are used with one part of warm water. It is sold in five pound packages, 100 pound drums, and 300 pound barrels.

For relief work the Lieno is put on the walls with a Lieno free hand relief machine made by the company and shown in Figure 45. This machine is made of brass, nickel plated, and has two cylinders for holding the mixture, so that the helper can be filling one while the operator is using the other. Pressure is applied by a ratchet and lever which forces the material through the tube. The machine should be held in the right hand and steadied with the left. The tube should rest lightly against the surface and at an angle to allow the material to flow out. A series of tubes are prepared through which the substance flows to the surface producing the various widths and shapes of lines and scrolls. A variety of designs are made from a few principal patterns grouped together in different ways. After the designs are made on the wall, they may be colored for any tint desired, or the coloring material can be used in making the relief.

These gypsum paints are now used in all parts of the country and have become very popular for interior decorations. An artistic painter can make original designs, giving variety and harmony of color. The inexperienced can secure patterns and careful directions from the companies.

§ 9. Trippolite.

In the building markets of Vienna a new gypsum mixture has appeared in recent years under the name of Trippolite, which has a gray color and contains mainly calcined gypsum and four or five per cent of powdered carbon. Trippolite is said to have double the strength of ordinary plaster and to remain under water without disintegration and can be used as a hydraulic mortar. Two analyses of this substance are here given:[1]

	A.	B.
Sand	1.16	1.40
Soluble silica	.....	1.35
Sulphate of lime	74.98	74.90
Sulphate of magnesia	0.11	.....
Carbonate of lime	6.44	4.61
Carbonate of magnesia	1.84	4.15
Iron oxide	0.55	0.54
Alumina, potash, soda	trace	trace
Carbon	11.60	11.44
Water	3.00	2.86
	99.68	101.25

[1]Handbuch der Chemischen Technologie, Bolley and Birnbaum, Band 6, p. 360; 1885.

§ 10. Pottery Moulds.

Plaster of Paris is used for the manufacture of moulds for various pottery designs, and this method of making pottery is taking the place of hand turning. In many of our American potteries, jugs, vases, etc., are made in these moulds.

In England 30,000 to 40,000 tons of plaster are used for this purpose annually, especially in Staffordshire potteries, and gypsum rock is often called in that section the potter's stone.

These moulds are used on a jolly wheel made like an ordinary turner's wheel, but provided with a hollow head which can receive moulds of various kinds. Each jolly wheel is provided with from 1,000 to 3,000 moulds. In a large pottery where a wheel is run all day on one kind of ware and each mould used twice, it would require 1,200 to 1,800 moulds for this one kind of pattern. The porous gypsum mould permits the evaporation of moisture from the clay while the surface of the ware is not exposed, thus avoiding any danger from strong drafts which are sometimes destructive in hand turned ware placed on open shelves.

§ 11. Plate Glass Polishing.

After the plates of heavy glass in the plate glass manufacture come from the kilns or leers, it is ground smooth under revolving brushes charged with emery flour. In order to hold the plate firmly and remove all strain, large circular tables 24½ feet in diameter and eight to ten inches thick with a weight of 66,000 pounds are covered with a coat of plaster pf Paris finely ground and free from all traces of grit. In this plaster the glass plates are imbedded. When the first side has been polished, the plaster is broken off at the edges and the plates removed. The table is then thoroughly cleaned and coated again with plaster and the smooth side of the plate imbedded, while the other side is polished.

In many factories the gypsum is calcined in kettles at the factory and the old set plaster is recalcined and mixed with the new for the first polishing, but for the second side new plaster must be used to avoid any danger of grit coming in contact with the polished surface.

It requires 2,200 pounds of plaster for 1,000 square feet of plate glass. The Michigan gypsum from Alabaster is held in high favor for this use on account of its purity, and most of the plaster used comes from this mine. In the plate glass factories of the United States, 40,000 tons of plaster are used annually.

At Saginaw is located a modern plate glass works with a capacity of 1,000,000 feet per year, and the Alabaster superfine plaster is used in the polishing of the plates.

§ 12. Plaster Relief Work.

A plaster industry which has been in existence from an early day came into special prominence at the World's Fair. The buildings at the Chicago fair were constructed on the outside of gypsum plaster and fiber, making a composition known as staff. Large quantities of gypsum plaster were consumed in the construction of these temporary buildings and ornaments. In the same way large quantities of this stuff were used at St. Louis for the fair buildings. Most of the staff plaster at Chicago came from Michigan, and most of the staff at St. Louis is shipped from this State.

Staff is especially adapted for decorative construction and remains in good condition for a considerable length of time in outside work, but the elements of the air will in a few years cause it to disintegrate and crumble, if not protected by some water-proof covering.

The use for interior relief and art decorations has increased to a remarkable extent since the Chicago exposition. The group figures and mouldings in American theaters, public halls, and even private residences, are now made from staff.

In this manufacture, the design is modelled by the artist, in clay and then a mould is made of gelatin glue. A mixture of stearic acid and coal oil is used to oil the mould and prevent the cast from adhering. Into this mould is thrown a mixture of plaster of Paris and Aber, and Anally on the outer surface pure plaster. The whole is worked into the mould with the Angers, or in large designs it is pressed into the proper form by means of a wooden die or scraper with its edge cut to the proper shape. The plaster is allowed to set and is then removed from the mould.

Large pieces are moulded over a steel frame which can be fastened in place by screws or staples. These designs are left in pure white or are painted in desired tints. Before painting they are coated with shellac. Large factories for this work are located in Detroit, Chicago, and other cities.

§ 13. Manufacture of Floor Blocks.

Gypsum plaster is sometimes mixed with sawdust and moulded into blocks which are then readily nailed to the wall for finish. The Mackolite Fire Proof Co., of Chicago, is engaged in the manufacture of Are-proof blocks for floors, walls, and ceilings, made from the Michigan plaster. The Grand Rapids Plaster Co., have recently started the manufacture of these boards.

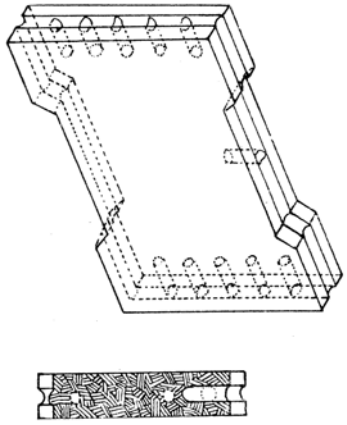


FIG. 45. Gypsum boards used in making walls where few uprights are used.

[45. Gypsum Floor Blocks]

The manufacture of these plaster building blocks for interior work is a prominent feature in the German gypsum industry. (See Figures 45-46.) These boards or blocks ("schilfbretter") are described in detail in the Thonindustrie, page 1089, 1899. Another account is given by Mr. Wilder of the Iowa Geological Survey[1] report, from which source the following account is taken:

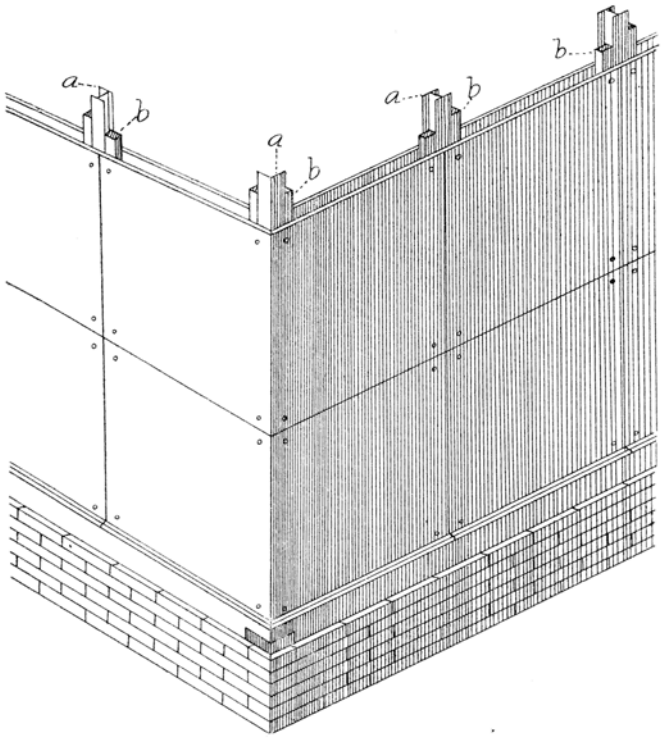


FIG. 46. Gypsum boards fastened to narrow wooden strips in iron uprights. Such a wall is practically fire proof.

[46. Gypsum Boards]

"Calcined plaster is mixed with water and a certain amount of saw dust. On an iron table with a heavy iron top are laid iron strips, which have a thickness equal to that intended for the gypsum boards. The space enclosed by these strips also determines the length and breadth of the board. Within this space are scattered

excelsior, jute, and rushes, and over these is poured the gypsum, water and sawdust mixture. The rushes and excelsior are carefully worked into the middle of the mass by hand. An iron bar is drawn over the top of the strips, leaving the surface of the mass either smooth or ridged. It is allowed to stand about five minutes, and then the iron table on which the mass rests is struck vigorously two or three times with a heavy mallet. This loosens the gypsum board from the iron plate and strips. A workman takes it on his shoulder and carries it to an open shed where it stands on end until dried by natural heat. The length of time required for drying depends wholly on the atmospheric conditions. Artificial heat for drying gypsum boards has proven very unsatisfactory, as the boards so dried crumble readily on exposure to the air. The weight of gypsum boards 2.5 centimeters thick is about 50 pounds per square meter, and for boards eight centimeters thick about 120 pounds."

[1]Vol. XII.

§ 14. Gypsum as a Basis for Portland Cement, with Sulphuric Acid as a By-Product.

Attempts have been made to manufacture Portland cement and sulphuric acid from gypsum. It is claimed that the process will cost about the same as in the ordinary methods of making cement and there will be the sulphuric acid in addition for profit. One or two patents have been issued for this work, but the process has not gone much beyond the experimental stage.

Patent number 342,785 was issued in 1860 to Uriah Cummings of Buffalo, New York,[1] which gives the following method for this manufacture:

"In practicing my invention, I mix together gypsum or sulphate of lime and clay in the proportion of about 1,260 pounds of gypsum to 400 pounds of clay. I prefer to pulverize the gypsum and dry the clay and pulverize the same, then intimately mix the pulverized gypsum and clay and add a small quantity of water, and mould the mixture into blocks substantially in the manner practiced in making Portland cement from carbonate of lime and clay by the well known dry process. I then subject this mixture to calcination in a suitable kiln. At the high degree of heat which is maintained during the process of calcination the silicic acid contained in the clay expels the sulphuric acid contained in the sulphate of lime and combines with the lime and alumina and produces therewith silicates of lime and alumina, which, upon being reduced to powder, are in every particular a hydraulic or Portland cement. The sulphuric acid is expelled during this process of calcination either in the form of vapor, or it is decomposed and forms sulphurous acid and oxygen; or perhaps the escaping gas is a mixture of vaporized sulphuric acid, sulphurous acid and oxygen, according to the degree of heat which is maintained during the process of calcination, and which may vary somewhat at different times, owing to differences in quantity and quality of the fuel employed, strength of draft, etc. The gases escaping during the process of calcination are cooled in suitable chambers or passages lined with lead, in which the sulphuric acid is condensed and collected. The sulphurous acid, if any, is converted into sulphuric acid in the ordinary manner by means of steam and nitric acid. The sulphuric acid so obtained is then concentrated or further treated in any usual manner practiced in the manufacture of sulphuric acid. The mixture of gypsum and clay above specified produces about 711 pounds of hydraulic or Portland cement and 580 pounds of sulphuric acid from every 1,660 pounds of the mixture, the balance being moisture which is expelled. The cost of the sulphate of lime is about the same as that of the carbonate of lime and the cost of manufacturing hydraulic or Portland cement by this improved method is about the same as that of the old method in which carbonate of lime is employed; but the sulphuric acid which is obtained in my improved method is valuable, and the value which it represents materially reduces the cost of the cement.

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

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

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

According to the method of P. Van Denberg of Buffalo, New York, under patent number 642,390, issued in 1900, sulphuric acid is made from gypsum by subjecting the gypsum to heat and electrolysis produced by an electric current within a furnace and applied to the material while molten. In the presence of an excess of free oxygen, sulphur oxide is formed which is hydrated later, yielding sulphuric acid.

[1]Iowa Geological Survey, Vol. XU, pp. 154-156.

APPENDIX A.

GYPSUM STATISTICS.

In order to show the Importance of the gypsum industry in the world, and especially in the State of Michigan, the following tables are presented. The tables have been taken from the reports on Mineral Resources published by the United States Geological Survey, and they are taken mainly from the 1901 report.

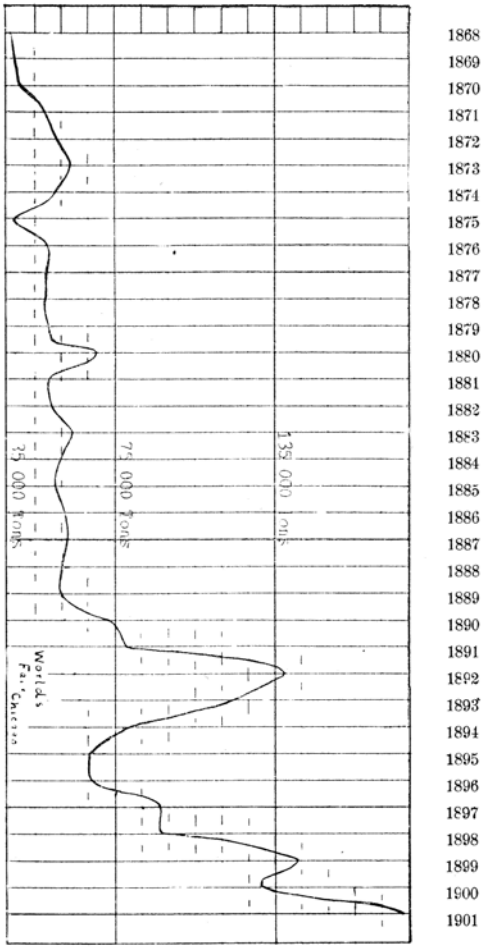


FIG 47. Total Production of Gypsum.

[47. Gypsum Statistics]

In the table of the Michigan production, the quantity of gypsum mined from 1867 to 1899 inclusive, is taken from Lawton's statistics as published in the government reports referred to above; but the amount of rock calcined into plaster, and the values were computed from these tables by the writer, taking estimated values for these years. The difference in the source of the statistics brings in a discrepancy between the values in 1889 and 1890.

A comparative study of these tables of statistics and of the diagrams accompanying them, brings out some interesting conclusions. From table I, it is seen that France has held first rank in the production of gypsum in the world during the years 1893 to 1901, and the United States has held second rank. In 1894 France produced over six times as much gypsum as the United States, and in 1900 France only produced three times as much as the United States.

[XXVII. Lieno Wall Decorations (U. S. Gypsum Co.)]

Table III and Figure 47 show that the production of gypsum in the United States has increased in 20 years from 1880 to 1900 from 90,000 to 594,462 tons or 560 per cent. The production of gypsum in 1901 was the greatest recorded in the United States. The production in 1900 was the greatest recorded up to that year in the United States, Canada, Germany, Cyprus; but was less than the preceding year in Great Britian, Algeria, and India.

The imports of crude gypsum into the United States, which come almost entirely from Canada, were greater in 1901 than in any other year. The total amount of gypsum used in the United States in 1901, from these tables was 897,969 tons, with a value of $1,904,163.

In 1890, 56,525 tons of gypsum were ground into land plaster, and 107,728 tons were calcined, or about one-third used for land plaster, and two-thirds used for plaster of Paris and like products. In 1901, 65,698 tons were ground into land plaster, and 521,292 tons calcined, or about one-ninth used for land plaster, and eight-ninths for calcined plasters.

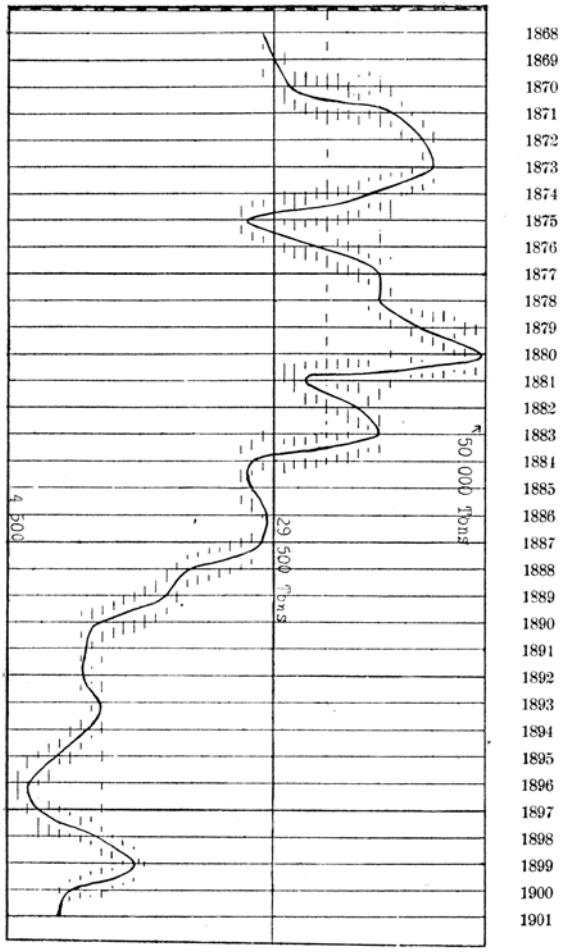


FIG. 48. Land Plaster Production.

[48. Gypsum Statistics]

Michigan.

From the study of Table V, it is seen that the total production of gypsum in Michigan since the beginning of the industry is 2,827,793 tons, one-half of which was converted into land plaster and one-half into calcined plaster. Before 1868 about one-tenth of the product was calcined and nine-tenths was ground for land plaster.

In 1901, out of a total production of 185,150 tons, 129,256 tons were calcined or 69 per cent; and about 5 per cent was ground into land plaster, the remaining portion was sold crude.

The total value of gypsum quarried since beginning of the industry in Michigan is over $10,000,000.

A study of the diagrams, Figures 48 and 49, shows that production of calcined gypsum has steadily increased and the land plaster production has decreased. A marked increase in calcined plaster is shown in the years 1892 and 1893 during the World's Fair, the buildings of this exposition requiring large quantities of plaster in their construction.

TABLE I.

World's Production of Gypsum, from 1893 to 1902 inclusive.

Year.	United States. Quantity, tons.	United States. Value.	Great Britain. Quantity, tons.	Great Britain. Value.	Canada. Quantity, tons.	Canada. Value.
1893	253,615	$696,615	158,122	$287,940	192,567	$196,150
1894	239,312	761,719	169,102	321,822	223,631	202.031
1895	265,503	797,447	196,037	348,400	226,178	212,608
1896	224,254	573,344	213,028	361,509	207,032	178.061
1897	288,982	755,864	203,151	325,513	239,691	244.531
1898	291,638	755,280	219,549	345,882	219,256	230,440
1899	486,235	1,287,080	238,071	372,073	244,566	257.329
1900	594,462	1,627,203	233,002	348,210	252,001	259,009
1901	633,791	1,506,641	224,919	344,650	293,879	340,148
1902	816,478	2,089,341	251,615	.....	332,045	356,317

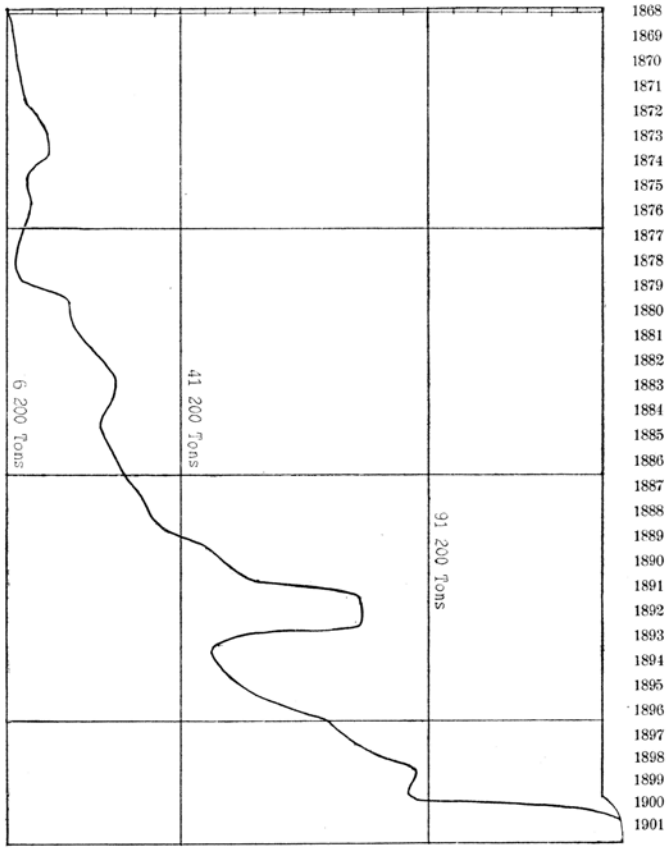


FIG. 49. Gypsum Calcined into Plaster.

[49. Gypsum Statistics]

TABLE I.—CONTINUED.

World's Production of Gypsum, from 1893 to 1902 inclusive.

Year.	France. Quantity, tons.	France. Value.	Algeria. Quantity, tons.	Algeria. Value.	Germany. Quantity, tons.	Germany. Value.
1893	.....	.....	.....	.....	.....	.....
1894	1,693,831	$2.891,365	36,355	$114,900	.....	.....
1895	2,175,448	3,392,768	50,127	133,226	23,994	$11,040
1896	1,866,498	2,661.200	41,350	114,361	31,736	14,598
1897	1,845,874	2,673,033	40,510	109,648	28,821	13,228
1898	1,931,712	2,777,816	41,156	110,660	28,315	13,136
1899	1,802,812	2,641,020	44,037	117,895	32,760	19,660
1900	1,761,835	2,772,221	41,446	139,190	39,103	17,199
1901	2,182,229	3,449,747	38,955	132,286	35,013	23,139

Year.	India. Quantity, tons.	India. Value.	Cyprus. Quantity, tons.	Cyprus. Value.
1893	.....	.....	2,357	$6,625
1894	3,548	$1,566	3,104	9,006
1895	7,511	2,987	2,093	5,252
1896	8,248	3,130	1,050	2,590
1897	9,025	3,333	4,167	8,162
1898	9,249	1,503	4,279	7,551
1899	7,216	768	4,402	8,866
1900	4,865	424	.....	.....

TABLE II.

Gypsum Production in the United States since 1889, by States.

States.	1889 Tons.	(a) Value.	1890 Tons.	(a) Value.	1891 Tons.	(a) Value.	1892 Tons.	(a) Value.
Kansas	17,332	$94,235	20,250	$72,457	40,217	$161,322	46,016	$195,197
California	.....	.....	.....	.....	.....	.....	(d)	(d)
Colorado	7,700	28,940	4,580	22,050	.....	.....	(d)	(d)
Iowa	21,789	55,250	20,900	47,350	31,385	58,095	(d)	(d)
Michigan	131,767	573,740	74,877	192,099	97,700	223,725	139,557	306,527
New York	52,608	79,476	32,903	73,073	30,135	58,571	32,394	61,100
Ohio	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)
South Dakota	320	2,650	2,900	7,750	3,615	9,618	.....	.....
Virginia	6,833	20,336	6,350	20,782	5,959	22,574	6,991	28,207
Other states (c)	29,420	109,491	20,235	138,942	17,115	94,146	31,301	104,461
Totals	267,769	$764,118	182,995	$574,523	208,126	$62,051	256,259	$695,482

States.	1893 Tons.	(a) Value.	1894 Tons.	(a) Value.	1895 Tons.	(b) Value.	1896 Tons.	(b) Value.
Kansas	43,631	$181,599	64,889	$301,884	71,852	$368,450	42,783	$199,563
California	(d)	(d)	(d)	(d)	5,158	51,014	1,310	12,580
Colorado	(d)	(d)	(d)	(d)	.....	.....	.....	.....
Iowa	21,447	55,538	17,906	44,700	18,600	43,710	18,631	34,020
Michigan	124 590	303,921	79,958	189,620	80,601	174,067	56,000	112,000
New York	37,126	65,392	31,798	60,262	29,176	50,806	22,923	39,771
Ohio	(d)	(d)	20,827	69,597	33,448	101,365	21,341	45,142
South Dakota	5,150	12,550	4,295	16,050	6,400	20,600	6,260	19,980
Texas	.....	.....	6,925	27,300	5,670	32,045	7,972	37,229
Virginia	7,014	24,359	8,106	24,431	8,515	32,068	5,444	18,210
Other states (c)	15,657	53,256	4,608	27,875	2,265	18,120	12,889	65,541
Totals	253,615	$696,615	239,312	$761,719	261,685	$892,245	195,553	$583,186

TABLE II.—CONTINUED.

Gypsum Production in the United States since 1889, by States.

States.	1897 (b) Tons.	Value.	1898 Quantity, short tons.	Value.	1898 Quantity, short tons.	Value.
California	2,200	$19,250	3,800	$24,977	2,950	$14,950
Colorado			5,390	23,712	0,675	24,954
Kansas	50,045	252,811	83,913	237,208	85,046	247,960
Iowa	65,000	195,000			75,574	296,220
Michigan	48,500	97,000	93,181	205,310	144,776	283,537
New York	22,885	40,253	31,655	81,969	52,149	105,533
Ohio	16,300	33,800	.....	.....	.....	.....
South Dakota	4 800	14,900	.....	.....	.....	.....
Texas	13,729	61,780	34,215	58,130	.....	.....
Virginia	5,207	13,812	8,378	23,388	11,480	32,043
Other states	13,195	91,071	31,106	101,586	108,585	282,153
Totals	241,861	$774,626	291,638	$755,280	486,235	$1,297,080

States.	1900 Quantity, short tons.	Value.	1901 Quantity, short tons.	Value.
California	3,280	$10,088	3,550	$4,200
Colorado	5,812	29,529	17,395	76,435
Kansas, Iowa	313,858	904,263	213,419	629,336
Michigan	129,654	285,119	185,150	267,243
New York	58,890	150,588	119,565	241,669
Ohio	.....	.....	.....	.....
South Dakota	.....	.....	.....	.....
Texas	.....	.....	.....	.....
Virginia	11,940	18,111	15,236	45,144
Other states	71,028	229,505	105,345	313,466
Totals	594,462	$1,627,203	659,659	$1,577,493

TABLE III.

Production of Gypsum in the United States, by Years.

Year.	Quantity, tons.	Value.	Year.	Quantity, tons.	Value.
1902	816,478	$2,089.341			
1901	633,791	1,506,641	1890	182,995	$574,523
1900	594,462	1,627,203	1889	267,769	764,118
1899	486,235	1,287,080	1888	110,000	550,000
1898	291,638	755,280	1887	95,000	425,000
1887	286,982	755,280	1886	95,250	428,625
1896	224,254	573,344	1885	90,405	405,000
1895	265,593	797,447	1884	90,000	390,000
1894	239,312	761,719	1883	90,000	420,000
1893	253,615	666,615	1882	100,000	450,000
1892	256,259	695,492	1881	85,000	350,000
1891	208,126	628,051	1880	90,000	400,000

TABLE IV.

Gypsum imported into the United States form 1867 to 1902, inclusive.

Year ending June 30.	Calcined. Quantity, long tons.	Value.	Unground. Quantity, long tons.	Value.	Value of Plaster of Paris.	Total Value.
1867	.....	$29,895	97,951	$95,386	.....	$125,281
1868	.....	33,988	87,694	80,362	.....	114.350
1869	.....	52,238	137,039	133,430	$844	186,512
1870	.....	46,872	107,237	100,416	1,432	148,720
1871	.....	64,465	100,400	88,256	1,292	154,013
1872	.....	66,418	95,339	99,902	2,553	168,873
1873	.....	35,628	118,926	122,495	7,336	165,459
1874	.....	36,410	123,717	130.172	4,319	170,901
1875	.....	52.155	93,772	115,664	3,277	171,096
1876	.....	47,588	139,713	127,084	4,398	179,070
1877	.....	49,445	97,656	105,629	7,843	162,917
1878	.....	33,496	89,239	100,102	6,989	140,587
1879	.....	18,339	96,963	99,027	8,176	125,542
1880	.....	17,074	120.327	120,642	12,693	150,409
1881	.....	24,915	128,607	128,107	18,702	171.724
1882	5,737	53,478	128,382	127,067	20.377	200,922
1883	4,291	44,118	157,851	152,982	21,869	218,969
1884	4,996	42,904	166,310	168,000	.....	210.904
1885	6,418	54,208	117,161	119,544	.....	173,752
1886	5,911	37,642	122,270	115,696	.....	153,338
1887	4,814	37,736	146,708	162,154	.....	199,890
Dec. 31.						
1888	3,340	20,764	156,697	170,023	.....	190,787
1889	5,466	40,291	170,965	179,849	.....	220,140
1890	7,568	55,250	171,289	174,609	.....	229,859
1891	9,560	97,316	110,257	129,003	.....	226,319
1892	6,832	75,608	181,104	232.403	.....	308,011
1893	3,363	31,670	164,300	190,254	.....	211,924
1894	2,027	16,823	162,500	179,237	.....	196,060
1895	3.295	21,526	192,549	215,705	10,352	247,583
1896	3,292	21,982	180,269	193,544	11,722	227,248
1897	2,664	17,028	163,201	178,686	16,715	212,429
1898	2,973	18,501	166,066	181,364	40,979	240,844
1899	3,265	19,250	196,579	220,603	58,073	297,926
1900	3,109	19,179	209,881	229,878	66,473	315,530
1901	3,106	19,627	235,204	238,440	68,603	326,670
1902	3,647	23,225	305,367	284,942	52,533	360,700

TABLE V.

Statistical table showing product on of gypsum in Michigan by years.

Year.	Land plaster, tons.	Gypsum calcined into plaster, tons.	Sold crude.	Total production, tons.	Total Value.
1902	13,022	158,320	68,885	240,227	459,621
1901	9,808	129,256	46,086	185,150	267,243
1900	10,354	86,972	33,328	129,654	285,119
1899	17,196	88,315	39,266	144,776	283,537
1898	13,345	77,852	1,984	93,181	204,310
1897	7,193	71,680	16,001	94,874	193,576
1896	6,582	60,352	700	67,634	146,424
1895	9,003	51,028	6,488	66,519	174,007
1894	11,982	47,976	20,000	79,958	189,620
1893	16,263	77,327	31,000	124,590	303,921
1892	14.458	77.599	47,500	139,557	306,527
1891	15,100	53,600	11,000	79,700	223,725
1890	12,714	47,163	15,000	74,877	192,099
1889	19,823	36,800	.....	56,623	353,869
1888	22,177	35,125	.....	57,302	347,531
1887	28,794	30,376	.....	59,170	329,392
1886	29,373	27,370	.....	56,748	308,094
1885	28,184	25,281	.....	53.465	286,802
1884	27,888	27,959	.....	55,847	335,382
1883	40,082	28,410	.....	68,492	377,567
1882	37,821	24,136	.....	61.957	34[illegible],374
1881	33,178	20,145	.....	53,323	293,872
1880	49,570	18,929	.....	68,499	349,710
1879	43,658	9,070	.....	52,728	247,192
1878	40,000	8,634	.....	48,634	229,070
1877	40,000	9,819	.....	49,819	238,550
1876	39,131	11,498	.....	50,629	248,504
1875	27,019	10,914	.....	37,933	195,386
1874	39,126	14,723	.....	53,849	274,284
1873	44,972	14,724	.....	59,696	297,678
1872	43,536	10,673	.....	54,209	259,524
1871	41,126	8,694	.....	49,820	234,054
1870	31,437	8,246	.....	39,683	191,718
1869	29,996	7,355	.....	37,351	178,824
1868	28,837	6,244	.....	35,081	165,298
Before.					
1868	132,043	14,285	.....	146,328	671,022
Total	1,035,795	1,436,850	336,238	2,827,793	$9,986,426

APPENDIX B.

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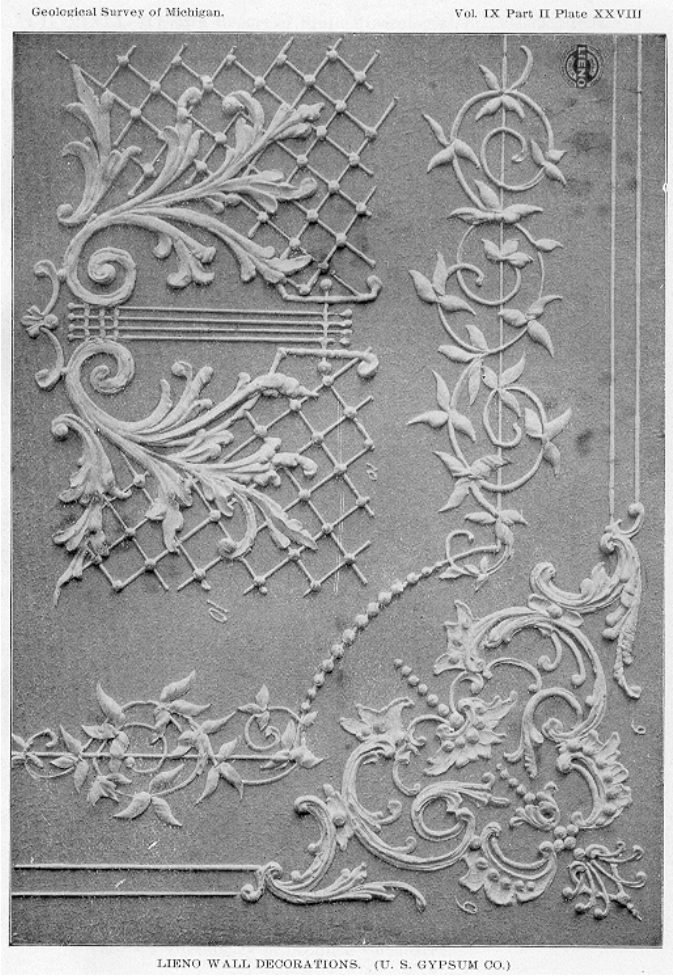

[XXVIII. Lieno Wall Decorations (U. S. Gypsum Co.)]

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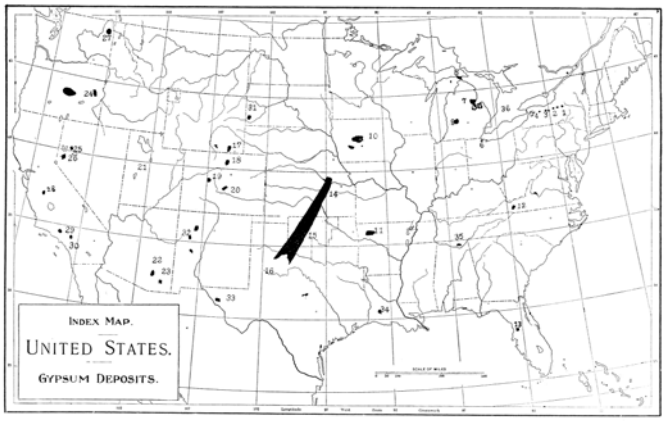

KEY.

1. Fayetteville, New York.
2. Union Springs, New York.
3. Mumford, New York
4. Oakfield, New York.
5. Buffalo, New York.
6. Port Clinton, Ohio.
7. Alabaster, Mich.
8. St. Ignace, Mich.
9. Grand Rapids, Mich.
10. Ft. Dodge, Iowa.
11. Plaster Bluffs, Ark.
12. Smyth County, Va.
13. Bear Island, Fla.
14. Blue Rapids, Medicine Lodge, Kans.
15. Oklahoma.
16. Quanah, Texas.
17. Laramie, Wyoming.
18. Loveland, Colorado.
19. Aspen, Colorado.
20. Canyon City, Colorado.
21. Juab, etc., Utah.
22. Tucson, Arizona.
23. Santa Rita, Arizona.
24. Huntington, Oregon.
25. Lovelock, Nevada.
26. Empire, Nevada.
27. Washington.
28. Coalinga, Cal.
29. Los Angeles, Cal.
30. Riverside, Cal.
31. Black Hills, Dakota.
32. New Mexico.
33. Rio Grande, Texas.
34. Lake Charles, La.
35. Scottsborough, Alabama.
36. Paris-Cayuga, Canada.
37. Huron County, Mich.

[XXIX. Index Map of the U. S. with Gypsum Fields located]