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HENRY LANDES, State Geologist

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THE MAGNESITE DEPOSITS OF WASHINGTON

Their Occurrence and Technology

By GEORGE E. WHITWELL
and ERNEST N. PATTY

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LETTER OF TRANSMITTAL

Governor Louis F. Hart, Chairman, and Members of the Board of Geological Survey:

GENTLEMEN: I have the honor to submit herewith a report entitled "The Magnesite Deposits of Washington; Their Occurrence and Technology," by George E. Whitwell and Ernest N. Patty, with the recommendation that it be printed as Bulletin No. 25 of the Survey reports.

Very respectfully,

HENRY LANDES,
State Geologist.

University Station, Seattle, January 15, 1921.

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GENERAL STATEMENT.

INTRODUCTION

While the United States is the world's largest consumer of magnesite, yet at the time of the opening of the war in 1914, over 96 per cent of all the magnesite used was imported from Europe, principally from Austria-Hungary. The discovery, during 1916, of the large deposits of magnesite in Stevens County, Washington, came as an answer to appeals for domestic magnesite with which to meet the emergency occasioned by the sudden termination of the foreign supply. The Stevens County deposits are today the largest source of supply on the Continent.

SCOPE OF FIELD WORK AND ACKNOWLEDGMENTS

This report is the result of a brief examination made by the writers at the close of the field season, in October, 1919. To assist the local magnesite producers as far as possible Mr. Whitwell undertook an extended laboratory investigation of the chemical and physical properties of the various magnesite products, in an effort to evolve larger commercial uses for the material. Preliminary to this investigation he spent two weeks in the Chewelah district visiting the calcining plants and studying the local practice of preparing dead-burned and caustic calcined magnesite. Mr. Patty spent eight days in the district, studying the geology and other general features of the deposits. This field work was cut short by an early snow fall which masked the rock outcrops and caused the examination to be confined to the various known deposits. No attempt was made to study the dolomite belt at points between the magnesite deposits; neither was it possible to attempt a detailed study of the complex

structural problems encountered. The Double Eagle and Crosby deposits were examined during August, 1920, when Mr. Patty was in that section in connection with metal mine investigations.

The writers are happy for this opportunity to express their indebtedness to R. B. Rogers, General Superintendent, and O. D. Rogers, Quarry Superintendent of the Northwest Magnesite Company; also to H. F. Wierum, General Manager, Mr. Griswold, Superintendent, and Dan Lawson, Quarry Superintendent, of the American Mineral Production Company, all of whom courteously furnished every encouragement possible to further the investigation.

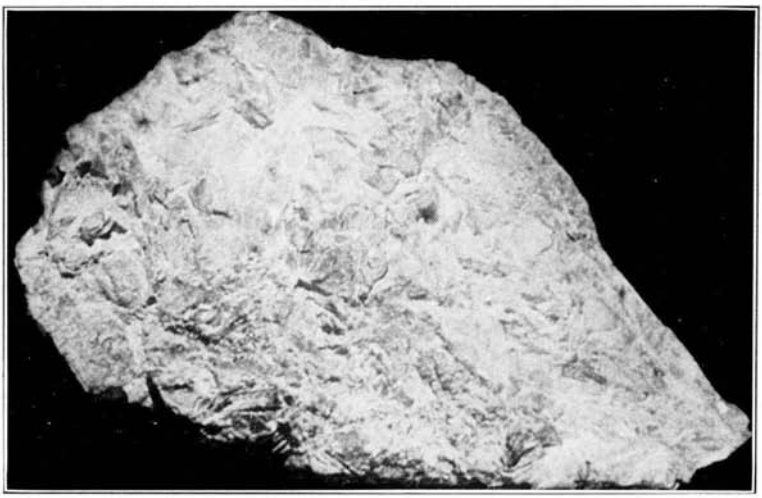
MINERALOGY AND COMPOSITION

The important non-metal magnesite is chemically the carbonate of magnesium, expressed as ($MgCO_3$), with a theoretical composition of 47.6% magnesium oxide and 52.4% carbon dioxide. It has a specific gravity of 3.0 to 3.12 and a hardness of 3.5 to 4.5. The material is somewhat heavier than calcite (2.7 specific gravity) and about one-third harder than that mineral. It is practically insoluble in cold hydrochloric acid but dissolves readily with pronounced effervescence in warm acid.

For purposes of classification magnesite can be easily divided into two distinct classes: crystalline magnesite, and the non-crystalline or amorphous magnesite. The crystalline variety develops well-defined crystals, which, in texture, vary from fine to coarse-grained. The physical appearance of the material is similar to limestone or dolomite. The crystalline variety of magnesite is usually found as massive, bedded deposits associated with dolomite and limestone. The deposits of Austria, those of Stevens County in this State, and the Grenville, Quebec, deposits are the leading examples of this important type.

The amorphous variety of magnesite is a compact fine-grained mineral, which, when pure, has a beautiful white color. It develops a conchoidal fracture that resembles in appearance broken chinaware. To this group belong the Grecian and nearly all of the California deposits. They occur as vein-like deposits and lenses in serpentine rocks.

Crude magnesite possesses but scant utility. However, when the material is heated to a high temperature,



A coarsely crystalline phase of the Washington magnesite.

(around 1,200 degrees Centigrade in commercial practice), the mineral is broken down and the carbon dioxide driven off as a gas, $MgCO_3 = MgO + CO_2$. The residue of magnesium oxide is an inert material which possesses high refractory and numerous other properties which give it commercial value. The loss of weight occasioned by the escape of the carbon dioxide reduces the weight of the material a little more than one-half. It requires 2.2 to 2.4 tons of crude magnesite to make one ton of caustic calcined magnesite or dead-burned magnesite.

GENERAL CHARACTER OF MAGNESITE

The physical appearance of the Stevens County magnesite varies. The untrained eye cannot differentiate some of the high-grade magnesite from limestone or dolomite. This resemblance is not so pronounced with certain phases of the material which is coarsely crystalline. Some of the magnesite develops aggregates of crystals whose diameters often attain one-fourth of an inch or more. The natural outcrops of magnesite often strikingly exhibit these crystal mosaics which would not be mistaken for dolomite or limestone by an observer familiar with this type. Other phases of the material are very fine grained; in fact all gradations between the fine and coarse grained varieties can be found in each deposit. A small hand-sample often shows pronounced gradations in texture and color, yet, all of the material may be high-grade.

The magnesite varies through a wide color range and it has been found that color is a poor guide for the determination of the grade. The variance in color is from creamy-white to almost black and some of the material exhibits intermediate shades such as pinkish-red, dark gray, mottled gray, etc. The color is influenced largely by the amount and nature of the iron impurities, while some of the darker shades are due to included carbonaceous material.

COMPARATIVE ANALYSES OF MAGNESITE.

SOURCE OF MAGNESITE	CO_2	SiO_2	CaO	FeO	Fe_2O_3	R_2O_3	MgO	H_2O	$MgCO_3$
Finch Quarry, N. W. Mag. Co. Stevens County, Wash. (a)	49.70	1.85	1.74	0.88	.....	.....	45.20	a	.....
Allen Quarry, American Mineral Prod. Co., Stevens County, Wash. (b)	47.91	2.07	1.02	1.03	.....	.....	44.50	b	.....
Moss Quarry, American Mineral Prod. Co. (c)	.....	3.40	0.93	.....	.....	.....	.....	.....	.....
Red Marble Quarry, Am. Min. Prod. Co., Stevens County, Wash (d)	49.51	4.27	1.07	0.78	.....	.....	45.02	d	.....
Double Eagle (e)	.....	2.5-3.0	0.5-1.0	.....	1.0-1.5	.....	.....	c	94.0-96.0
Austrian Magnesite, average analysis	50.00	1 to 5	1 to 3	2 to 7	.....	.....	38 to 44	.....	.....
Grecian Magnesite, composite analysis	.....	1.49	2.09	.....	2.45	.....	.....	.....	93.55
Grecian Magnesite, typical analysis	49.88	1.63	1.44	.....	1.36	45.75	.....	.....	.....
California Magnesite, Porterville, Tulare County (f)	50.74	2.28	1.35	.....	0.29	.....	45.17	f	.....
Napa County, California (g)	49.05	4.35	2.11	1.71	.....	.....	42.62	g	.....
Grenville District, Quebec, International Magnesite Co. (h)	49.72	1.60	7.89	.....	1.81	.....	39.25	h	.....
Grenville District, Quebec, Shaw Mine	.....	0.90	10.44	.....	.....	.....	37.60	k	.....
Hydromagnesite, Atlin, B. C. (l)	35.98	1.86	2.04	0.60	.82	.....	41.13	18.02	.....
Bridge River District, B. C.	47.28	7.46	0.46	0.56	.48	.....	43.42	.58	.....

a. Laboratory, N. W. Mag. Co.
b. Composite analysis, Am. Min. Prod. Co.
c. Composite analysis, Am. Min. Prod. Co.
d. Sample from stock pile.
e. Washington Geological Survey, Bull. 20.
f. Bull. 355, U. S. Geological Survey, 1908, p. 56.
g. Bull. 355, U. S. Geological Survey, 1908, p. 56.
h. Can. Geol. Sur. Memoir 98, 1917, pp. 38-41.
l. Rept. Minister of Mines, B. C., 1915, pp. 82-83.

DESCRIPTION OF THE DEPOSITS

LOCATION

The present known magnesite deposits of Washington are found in a relatively limited area in Stevens County. They are 60 miles north of Spokane and at a distance varying between five and fifteen miles from the towns of Chewelah and Valley on the Spokane & Northern branch of the Great Northern Railway. The occurrence of the magnesite is apparently confined to a narrow semi-continuous belt of dolomite which trends along the eastern flank of the Huckleberry Mountains, well up near the crest of the range.

DISCOVERY AND DEVELOPMENT

Through the history of the discovery and war-time development of the immense Washington deposits of magnesite, runs an interesting thread colored with the romance that so frequently attends the history of mining activity.

The material was not recognized as true magnesite in quantity until 1916. The Finch deposit was first located for limestone but the owner became discouraged with his location and it is said he once unsuccessfully offered to trade it to a neighbor for a second-hand Ford automobile. This is the ore body that today is credited with the largest production of any deposit on the continent. Just across the canyon from the Finch are the Allen and Moss deposits and these three have supplied practically the entire production of the district. The others are apparently of equal grade but on account of the superior location of the Allen, Moss and Finch quarries they are being worked first and the others held in reserve.

The Keystone and Red Marble deposits were first located for marble and the Keystone is credited with a production of $100,000 in dressed stone. In fact some of the old drill holes of the Marble Company are still evident in the quarry face.

The magnesite was mistaken for limestone, marble and dolomite. In several instances the high magnesium content of the supposed dolomite was recognized but the utility of the material as magnesite was not appreciated.

In 1903 Frank W. Clark[1] described a pseudo-serpentine that was apparently collected from a so-called serpentine quarry adjoining the Keystone: "To the unaided eye the rock appears to be an ordinary yellowish-green serpentine. Chemical and petrographic examinations were made and the rock found to be, not serpentine, but rather a mixture of hydro-magnesite, brucite, clinochlore and serpentine."

Shedd,[2] when reporting on the marble quarries of Stevens County, recognized the high magnesium content of some of the material.

When describing the deposit of the United States Marble Co., which is now the Keystone magnesite quarry, he wrote as follows: "The material takes a very good polish but is quite hard and not easily worked. As shown by the accompanying chemical analysis this is almost a pure magnesium carbonate and has much the same composition as magnesite but it differs from most magnesite in the fact that it is crystalline."

During 1905 Eckel[3] mentioned the occurrence of crystalline limestone and marble in Stevens County,

[1] Am. Journal of Science, fourth series, Vol. 15, pp. 397-8.

[2] Shedd, Solon, Wash. Geol. Survey, Ann. Rept., Vol. 2, pp. 87-105, 1902.

[3] Eckel, Edwin C., Cement Materials and Industry of the U. S., U. S. Geol. Survey, Bull. 243, 1905.

Washington. In these descriptions he noted the high magnesium content of many of the samples.

Shedd[1] gives the following analyses of limestone from west of Valley, Stevens County:

	1	2	3	4
Silica (SiO_2)	6.48	18.18	5.79	0.89
Alumina (Al_2O_3)	.....	0.44	0.43	none
Ferric Iron (Fe_2O_3)	4.20	0.45	0.85	none
Ferrous Iron (FeO)	.....	1.17	none	0.58
Lime (CaO)	2.52	24.74	1.69	none
Magnesia (MgO)	41.53	16.10	42.07	45.76
Carbon Dioxide (CO_2)	.....	38.18	47.23	49.24
Moisture	.....	0.05	.....	.....
Undetermined substances	.....	0.69	1.94	3.53
Total	98.83	100.00	100.00	100.00

1. Light gray in color, Secs. 30 and 31, T. 32N., R. 40 E.; A. A. Hammer, Analyst.
2. Pinkish in color, Secs. 1 and 12, T. 31N., R. 39E., and Secs. 6 and 7, T. 31N., R. 40E.; R. W. Thatcher, Analyst.
3. Dark, coarsely crystalline; Secs. 8 and 9, T. 31N., R. 39E.; R. W. Thatcher, Analyst.
4. Pink, coarsely crystalline; Sec. 19, T. 31N., R. 39E.; R. W. Thatcher, Analyst.

Sample No. 1 was probably taken from what are now known as the Finch, Allen, or Moss deposits. Sample No. 2 came from near the Woodbury deposit. Sample No. 3 was taken from the Keystone. These reports of Shedd later played an important role in aiding the discovery of the property.

During 1916 the nation was sorely pressed for magnesite and appeals were sent out to stimulate the search for new domestic deposits. Professor F. M. Handy, of Washington State College, noted the high magnesium analyses quoted in the report of Shedd and was one of the first to appreciate the true utility of the magnesite and began actively acquiring property. Apparently at about the same time several other men recognized the value of the material and it was not long until all the known deposits high in magnesium had been acquired. Among the pioneers in the field was R. S. Talbot of the

[1] Shedd, Solon, The Cement Materials of Washington, Wash. Geol. Survey, Bull. No. 4, 1914.

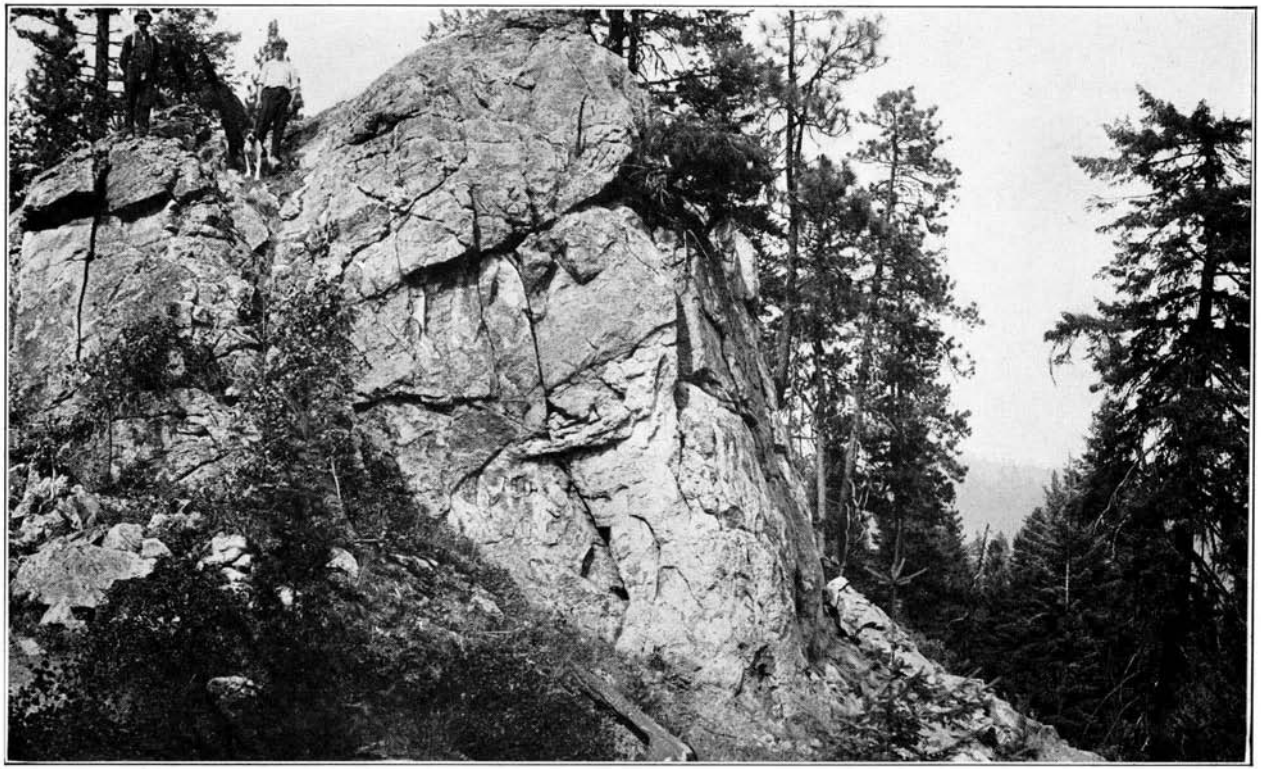
Inland Empire Paper Company of Spokane. Mr. Talbot came into possession of samples of the material from the abandoned U. S. Marble Quarry. Analyses showed these samples to be the mineral brucite, the hydrated magnesium oxide. Title was acquired to the property and the Washington Magnesite Company was organized. From November 1916, to May, 1917, about 5,000 tons of crude magnesite were shipped from this deposit, and these shipments were probably the first made from the Stevens County area. The deposit was first known by its old name, the U. S. Marble Quarry, but to avoid confusion with the Red Marble Quarry the name was changed to the Keystone. The Washington Magnesite Company also acquired title to the Finch deposit and during May, 1917, Mr. Talbot became associated with California interests and the Northwest Magnesite Company was organized to take over the holdings of the Washington Magnesite Company. Roy N. Bishop of San Francisco became general manager and Bart L. Thane, consulting engineer. By December, 1917, the company had completed, at a cost of more than $600,000, a modern calcining plant at Chewelah. The plant has a capacity of 7,500 tons of dead-burned or ferro-magnesite per month. The Finch deposit was developed and put on an efficient mining basis and a five mile aerial tram was built to connect the Finch with the calcining plant at Chewelah.

About the time the Northwest Magnesite Company was beginning to take corporate shape the American Mineral Production Company was organized with head offices at Chicago. The company acquired the Allen, Moss, Woodbury, and Red Marble deposits and today stand second only to the Northwest Company in point of production. This company was unfortunate in that during the early period of its activity it was not as skillfully guided as should be desired. The costs of developing their deposits and providing railroad trans-

portation used up a large part of the working capital. Later it became necessary to ship dead-burned rather than crude magnesite. The uncertainty of the market following the close of the war further mitigated against additional investments in a large calcining plant and the company has been more or less compelled to "mark time" until the fate of the domestic industry is more clearly defined. Through various arrangements, mentioned later in the report, they are at the present time actively operating the Moss and Allen quarries and are important producers of magnesite.

The Allen deposit, now owned by the American Mineral Production Company, was located for magnesite by Mr. Raymond Allen of Ione, Washington, September 24, 1916. Mr. Allen states[1] that during the summer of 1916 he was in Stevens County looking for a deposit of very pure limestone. He was using Bulletin No. 4 of the Washington Geological Survey as a guide and noted in that report the high magnesium content of the limestone belt west of Valley. Knowing of the demand for magnesite he secured samples from the Red Marble Quarry and sent them to the Harbison-Walker Refractory Company of Pittsburg, who immediately began to wire and write for particulars and carload samples. An attempt was made to secure an option on the Red Marble Quarry but the owners, who were holding it as a marble deposit, asked $75,000 for the property. He visited other localities mentioned in Bulletin No. 4 and soon succeeded in locating the deposit now known as the Allen Quarry. During December, 1916, he sold the deposit to Mr. F. M. Handy, who was at that time representing the American Mineral Production Company.

[1] Personal Communication.



Moss Peak, site of the Moss quarry, just previous to the beginning of mining operations. Photograph shows the tendency of the pure magnesite to resist erosion and form bold outcrops.

TRANSPORTATION

The most favorably located of the magnesite deposits are the Finch, Allen and Moss properties which are five miles by air line, and about six and one-half miles by highway from the railroad. It naturally follows that these more favorably located properties should be the first mined.

The output of these quarries averages from 400 to 800 tons per day. During the earlier days of production auto trucks and teams were pressed into service until cheaper transportation could be installed.

In order to provide economical transportation from their quarries to the railroad at Valley the Spokane Valley & Northern Railway Company was organized during 1917, as a subsidiary to the American Mineral Production Company. A standard guage line from near the town of Valley to the Allen and Moss quarries was built, a distance of six miles. Eight additional miles of grade and bridges were constructed from the Allen to the Red Marble and Double Eagle deposits. Even ties and rails were distributed along the right-of-way before a sudden break in the magnesite market halted the work. The total cost of the railroad construction was about one-half million dollars. It was built in 150 days under the handicap of war conditions. The road operates under the I. C. C. regulations as a common carrier; its present principal income is now derived from transporting logs and lumber.

The Northwest Magnesite Company built its large calcining plant at the railroad a mile south of Chewelah and solved its transportation problem by the construction of a five-mile aerial tram to connect the Finch quarries with the calcining plant. The tram was constructed at a cost of about $60,000. It is of the double rope type with a 1⅜″ track cable on the load side and a 1″ cable on the return side; the traction rope measures

⅝″. The tram has a capacity of 1,200 tons per day. The buckets carrying 1,000 pounds of rock are spaced one minute and 10 seconds apart or each 600 feet on the tram. The time of travel between terminals is 50 minutes. The cost of transportation is about 50 cents per ton. A tram line has also been surveyed by the company to the Keystone deposit about five miles southwest of the Finch. This additional tram unit will be constructed when the necessity arises to open the Keystone.

The entire present production from the Double Eagle and Red Marble quarries is hauled by auto trucks to the railroad at Valley, a distance of 12 miles. The average haulage charge is $4.50 per ton. If a large scale production is required from these two quarries the line of the Spokane Valley & Northern railroad will probably be completed over the existing grade.

MINING METHODS

Practically all of the magnesite produced at present in Stevens County goes into the manufacture of refractories. The manufacturing companies have specified that the crude product must not carry over 3.5 per cent silica or two per cent calcium oxide. These demands cause a large wastage of medium grade magnesite in the quarries and also materially increase the mining costs. Loading the rock out of the quarries by steam-shovel or large glory hole methods cannot be considered if the grade of lime and silica is to be kept below specifications. Some of the limited richer belts have been mined by small glory holes but these can never be extended to large size. The Austrian deposits were very unfortunate in this respect, it being necessary for them to reject from 50 to 65 per cent of all the material mined in order to meet grade specifications. The Washington deposits, however, are more fortunate, only 20 to 45 per cent of the material mined being sent to waste.

One of the quarries of the Finch deposit. Note the variations in the dip of the beds, also the blocky nature of the magnesite.

Judging from data furnished by the quarry superintendents and the size of the waste dumps it seems probable that an average of 33 per cent of the material mined will cover the sorting reject for the Stevens County deposits. Some of the waste dumps contain magnesite of medium grade and at some future time these dumps will no doubt be reworked and efficiently utilized.

The open quarry method of mining is the most common system employed. Air driven jackhammer drills are used to put down 12 to 16-foot holes along the breast, and the rock blasted down. The larger boulders are blockholed with jackhammers. In order to maintain the grade the material must be loaded and sorted by hand. The general physical appearance of the material is a poor guide in attempting to sort out rock containing high lime or silica. Theoretically, rock containing six or seven per cent lime or silica should be discarded while the material carrying two or three per cent of these impurities should be retained. The color and coarseness of texture are but local guides at the best and it is necessary to continually sample the exposures and to use type samples to educate the men that they may know just what type of rock shold be discarded from a certain face. In spite of all these handicaps the workmen as a general rule do remarkably well in maintaining the grade.

The magnesite is traversed with many small one-half inch to two-inch seams which often run high in lime or silica. In blasting this seamy ground the filling in the seams would naturally tend to go into the "fines". The companies were quick to appreciate that the "fines" usually ran high in impurities and they are largely eliminated by having the loaders use forks instead of shovels for handling them; and more effectively, by putting an inch and one-half grizzly ahead of the crusher, thus bypassing the fines and sending them to the waste pile.

The magnesite after being loaded into one-ton cars at the quarry is usually handled to the main bunkers by "jig-back" or surface trams. Another common practice is to drive an adit tunnel at a depth of 100 to 200 feet below the quarries and then drive a chute-raise through to the quarry floor. The rock is dumped down these raises, drawn off in the adit, and trammed to the main bins.

In several instances a limited tonnage has been won by shrinkage stoping similar to metal mining practice. The magnesite stands well in the stopes without timber but stoping can only be practiced in certain belts of high-grade material which does not require sorting.

The slowness of hand sorting when loading adds heavily to the mining costs. Further, magnesite of excellent grade is often rejected through carelessless or sorting errors. Sorting from a picking belt has not been tried in the district. In metal mining practice, picking belts are commonly used and if they can be successfully utilized in the magnesite industry the costs of mining and loading will be materially reduced and a better control of the grade secured.

POWER

The Northwest Magnesite Company uses electricity for all of its power operations. This was at first entirely secured from the Meyers Falls plant of the Stevens County Power & Light Company. During low water periods this plant was unable to meet the heavy demands and the Northwest Company was forced to install a 100-horsepower distillate engine, in the calcining plant, for use as a booster during emergency periods. To relieve this situation a contract was made with the Washington Water Power Company of Spokane and during 1920 a 30-mile power line was built to connect the Chewelah district with the large power plant at Long Lake.

At the quarries not operated by the Northwest Company, distillate engines are employed to drive the crushing machinery. All railway haulage is done under steam power.

GEOLOGY

OCCURRENCE

A large portion of Stevens County is underlain by an extensive series of metamorphosed sediments consisting of argillites, quartzites, limestones and dolomite. These range in age from possible Pre-Cambrian to the Carboniferous, and have been named by Weaver[1] the Stevens series. He estimates that their maximum thickness was at one time 42,000 feet. After deposition they were uplifted, metamorphosed and severely folded and faulted. During the early Mesozoic these sediments were intruded by a granitic batholith which now forms the basement of the county. Erosion has removed a large portion of the Stevens series until in places large patches of the underlying granite are exposed.

One of the lower members of the Stevens series is a long, narrow, semi-continuous belt of dolomite which has been named the Stensgar dolomite. Starting three miles south of the town of Turk, in the Deer Trail Mining District, the belt trends in a northeast direction through the county for a distance of 20 miles; its width varies between 800 and 1,500 feet. The northeastern extremity is at the western rim of Colville Valley near the town of Chewelah. For its full length the belt conforms to the trend of Huckleberry Mountains and is found near the crest, on the east slope of the range.

The magnesite of Stevens County occurs as massive bedded deposits associated with this dolomite. All of the deposits are extensive in size and several of them will average over 500 feet in length, 300 feet in width,

[1] Washington Geological Survey, Bull. 20; Weaver, C. E., Mineral Resources of Stevens County, Wash., p. 49, 1920.

and 200 feet in thickness. The present commercial deposits are confined to the northern half of the dolomite belt. The Finch deposit is near the northern tip of the belt and nine miles further southwest is the Red Marble, the most southerly deposit. It is quite likely that new discoveries of magnesite will be made in that portion of the belt southwest of the Red Marble deposit.

The Stensgar dolomite is conformably interbedded between belts of argillite designated by Weaver[1] the Deer Trail argillite. The lower belt of argillite is of considerable thickness while as a rule the overlying belt of argillite is comparatively thin. This upper belt is in turn conformably overlain by the thick belt of Addy quartzite.

RESERVES

There are seven known commercial magnesite deposits in Stevens County. Named in order of their location they are as follows: Finch, Allen, Moss, Woodbury, Keystone, Double Eagle, and the Red Marble. It is conservative to estimate the reserves of these deposits as 5,000,000 tons of commercial magnesite, and as mining is carried on new reserves will probably be developed. The reserves alone could supply the entire present demands of the American refractory trade for 30 years. At the end of this time there would still be available a large tonnage of impure magnesite probably averaging as low as 12 per cent lime and 10 per cent silica.

STRUCTURE

The belt of Stensgar dolomite lies on the northwestern limb of a prominent anticline, the axis of which trends about N. 20° E. The belts of argillite, dolomite, magnesite, etc., have an average strike of N. 20° E. and dip N. 70° W. at angles varying between 35 and 50 degrees. Another important structural feature is that the axis of the fold has an inclination toward the northeast.

[1] Wash. Geol. Survey, Bull. 20, p. 59.

In the quarries there are many small transverse faults cutting and displacing the magnesite. The mine workings sometimes show abrupt changes from magnesite to dolomite or *vice versa*. Where these interruptions of strata are encountered, close examination will usually reveal the tell-tale slip-plane of a fault.

The geologic associations of the dolomite-magnesite belt are essentially similar in the vicinity of all the major deposits. The belt is underlain by thick strata of dark-colored argillite. A similar band of argillite, 200 feet in average thickness overlays the dolomite-magnesite, and is in turn overlain by an extensive belt of quartzite. Certain of the field evidence suggests that these formations have been reversed by an overthrust and the quartzite and thin band of argillite should normally underlay the Stensgar dolomite. Such a condition is found at the Crosby deposit and detailed mapping may show that here the belts are in their normal position.

The structural features of the area are expressed by the topography. The stream valleys are cut principally through the relatively soft and platy argillite. The bold ridges which form the crest of the range are generally of hard resistant quartzite. These ridges usually average 4,000 feet in elevation and boast of an occasional prominence of quartzite that rises 1,000 to 2,000 feet above the general crest of the range.

The very complex structural geology of Stevens County has been ably worked out from a generalized standpoint by Weaver[1], and a portion of his report covering the area involved is included here.

"A prominent anticline, trending about N. 20° E., lies three miles east of the summit of the Huckleberry Range. The Deer Trail argillite below and the Addy quartzite above are involved in this fold, which has been deeply

[1] Wash. Geol. Survey, Bull. 20, p. 108.

carved by erosion so that for a distance of 15 miles the overlying Addy quartzite has been removed, and a belt three miles in width, of the Deer Trail argillite exposed. The truncated edges of the Addy quartzite, which constitutes the east and west limbs of the fold, form two broad parallel belts. The latter are on the south, terminated by intrusive granite and disappear beneath a covering of Tertiary lavas. In the middle portion of T. 32 N., R. 40 E., the two belts join as the anticline pitches to the northeast beneath Colville Valley and beyond. The dips of the strata in this fold vary greatly, but have a predominant slope to the northwest. This fold is designated as the Deer Trail anticline.

The Deer Trail anticline crosses Colville Valley between Addy and Chewelah and continues northeasterly for a distance of about nine miles where it is terminated by the batholithic intrusion of the Loon Lake granite. The continuation of the fold northeast of Blue Creek is referred to as the Blue Creek anticline. In the vicinity of Blue Creek this fold has been greatly appressed and overturned so that the strata dip to the northwest at angles as low as 30°. At no point do the underlying Deer Trail argillites appear at the surface. The northwestern limb of the fold has been invaded by masses of granite.

In the southern part of T. 32 N., R. 39 E., the nose of a synclinal fold has been developed in the western limb of the Deer Trail anticline (see Plate I). The two limbs of the fold are composed of the Addy quartzite. The formation in the central part is the Chewelah argillite. The axis of the fold trends nearly north and south for a distance of about ten miles where it terminates against a mass of intrusive granite. All of the strata in both limbs are dipping to the west, indicating a closely appressed and overturned fold. This fold is named the Addy syncline."

This information furnishes a generalized perspective of the structure of the magnesite area. When the individual deposits are visited it soon becomes evident that the problem is highly complicated by many minor folds and faults. These structural problems are so complex that they can only be solved by the most detailed structural mapping. Their ultimate solution has a definite economic bearing, for only in this way can prospecting for new magnesite deposits be intelligently directed. During 1920 Dr. Bailey Willis was employed by the Northwest Magnesite Company in making a geologic investigation of the Stevens County magnesite. Dr. Willis informed the writer[1] that the Stevens County magnesite area presents the most complex structural problems he has yet encountered. He spent some 10 weeks on the problem, during which time it was found necessary to construct a topographic base map to facilitate the geologic mapping.

GENESIS

The origin of the Stevens County magnesite deposits is rather obscure and the writer found that the field evidence observed in one part of a deposit was sometimes contradicted by later observed evidence. The deposits are undoubtedly of sedimentary origin and are closely related to the associated Stensgar dolomite. This links us with the problems concerning the origin of dolomite; one that is perplexing because of lack of tangible conclusive evidence, and the contradictory nature of field and experimental evidence. The origin of dolomite has been the subject of numerous investigations and since the best authorities have arrived at variant conclusions it can be readily appreciated that the question of origin of the crystalline type of magnesite (which occurs associated with dolomite) is subject to considerable difference of opinion. The following are the theories that are

[1] Oral Communication.

advanced to account for the origin of the crystalline type of magnesite:

1. Chemical deposition of magnesium carbonate from waters rich in magnesium and poor in lime.

2. Limestone or dolomite deposited and then enriched by hot magnesium-charged waters accompanying basic intrusive or extrusive rocks.

3. Replacement of limestone or magnesium-limestone by percolating waters carrying magnesium. Dolomite thus being formed and then further replacement from dolomite in magnesite.

4. Direct sedimentary deposition of mixed salts of calcium and magnesium carbonates. Soluble calcium carbonate removed before the mixed salts are converted by metamorphic agencies, to the double salt dolomite.

(1) For the first day or two in the field an investigator might be seriously tempted to lean toward the first hypothesis. It is difficult to understand why the associated dolomite has not been leached of its lime content, for it is apparently as badly fractured and offers just as favorable opportunity for leaching reactions as does the magnesite belt. However, there is a general assumption based on chemical and geological evidence that magnesite would not be deposited in this way. [1-2].

When a perspective is gained of the deposits and associated formations, it is evident that the magnesite occurs as localized deposits in the long, narrow belt of dolomite and the deposits are evidently the result of localized replacement. The writer believes that the first hypothesis is untenable.

(2) It is an interesting fact that meta-diabase dikes cut the formations in the vicinity of each commercial deposit of magnesite. The Red Marble deposit is underlain by a sill-like dike of this character. Stone[3] suggests that the recrystallization of the purer magnesium car-

[1] Van Hise, C. R., A Treatise on Metamorphism; U. S. Geol. Survey, Mon. 47, 1904; pp. 802, 808.

[2] Johns, I., The solubility product constants of calcium and magnesium carbonates. Jour. Am. Chem. Soc., Vol. 37, 1915; p. 200.

[3] Stone, R. W., U. S. Geol. Survey, Min. Res. of the U. S.; 1917, part 2, p. 72.

bonate may have been secondary, possibly influenced by the basic magnesium intrusive rocks. The rocks adjoining these dikes were observed in both the Finch and Allen quarries. Dolomite was found not far distant from the dikes but in most cases the nearest commercial mag-

One of the upper quarries on the Finch magnesite deposit.

nesite was 200 feet or more from the dikes. It is possible, however, that magnesian solutions accompanying these intrusions could have ascended along the myriad number of joints and cracks in the dolomite belt and locally replaced the calcium with magnesium.

(3) The most generally accepted theory of origin is that first offered by Redlich[1] for the magnesite deposits of Austria-Hungary. He suggested the formation as

[1] Tschermak's Mineralogische Mitt., 1909, p. 499.

the result of two reactions, dolomite being formed in the first and magnesite in the second.

1. $2CaCO_3 + MgCO_3 = MgCaCO_3 + CaCO_3$
2. $MgCaCO_3 + MgCO_3 = 2MgCO_3 + CaCO_3$

If these reactions hold true for the Stevens County deposits, the second reaction was not carried to completion for it is not uncommon to find remnants of dolomite scattered through the magnesite. Some of the strongest evidence offered for the replacement hypothesis was found in the Finch and Allen deposits where in several instances samples broken from the quarry face showed the transition from dolomite to magnesite, that is, a fraction of the specimen was dolomite which graded out into magnesite.

Redlich's hypothesis seems to imply first, the deposition of limestone on the sea floor; later, percolation of magnesium carbonate solutions through the limestone effecting a gradual replacement of magnesium for calcium; still later the more soluble calcium carbonate was washed out and as the further percolation of magnesium proceeded the dolomite was gradually carried over into magnesite. This replacement might be carried on before the material emerges from the sea. It is more generally assumed, however, that other sediments were deposited over the area and then the belts elevated above the sea, folded and metamorphosed. These orogenic movements would cause the belt to develop many cracks and crevices through which underground waters rich in magnesium could percolate and effect the replacement. Van Hise[1] suggests that pressure tends to promote these replacement reactions; thus, the deeper the rock the greater the tendency of calcium to be replaced by magnesium, for as a result of the substitution of magnesite

[1] Van Hise, C. R., A Treatise on Metamorphism; U. S. Geol. Survey, Mon. 47, p. 806, 1904.

for one-half calcium there is a volume change of 12.3 per cent.

Weaver[1] considers that the magnesite is the result of the replacement of dolomite along fracture zones; this replacement being effected after the overlying sediments were deposited and the belts lifted above the sea.

(4) It was largely the writer's inability to understand how this replacement from dolomite into magnesite could locally be carried so near the end point, that caused the advancement of No. 4 as a possible hypothesis. When we remember that the replacing solutions are supposed to have acted along the fractures through the belt, one would naturally expect nearly pure magnesite near the conduits. In the center of a block of magnesite bounded by fractures there should be at least a kernel of unaltered dolomite. As far as the writer could observe the numerous cracks and crevices traversing the belt bear little relation to the grade of the material. The seams were found to be filled with varying types of material; some are filled with calcite; others are rich in magnesite and still others carry talcose matter high in silica.

The writer believes that the replacement theory best explains the Stevens County deposits but he wishes to advance certain new modifications that appear to play a logical part in the solution of this particular problem. There is considerable evidence to support the supposition that the deposit originated through the direct sedimentary deposition of mixed salts of calcium and magnesium carbonates. The calcium carbonate, which is highly soluble, could be removed before the mixed salts are converted by metamorphic agencies to the double salt, dolomite.

[1] Wash. Geol. Survey, Bull. 20, p. 322.

Analyses of oceanic salts show that at the present time there is over three times as much magnesium in the sea water as there is calcium. Under certain conditions it seems possible that this magnesium could be deposited along with the calcium. In the arms or shut-off portions of the sea where the conditions are favorable for unusual concentration, the amount of magnesium in such waters may be even greater than that in the normal waters and under these circumstances magnesium would be precipitated. The coral reefs of Metia, which are heavy in magnesium, form a concrete example.[1]

Dana compares concentration of magnesium carbonates in lagoons, which are mainly shut off from the sea, to concentration in salt pans.

If we can assume that under favorable conditions magnesium and calcium carbonates can be precipitated together, we must next determine whether this precipitate would be in the form of the mixed salts or in that of the double salt, dolomite. It is the writer's belief that as a general rule the mixed salts are first precipitated and that these do not combine to form dolomite until subjected to moderate temperature or pressure.

Deposition of magnesium travertine by the mineral springs of St. Allyre, near Clermont, France, has been reported by J. Girardin.[2] In recent travertine he found 28.8 per cent magnesium carbonate with 24.4 per cent calcium carbonate, and in old travertine the proportions were 26.86 and 40.22 per cent, respectively. Whether this represents dolomite or a mixture of the carbonates, was not determined.

E. von Gorup-Besaney[3] found that springs from the dolomites of Jura, which contain calcium and magnesium

[1] Dana, Jas. D., Corals and Coral Islands, New York, Dodd Mead & Co., 3rd Ed., p. 394, 1890.

[2] Annales des mines, 3rd Ser., Vol. 11, 1837, p. 460.

[3] Liebig's Annalen, Beil Band 8, 1872, p. 230.

carbonates in the dolomite ratio, deposited the mixed salts upon evaporation, and not the double compound.

T. Sterry Hunt[1] found that when the pasty mass formed by precipitating the two carbonates together was heated to temperatures above 120 degrees, union took place and dolomite was formed.

That temperature and pressure are important factors in the formation of dolomite is evidenced by experimental data which show that dolomite can be formed in several ways. Synthetic experiments[2] show that mixed carbonates of calcium and magnesium, and not true dolomite are first precipitated. A study of the literature reveals that all attempts to produce dolomite artificially as a direct precipitate under ordinary conditions have been unsuccessful. Scheerer[3] failed to obtain it by mixing solutions of $CaCO_3$ and $MgCO_3$ together in different proportions and evaporating at ordinary temperatures. The two carbonates were thrown down separately as characteristic rhombohedrons of calcite and prisms of hydrous magnesium carbonate. Recently Leitmeir[4] repeated this experiment, evaporating the solutions at temperatures from 10° to 100° but secured the same results. Van Tuyl[5] also carried on experiments along the same line. He reports separate solutions of the bicarbonate of calcium and magnesium after being standardized were mixed in molecular equivalent proportions in order to give the same ratio of $CaCO_3$ and $MgCO_3$ as exists in normal dolomite. The solution was then allowed to evaporate spontaneously during a period of one month. It was noted that the carbonates came down separately with the $CaCO_3$ much in advance of the $MgCO_3$, which

[1] A. Jour. Sci., 2d series, Vol. 28, 1859, pp. 170, 365; Vol. 42, 1866, p. 49.

[2] Data of Geochemistry, U. S. Geol. Survey Bull. 695, p. 563, 1920.

[3] Neues Jahrbuch, 1866, p. 1.

[4] Doelter's Handbuch der Mineralchemie; Vol. 1, 1912, p. 395.

[5] Van Tuyl, Francis M., The Origin of Dolomite; Ann. Rept. Iowa Geol. Survey, Vol. 25, p. 299, 1914.

was deposited in the hydrous form ($MgCO_3H_2O$). Negative results still were obtained when a solution prepared as above was inoculated with a crystal of dolomite and allowed to evaporate. The crystal did not grow and no dolomite could be found in the residue. Nor could the double carbonate be prepared by evaporating spontaneously a solution of the two carbonates obtained by the action of carbonated waters on normal dolomite, even when a dolomite crystal was introduced and a concentrated solution of NaCl and magnesium salts was also introduced. Numerous experimenters, however, have succeeded in preparing dolomite artificially from the mixed salts at elevated temperatures[1] under slight pressure.

It seems logical that local replacement reactions could be much better carried to completion while the mixed salts were in a more or less unconsolidated stage, and before they have been combined into the double salt, dolomite, and then hardened still further by metamorphic reactions into a compressed belt. If, at several points along the belt the calcium could, by local agencies, be leached out before dolomitization set in, our conditions would be fulfilled.

The belt of quartzite overlying the Stensgar dolomite suggests that following the deposition of the dolomite belt, the material was elevated so nearly to sea level that sandstone was deposited as a cover over the dolomite. The weight of the sandstone was enough to effect dolomitization. Later, intense metamorphic reaction converted the sandstone into a quartzite, the shale into argillite and highly metamorphosed the dolomite and magnesite.

The writer's hypothesis concerning the origin of the magnesite deposits of Stevens County can be summed

[1] Van Tuyl, Francis M., The Origin of Dolomite, Ann. Rept. Iowa Geol. Survey, Vol. 25, pp. 300-6, 1914.

up as follows: First, the existence during late Paleozoic time of a long, shallow, inland sea or lagoon. In this sea concentration of magnesium and calcium salts by evaporation and saturation would cause the mixed salts of calcium carbonate and magnesium carbonate to be precipitated. Before these mixed salts were converted into dolomite, certain points along the belt were subjected to local leaching action, which removed the more soluble calcium carbonate. Subsequent metamorphic agencies, either heat or pressure, crystallized the magnesium carbonate and also converted the remaining mixed salts of calcium and magnesium carbonates into the double salt, dolomite.

PROSPECTING

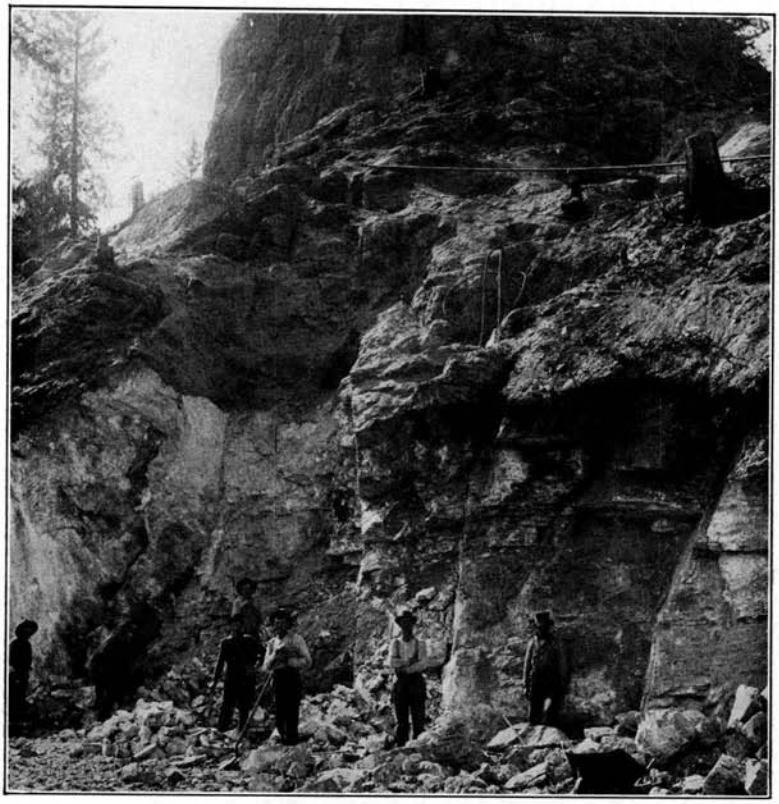
It is not likely that all of the commercial magnesite deposits of Stevens County have been found. Following the first discoveries in 1916 there was a rush of prospecting carried on in most part by local men, but the excitement gradually subsided and at the present time there is little new prospecting being conducted. The present reserves are ample for all needs for many years to come and this has served to partially remove the incentive for the search of new deposits.

The flanks of Huckleberry Range are veneered with a thick coating of hillside wash and glacial debris, which support a good stand of timber and heavy underbrush. These combined agencies cover much of the bedrock and hamper prospecting.

All of the commercial deposits of magnesite occur in the long, narrow belt of Stensgar dolomite and it is obvious that this belt offers the most likely ground for prospecting. Particularly is this true along the southwestern half of the belt which is not so well known. A number of limestone belts in northeastern Washington carry an appreciable magnesium content. Samples from the Old Dominion limestone belt average about 20 per

cent magnesium oxide and 30 per cent calcium oxide. Limestones from near the headwaters of Stranger Creek and from Riverside, Okanogan County, carry similarly high percentages of magnesium and it is possible that lenses of magnesite may later be found in these dolomitic limestones.

On account of its insoluble nature and superior hardness, magnesite offers more resistance to erosion than does limestone or dolomite. Thus magnesite often forms small knobs or prominent outcrops to aid the prospector. Another distinguishing feature is that limestone and



Original opening of the Moss deposit, during 1917. In the upper part of the view note the bold outcropping of magnesite, known as Moss Peak.

dolomitic limestone (carrying free calcium carbonate) will effervesce when treated with a drop of cold hydrochloric acid. Magnesite cannot be distinguished from true dolomite by this test, however, for neither effervesce unless treated with warm hydrochloric acid. Material that is apparently limestone yet which will not effervesce under cold hydrochloric acid should be considered worthy of analysis.

NORTHWEST MAGNESITE COMPANY

FINCH DEPOSIT

General Features. From this deposit has come the principal production of the Northwest Magnesite Company for the past three years. It stands as the premier magnesite deposit in point of production for the years 1918, 1919, and 1920.

The property embraces the NE¼ of the NW¼, the NW¼ of the NW¼, and the SW¼ of the NW¼ of S. 30, T. 32 N., R. 40 E. The quarry proper is situated in the SW¼ of the NW¼ of section 30, near the northern tip of the Stensgar dolomite belt and five miles by air line from the company's plant near Chewelah.

From November, 1916, to May, 1917, it was operated by R. S. Talbot as the Washington Magnesite Co. The present company was organized in May, 1917. The operating office is located at Chewelah and the head offices are in San Francisco. R. B. Rodgers is general superintendent; O. D. Rodgers is superintendent of the quarries.

Description of the Deposit. The magnesite and dolomite outcrops extend along the valley wall from near the level of the valley practically to the crest of the hillside. The general trend of the belt is N. 5° E. and it dips 35° to 50° toward the west. The maximum width of the belt is 600 feet, the length is about 1,000 feet, and the thickness in some places exceeds 250 feet. All varieties of gradations from dolomite to magnesite are found.

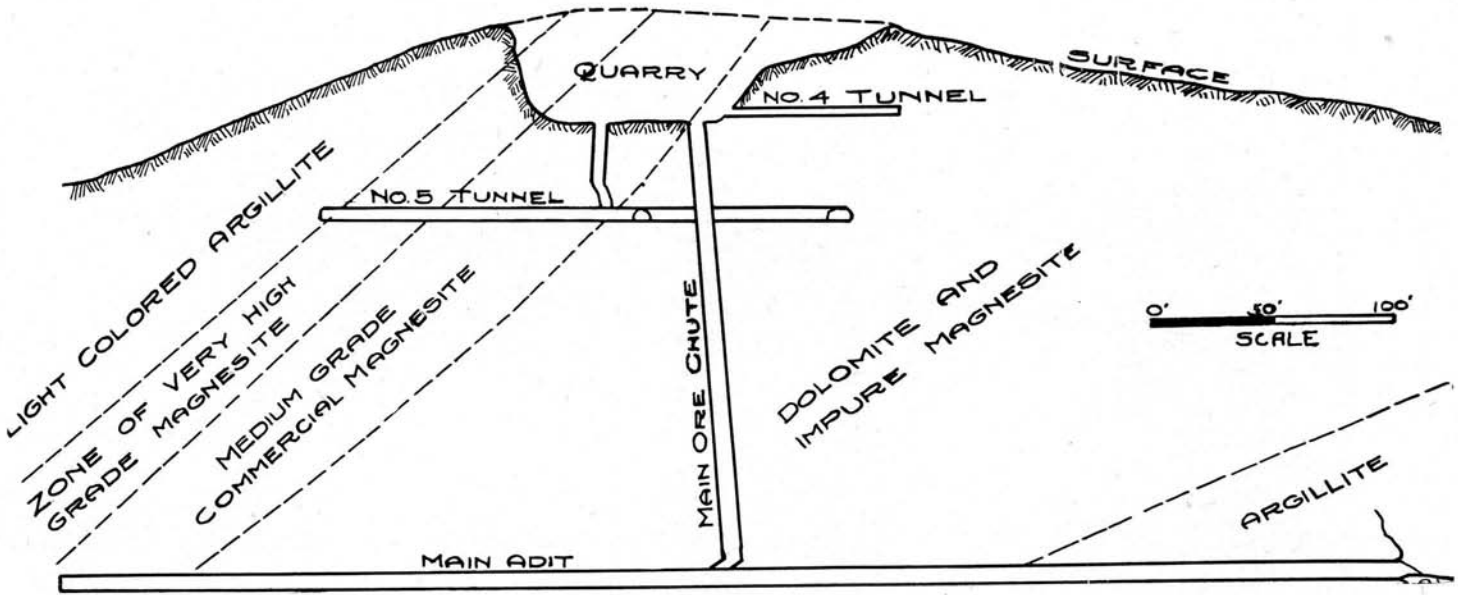


FIG 1.—Ideal section through Finch quarry workings, to show relation of the magnesite to associated formations.

By referring to the ideal cross-section (Fig. 2) the best general idea of the relations of the magnesite and associated formations can be gained. The deposit is underlain by thinly-bedded, argillaceous shales. Argillites flank the dolomite and magnesite on the east, and a narrow belt of overlying argillite on the west gives way to a bold exposure of quartzite. About 400 feet from the portal of the lower adit tunnel the dolomite is found resting on the argillaceous shales. This is the bottom of the dolomite-magnesite belt. The contact between the two beds is sharply defined and dips at a 20° angle toward the north.

The series have been subjected to intense local folding, buckling and faulting which tend to obscure the major structural features. Many small seams traverse the beds. These are usually high in silica, although in some cases they may be filled with pure calcite or again pure magnesite.

At the time of visiting the quarries numbers 10 and 11 were being opened up near the crest of the hill. The exploratory work has exposed a 12-foot meta-diabase dike striking east and west and cutting vertically through the dolomite. This is the only sign of igneous rock so far exposed in the Finch workings. The rocks in the vicinity of the dike are badly contorted and some serpentine is developed. There is nothing to indicate, however, that the igneous activity played any part in the replacement of the magnesite from dolomite, excepting that it is possible that the heat of the igneous dike assisted dolomitization of the calcium and magnesium salts.

Mining Methods. The Finch deposit has been carefully diamond drilled and the drill records have been of material aid toward defining the workable zones and thus promoting more comprehensive development.

At the Finch deposit the magnesite is developed by a series of quarries opened at intervals up the hillside.

It is the policy of the management to have several working faces open at the same time in order to be better able to meet any peak demands. It is a common practice to mix rock from two quarries when one quarry is running high in silica and low in lime and the other quarry showing high lime impurities and low in silica. The Finch quarry has also a 60-foot zone of practically pure magnesite, known locally as the "sugar pot." This zone is mined by underground shrinkage stoping and when necessary is mixed with the day's tonnage to "sweeten" the grade.

After the magnesite is loaded into the cars at the quarry face it has two means of transit to the coarse crushing plant below. A portion of the tonnage is handled by a "jig-back" tram operating from the level of No. 4 quarry to the crusher bins. At the level of the crushing plant a long adit is driven under the main quarries and north far enough to tap the belt of high grade magnesite on its dip. From the adit, chute-raises have been driven up to the quarry floor. A large part of the broken rock is dumped down this raise, drawn off at will in the adit, and trammed by mule train to the crushing plant.

All drilling is done by power furnished by a 500 cubic-foot ten machine compressor operated by a 100 horse-power, 2,200 volt motor.

Coarse Crushing Plant. The ore from the quarries is dumped into a 75 ton receiving bin from which it is fed to an 18x29 inch Bull Dog jaw-crusher breaking to about five inches. The rock from the crusher falls onto a 22 inch belt conveyor, set at an angle of 17°, which elevates the rock to a 75 ton head bin. At the upper end of the bin the material passes over a grizzly set to one and one-half inches. The undersize being high in impurities usually goes to the waste dump. If the grade is better the "fines" are by-passed to a trommel carry-

View of workings on Finch deposit (June, 1920). Note the resistance to erosion of the magnesite belt as compared with the flanking belts of argillite. The peak showing in the extreme left of view is composed of quartzite.

ing a ½ inch screen; the undersize goes to waste and the oversize is sent to the ore bins. The rock is next fed to two Gates No. 5 gyratory crushers breaking to about two inches. A bucket elevator lifts the crushed rock to a 300 ton tram bin where it is subsequently loaded into tram buckets and carried five miles to the company's plant at Chewelah. All machines are motor driven. The bins in the crushing plant are all oversize in order to provide ample storage capacity to ward against temporary delays.

Excellently constructed and appointed living quarters and a club house are provided for the employees and bungalows have been built for the superintendents. A crew of 120 men is ordinarily employed on two shifts.

An average of 12,000 to 18,000 tons of rock are mined each month at the Finch quarries. About 70 per cent of this is sent to the Chewelah plant, the remainder being waste.

KEYSTONE DEPOSIT

The Keystone deposit is now owned by the Northwest Magnesite Company. It was first known as the U. S. Marble Co. and from 1898 to 1903 this company opened a quarry in the magnesite and marketed a large tonnage of the material under the impression that it was marble. Their lines of drill holes still show in the quarry face. Title to the property was acquired by R. S. Talbot of Spokane who organized the Washington Magnesite Co. and from this property made the first shipments of magnesite from the Stevens County area. Later, the Washington Magnesite Co. was reorganized as the Northwest Magnesite Co. The Finch deposit was acquired by the Northwest Co. and on account of its superior location operations are now centered on the Finch deposit while the Keystone is held in reserve.

The property is located about 10 miles by road from Valley and about five miles by air line southwest of the

Finch quarries. The exact location is in sections 8 and 9, R. 31 E., T. 39 N. The quarry face is about 600 feet above the road, the bold outcroppings of magnesite forming a prominent ridge.

The deposit is known to be 200 feet thick, 225 feet wide and 600 feet long. There are belts of dolomite interspersed through magnesite but the magnesite is said to average good shipping grade. An estimate of one million tons of commercial magnesite is probably a con-

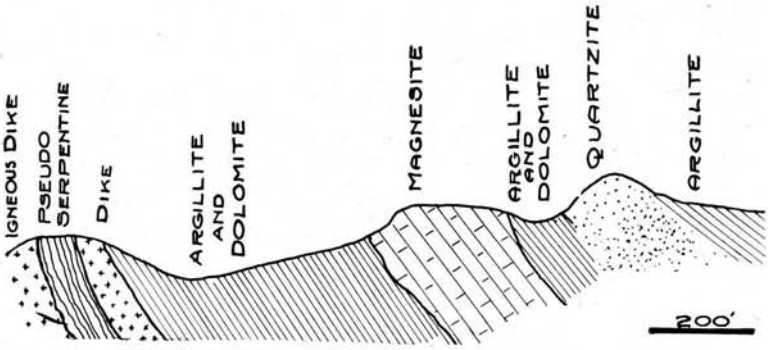


FIG. 2.—Ideal geologic cross-section in the vicinity of the Keystone magnesite deposit.

servative figure. The outcropping and quarry face have been systematically channel sampled.

Near the center of the quarry there is a large lenticular mass of brucite (MgO, H_2O), about 40 feet long and 20 feet thick. The brucite is frozen to a nearly vertical, strongly striated face of magnesite. This slip-plane suggests the possible means of alteration from magnesite to brucite. The action of heat and steam from an associated igneous dike during its period of cooling may have used this slip-plane as a vent with the result that a portion of the adjacent magnesite was calcined and hydrated. On the southwest side of the quarry the brucite merges into fine-grained, white magnesite. The brucite varies from light green to a chalky white color and is highly

translucent. It is capable of being carved into intricate ornaments and takes a very high polish.

The magnesite from the deposit is generally dark blue to bluish-black in color and is coarsely crystalline. The outcrops of magnesite weather to a rough pattern of sheaf-like crystal aggregates.

The magnesite-dolomite belts are underlain by argillaceous shales and overlain by quartzite. A dark, fine-grained igneous dike cuts the belt.

Northeast of the magnesite quarry 400 feet, a second quarry was opened some years ago and a considerable production of serpentine-marble made. The lens is flanked on two sides by dark, fine-grained igneous dikes which are responsible for the serpentization of what was once an impure magnesium limestone to which silica was probably added by the igneous intrusion. The so-called serpentine is dense and fine-grained, of a light green color, wax-like luster and quite sectile. It takes a good polish and should make an excellent ornamental stone. While the material was marketed as serpentine, it is no doubt the formation from which came the samples examined by Clark[1] and pronounced by him to be not serpentine, but a mixture of hydro-magnesite, brucite, clinachlore and serpentine.

MIDNIGHT CLAIM

Weaver[1] briefly mentions the Midnight Claim as being located in the west half of the SE¼ of Sec. 7, T. 31 N., R. 39 E. No production has been made from this property, which is owned by the Northwest Magnesite Company. On account of the time available for field work this property was not visited. Later, when attempting to plot the deposit on the areal geologic map, it was found that the Midnight Claim did not fall within the Stensgar dolomite belt. This suggests that the loca-

[1] Clark, F. W., Am. Journal of Science, fourth series, Vol. 15, pp. 397-398.

tion marks an erratic occurrence of magnesite and the geological relations at the deposit might throw some interesting light on the structural and genetic problems of the area.

AMERICAN MINERAL PRODUCTION CO.

GENERAL STATEMENT

Early in 1917 the American Mineral Production Co. of Chicago acquired the Allen, Moss and Woodbury quarries and liberally expended capital to develop them and to provide cheap transportation. A standard gauge railroad was built to link the quarries with the railroad at Valley, six miles distant. Four vertical kilns were constructed at the Allen quarry in 1917. They were built to drive off a part of the carbon dioxide as a gas and so reduce freight costs. A considerable production of raw and burned magnesite was shipped out via Valley in 1917 and 1918, these quarries being second only to the Finch in point of production. During 1918 the demands for dead burned magnesite became more incessant and the company shipped its magnesite to the Inland Portland Cement Co. at Irvin, near Spokane, where it was dead-burned in rotary cement kilns. On account of uncertain market conditions the quarries were idle from December, 1918, until August, 1919. Arrangements have since been made with the Northwest Magnesite Co. to handle 200 tons daily through their Chewelah plant. The magnesite from the Allen and Moss quarries is now transported to the Finch quarry over a short, narrow-gauge road, and from there handled over the five-mile aerial tram of the Northwest Co. H. F. Wierum is general manager of the company and Mr. Griswold is assistant manager.

ALLEN AND MOSS DEPOSITS

These deposits are opened by two series of adjoining quarries located on the same magnesite lens. The Allen deposit is about 600 yards south of the Finch, and on

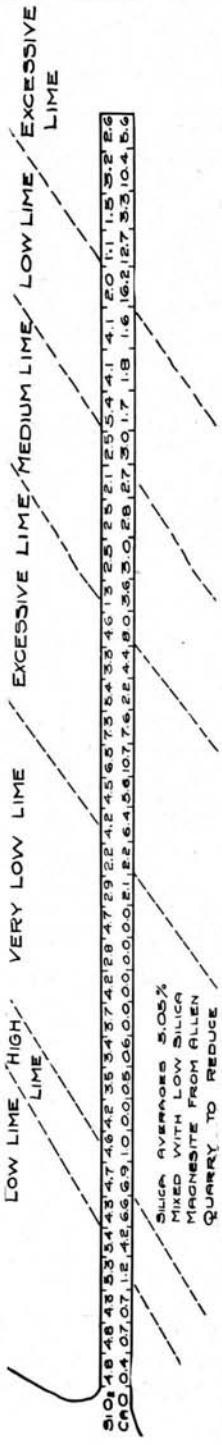


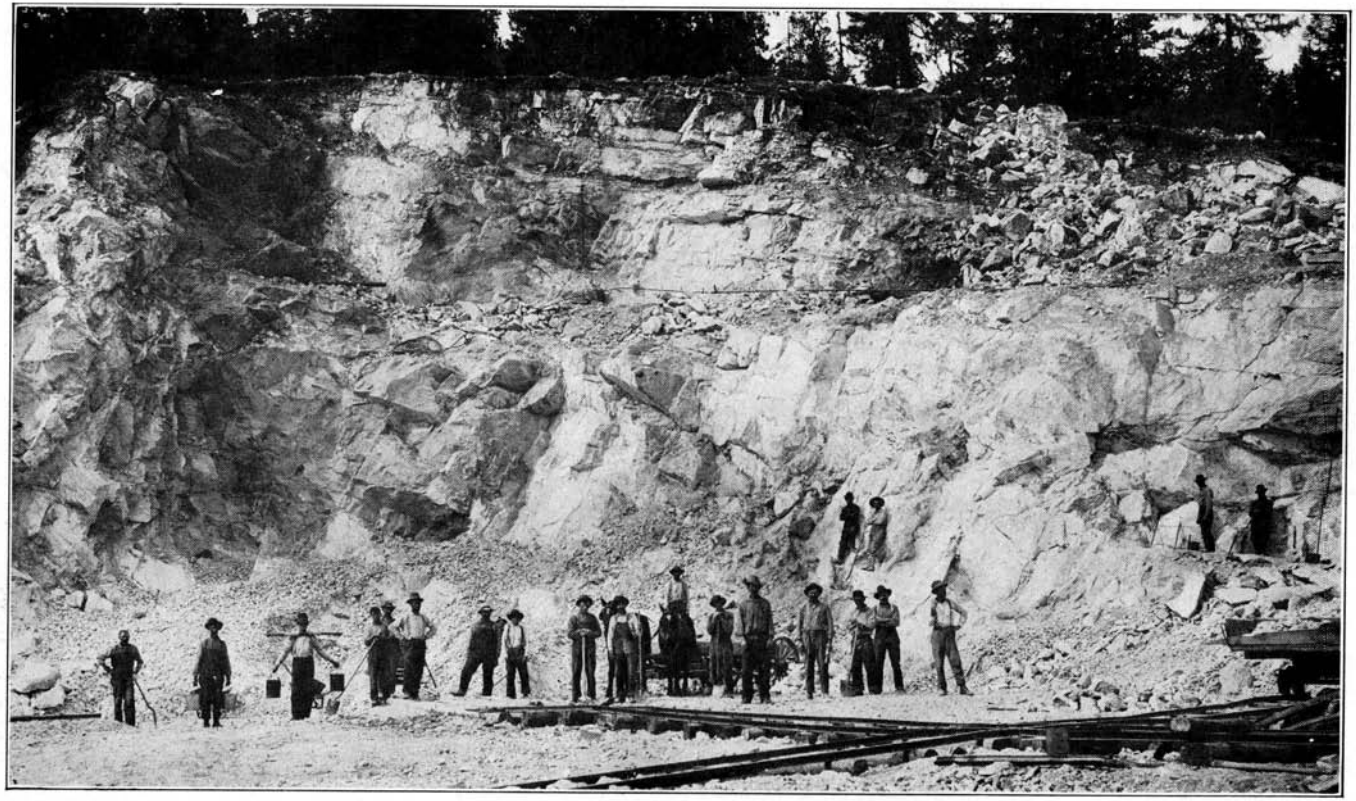
FIG 3.—Generalized section along Moss tunnel. Compiled from analyses covering 10-foot sample sections.

the opposite side of the gulch, and at about the same elevation. The Moss quarries adjoin the Allen on the south. It is only 100 yards from the Allen quarry proper to the Moss quarries. The Finch, Allen and Moss deposits were at one time linked together but have been severed by erosion.

The belt of magnesite opened on the two properties is from 250 to 300 feet wide, about 1,000 feet long, and will average 200 feet in thickness. This entire belt is, of course, not all commercial ore.

The magnesite, being very resistant to weathering, forms bold outcrops along an intermediate crest of the hill. A belt of quartzite forms a prominent ridge above the magnesite on the west. The magnesite-dolomite belt is underlain by argillite, similar to the Finch deposit. The beds dip at an angle of 20 degrees to the north, contain many minor folds and slips, and like the Finch show the ravages of metamorphism. The lime and silica impurities vary erratically, making always necessary, constant sorting vigilance and chemical testing.

The ore is mined principally by the open quarry method, similar to that described under the Finch quarries. A limited amount of underground stoping has been tried.



One of the working faces on the Allen deposit.

The future plans of the management are to complete a long adit tunnel now in 600 feet, and to handle most of the tonnage through this adit. This will give them an effective depth of about 120 to 170 feet below both the Allen and Moss quarries.

The rock from all quarries is broken to about five inches in a large Blake jaw crusher and is then transported by a gravity cable car to the ore bins at the railroad tracks.

Power for the drills is furnished by a 5-machine air compressor operated by an 80-horsepower steam boiler. An experiment of using sawdust as fuel from a nearby sawmill is proving very successful and results in an appreciable saving on fuel costs. A crew of about 80 men is employed on the one shift being worked. Dan Lawson is superintendent of the quarries.

RED MARBLE DEPOSIT

This interesting deposit is at about the center of the Stensgar dolomite belt and is the most southerly deposit of magnesite so far located. It occurs on one of the ridges of the Huckleberry Mountains in sections 24 and 25, T. 31 N., R. 38 E. The main openings are at an elevation of about 4,200 feet.

The deposit is owned by the American Mineral Production Co. and a railroad grade has been constructed to the property, bridges built and a considerable quantity of ties and rails distributed along the right-of-way. These were never laid on account of the uncertain magnesite market which later developed, and also because the Allen and Moss quarries, more favorably located, are capable of meeting the present demands. A 6,000-foot aerial tramway has been constructed from the railroad grade in Deer Creek Canyon to the quarry on the crest of the hill. The tram terminals have a difference of elevation of about 1,000 feet. A large quarry was opened

on the deposit in 1917 and a considerable tonnage hauled to Valley with auto trucks. The property is idle at present, being held by the company as a potential source of supply for the future.

This deposit should be capable of developing the largest tonnage of any along the magnesite belt. Its exact limits are not definitely known as yet. It is probably 1,200 feet long, 400 feet wide and with a thickness that will likely exceed 300 feet. How much of this is commercial ore is not definitely known. If the body will average fairly consistently, a total of two and one-half million tons of commercial ore would be a conservative estimate.

The magnesite varies from coarsely crystalline to a fine groundmass. It has a distinct reddish-brown to rose-red cast, which is due to impurities of salts of iron and manganese. It is from this coloration that the deposit received its name. At one time an attempt was made to develop the property as a marble quarry.

Practically the same geologic associations hold here as observed at the other deposits. The east side of the belt is underlain by argillaceous shales which dip 45° toward the N. W. and strike N. 25° E. Then appears a narrow exposure of meta-diabase intrusive between the shale and a belt of dolomite. The dolomite dips 45° toward the N. W. and strikes N. 30° E.; this dolomite grades into the magnesite. On the west the magnesite is overlain by a heavy belt of quartzite extending to form the backbone of a higher ridge of the Huckleberry Mountains.

WOODBURY DEPOSIT

The Woodbury was the first shipping quarry opened by the American Mineral Production Company. It was operated from November, 1916, until August, 1918, and is credited with an output of approximately 25,000 tons of crude magnesite. On account of the more consistent quality of the magnesite and cheaper conditions for min-

ing at the extensive Allen and Moss deposits, operations were suspended at the Woodbury during August, 1918, and all work concentrated on the Allen and Moss.

The deposit is in the NW¼ of the NW¼ of sec. 1, T. 31 N., R. 39 E., one and one-half miles southwest of the Allen and Moss quarries.

There is but one exposure on the Woodbury deposit, and this permits a quarry face 150 feet long and 25 feet high. The bed of magnesite is comparatively shallow and cannot be expected to develop a reserve tonnage comparable with the major deposits.

During May, 1917, there was built at the Woodbury a shaft kiln having a vertical steel cylindrical shell, three feet inside diameter, 16 feet high and lined with fire brick. A few months later a second kiln, of brick construction, was built. This has an inside diameter of six feet and a height of 20 feet. The combined output of the two kilns averaged 30 tons of calcined magnesite daily.

AMERICAN REFRACTORIES COMPANY

DOUBLE EAGLE DEPOSIT

General Statement. This deposit was discovered and developed by F. M. Handy, one of the first men to recognize the commercial importance of the Stevens County magnesite. Upright kilns were built at the property during 1917 and considerable shipments of both crude and calcined ore made. For a time the property was idle but it was reopened during October, 1919, by Mr. Handy and B. E. Keehler and shipments of calcined magnesite resumed. Since January 1, 1920, the deposit has been operated under lease and bond by the American Refractories Company of Pittsburg. A crew of 65 men was employed during 1920 and a daily production of 80 tons of crude ore maintained. This is burned in the three upright kilns, and the calcine shipped east for use in the manufacture of refractories. The burned material can-

not be strictly classed as dead-burned, for it contains 1½ to 2 per cent carbon dioxide. It is not, however, classed as caustic-calcined magnesite as that term is used in referring to the product consumed by the plastic trade.

Location and Accessibility. The holdings are in secs. 17 and 18, T. 39 N., R. 31 E., which is across Deer Creek, about one and one-half miles northeast of the Red Marble deposit. Near the foot of the mountain the kilns and general camp buildings are located. The quarries are near the crest of the mountain and connected with the kilns by a surface tram 2,800 feet in length, and by a switchback wagon road. The calcined ore is hauled to the railroad at Valley, 12 miles distant. The auto trucking is handled under contract and costs $4.50 to the ton.

Geology. The main quarry when visited during August, 1920 had a face 70 feet high and 60 feet wide, while the quarry bench was 70 feet deep. The magnesite being mined was of excellent grade and requires little sorting. The impurities are principally in the form of small stringers of calcite and quartz cutting the beds. The magnesite varies in color from bluish-gray to white and does not essentially differ in physical appearance from the material being mined in the Finch, Allen and Moss deposits. In point of actual production the Double Eagle is surpassed only by these three deposits.

The magnesite body occurs in a belt of dolomite which is 200 feet in average width, and which is involved in a local fold. The magnesite exposed in the quarry has a strike of N. 70° E. and pitches 45° toward the north. One hundred feet up the hillside from the quarry the dolomite belt gives way to a band of argillite 150 feet in width, which strikes S. 40° E. and pitches 65° N. E. Near the crest of the hill quartzite appears as a broad belt conformably overlaying the argillite. Above the quarry these bands of argillite and quartzite are twisted

into a sharp fold and at a point 200 feet east of the quarry the compression was relieved by a fault.

At a point 800 feet west of, and 300 lower in elevation than the main ore body there is a quarry which is said to have yielded a good tonnage of ore during the early history of the property. It was abandoned when the material began to show excessively high amounts of impurities. These workings are on the same dolomite-magnesite belt as the main quarry. The continuity of the beds between the two quarries is broken by several transverse faults. The Double Eagle deposit cannot be expected to develop a tonnage of magnesite comparable with the major ore bodies of the area.

The Double Eagle and adjacent Crosby deposits suggest the presence of two belts of dolomite-magnesite. However, when the complex structural problems are solved it may be found that both deposits belong to a single belt and that they have been duplicated by faulting.

U. S. MAGNESITE COMPANY

The most southerly exposure of magnesite is that on the property of the U. S. Magnesite Company, in sec. 10, T. 30 N., R. 38 E., 18 miles west of Springdale and six miles from the logging railroad of the Phoenix Lumber Company. Shipments made from the property during 1917 proved to carry excessive amounts of lime and silica. This caused the property to close down during August, 1917, and so far as the writer is aware no further work has been attempted.

The deposit occurs as a lens in the Stensgar dolomite; it is said to be 75 to 100 feet wide and uncovered for a length of 150 feet. Weaver[1] gives the following geologic section across the deposit: "Underlying the deposit is argillite; above this there is a narrow band of dolomitic

[1]Weaver, C. E., The Mineral Resources of Stevens County: Wash. Geological Survey, Bull. 20, p. 331, 1920.

limestone; this is followed by 36 feet of magnesite, six feet of dolomite, six feet of magnesite, nine feet of dolomite, 10 feet of magnesite, 24 feet concealed, 15 feet of dolomite and finally an argillite hanging-wall."

This section suggests that when the original shipments were mined the dolomite belt was blasted along with the magnesite, in which event it was hardly possible to sort the dolomite out completely. If such were the case, and the analyses show the 36-foot belt of magnesite to be of commercial grade, it could be won by changing the system of mining in order to break it separately from the dolomite. This, however, would entail heavier mining costs than for the other deposits.

CROSBY MAGNESITE COMPANY

CROSBY DEPOSIT

The Crosby magnesite deposit is one-quarter mile southwest of the Double Eagle. It was developed during 1917 and 1918 but failed to show a large tonnage of magnesite of a grade sufficient to meet commercial specifications and operations were suspended. The property is owned by Duluth, Minnesota, capital.

Most of the magnesite exposed has the reddish-pink color which characterizes the Red Marble deposit, a mile farther southward.

While the deposit has not proven of economic value it does however offer a possible aid towards the solution of the complex structural problems governing the magnesite deposits. The structural relations of the various belts exposed on the Crosby property are the reverse of those observed at the Finch, Allen, Double Eagle, and other properties visited. The broad belt of quartzite which overlays the magnesite at these deposits, is found beneath the magnesite at the Crosby.

A short east-to-west traverse was run in the vicinity of the Crosby quarry and the following relations were ob-

served: East of the quarry 1,000 feet a broad band of quartzite appears with a strike N. 40° E. and a dip of 40° N.W. This is conformably overlain by 600 feet of argillite oriented in the same general position. The argillite is in turn overlain by the dolomite-magnesite belt, which when measured at one point was 150 feet in width. Beyond this belt argillite again appears. The strike of the dolomite-magnesite belt is N. 25° E. and the dip 60° N.W. This same series was again observed at a point 1,000 feet south of the quarry where their trend had changed to an average of N. 10° E.

Since at the Crosby the quartzite underlays the dolomite-magnesite belt and at the other deposits the quartzite is above this belt, it follows that in one case or the other the positions of the belts have been reversed by an overthrust. On the basis of the number of occurrences it would be natural to assume that it was the belts in the immediate vicinity of the Crosby deposit that have been reversed. On the other hand there is field evidence which suggests that the quartzite is older than the dolomite-magnesite and that it is the belts in the vicinity of the major deposits that have suffered overthrust faulting. These problems will only be decisively solved after the most detailed geologic mapping of the involved area.

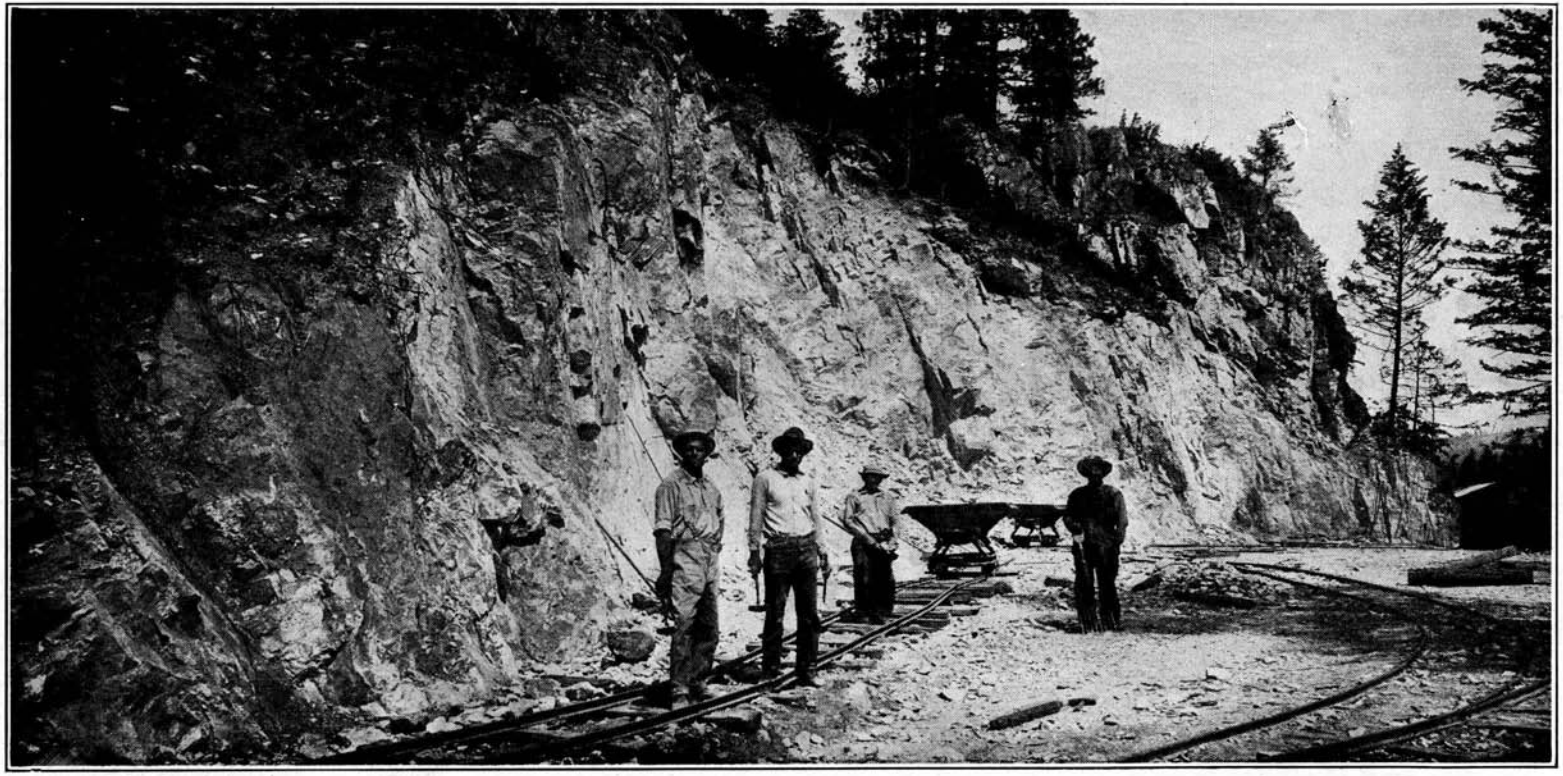
DOLOMITE

TULARE MINING COMPANY

The Tulare Mining Company, with head offices at San Francisco, started in 1917 to open a quarry of dolomite in sec. 18, T. 35 N., R. 40 E., about five miles east of Colville. The first shipment was made during October of that year and it has been producing regularly since that time. The average production is about 500 tons of calcined product per month. The material is hauled with auto trucks to Colville and shipped to the Crown Paper Company's plants at Camas, Washington, and Oregon City, Oregon, where it is used in making bisulphide acid for cooking the wood pulp in paper manufacture.

Geology. Dolomite is the double salt of calcium and magnesium carbonates. Its chemical formula is $Ca\ Mg(CO_3)_2$. According to the ideal calculated percentages, pure dolomite should contain 54.35 per cent calcium carbonate and 45.65 per cent magnesium carbonate. It is notably true that calcium and magnesium are capable of replacing one another in nearly all proportions to form magnesium limestones, and so the percentages of calcium or magnesium may vary through quite a wide range and for all practical purposes the rock yet be classed as dolomite. Ordinarily, magnesium limestone is a mixture of dolomite and calcite with other impurities of a minor nature.

The dolomite occurs in the Old Dominion limestone. It occupies a narrow east-west belt about one-quarter of a mile wide and likely about one-half mile long. West of the quarries the material is of uneven grade but east of the quarries surface sampling has defined an excellent grade of dolomite over a length of 2,200 feet. The thickness of the deposit has not been determined. The ridge made up of dolomite attains a height of 500 feet above



No. 2 dolomite quarry of Tulare Mining Co.

the road which intersects it and this entire depth is in dolomite of apparently an even grade. It can readily be appreciated, that if the dolomite continues to sustain its regular grade the available tonnage, at present demands, is practically unlimited.

The company desires that the finished product shall contain approximately 53 per cent calcium oxide and 47 per cent magnesium oxide. Since calcium and magnesium are capable of replacing one another in almost all proportions, the company feels fortunate in finding a deposit so closely approaching the ideal formula. Analyses of type samples from the quarries gave the following results:[1]

	Sample Number	
	1	2
Ignition loss	4.20	4.00
Insoluble	3.80	2.00
Iron and Aluminum oxides	1.35	1.40
CaO	50.50	51.50
MgO (By difference)	40.15	41.10

The dolomite opened by the Tulare quarries is of the dense crystalline variety and has been highly metamorphosed until the original bedding planes have been obliterated. It has a bluish-gray cast and contains frequent splotches of calcite.

The dolomite is associated with granite outcrops to the south and east and with quartzite on the north and west.

Methods of Mining. The hillside slope has been advantageously utilized in opening the quarries and designing the calcining plant, thus giving a gravity delivery from the time the rock is loaded into cars at the quarry face until the finished product is sacked in the warehouse at the roadside.

Two quarries have been opened in the hillside, the quarry floors being at about the same elevation as the

[1] Analyses furnished by the Tulare Mining Company.

head of the plant storage bins. Quarry No. 1 is about 250 feet south of the plant. The face of the quarry is 125 feet high, and 80 feet wide; the depth of the quarry bench is 60 feet. Ten to 15 foot holes are put down by double hand-hammer drilling and the face blasted down. The larger boulders are "bulldozed" by hand until the maximum lump of ore will not weigh over 35 pounds. The waste is sorted out and the dolomite loaded by hand into one-ton side dump cars and then trammed to the storage bins at the head of the plant. The waste will average between 15 and 20 per cent of the material mined.

Quarry No. 2 is to the west of the storage bin about 300 feet. The height of the quarry face is 140 feet, the width 200 feet and the depth of bench 85 feet. The same mining methods are practiced here as in Quarry No. 1. The bench of Quarry No. 2 has now gained sufficient depth to allow space for a "Coyote hole blast." This method will break several thousand tons of rock at one blast and at a substantial reduction in cost. It is surprising that in an operation of this size, air drills are not installed. They should prove decidedly more economical and efficient for drilling and bulldozing the rock.

About 1,000 tons of dolomite are mined each month. During calcining the loss of weight, due to driving off the carbon dioxide, is equal to nearly one-half of the crude dolomite. It is, therefore, necessary to mine about 1,000 tons of crude rock to meet the demands for 500 tons production.

Description of the Plant. The purpose of burning the crude dolomite is to drive off the carbon dioxide as a gas and to render the calcium and magnesium into the oxide state for the purpose of hydration. Magnesium oxide will not hydrate while calcium oxide will do so readily.

The dolomite is burned in two rectangular upright kilns. Each kiln is 12 feet wide, 24 feet long and 12 feet deep. They are constructed of granite blocks and lined with fire-brick. Each kiln has three fireboxes, wood being used as the fuel.

In preparing to charge a furnace 60 tons of coarsely broken dolomite are brought down and used in constructing arches in order to better facilitate the passage of heat and gases up through the charge. The gates to the storage bins are then opened and 200 additional tons of raw dolomite allowed to fill in the kiln. The finely broken material is scattered through the charge to prevent closure of the air spaces between the lumps. The fires are started and a heat of 1,000 to 1,200 degrees C. maintained. Usually five days are required to complete the burning.

After being allowed to cool the burned material is drawn out of the bottom of the kilns and sacked into 250 pound bags for shipment. Eight of the bags in groups are placed on a board platform and these platforms handled by a Cowan transveyor, an ingenious trucking device, which promotes quick, efficient handling of eight bags at once from the sacking machine to the warehouse or from the warehouse to auto trucks. By using the transveyor two men can load a four-ton truck in three or four minutes.

It requires 10 cords of wood per day for each kiln. The wood is secured locally and 3,000 cords are now stored in the yards as a reserve. The company has built an excellent camp and provided good accommodations for its employees. About 70 men are employed in the quarries and plant. Mr. W. P. Bartlett is General Superintendent of the company.

Possibilities of Developing Other Dolomite Deposits. There are several large belts of limestone making up the Paleozoic series of sediments in Stevens County. It

Plant of the Tulare Mining Company. No. 2 Quarry is visible in extreme left of picture.

is notably true that a considerable portion of this limestone is quite rich in magnesia and that it sometimes grades strongly into dolomite. Since calcium and magnesium are capable of replacing each other in practically all proportions to form calcium magnesium combinations, it should be possible to find almost any desired grade of magnesium limestones or true dolomite. The Stensgar dolomite belt along which are located the magnesite deposits, may yield some excellent grades of dolomite.

—3

WORLD PRODUCTION OF MAGNESITE

NORTH AMERICA

CALIFORNIA

The only known commercial deposits of magnesite in the United States are those of Washington and California. The latter are generally of the amorphous variety and occur as veins and lens-like masses in serpentine rock. The California magnesite, when comparatively pure, is ordinarily a beautiful white, fine-grained rock with a conchoidal fracture. These vein-like deposits are in some cases erratic in occurrence and are frequently interrupted by faults. Many of the veins, however, are quite continuous along the strike and it is fair to assume that the magnesite will normally extend to depths easily reached by circulating surface waters—under favorable conditions this may be several hundred feet. It is not reliable, therefor, to estimate available tonnages in advance of mining operations.

The California deposits are found along the Coast Range and on the western slopes of the Sierra Nevada Mountains. The workable deposits are scattered, occuring in 13 counties, ranging from Mendocino County, 70 miles north of San Francisco, southward to Riverside County, a distance of over 500 miles. Approximately two-thirds of California's magnesite comes from Fresno, Tulare and Kern Counties, where are located the holdings of the Porterville Magnesite Company and the Tulare Mining Company.

The magnesite market is east of the Mississippi River. The California deposits located on the western rim of the continent, were forced to pay a freight rate, which before the war averaged about $10.00 per ton and now averages $15.00 to the ton. Previous to the curtailment of the European magnesite industry the California deposits were totally unable to compete with the foreign

supply in the markets along the Atlantic seaboard. A few of the more favorable deposits were worked in a limited and sporadic way to supply the demands of the Pacific Coast industries, which totalled about three per cent of the national demand. When the foreign supply of magnesite was suddenly stopped the only available deposits were the scattered undeveloped properties of California and the semi-developed dolomitic-magnesite deposits of Quebec. The crisis confronting the users of magnesite was at that time a serious one. The remarkable growth of the industry in California can best be appreciated when we remember that during 1917 there were 65 magnesite mines operating in California, the total yearly production being 210,000 tons; in contrast are the 1914 figures, showing six mines operating and the total production but 11,000 tons.

The California magnesite is generally considered to be formed by the breaking down of minerals rich in magnesium, that is, from serpentine-making minerals such as olivine, enstatite, or serpentine itself. Van Hise[1] supposes that in the decay of olivine, a third of the magnesium may pass into magnesite, in which case he would write the reactions:

$$3Mg_3\ FeSi_2O_8 + 3Co_2 + 4H_20 + 0 = 2H_4Mg_3SiO_9 + Fe_3O_4 +$$

Olivine Carbon Dioxide Water 0 Serpentine Magnetite

$$3MgCO_3 + K$$

Magnesite Heat liberated.

Hess[2] suggests that to such an equation water might be added to hydrate the iron (hydrated oxides of iron are commonly associated with the California deposits). At the same time vastly more carbonated water is ordinarily present than demanded by the equation, so that it seems

[1] Van Hise, C. R., A Treatise on Metamorphism; Mon. U. S. Geol Sur., Vol. 47, p. 309, 1904.

[2] Hess, Frank L., The Magnesite Deposits of California, U. S. Geol. Sur. Bull. No. 355, p. 18, 1906.

possible under certain conditions, that with this excess of carbon dioxide at hand, the entire amount of magnesium contained in olivine carrying equal numbers of magnesium and iron atoms may pass into magnesite.

$$4Mg_2Fe_2Si_2O_8 + 6H_2O + 8CO_2 + 4O = 2(2Fe_2O_3\,3H_2O) +$$

Olivine Water Carbon Dioxide Oxygen Limonite

$$8MgCO_3 + 8SiO_2.$$

Magnesite Quartz

As the magnesium mineral decays the magnesia is dissolved by carbonated waters and precipitated in rock crevices as veins. As would naturally be expected these veins are usually of limited size and extent.

Near Bissell, California, are found deposits of magnesite which are considered to be the results of direct chemical precipitation. These deposits are regular in extent and their tonnages can be quite accurately estimated.

NEW MEXICO

Magnesite similar to the California deposits is reported to occur near Lordsburg, New Mexico. According to analysis[1] furnished the United States Geological Survey, the material is of excellent quality.

NEVADA

An extensive sedimentary bed of magnesite is known to occur in the valley of Muddy River, Clark County. The magnesite from this deposit carries more than 5 per cent lime and more than 11 per cent silica and it has therefor not been developed.

CANADA

Grenville District, Quebec

Canada. The most important deposits of magnesite in Canada are those of the Grenville District, Argenteuil

[1] Mineral Resources of the United States: U. S. Geol. Survey, Part II, p. 149, 1918.

County, Quebec. These deposits are of dolomitic magnesite, so-called because they contain seven per cent to twelve per cent lime. In spite of the high lime content this material played an important role in supplying the demands of the refractory trade of the United States and Canada. It was the Quebec and the California deposits which bore the brunt of heavy war demands until 1916 when the Stevens County deposits were discovered and rapidly put on a producing basis. The production of magnesite in Canada increased from 515 tons in 1913 valued at $3,335 to 55,413 tons having a value of $563,829 in 1916.

The Quebec magnesite is a glistening, cream-white to gray colored material, occurring in extensive serpentine.[1] Serpentine also occurs disseminated in the magnesite in places and the magnesite nearly everywhere contains more or less included dolomite. The most conspicuous structural feature of the magnesite deposits is their lenticular form. The deposits have been intensely faulted, crumpled, and otherwise deformed. Outcrops of the deposits are as much as 1,000 feet in length and 300 feet in width. They are considered to be the result of replacement of limestone by magnesia similar to the massive deposits of Austria-Hungary.

According to an estimate made late in 1917 by M. E. Wilson[2] the reserves total 686,900 tons of magnesite carrying less than 12 per cent lime, and 433,700 tons of dolomitic magnesite containing more than 12 per cent lime.

Atlin District, British Columbia

Near the town of Atlin, B. C., there exists rather extensive deposits of hydro-magnesite, so-called because the material carries approximately 18 per cent moisture. These deposits are superficial and are found in

[1] Wilson, M. E., Magnesite Deposits of Grenville District, Quebec; C. G. S., Memoir 98, 1917.

[2] Idem., p. 62.

beds of a fine, powdery-white hydro-magnesite; the beds vary in thickness from six to eight feet and cover an area up to 18 acres in extent. It is estimated that two groups of the deposits occurring in the outskirts of Atlin, contain approximately 180,000 tons of hydro-magnesite. Mr. Nichol Thompson,[1] who is interested in the Atlin deposits, states that the present reserves are considerably over 200,000 tons and that the moisture determinations of some of the material recently mined and shipped were lower than 10 per cent. During the war several large shipments of the Atlin magnesite were sent to England.

Magnesite is known to occur near the northwestern end of Liza Lake in the Bridge River District, Lillooet Mining Division, B. C.

MEXICO

Some excellent deposits of magnesite are known to occur on the Island of Santa Margarita in Magdalena Bay, off the coast of Lower California. These are similar in character to the California deposits and during 1918 some of the crude material was mined and shipped to California. The extent of these deposits is not definitely known at the present time, although it is reported that a considerable tonnage is available.

SOUTH AMERICA

VENEZUELA

Deposits of magnesite of the California type occur on Margarita Island off the coast of Venezuela. Most of them are in the northern part of the island. The supply is estimated at 3,200,000 tons in six groups of deposits. They are reported to have an excellent degree of purity. Certain of the deposits are now controlled by American capital and during the past few years a number of shipments have been made to the United States.

[1] Oral communication.

EUROPE

AUSTRIA-HUNGARY

The deposits of magnesite occurring in Austria-Hungary are among the largest known. Before the war they dominated the entire refractory market; approximately 95 per cent of all the magnesite used in the United States at that time came from these large quarries. They were described by Morganroth[1] and the following excerpt from that report made by W. C. Phalen of the U. S. Bureau of Mines, is recopied here.

THE MAGNESITE INDUSTRY IN AUSTRIA

Location. Though the term "magnesite" is generally applied to the iron-bearing carbonate of magnesium, such as is found in Austria and Hungary, by some Austrian magnesite is referred to as breunnerite The mineral breunnerite has become of commercial importance only in Austria. The important deposits are found in Styria, lower Austria and northern Hungary. It is of interest to know that the world's largest deposit of spathic iron ore, or iron carbonate ($FeCO_3$), occurs at Eisenerz, Styria, while the world's largest deposit of spathic breunnerite is found at Veitsch in the same province.

The Styrian and lower Austrian deposits are located much nearer the Adriatic sea than are the deposits of Northern Hungary; and it is from the former that most of the exported magnesite has come. They are located southwest of Vienna, and extend west from Semmering through the Murz Valley to Tyrol. The chief deposits reckoning from east to west are those of Semmering, Veitsch, Breitenau, Trieben, Radentheim, and Dienten.

The largest and most important deposit is that at Veitsch located near Mitterdorf, on the South Austrian

[1] Morganroth, L. C., The Occurrence, Preparation and Use of Magnesite; Bull. Am. Inst. Min. Engineers, No. 50, pp. 890-896, 1914.

Railroad in the Murz Valley, Styria. Here the magnesite, which occurs in the form of a lens is quarried on the slope of a hill in a series of terraces about 50 feet apart. The entire work extends through a vertical distance of 500 feet. The huge magnesite lens is nearly three-fourths of a mile long and over 1,000 feet in width, and probably extends to a considerable depth.

The formation containing the magnesite extends eastward beyond Vienna into Northern Hungary where magnesite is quarried beyond Jolsva and Nyustya in the Gomor district. In spite of the remote location of these deposits as compared with those in Styria, magnesite was shipped from them before the war a distance of 360 miles to the port of Fiume for overseas shipments to other parts of Europe and to America.

Composition. The average analysis showing the composition of the Austria-Hungary mineral is as follows:

Magnesia	38 to 44%
Lime	1 to 3%
Ferrous oxide and alumina	2 to 7%
Silica	1 to 5%
Carbon Dioxide	50%
Water	....

Character of the Sintered Product. The magnesite occurs as lenticular masses in a belt of Carboniferous rocks consisting mainly of metamorphosed shales, sandstones, conglomerates, and limestone. It is grayish in color when fresh, and contains sufficient ferrous carbonate to blacken it when calcined. It turns brown owing to the oxidation of the ferrous carbonate when exposed to the air. The quantity of carbonate of iron is variable and different analyses show that it ranges up to 13 or 14%.

For the most part, only the sintered article has been imported into the United States. This material has achieved an enviable reputation for its uniformity both

as to chemical and physical characteristics. The homogeneity of the sintered Austrian magnesite is doubtless due in part to the averaging effect of the different operations, such as crushing, dressing, sintering, and mixing, an effect which is not obtainable in mere hand samples.

There is comparatively little variability in the sintered magnesite as marketed, and five analyses of this sintered magnesite as quoted by Cornu* are as follows:

Magnesia (MgO)	85.53 to 90.07
Lime (CaO)	0.96 to 3.52
Ferrous Oxide (Fe_2O_3)	7.43 to 9.96
Alumina (Al_2O_3)	0 to 2.22
Manganese Oxide (Mn_3O_4)	0.15 to 0.76
Silica (SiO_2)	0.26 to 1.34

Mining and Preparation. The methods of mining and preparing magnesite in Austria and Hungary are similar at most of the different plants. On the outskirts of the village of Veitsch, about 56 miles southwest of Vienna, is found one of the largest deposits, and one which has been worked the longest. Since the methods of mining and preparation here are fairly typical, they will be outlined.

As stated above, the magnesite quarry at Veitsch is worked in a series of steps or levels about 50 feet apart vertically. The material is blasted out of the solid by the ordinary methods of rock quarrying. It is next broken in pieces which can be handled readily by one man, and the dolomite and quartz are carefully picked out. Even in the best of the deposit, there is a large quantity of this gangue material and estimates of the waste rock vary from 50% to 66 2/3% of all the material quarried. Terrace quarrying and working conditions in general like these at Veitsch are practised at Breitenau and at Eichberg.

The coarse quarried material is cobbed to free it as far as possible from impurities like schist, dolomite, and

*F. Cornu: Zeit, f. Prakt. Geol. 1908.

quartz, and the lumps are sorted. The cleaner portions of the magnesite are reduced to pieces about the size of a man's head. Less pure portions have to be broken into pieces about the size of a man's fist. These dressing operations involve a considerable loss of magnesite in the form of small fragments—too small to be burned in shaft kilns. The raw material thus obtained in the quarries at Veitsch is transported by gravity planes to the sintering kilns at the foot of the hill.

Other Commercial Conditions. At Veitsch, the marketable sinter is trammed on an aerial tramway about 4 miles long to Wartberg Station. The works at Treiben are near the station which is located about three miles from the deposit at Sunk where the material is quarried. At Radentheim, work was begun by American capital in 1908, and from that time till the war cut off the supply a great deal was shipped to Philadelphia, New Orleans, and New York. The shipments from Europe were usually made through the port of Trieste and before the war, ocean freight per ton was $2.50.

The facts that the Austrian deposits are large and are easily quarried; that they are within easy reach of transportation facilities, and the additional fact that labor, at least before the war, was cheap have all tended to give Austrian magnesite commercial supremacy in the world's markets. These conditions, moreover, held to explain the success which Austrian magnesite has achieved in the past and indicate the possibility of the competition which it may be able to exert in the future. Only the massive deposits of the Veitsch type can be quarried and worked at a profit, however, and some of the larger deposits, not well located, have been unable to compete in the past.

RUSSIA

Magnesite has been mined in the Orenburg Government east of Ufa; also in the Kuban District on the north

slope of the Caucasus, but no information is available on the deposits.

NORWAY

Magnesite is mined from deposits in Norway at Snarum[1] in the Modums division of Buskerud bailiwick, on the Kroder line, a spur of the Dammen Randsfjord line, 35 miles from Dammen, the nearest port. The magnesite is found in serpentinized olivine rocks which occur with quartzites and schists.

There are two principal fields—the Dybingdals, three miles north of Snarum station and the Langerud field, one and one-third miles west of Snarum station. In the former the magnesite area covers about 1,200 square meters. The veins average about 13 feet in width and are worked by underhand stoping. In the Langerud field magnesite is exposed for 135 feet along Snarum or Halling River, and also 100 yards farther southwest. There are also smaller deposits in the neighborhood of these fields. A factory which has a capacity of about 2500 tons of brick per year is operated near Snarum. Analyses quoted show the material to be remarkably free from lime but high in silica.

ITALY

Magnesite veins of workable thickness occur at Castiglioncello and at Monternfoli, near the seaport Livorno, and have been worked in recent years. There are veins up to 10 inches thick in the Turin district, and on the island of Elba there is a stockwork of small veins in serpentine which have been worked in a limited manner.

MACEDONIA

Magnesite is found in large quantities in Macedonia near the coast not far from the Greek border. It is of the

[1]Daumann, E., Magnesite fran Snarum: Bihangtill Jern-Kontorels Annaler for 1905, Stockholm, 1905, pp. 222-235.

compact type and occurs as veins in serpentine. The principal field covering several square miles lies five to ten miles south of Salonika.

GREECE

The Grecian deposits supplied a large portion of the magnesite to England and France during the war period. The most important deposits are on the west side of the Island of Euboea. The ore occurs in veins and lenses in serpentine. Some of the veins are of great size, one 50 feet wide, 75 to 100 feet high and fully 200 feet long. The material is pure white and of very good grade. During normal times it is used mostly for the manufacture of caustic-calcined magnesite.

AFRICA

TRANSVAAL

Extensive deposits of magnesite occur in the Kaapmuiden and Malelane (Barberton District) two miles south of the Pretoria-Delagoa Bay Railway. The deposits occur as veins in serpentine. The veins range up to four feet in thickness.

Great deposits of magnesite are reported in Portuguese West Africa. The deposits are near, or associated with, boiling springs.

ASIA

INDIA

The chief deposits are in the Chalk Hills, near Salem, Madras Presidency. The magnesite occurs as veins in serpentine. The main deposits occur over an area of 10 square miles and they have yielded more than 2,000 tons in a single year. Magnesite also occurs near Kadakola in Mysore in the south-central part of the India Peninsula, also at Yelwai, but apparently the deposits are of unknown extent.

AUSTRALIA

NEW SOUTH WALES

It is reported that large tonnages of magnesite are available northwest of Fifield. Several thousand tons of the ore have been marketed.

SOUTH AUSTRALIA

Large deposits of magnesite are reported to occur east of Port Pirie in Flinders Range; other deposits are reported near Tumby Bay and Robertstown.

WESTERN AUSTRALIA

Short irregular veins two feet thick occur at Bulong, northeast Coolgardie; and in Victoria. Veins one to six feet thick are known at Heathcote and a vein two to four feet thick occurs near Redesdale.[1]

MISCELLANEOUS FOREIGN OCCURRENCES

Magnesite deposits are known to occur in the province of Santander in northern Spain; in Macedonia not far from the Greek border; in Manchuria magnesite is mined in the Manchurian Mountains near Darien. In Asia Minor it is reported to occur in beds three to 15 feet thick near Eskechehio station Saruchan Province about 75 kilometers from Smyrna.[2]

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[1] U. S. Geological Survey, Mineral Res. of the U. S., 1918, Part 2, p. 157.

[2] Idem., pp. 153-157.

THE REDUCTION OF MAGNESITE FOR REFRACTORY USES

INTRODUCTION

Magnesite loses about half its weight when heated to 800-900°C. (1472-1652°F.), evolving all but approximately 7 per cent of its carbon dioxide and forming caustic calcined magnesite or, more loosely, caustic magnesia.[1] In this condition, it finds use in various cements but is in no way suitable for refractory purposes. If, however, this caustic magnesia is heated still more strongly, it becomes dense and gradually vitrifies or sinters and forms a very hard igneous material known, in this country, as dead-burned magnesite and, in European countries, as dead-burned magnesia. In this form

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[1] Because of the somewhat confusing interchangeable use of the terms designating magnesite products dissimilar in character the authors are reproducing herewith the nomenclature published by McDowell & Howe, Magnesite Refractories, Journ. Am. Ceram. Soc., Vol. 3, p. 201, 1920.

Magnesite: (1) The mineral $MgCO_3$, the crude material of the industry; (2) a term applied to various products manufactured from the mineral $MgCO_3$, such as "dead-burned" and "plastic" magnesite, magnesite brick and so forth.

Plastic Magnesite or Caustic Burned Magnesia: The product which results from calcining crude magnesite at a comparatively low temperature, and which contains about 2 per cent to 5 per cent CO_2; called also calcined magnesite.

Calcined Magnesite: (1) Magnesite which has been calcined at any temperature, including both caustic and dead-burned; (2) an intermediate product between caustic and dead-burned magnesite, *i. e.*, magnesite which has been calcined but not sintered, and in which the CO_2 content is below 2 per cent, usually about 1 per cent.

Dead Burned Magnesite or Dead Burned Magnesia: A sintered product obtained by calcining magnesite at a high temperature; it usually contains less than 0.5 per cent CO_2 and almost invariably contains 4.5 to 8 per cent Fe_2O_3, either naturally or by additions of iron ore during treatment.

Electrically Shrunk Magnesia: Magnesite calcined in the electric furnace to effect complete shrinkage; usually of a high degree of purity.

Magnesia or Magnesite Brick: Brick consisting essentially of MgO, generally containing from 4.5 to 8 per cent Fe_2O_3. It has been suggested that brick with this amount of iron be called "magnesite brick," and those nearly free from iron "magnesia brick," but the latter term is more frequently applied to both.

Magnesia: (1) The pure oxide of magnesium; (2) a term applied synonymously with "magnesite" to brick, dead-burned material, and so forth; (3) to certain magnesite products low in impurities and high in MgO, as magnesia crucibles, electrically shrunk or fused magnesia, and so forth, and (4) also applied to precipitated or basic carbonate of magnesia.

Basic Carbonate of Magnesia: A light powdery material prepared either by boiling a solution of acid magnesium carbonate, or by double decomposition of a soluble magnesium salt and a soluble carbonate. The composition of the commercial product varies somewhat but is generally given as $3MgCo_3.Mg(OH)_2+3H_2O$, the same as that of hydromagnesite.

the product contains, on an average, in the neighborhood of 0.25 per cent carbon dioxide. It is this material that possesses the desired refractory properties.

The temperature required to produce dead-burned magnesite depends upon the impurities present;[1] usually it is above 1530°C. (2786°F.) and may reach 1790°C. (3254°F.). Some of the less scrupulous firms sell as dead-burned magnesite a product which has not been heated above 1480°C. (2696°F.). This product, however, may be recognized by its low specific gravity (below 3.0) and by its shrinkage on re-heating to 1580°C. (2876°F.).

EFFECT OF KILN HEATING

It may be well to insert at this time some discussion of the physical and chemical changes occurring in magnesite as it is kiln heated. Although these changes still offer a wide field for fruitful research, it will be possible to give some information here as the result of the work of the Northwest Magnesite Co.[2] and others who have studied the systems involving silica, lime, magnesia and iron oxide.

"Although[2] the ore may be either crystalline or amorphous as it occurs in nature with a specific gravity of 2.63 to 3.1, the crystalline ore, when subjected to heat of 800-900°C. (1472-1652°F.) so that caustic calcination occurs, becomes amorphous. The distinction between crystalline and amorphous magnesite therefore ends at at this point, the product being composed of oxide of magnesium in the amorphous or alpha form and of other oxides occurring as such or derived from carbonates in the original ore. Its specific gravity is about 3.01.

"If the calcination be continued long enough and at a high enough temperature, all of the oxide of magnesium

[1] McDowell & Howe, Magnesite Refractories, Journ. Am. Ceram., Soc., Vol. 3, p. 185, 1920. Searles, Refractory Materials, their Manufacture and Uses, Chas. Griffin & Co., p. 119, 1917.

[2] Advertising booklet of the Northwest Magnesite Co., 1919.

present will be converted from the alpha form to the beta form, the latter being the mineral periclase, which is the stable or unchanging form of crystalline magnesia. The specific gravity of periclase is 3.67, which gives a measure of the shrinkage in passing from the amorphous or alpha form to the beta or crystalline form. If the magnesia has practically no other oxides associated with it, the heat of the electric furnace (above 1600°C.) is necessary to accomplish the transformation to periclase. If the other oxides associated with the oxide of magnesium are those which occur in magnesite refractory materials, the transformation takes place at temperatures which are practical in brick kilns, rotary kilns, and shaft furnaces (about 1450° to 1500°C.).

"The resulting material is known as dead-burned magnesite, as sintered magnesite or as ferromagnesite, all of these terms being interchangeable, and all being equivalent to the term refractory magnesite. It is largely composed of polygonal crystals of the mineral periclase showing a mosaic structure. The periclase crystals have inclusions of small skeleton crystals or tiny particles which are the mineral magnesio-ferrite ($MgO.Fe_2O_3$),[1] and their borders are fringed with silicate materials, including the mineral forsterite ($2MgO.SiO_2$), which fill the ground mass and aid as a binder for the periclase crystals. The final result is the same whether the other oxides occur naturally with the magnesite ore or whether they are intimately mixed with it before calcination. The same definite transformation from one mineral form through the amorphous stage to another mineral form takes place in either case.

[1] F. Cornu, on the Composition of Magnesia Brick, Especially their Content of Periclase, Z. prakt. Geol., Vol. 16, p. 449, 1908; F. Redlich, Doelters Handbuch der Mineral Chemie, Vol. 1, p. 253, 1912; McDowell & Howe, Magnesite Refractories, Journ. Amer. Ceram. Soc., Vol. 3, pp. 229-237, 1920; H. B. Cronshaw, A Curious Mineral Occurring in a Magnesia Brick, Trans. Ceram. Soc. (Eng.), Vol. 16, part 1, p. 101, 1916-17.

"Another definition of refractory magnesite may then be that it is the mineral periclase with which are included sufficient other oxides to have effected the transformation from the amorphous form of magnesia at practical furnace temperatures and to have cemented the periclase crystals together in a dense, strong mass.

"It is therefore seen that certain other oxides have a useful function in refractory magnesite,[1] for without them the temperatures required to produce a satisfactory refractory would be beyond the range attainable in ordinary commercial practice. The principal oxides occurring in refractory magnesites, other than the oxide of magnesium, are ferric oxide, silica, and lime. All of these oxides function differently. The present state of our knowledge of their action is not complete, but microscopic investigations have thus far shown that ferric oxide is principally responsible for the conversion of amorphous magnesite to the crystalline periclase at practical furnace temperatures, and that a marked advantage is therefore derived from its presence in moderate amount.

"It has also been found that a moderate amount of silica forms the magnesium silicate mineral, forsterite, which coats the periclase crystals, thus helping to cement them together and proving of benefit by adding to the compressive strength of the refractory at high temperatures. Kowalke and Hougen[2] experimented with mixtures of pure magnesia and silica and found that a mixture containing 7.5 per cent of silica gave maximum compressive strength at high temperatures.

"The action of lime is not yet clearly understood, but in small amounts it does not appear to be detri-

[1] A. Scott, Note on the Microstructure of Magnesite Bricks, Ibid., Vol. 17, part 2, p. 475, 1917-18; W. Donald, Magnesite and Magnesite Bricks, Ibid., Vol. 17, part 2, pp. 494, 521, 1917-18.

[2] Kowalke & Hougen, Crushing Strength of Magnesia-Silica Mixtures at High Temperatures, Trans. Am. Electro-Chem. Soc., Vol. 33, p. 215, 1918.

mental.[1] It cannot be said, however, that lime has any beneficial effect so that its amount should be kept as small as possible. All of these other oxides reduce refractoriness or heat resistance, but practical experience has shown that if their total does not exceed 18 per cent, the magnesia will be refractory enough for all ordinary purposes."

DISSOCIATION OF MINERAL CARBONATES

Much work has been done on the decomposition of the mineral carbonates when they are heated. Inasmuch as this work has pointed the way toward the greatly improved understanding of the heat treatment of carbonates, it is necessary to insert here a brief resume of the literature on the subject.

In regard to calcium carbonate, Montgomery and Groves[2] found that in heating pure precipitated $CaCO_3$, a loss in weight of 2.35 per cent per hour occurred at 620-627°C. (1148-1160°F.), of 4 per cent per hour at 647°C. (1200°F.) and that after 15 hours at 647°C. (1200°F.) the CO_2 was completely driven off. Different observers give the dissociation point of calcium carbonate[3] as 880°C. (1616°F.) (limestone)[4], 886°C. (1626°F.)[5], 898°C. (1650°F.)[6], 910°C. (1670°F.)[7] and 913-923°C.

[1] Ferguson & Merwin, The Ternary System CaO-MgO-SiO_2, Am. J. Sci., Vol. 48, p. 81, 1919.

[2] Montgomery & Groves, Note on Determination of Several Dissociation Points, Trans. Am. Ceram. Soc., Vol. 18, p. 214, 1916.

[3] E. H. Riesenfeld, The Decomposition of the Carbonate of Lime, J. Chem. Phys., Vol. 7, p. 561, 1908; Chem. Abstracts, Vol. 4, p. 982, 1910.

[4] Bleininger & Emley, The Burning Temperature of Limestones, Trans. Am. Ceram. Soc., Vol. 13, p. 618, 1911.

[5] DeForcrand, Carbonates of the Alkalis and Alkali-Earths, Compt. Rend., Vol. 146, p. 511, 1908.

[6] John Johnston, The Thermal Dissociation of Calcium Carbonate, J. Am. Chem. Soc., Vol. 32, p. 938, 1910.

[7] D. Zavreiff, The Dissociation of Calcium Carbonate, Compt. Rend, Vol. 145, p. 428, 1907; J. Chem. Phys., Vol. 7, p. 31, 1908; Chem. Abstracts, Vol. 3, p. 1112, 1909

(1676-1694°F.)[1]. In the opinion of McDowell and Howe[2] Johnston's determination of 898°C. (1650°F.) is probably most accurate. He gives the dissociation pressures of $CaCO_3$ in millimeters of mercury as

DISSOCIATION PRESSURES OF $CaCO_3$

°C	°F	Pressure	°C	°F	Pressure
500	932	0.11	850	1562	373.0
600	1112	2.35	898	1649	760.0
700	1292	25.3	900	1652	773.0
750	1382	68.0	950	1742	1490.0
800	1472	168.0	1000	1832	2710.0

Concerning magnesite, data are available on both the natural mineral and carefully prepared and purified magnesium carbonate, although the results of the two are not comparable one with the other. Hedvall[3] reports that with the former the dissociation pressure reaches one atmosphere at 531-570°C. (988-1058°F.). Wülfing[4] found that in a furnace kept at a constant temperature of 500°C. (932°F.) magnesite lost less than half its CO_2 in two hours, and that not all the CO_2 had been driven off in 12 hours. Kallauner[5], as reported by McDowell and Howe[6], found that amorphous magnesite begins to dissociate at about 500°C. (932°F.) and that CO_2 is evolved very rapidly at 620-625°C. (1148-1157°F.). He finds also that the dissociation of normal dolomite begins at 500°C. (932°F.), increases rapidly with rising temperature and reaches a maximum between 710 and 730°C.

[1] J. A. Hedvall, Formation and Decomposition Temperatures of the Carbonates of Strontium, Barium, Calcium and Magnesium, Z. Anorg. Allgem. Chem., Vol. 98, p. 147, 1916.

[2] McDowell and Howe, Magnesite Refractories, Trans. Am. Ceram. Soc., Vol. 3, p. 193, 1920.

[3] Op. Cit.

[4] E. Wülfing, 1900, as quoted in Doelters Handbuch der Mineral Chemie, Vol. 1, p. 231.

[5] O. Kallauner, Thermal Dissociation of Amorphous Magnesite, Chem. Ztg., Vol. 37, p. 182, 1913; Thermal Dissociation of Normal Dolomite, Chem. Ztg., Vol 37, p. 1317, 1913.

[6] Op. Cit.

(1310 and 1346°F.); from 730-870°C. (1346-1598°F.) dissociation is slow, but it increases above 870°C. (1598°F.) and reaches another maximum at 900-915°C. (1652-1680°F.). Calcium oxide did not appear in the heated material below 875°C. (1607°F.). It was believed that the dolomite, $MgCO_3$. $CaCO_3$, began to separate into its components $MgCO_3$ and $CaCO_3$ at about 500°C. (932°F.), that the $MgCO_3$ formed dissociated rapidly at 710-730°C. (1310-1346°F.), and that dissociation of the $CaCO_3$ began at 870°C. (1598°F.).

Working with the prepared and purified materials, O. Brill[1] found that magnesium carbonate begins to dissociate at 237°C. (459°F.) under a pressure of one atmosphere of CO_2; evolution of CO_2 takes place in steps forming a series of basic carbonates with different dissociation temperatures. The final member of this series ($7MgO—CO_3$) dissociates completely at 510°C. (950°F.).

USE OF MAGNESITE IN METALLURGICAL FURNACES

Magnesite is used in metallurgical furnaces in two ways, first, dead-burned as grain in lining bottoms and second, dead-burned as brick in lining walls. In the former case the source of the material may be either deposits of amorphous magnesite as found in Greece and California or crystalline as found in Austria and Washington. It is even claimed that the dolomitic or high lime content product of Canada will serve for this purpose, but this question is open to argument, is one on which the Mines Experiment Station at Columbus is now conducting a research, and at best is only the use of a substitute for true magnesite. In the latter case where bricks are to be made it is apparently necessary to use for the raw material the crystalline ore of Austria and

[1] O. Brill, The Dissociation of the Carbonates of the Alkaline Earths and Magnesium, Z. Anorg. Chem. Vol. 45, p. 275, 1905.

Washington.[1] In any event the magnesite must be subjected to the dead-burning operation. When satisfactorily dead-burned, magnesite will withstand the destructive action of high temperatures, hot gases, fluxes and corroding influences better than any other refractory on the market.

Much controversy has arisen since the entry of American magnesite into the field as to the exact effect of and necessity for the presence of the oxide of iron in manufacturing a suitable refractory. One explanation of this factor has already been given. The discussion was induced because in the content of oxide of iron lies the great fundamental difference between imported and domestic magnesite, and although the question of the necessity for such iron content has not been settled, the matter of its deficiency in the domestic product has been remedied artificially by the actual addition of iron ore before introducing the material into the kilns. The tables on page 15, giving analyses of magnesite from various sources, will serve to show wherein other deposits differ from the Austrian which may be accepted as the standard source for refractories inasmuch as it is used without modification other than that obtained by hand-picking at the quarries. A further comparison of these tables with those on page 101 wherein appear analyses of dead-burned material from Austria and Washington will serve to show to what extent the reduction process obtains uniformity

[1]On this point McDowell and Howe[2] write, "The fact that amorphous magnesite is preferred for the production of caustic magnesia, and the crystalline variety for that of dead-burned magnesite, has often led to the conclusion that amorphous magnesite only can be used in the manufacture of caustic burned magnesia and the crystalline magnesite only in the preparation of dead-burned magnesite. As a matter of fact, caustic burned magnesia of excellent grade (color excepted) has been produced from crystalline magnesite[3]; and dead-burned magnesite of high quality has been produced in this country since 1914 from magnesite of the amorphous type."

[2] Op. Cit.

[3] R. D. Pike, Northwest Magnesite Company, private communication to McDowell and Howe.

of chemical composition among foreign and domestic magnesite refractories.

It can be seen that insofar as magnesia content is concerned, the domestic product has an advantage in purity which has been used against it in its fight for preference in the refractory field. In regard to the silica and lime impurities, it may be said that a limit is set upon their content in the finished product so that all producers by judicious mixing of the raw material are able to come within this limit and, at the same time, utilize much of their deposits that, worked alone, would be rejected. The content of iron and alumina, reported together as combined oxides, is in favor of the Austrian material in light of the fact that about five per cent of these constituents is deemed necessary for the best dead-burned product. An exception to this statement is found in certain limited California deposits which contain naturally sufficient iron and alumina.

Inasmuch as it has always been believed that the higher iron content was essential to good refractory properties, and such belief has not yet been successfully refuted, the preparation of the Austrian dead-burned product from the raw material has been a comparatively simple matter, it having been unnecessary to artificially raise the percentage of iron.

REFRACTORY REDUCTION METHODS[1]

AUSTRIA

As an example of the methods of reduction in use in Austria, consideration may well be taken of the methods employed in the vicinity of Veitsch.

According to Morganroth, continuous kilns of the bottle variety are used and producer gas is employed as

[1] L. C. Morganroth, Occurrence, Preparation and Use of Magnesite, Trans. Am. Inst. Mining Eng., Vol. 50, p. 890, 1914; Anonymous, Works of the Austro-American Magnesite Co., Iron Trade Review, Vol. 48, p. 111, 1911; Anonymous, An Austrian Magnesite Property Developed by American Capital, Ibid., Vol. 55, p. 772, 1914.

fuel. These kilns burn on an average of 15 to 24 tons of calcines per 24-hour day. Recently a few plants have installed rotary kilns of the cement type to burn the magnesite, powdered coal being used as fuel. Such a kiln has a capacity of 50 to 60 tons per 24 hours. The magnesite can be burned as thoroughly in these kilns as in the bottle kilns, but they have one disadvantage in that a larger per cent of fines is produced. The magnesite as burned in the bottle kilns is drawn every 6 hours.

The sintering temperature varies from 2700°F. (1483°C.) for material containing considerable iron oxide, to 3100°F. (1704°C.) for material poor in iron oxide. It is generally considered advisable to carry the sintering temperature to at least 2700°F. (1483°C.) for best results in dead-burned product. In regard to the amount of coal required to sinter Austrian magnesite, two figures are available, first, of coal which gives 10,800 B.T. U. per pound, 600 to 800 pounds are required per ton of dead-burned magnesite, and second of coal which gives 7200 B. T. U. per pound, 1,000 pounds are required per ton of dead-burned magnesite. In general, it is considered good practice in Austria if one ton of dead-burned magnesite is obtained from each two and one-half tons of raw material into the kilns.

The material from the kilns is quenched, sized and hand-picked for dolomite, quartz and under-burned material. The larger lumps are crushed until the whole is in pieces the size of kernels of corn when it is again hand-picked, and is ready to be used directly for grain furnace linings or made up into magnesite brick for wall lining.

GREECE

Large bottle-shaped kilns are used on the Island of Euboea[1]. Producer gas is the fuel employed. The Gre-

[1] W. C. Phalen, The Present Situation in the Magnesite Industry, Bureau of Mines Separate, July, 1919.

cian magnesite, however, is largely only caustic calcined and before the war was shipped as such to Germany for use in building operations.

CANADA

SCOTTISH CANADIAN MAGNESITE COMPANY, LTD.

The material is hauled out on a narrow gauge railroad and was formerly shipped to the plant of the Canadian Cement Company at Hull, Quebec. Beginning in October, 1917, one rotary kiln was used with an initial production of 35 tons of grain magnesite per day, but the exigencies of the war necessitated further production until by May, 1918, three kilns were in operation with an output of 100 tons per day. Such conditions warranted the installation by the company of a new plant near the Grenville quarry.

In this new plant the selected magnesite is passed through a jaw crusher and ball mill until it passes a 100 mesh screen, when it is mixed with 6% of iron ore and fed into three 60 foot cement kilns and subjected during the hour required for its passage through the kiln to a temperature of 2800°F. (1538°C.). The kilns are fired with powdered coal blown in under pressure. The resulting dead-burned product is sized and can be used for brick or grain lining.

INTERNATIONAL MAGNESITE COMPANY

Reduction here is effected in a vertical kiln about 50 feet high and 10 feet in diameter. Wood is the fuel used. The resulting product, however, is not dead-burned but caustic calcined so is not suitable for refractory use.

NORTH AMERICAN MAGNESITE COMPANY

Like the International Company, the calcining has formerly been carried on in wood-fired vertical kilns. However, a new calcining plant with rotary kiln is being

installed at Calumet and it will then be possible to produce about 70 tons of dead-burned material daily.

CALIFORNIA[1]

Of the operators in California the principal ones that have produced dead-burned product are the White Rock mine, Sonoma Magnesite Co., the Refractory Magnesite Co. and the Porterville Magnesite Co. and of these, the first three are not now operating and the fourth is calcining only intermittently.

THE WHITE ROCK MINE

Like the Austrian deposits, this magnesite is a natural ferro-magnesite and was dead-burned in coke fired vertical kilns to a product carrying as high as 5 per cent iron oxide.

REFRACTORY MAGNESITE COMPANY

This magnesite likewise is naturally sufficiently high in iron to be directly converted into dead-burned grain. Here, too, a vertical, cylindrical kiln, 40 feet high, 4 feet 6 inches in diameter at the top but 5 feet 6 inches at and below the flame, is employed. Oil fired, the ore is fed into the top which is wide open to the air, passes through the main calcining zone (26 feet in length) where the maximum temperature is 2200°F. (1204°C.), into a cooling zone 14 feet below the flame and is delivered as pea size and practically cool from the base of the kiln. Reduced to smaller size by rolls, it is powdered in a mill and is shipped to be manufactured into brick.

THE PORTERVILLE MAGNESITE COMPANY

This company produces both dead-burned and caustic calcined magnesite. Operating on the principle that long exposure to high temperature with comparatively slow removal of carbon dioxide produces a more satisfactory

[1] W. C. Phalen, Op. Cit.; W. C. Phalen, The Magnesite Industry in the United States, Mining Sci. Press, Vol. 119, p. 295, 1919.

dead-burned product than exposure to excessive heat for a short time, calcination is here accomplished in a 125 foot rotary kiln fired with crude oil.

WASHINGTON REFRACTORY REDUCTION METHODS[1]

The principal producers in the Washington field have been the Valley Magnesite Co., the American Refractories Company, the American Mineral Production Company and the Northwest Magnesite Co. Inasmuch as the first two concerns are but very small producers, the Valley Co. having operated sporadically and the American Refractories Company[2] having entered the field so recently that but little is known of its intentions, the methods of the last two companies only will be given detailed description.

AMERICAN MINERAL PRODUCTION COMPANY

The practice here was to subject the magnesite, ground through 200 mesh and mixed with iron ore, to a temperature of 2900°F. (1593°C.) in a 165 foot rotary kiln at the plant of the International Portland Cement Co. near Spokane. Since the early part of 1919, this company has operated but intermittently, during part of this time, shipping its product to the plant of the Northwest Magnesite Company for reduction. Vertical kilns erected at the quarries have been used to some extent but were not satisfactory for complete dead-burning so that, although it was quite common practice to subject the magnesite to preliminary calcination in these kilns in

[1] On January 1, 1921, none of the properties in the state of Washington were operating. R. W. Stone, writing in the Engineering and Mining Journal, Vol. III, p. 464, 1921, ascribes this fact not so much to Austrian competition, since little or none of this product has entered the United States since the war, but rather to the lack of demand on the part of the steel industry.

[2] During the entire year, 1920, the Double Eagle deposit was operated by the American Refractories Company. Burning in three upright kilns, the calcine was shipped to the manufacturer of refractories although it contained 1.5 per cent to 2.0 per cent carbon dioxide after calcination.

order to reduce shipping weight, it was not possible to produce a high grade final dead-burned product without final calcination in the rotary kilns.

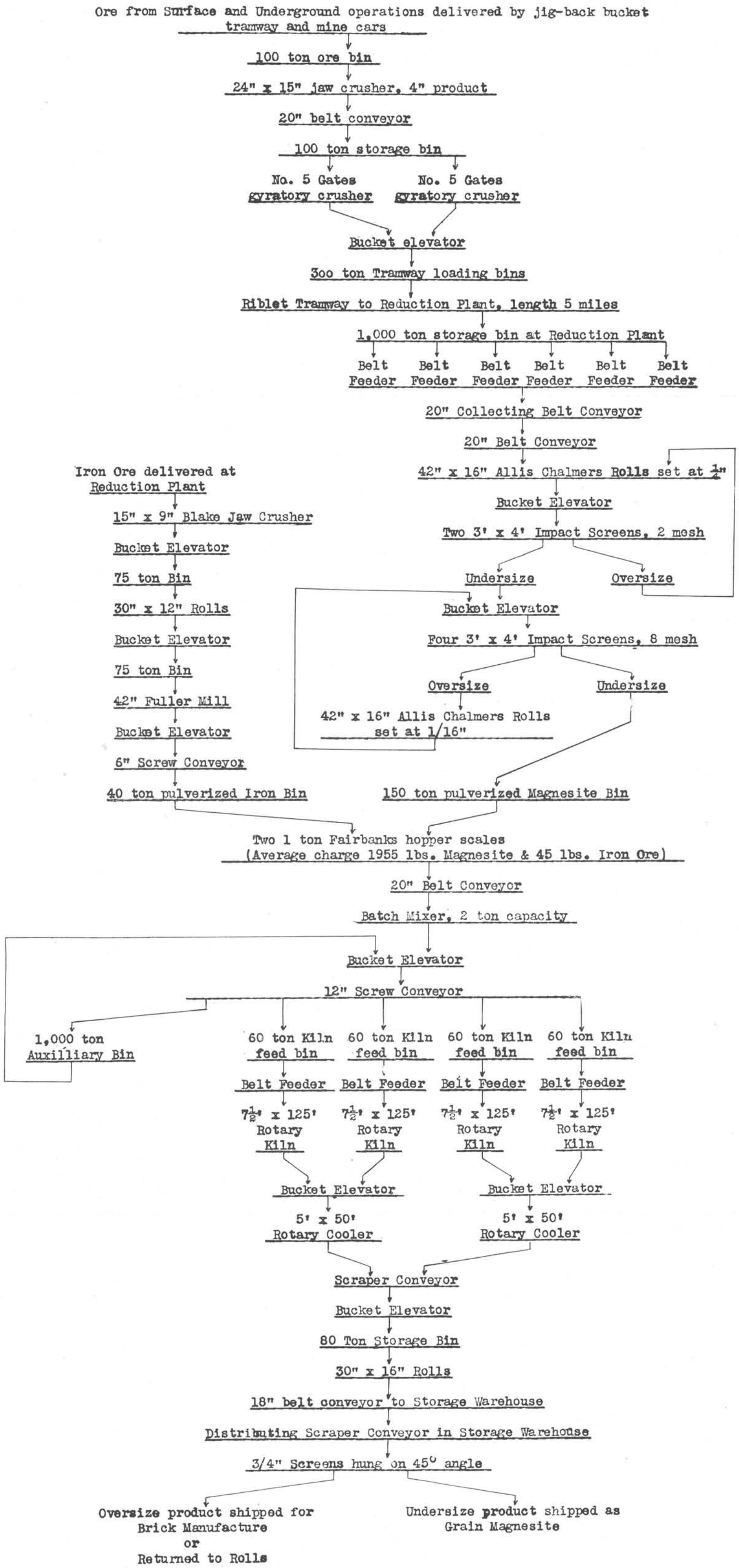
THE NORTHWEST MAGNESITE COMPANY

Inasmuch as this company has apparently been best able to cope with the technical problems involved and has erected the most modern calcining plant of all those which have come to the writer's attention so that it has been by far the largest producer of refractory magnesite in the United States, it has been deemed advisable to give here a very detailed description of the equipment and operations at this plant. To further explain this process a flow sheet has been obtained through the courtesy of the company and is reproduced herewith. Inasmuch as a detailed description of the quarries owned by the company, together with the mining methods it employs, the preliminary treatment of the rock at quarries and the tramway and transportation methods to the reduction plant have been already set forth on page 41 and following of this publication, it will suffice if the further description is limited to the mill and reduction plant located on the Great Northern Railway one mile south of Chewelah, Stevens County.

Mill Storage. Directly beneath the discharge end of the Riblet tramway is located the storage bin for the 2-3 inch raw material that has been sorted, crushed and delivered from the quarries five miles distant. The storage capacity at this plant is 1,000 tons. With this arrangement and the capacity of the tramway it is necessary to run mill and tramway something less than two shifts to each three for the calcining furnaces, thus providing for future expansion of calcining ability to more than one and one-half times the present capacity without the necessity for enlarging the mill. Six hoppers lead from the bin and discharge on a 20 inch collecting belt

NORTHWEST MAGNESITE COMPANY.

Flow Sheet Mine to Cars.



conveyor which in turn discharges on a 20 inch elevating belt conveyor leading to the first set of rolls. A magnetic separator on this belt protects the rolls from any possible injury because of metallic scrap accidentally mixed with the ore. A representative sample taken from this belt shows the following chemical analysis[1]:

ANALYSIS MILL STORAGE NORTHWEST MAGNESITE COMPANY

SiO_2	CaO	Fe_2O_3	Al_2O_3	Ig Loss
2-4 pr ct	1-3 pr ct	0.50 pr ct	0.50 pr ct	48-49 pr ct

Crushing and Grinding. Led into a set of 42 inch by 16 inch Allis Chalmers rolls set at ¼ inch the raw material is removed and raised by bucket elevator to two 3 foot by 4 foot 2-mesh impact screens where the oversize is returned to the rolls and the undersize led by bucket elevator to four 3 foot by 4 foot 8-mesh impact screens. The undersize therefrom is led directly to the 150 ton pulverized magnesite bin; the oversize is put through a set of 42 inch by 16 inch Allis Chalmers rolls set at 1/16 inch until it, too, can be conveyed to this bin. The rolls have proved satisfactory for the work required of them. The depreciation has not been excessive and rolls are changed with comparative ease when necessary. The power is supplied by electrically driven motors as is all the power used for mechanical work throughout the plant. In some cases, the motors are directly connected, in others, the power is transmitted by belts and pulleys. The dust loss in the mill is low, the air being unusually free from this sort of contamination.

Treatment of Iron Ore. Iron ore from Chesaw, Washington, showing an analysis of Fe_2O_3, 87-93 per cent; SiO_2, 3-8 per cent; CaO, 4-6 per cent, is introduced into a 15 inch by 9 inch Blake crusher and the discharge therefrom is raised by bucket elevator to a 75 ton bin. From here it is led through 30 inch by 12 inch rolls, ele-

[1]This analysis and those following, together with plant figures obtained directly from the Northwest Magnesite Company.

vated to another 75 ton storage bin and thence into a Fuller mill. The powdered ore is raised by bucket elevator to a 6 inch screw conveyor leading to the 40 ton pulverized iron ore bin located directly alongside of the 150 ton pulverized magnesite bin. This iron ore must be high grade material in order that as little lime and silica as possible may be introduced into the final product and it must be very finely pulverized. Magnetic iron oxide is usually chosen.

Mixing. This is accomplished in a 2 ton batch mixer of the type generally employed in the mixing of concrete and located under the storage bins. Proper proportions of iron ore and magnesite are determined by the analyses of these materials and are weighed on two 1 ton Fairbanks hopper scales. An average charge to the mixer would be in the ratio of 1955 pounds of magnesite to 45 pounds of iron ore. The resulting product is called the raw mix and is led by bucket elevator and 12 inch screw conveyor either to one of the 60 ton kiln feed bins over each kiln or to a 1,000 ton auxiliary storage bin. The following tables show chemical and screen analyses of the raw mix:

CHEMICAL ANALYSIS RAW MIX NORTHWEST MAGNESITE COMPANY

1918	SiO_2 Per Cent	$Al_2O_3+Fe_2O_3$ Per Cent	CaO Per Cent	Avg. Days
July	2.94	3.56	0.94	30
August	3.14	3.72	1.81	31
September	3.42	3.72	1.97	29
October	3.45	3.82	1.85	31
November	3.70	3.91	1.51	29
December	3.61	3.91	1.39	29
1919				
January	3.46	3.90	1.91	30
February	3.40	3.77	1.94	26
March	3.25	3.58	1.65	25
April	2.98	3.20	1.32	29
Average	3.24	3.71	1.63	289

SCREEN TEST RAW MIX, APRIL, 1919, NORTHWEST MAGNESITE COMPANY

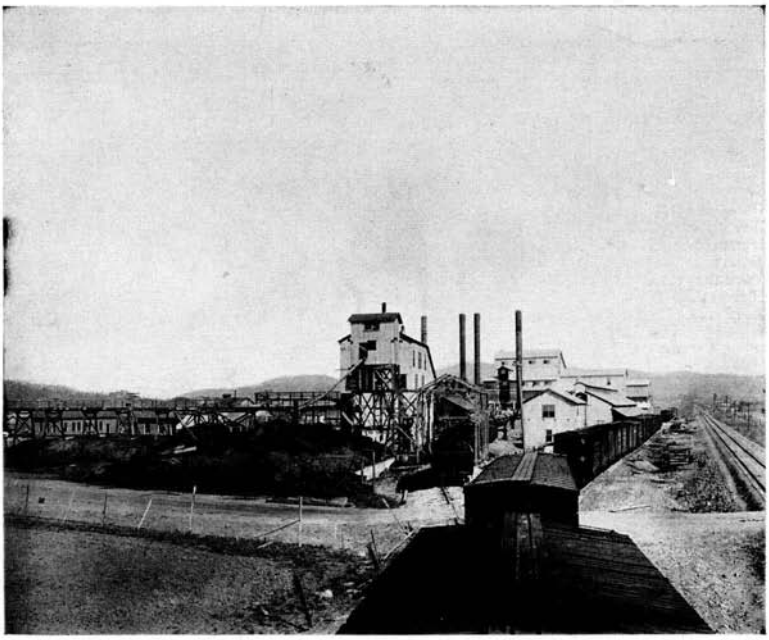
		Per Cent
On 8 mesh	Max.	7.1
	Min.	2.8
	Avg.	4.6
On 10 mesh	Max.	19.3
	Min.	11.8
	Avg.	14.7
On 20 mesh	Max.	41.3
	Min.	31.1
	Avg.	37.3
On 30 mesh	Max.	51.8
	Min.	44.9
	Avg.	49.3
On 100 mesh	Max.	78.8
	Min.	67.1
	Avg.	73.1

Chemical control at this stage of the process is a very important factor in ultimate success in the dead-burned product. Buyers generally place a limit of 7 per cent on the silica and 3 per cent on the lime content of the final product so that it is essential that these compounds show roughly half these amounts in the raw mix. Moreover, as has been pointed out, a successful calcination is largely dependent upon the iron content of the raw mix. The proportion of fine material is important for it assists materially in the reaction taking place between the oxide of iron and the magnesite in the rotary kilns. It may be noted that the analysis of the raw mix as herein given approximates very closely that given on page 72 for the Austrian raw material.

The Rotary Kilns. The kilns are of the rotary type 7 feet 6 inches in diameter and 125 feet long. They are lined throughout with 9 inches of No. 1 fire clay brick. The fuel used is sub-bituminous coal powdered at the coal mill, treated at the plant and delivered to the burner under pressure. The feed of raw mix from the kiln storage bin is controlled automatically by the rate of feed of fuel. Each kiln is provided with its own stack located at the charge end and the product from two kilns leads

to a common pit where it is elevated to a 5 foot by 50 foot steel cooler in which the incandescent dead-burned magnesite is air cooled. The maximum temperature used is about 1550°C. (2800°F.). Five kilns are set up, each with a capacity of 60 to 65 tons of dead-burned magnesite per 24 hours or a total capacity of approximately 10,000 tons per month. Action in the rotary kiln is continuous

WASHINGTON GEOLOGICAL SURVEY BULLETIN NO. 25. PLATE XI



Calcining plant of the Northwest Magnesite Company at Chewelah, Wash.

and control is largely by means of the experience of the furnace operator who is able to judge by eye the success of the calcination and, by regulation of the rate of feed of the fuel and raw mix lengthen or shorten the time of exposure of the magnesite to a greater or less heat as it travels slowly down the slightly inclined, rotating kilns. Figures for six months' operation show the consumption

of coal giving 6,000 calories per gram or 10,800 B. T. U. per pound to be 770 pounds per ton of dead-burned magnesite or about the same as that obtained by the Austrians. In regard, however, to the ratio of the material charged to kiln to dead-burned magnesite produced, the American practice is much more efficient in that it shows approximately 2.2 to 1 as compared with the Austrians 2.5 to 1. The following tables give much data in regard to analyses, yields and general operations of the plant.

ANALYSES OF DEAD-BURNED MAGNESITE—NORTHWEST MAGNESITE CO.

DATE	SiO_2 Per Cent	R_2O_3 Per Cent	CaO Per Cent	$MgCO_3$ Per Cent	Avg. Dys.
July, 1918	6.35	7.24	2.15	84.26	29
August	6.62	6.99	3.42	82.97	31
September	6.72	6.76	3.68	82.84	29
October	6.99	7.15	3.30	82.56	30
November	7.27	7.17	2.65	82.91	29
December	7.15	7.18	2.60	83.07	30
January, 1919	6.88	7.06	3.42	82.64	31
February	6.53	6.79	3.55	83.13	25
March	6.50	6.86	3.20	83.44	28
April	6.54	6.83	2.54	84.09	30
Average	6.76	7.00	3.05	83.19	292

REPORT OF SHIPMENTS OF DEAD-BURNED MAGNESITE FROM CHEWELAH, WASH.

DATE	Total Net Tons
May, 1918	45.90
June	2118.14
July	3213.39
August	4697.09
September	3764.78
October	4481.68
November	4125.61
December	5816.93
January, 1919	6544.67
February	3091.58
March	3001.27
April	1573.46
Total	42,474.50

RECORD OF MAGNESITE PLANT OPERATION NORTHWEST MAGNESITE CO.

DATE	Crude Net Tons	Iron Net Tons	Total Net Tons	Shipments Net Tons	Production Net Tons	Theo. Yield Net Tons	Act. Yield Net Tons	Loss Per Cent
June, 1918	5320	103	5,423	2,164	2,473	2,763	2,473	10.5
July	6544	151	6,695	3,213	3,064	3,423	3,064	10.5
Aug	9845	227	10,072	4,697	4,637	5,150	4,637	10.0
Sept	8053	185	8,238	3,765	3,940	4,212	3,940	7.4
Oct	9071	209	9,280	4,482	4,237	4,745	4,237	10.7
Nov	9187	212	9,399	4,126	4,176	4,806	4,176	13.1
Dec	12311	283	12,594	5,817	5,797	6,439	5,797	10.0
Jan., 1919	14184	327	14,511	6,545	6,485	7,419	6,485	12.6
Feb	7464	173	7,637	3,092	3,382	3,905	3,382	13.4

COAL MILL OPERATION NORTHWEST MAGNESITE COMPANY

MONTH	Coal Net Tons	Ratio Net Tons Coal to Net Tons Raw Mix	Ratio Net Tons Coal to Net Tons Dead Burned Magnesite
June, 1918	1119	.206	.452
July	1281	.190	.418
August	1739	.170	.375
September	1384	.170	.351
October	1636	.180	.386
November	1547	.170	.370
December	2211	.170	.380
January, 1919	2679	.185	.413
February	1367	.178	.404

KILN OPERATION NORTHWEST MAGNESITE COMPANY

MONTH	Kiln Hours Operated	Raw Mix Per Kiln Hour Tons	Dead-Burned Magnesite Per Kiln Hour
June, 1918	1199	4.52	2.06
July	1243	5.37	2.47
August	1854	5.43	2.50
September	1479	5.57	2.66
October	1723	5.40	2.46
November	1797	5.20	2.32
December	2419	5.20	2.41
January, 1919	2663	5.45	2.44
February	1261	5.80	2.68

MONTH	Ratio Raw Mix to Dead-Burned Magnesite	Ratio Dead-Burned Magnesite to Raw Mix
June, 1918	2.19	.456
July	2.19	.457
August	2.17	.460
September	2.09	.478
October	2.19	.460
November	2.05	.444
December	2.17	.460
January, 1919	2.24	.447
February	2.25	.443

RECORD OF KILN NO. 4 NORTHWEST MAGNESITE COMPANY.

MONTH	Hours Operated	Approximate Outturn Net Tons	Shut Down
June, 1918	.....	.....	.....
July	*85.5	211	.....
August	654.0	1635	3 times
September	639.0	1698	2 times
October	572.5	1408	3 times
November	654.5	1519	1 time
December	560.5	1350	1 time
January, 1919	640.0	1562	3 times
February	641.0	1717	1 time

* Started 2:30 p. m. July 27, 1918.

Kiln Lining. Inasmuch as the kiln lining has given, at various plants, as much trouble as any other one feature of the whole process, it will probably be valuable to give here the factors, which in the opinion of the Harbison-Walker Refractory Company,[1] are responsible for

[1] Private communication from E. B. Guenther to Kenneth Seaver, both of the Harbison Walker Refractories Co.

the remarkable performance of the No. 4 kiln as shown in Table (15). The "blox" referred to are H. W. Special R. K. Blox.

"*Factors Favorably Influencing the Life of the Lining.*

"1. Method of laying the blox insuring a tight fit, thereby preventing heat penetration through the seams. The blox were placed in the shell and driven up tight against the shell and against each other. This resulted in a tight brick to brick joint next to the shell. The entire lining was then grouted with very thin cement. Experience at this plant has been that cement gives better results than fire clay. Whether the fault has been with the particular fire clay available the writer cannot say. The fact seems to have been established beyond a reasonable doubt in the mind of the plant foreman. One claim he makes which cannot be gainsaid is that the cement does not dry so fast and consequently more completely fills the joints. Examinations of portions of lining as they were removed from the other kilns proved this to be true.

"2. Care exercised in initial heating and building up of magnesite coating on the lining.

"3. Coal firing which is less abrasive than oil firing though perhaps not any more so than gas firing.

"4. Alignment of coal feed burner pipe. The pipe is inclined slightly downward and laterally so that the flame plays upon the material as it comes forward.

"5. Keeping the quality of the raw material fed to the kilns as uniform as possible, thereby obviating the necessity of frequently changing the coal feed and bringing about more constant conditions of temperature within the kiln.

"6. It has never been necessary to resort to the use of either air or water in cooling the kiln in order to make quick repairs. The kiln was in every case allowed to cool

by natural draft. By the use of water the coating can be made to contract rapidly and break apart, thereby speeding up its removal. The use of water should never be recommended because it weakens the brick structure and hence its life.

"7. The kiln is well aligned and runs very smoothly with no perceptible jarring or chattering.

"8. The stack chamber is amply large and is provided with draft regulating doors. Proper regulation prevents excessive back pressure on the kiln, hence the combustion process takes place without pulsations.

"9. It has been the writer's experience that when an analysis of the dead-burned magnesite disclosed a lime (CaO) content of five per cent or over there was an excessive building up of coating on the lining and a balling up of the material, the balls sometimes becoming very large (as much as three feet in diameter). This condition naturally results in a shut-down. Frequent shutting down lessens the life of the lining. At this plant both the silica (SiO_2) and the lime (CaO) contents have been under control and no difficulty has been experienced due either to excessive coating of the lining or the formation of balls."

Final Steps in the Process. Leaving the rotary coolers, the dead-burned magnesite is transported by scraper conveyor and bucket elevator to an 80 ton storage bin which leads directly to a set of 30 inch by 16 inch rolls and thence by belt conveyor to the storage warehouse. Here it is distributed and screened through ¾ inch screens hung on 45° angle, the oversize product being shipped for manufacture into dead-burned magnesite brick, and the undersize being shipped as dead-burned grain magnesite. Shipment is in box cars. The following table gives average chemical analyses of samples of dead-burned magnesite produced from raw material obtained in Austria and in Washington.

AVERAGE CHEMICAL ANALYSIS—DEAD-BURNED MAGNESITE

	Austria Per Cent	Washington Per Cent
MgO	85.6	83.1
CaO	2.9	3.1
SiO_2	2.8	6.8
Al_2O_3	0.6	2.0
Fe_2O_3	7.1	5.0
Mn_3O_4	0.6	Trace

PROPERTIES OF CAUSTIC, DEAD-BURNED AND FUSED MAGNESIA

In other portions of this report (see pp. 13, 79, 110, 122) the authors have given in some detail the physical and chemical properties of the raw magnesite and the finished brick and caustic calcined material. For the sake of completeness some mention should be here made of the properties of caustic, dead-burned and fused magnesia as these products come from the various kilns and furnaces and before fabrication into finished products. Inasmuch, however, as these properties have been thoroughly treated by McDowell and Howe it will suffice to here merely mention the various ones and refer the reader to the literature for more complete information.

APPEARANCE

According to McDowell and Howe,[1] the caustic burned magnesia sold for various purposes is usually white, the color preferred by most users; it is sometimes buff or reddish brown, depending upon the amount and character of the impurities present. It is easily pulverized, and lumps fall readily to powder upon exposure to the air.

Dead-burned magnesite is red, reddish brown, chocolate brown, black, or of intermediate color. Iron oxide in the absence of manganese imparts a reddish color, while the combined coloring effect of iron oxide and small

[1] McDowell and Howe, Magnesite Refractories, Trans. Am. Ceram. Soc., Vol. 3, p. 210, 1920.

quantities of manganese produces rich chocolate brown to black. Dead-burned magnesite is hard and dense; it is marketed in the form of nodules or grains varying from ⅝ inch diameter to extremely fine particles.

Fused magnesia prepared in the electric furnace is generally low in impurities and white in color. It is very hard (hardness 5 to 6) and resembles glazed porcelain. When cooled rapidly the crystals are minute and compact; if cooled slowly they are fairly large and in well-defined layers.

The latent heat of fusion of MgO is 700(±15 per cent) calories per gram.[1] Its fusion point is 2800°C. (5072°F.)[2] while that of commercial dead-burned magnesite containing 12 per cent impurities does not melt below 2000°C. (3632°F.).[3]

SPECIFIC HEAT

The mean specific heat of pure magnesia at various temperatures is as follows:

MEAN SPECIFIC HEAT OF PURE MAGNESIA

Degrees Centigrade t_1	t_2	Mean t	Mean Specific Heat Between t_1 and t_2	Observer
-191	-80	-135	0.1006	Russell[4]
-79	0	-39	0.1933	Russell
22	99	61	0.2340	Magnus[5]
15	268	142	0.2520	Magnus
15	559	287	0.2670	Magnus
16	765	390	0.2762	Magnus

[1] E. W. Washburn, Latent Heats of Fusion of Lime and Magnesia, Trans. Am. Ceram. Soc., Vol. 19, p. 195, 1917.

[2] C. W. Kanolt, The Melting Points of Some Refractory Oxides, J. Wash. Acad. Sci., Vol. 3, p. 315, 1913.

[3] McDowell and Howe, op. cit.

[4] A. S. Russell, Measurements of Specific Heats at Low Temperatures, Phys. Ztg., Vol. 13, p. 59, 1912.

[5] A. Magnus, Measurements of Specific Heats of Solids at High Temperatures, Ibid. Vol. 14, p. 5, 1913.

THERMAL EXPANSION, HYDRATION AND SLAKING

Goodwin and Mailey[1] give interesting information on these properties. Suffice it here to say that the coefficient of expansion of fused magnesia is not far different from that of platinum.

COEFFICIENT OF EXPANSION OF FUSED MAGNESIA

At 120°C. (248°F.)		At 270°C. (518°F.)	
Fused Magnesia	Platinum	Fused Magnesia	Platinum
1.14×10^{-5}	0.904×10^{-5}	1.278×10^{-5}	0.923×10^{-5}

Gosrow[2] exposing one-quarter inch lumps of caustic calcined amorphous magnesite to the action of moist air obtained the following figures:

HYDRATION OF CAUSTIC CALCINED AMORPHOUS MAGNESITE

Analysis of material used	Per Cent	Time of exposure to moist air, hours	Increase in weight Per cent
MgO	94.70	30	2.50
CaO	0.10	44	3.25
R_2O_3	1.90	76	3.70
Insoluble	0.85	100	4.60
Ignition loss	2.20	125	5.25
		150	5.60
	99.75	172	6.00

Campbell[3] has pointed out that a given sample of light burned magnesia required 44.59 per cent of its own weight of water for complete hydration, and that the temperature of ignition markedly affects the time required for this hydration. Samples burned at 600, 700 or 800° C. (1112, 1292, or 1472°F.) were completely hy-

[1] Goodwin and Mailey, Properties of Fused Magnesium Oxide, Trans. Am. Electrochem. Soc., Vol. 9, p. 89, 1906.

[2] R. C. Gosrow, Refractory Magnesia, Met. Chem. Eng., Vol. 17, p. 415, 1917.

[3] E. DeMille Campbell, The Influence of the Temperature of Burning on the Rate of Hydration of Magnesium Oxide, J. Ind. Eng. Chem., Vol. 1, p. 665, 1909; Vol. 10, p. 595, 1918.

drated when kept barely covered with water three days. Calcination at other temperatures showed:

HYDRATION OF LIGHT BURNED MAGNESIA

Temperature of Calcining	Per cent—complete hydration, years		
	1	3	6
1200° C (2192°F)	91.8	100.0	....
1300° C (2372°F)	64.0	76.2	83.5
1400° C (2552°F)	62.0	75.3	81.0
1450° C (2642°F)	51.2	61.7	70.3

The deleterious effect of steam on dead-burned magnesite has been reported by Youngman[1], while McDowell and Howe[2] have studied at the Mellon Institute the resistance to slaking of commercial dead-burned magnesite, treated dolomite and burned dolomite. Fitzgerald and Bennie[3] have published some interesting data on the effect of water and carbon dioxide on fused magnesia.

ACTION OF CARBON, PHOSPHORUS AND SILICON AT HIGH TEMPERATURES UPON DEAD-BURNED MAGNESITE.

Many observers have reported the effect of these elements upon magnesia at high temperatures. The interested reader is referred to the literature for further details on this subject.[1]

MAGNESIA CRUCIBLES

There is much in the literature on the manufacture of magnesia crucibles so that it is here merely the inten-

[1] R. H. Youngman, The Effect of Steam upon Magnesite Brick and Calcined Magnesite, J. Ind. Eng. Chem., Vol. 6, p. 1037, 1914; Met. Chem. Eng., Vol. 12, p. 620, 1914.

[2] McDowell and Howe, Basic Refractories for the Open Hearth, Trans. Am. Inst. Mining Eng., Vol. 55, p. 291, 1919; Magnesite Refractories, Trans. Am. Ceram. Soc., Vol. 3, p. 216, 1920.

[3] Fitzgerald and Bennie, Trans. Am. Electrochem. Soc., Vol. 9, p. 103, 1906; F. A. J. Fitzgerald, Refractories, Met. Chem. Eng., Vol. 10, p. 129, 1912.

[1] O. P. Watts, The Action of Carbon on Magnesia at High Temperatures, Trans. Am. Electrochem. Soc., Vol. 11, p. 279, 1907; Goodwin and Mailey, Physical Properties of Fused Magnesia, Ibid. Vol. 9, p. 89, 1906; E. F. Northrup, Ibid. Vol. 27, p. 234, 1915; Kowalke and Grenfell, Ibid. Vol. 27, p. 221, 1915; R. E. Slade, Reduction of Magnesia by Carbon, J. Chem. Soc., Vol. 93, p. 327, 1908; P. Libeau, Reduction of Magnesia by Carbon, Compt. Rend., Vol. 144, p. 799, 1907; McDowell and Howe, op. cit.

tion of the authors to mention a few of those who have published their results. Liddell[1] has had success in muffle practice by machining magnesite brick. Watts[2] has made magnesia linings for graphite laboratory crucibles. Yensen[3] has fused calcined magnesia in an electric arc furnace, thereby obtaining crucibles for laboratory use. Fitzgerald[4] had best success in crucible manufacture when he heated above cone 35 (1755°C.) and slowly cooled. Searle[5] has a short description of the manufacturing methods usually employed. McDowell and Howe[6] have briefly reviewed the subject of magnesia crucibles.

THE MANUFACTURE OF DEAD-BURNED MAGNESITE BRICK

It is difficult to give, without going too completely into individual processes, a detailed method for the manufacture of dead-burned magnesite brick. Each manufacturer has unique features which he has found useful and which, in some cases, are considered trade secrets and have, therefore, not been divulged. However, it is possible to briefly outline the general features of the process with whatever detail the importance of each individual step may require. The writer has found the system employed by A. B. Searle in his "Refractory Materials: Their Manufacture and Uses" of value in the presentation of this phase of the work.

BINDERS

Among the binders found in connection with the manufacture of magnesite bricks may be listed the following:

[1] Donald M. Liddell, Magnesite Crucibles, Eng. Mining J., Vol. 96, p. 503, 1913.

[2] O. P. Watts, Making of Magnesia Crucibles, Mining Sci., Vol. 66, p. 413, 1912.

[3] T. D. Yensen, Magnesia Ware, J. Am. Ceram. Soc., Vol. 1, p. 730, 1918.

[4] F. A. Fitzgerald, Refractories, Met. Chem. Eng., Vol. 10, p. 129, 1912.

[5] A. B. Searle, Refractory Materials; Their Manufacture and Uses, C. Griffin and Co., Ltd., p. 303, 1917.

[6] McDowell and Howe, Magnesite Refractories, J. Am. Ceram. Soc. Vol. 3, p. 207, 1920.

1. Caustic magnesia. The drawback to the use of this bond is the large amount required and the great shrinkage of the bricks on burning. Its use is gradually diminishing and has been abandoned in many works.

2. Clay.

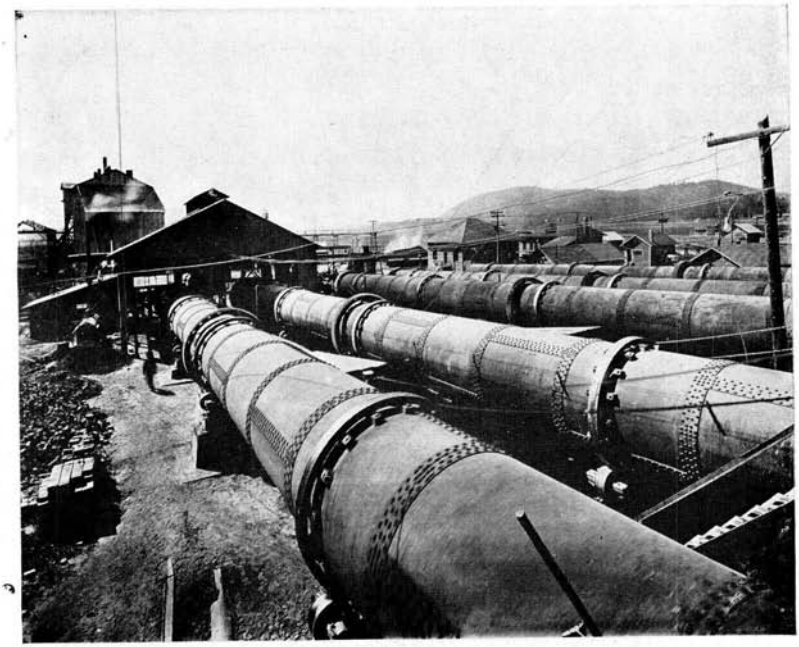
3. Water glass. This is too fusible to be very satisfactory.

4. Milk of lime. Unavailable for best bricks.

5. Feldspar or fluorspar. Too fusible.

6. Gelatinous silica. This combines with the magnesia, forming strong bricks, but is difficult to use.

7. Boric acid, caustic soda, slag, sulphuric acid, magnesium chloride or magnesium sulphate, serpentine. These are mostly patented devices and can hardly be



Kilns for dead-burning magnesite raw mix at the Chewelah plant of the Northwest Magnesite Company.

regarded as more than experimental bonds worthy of further attention.

8. Colloidal matter other than silica. In the patent of E. Podzus, 1912, this consists of finely powdered magnesia (all the particles being less than 0.05 mm. diameter) mixed with a solution of magnesium nitrate and 0.3 per cent of nitric acid. The mixture is dialyzed to separate the colloidal matter. When in use the colloidal particles become enmeshed in the coarser ones and the material as a whole is made more plastic.

9. A temporary bond, such as tar, boiled linseed oil, fat, cellulose, lye, peat, gelatine, molasses, sugar, dextrine, gum or starch may be used to unite the particles until they have attained a temperature at which they will be united by the flux produced on heating them. These temporary bonds burn away in the kiln.

10. Plumbago or graphite.

Of these, the bonds which act as fluxes reduce the refractoriness of the magnesia, while those which burn out produce bricks which are somewhat deficient in mechanical strength.

CRUSHING

The dead-burned magnesite and the bond should be crushed separately and screened so that all particles over 1-16 inch diameter and all very fine material are removed.

PROPORTIONING

A bond may be added in sufficient proportion to the dead-burned magnesite but the best present practice is to omit the bond altogether inasmuch as it is believed that, under proper conditions of burning, the finest particles of magnesia sublime, pass into the interstices of the mass of magnesia, when they form a crystalline bond. In this case the material is moistened with sufficient water as determined by trial, in general about 1 per cent, and thoroughly mixed. When a bond is used,

caustic magnesia is considered the best one to employ, the dead-burned material being mixed with 10 to 15 per cent of its weight of caustic magnesia and 10 to 15 per cent of water. The use of bonding material is not customary in American practise.[1]

MIXING

"The materials and water are mixed in an open trough mixer with two sets of blades, though in some works a pan mill is preferred. The plasticity of the materials is so slight that there is little, if any, difference between the products of these two types of mixers, provided that each is allowed to do its work thoroughly.

"The mixed material should be allowed to stand for two or three days, so that the moisture may be uniformly distributed, and should then be passed through a sieve to insure the mixing being complete.

"It is very desirable that the volume-weight or apparent density of the powder should be determined at this stage, so that the mixture sent to the presses shall be as uniform as possible.

"The volume-weight gives an indication of the amount of shrinkage which is likely to occur, and its determination enables the manufacturer to make a uniform product by mixing several batches of magnesia together, so as to form a material with a definite volume-weight."

PRESSING

The damp powder is next pressed into bricks in which any press suitable for making bricks by the semi-dry process may be employed. The pressure required varies with the nature of the magnesia of which the bricks are made and upon the temperature at which sintering will occur. If it is easily fusible with a specific gravity of about 3.4 and contains grains of all sizes up to 1-16

[1] McDowell and Howe, Magnesite Refractories. J. Am. Ceram. Soc. Vol. 3, p. 208, 1920.

inch in diameter a pressure of 3,550 pounds per square inch will suffice; if more refractory and a finer flour, 5,000 to 7,000 pounds per square inch will be necessary. With ready sintering a pressure of 4,000 pounds per square inch is sufficient, otherwise 5,000 to 7,000 pounds per square inch will be required.

DRYING

"When the bricks come from the press they should be placed on racks and dried in a well-ventilated shed without heat, though steam pipes may be used during the winter months. Magnesia bricks vary greatly as regards their tendency to crack during drying, and each manufacturer must, therefore, ascertain by trial what conditions of heating are applicable to his bricks.

"Steam-heated floors and tunnel dryers are seldom satisfactory for magnesia bricks, as they dry the bricks too rapidly.

"If magnesia bricks are kept in a warm, *moist* atmosphere for some time, they can afterward be dried more rapidly and at a higher temperature, with very little tendency to crack. The importance of this has not been recognized by most manufacturers of magnesia bricks.

"As the burning is a costly part of the manufacture, several continental firms have placed the freshly made bricks in an autoclave heated with steam at 120 pounds pressure. This hydrates a portion of the magnesia and makes hard bricks of considerable strength. These are sold in an unburned state, but the shrinkage they undergo in use is so great that they are not likely to replace well-burned bricks, except in a few special cases."

The bricks must be set in the kiln with great care, as any slight load may cause them to become deformed. Hence it is quite customary to burn them in the same kilns with silica brick, the latter so arranged as to take

the load and protect the magnesite bricks from direct contact with the flames.

BURNING

"The finishing temperatures for magnesia bricks correspond to Seger cones 11 to 12 for bricks rich in iron and cones 17 to 18 for the best magnesite bricks. The higher the finishing temperature the better will be the quality of the bricks as it is almost impossible to overheat magnesia bricks during manufacture. A number of German manufacturers heat the bricks until Seger cone 26 (1580°C.) has been bent down and the Societe des Travaux Publics et Communaux, which is the chief brick manufacturing firm in Euboea, have stated that they burn all their bricks in a Mendheim gas-fired kiln at Seger cone 35."

SORTING

"The bricks must be carefully sorted according to size, thickness, and regularity of shape, as it is of great importance that they should be laid in the furnace with the thinnest possible joints. This is the more necessary as magnesia bricks are too hard for them to be cut to shape without a very wasteful expenditure of time."

PROPERTIES OF DEAD-BURNED MAGNESITE BRICKS

GENERAL

According to Searle, magnesite bricks are usually gray or dark brown in color; have a dense structure, great mechanical strength, and emit a clear, ringing sound when struck; if heated slowly, are very durable, neither expanding nor contracting in use; if heated or cooled rapidly, however, crack badly; and can attribute their value to basic properties combined with high refractoriness.

CHEMICAL COMPOSITION

This depends on the bond (if any). The following are typical analyses:

CHEMICAL ANALYSIS DEAD-BURNED MAGNESITE BRICK[1]

	Veitsch Bricks	English Bricks of Greek Magnesite	
	Per-Cent	Per Cent	Per Cent
Magnesia	85.31	94.74	91.86
Alumina	1.03	2.67	1.95
Iron oxide	8.02	trace	trace
Manganese oxide	0.52	.....	.....
Lime	trace	0.60	0.92
Silica	5.01	1.53	4.68
Loss on ignition	.....	0.24	0.22
Totals	99.89	99.78	99.63

SPECIFIC GRAVITY

The specific gravity varies from 3.05 to 3.58 according to the extent they have been burned and the amount of impurities present. McDowell and Howe[2] give the bulk specific gravity as 2.60 to 2.75; the true specific gravity as 3.44 to 3.60, averaging 3.52.

REFRACTORINESS.

Well made magnesia bricks should not begin to lose their shape at a temperature below Seger cone 40 (2000°C.) and the best grades will usually withstand a temperature of 2150°C. (3900°F.) for two hours. Meller[3] attributes the cracking of these bricks at high temperatures to the change from amorphous magnesia to periclase, a change which should not occur, however, if the magnesite has been completely dead-burned.

HEAT CONDUCTIVITY, DIFFUSIVITY AND POROSITY

The following tables are of interest as giving comparative data on these properties:

[1] A. B. Searle, op. cit.

[2] Op. cit.

[3] J. W. Mellor, Spalling of Magnesite Brick, Trans. Ceram. Soc. (Eng.) Vol. 16, p. 85. 1916-17; Eng. Mining J., Vol. 104, p. 229, 1917.

HEAT CONDUCTIVITY AND POROSITY DEAD-BURNED MAGNESITE BRICK[1]

TEMPERATURE OF BURNING	CONDUCTIVITY		POROSITY
	Kg. Cal. per. Sec. per Sq. Cm. per Cm. Thickness per °C. Temp. Difference	Kg. Cal. per Hr. per Sq. M. per M. Thickness per °C. Temp. Difference	Per Cent by Volume
1300°C. (2372°F.)	0.0065	2.35	41.0

HEAT CONDUCTIVITY AND POROSITY DEAD-BURNED MAGNESITE BRICK[2]

Chemical Analysis	Per Cent	Thickness	Sp.Gr.	Pa	Pb	Temp. Range of Measurement		Mean K
						Lower Surface	Upper Surface	
						°C	°C	
SiO_2	5.0	2.5 in.	3.51	31.4	45.9	380	270	0.0170
Al_2O_2	0.4	.....	.....	.....	.....	560	325	0.0151
Fe_2O_3	1.6	.....	.....	.....	.....	600	400	0.0148
CaO	1.7	.....	.....	.....	.....	700	450	0.0132
MgO	92.1	.....	.....	.....	.....	750	470	0.0116
.....	.....	.....	.....	.....	.....	875	525	0.0110
.....	.....	.....	.....	.....	.....	1025	580	0.0101
.....	.....	.....	.....	.....	.....	1040	590	0.0098
.....	.....	.....	.....	.....	.....	1370	690	0.0091

Pa is the ratio of the volume of the pores to the total volume of the brick.

Pb is the ratio of the volume of the pores to the volume of the solid portion of the brick.

K is the thermal conductivity in gram calories per second per °C for a cube of 1 cm.

ANALYSIS OF BRICK

Porosity	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ig. Loss	Ap. Density
	%	%	%	%	%	%	
..	2.50[3]	0.50	7.00	2.75	86.50	0.10	2.46
34	2.66[4]	6.47	4.45	....	86.42	....	2.34

HEAT CONDUCTIVITY

Exp. Temp Range	Mean K. Over Exp. Range	Av. K. at 1000°C. (1832°F)
445-830°C (833-1526°F)	0.0135	0.0135
0-1000°C. (32-1832°F)	0.100	0.0080

[1] A. B. Searle, op. cit.

[2] Dougill, Hodsman and Cobb, Thermal Conductivity of Refractory Materials, J. Soc. Chem. Ind., Vol. 34, p. 465, 1915.

[3] Boyd Dudley, The Thermal Conductivity of Refractories, Trans. Am. Electrochem. Soc., Vol. 27, p. 285, 1915.

[4] Goerens and Gillis, The Thermal Conductivity of Refractory Materials, Ferrum, Vol. 12, p. 17, 1915.

McDowell and Howe[1] have plotted the results shown in the foregoing table and have compared them with similar data for silica and fire brick. In general the thermal conductivity of magnesia brick is higher than that of other common refractories and seems to decrease with rise in temperature.

THERMAL EXPANSION

McDowell and Howe[2] give an excellent table on this property of magnesia brick.

PER CENT LINEAR EXPANSION OF MAGNESIA BRICKS.

Source of Raw Material	Observer	Per Cent °C.							
		200	400	600	800	1000	1200	1400	1600
Washington.....	S. M. Phelps.....	.....	.....	.....	1.04	.....	.....	1.95	.....
Washington.....	S. M. Phelps.....	.....	.....	.....	.90	.....	.....	1.81	.....
Austria.....	LeChatelier.	0.21	0.55	0.85	1.10	.....	.....	.....	.....
Greece.....	LeChatelier	.25	.52	.79	1.02	.....	.....	.....	.....
Austria.....	R. H. H. Pierce....	.25	.46	.57	.79	1.08	1.50	1.88	1.88
Average.....	.....	.24	.51	.74	.97	1.08	1.50	1.88	1.88

In addition it was found that under load the figures did not differ appreciably from those given in the table.

[1] Op. Cit.

[2] McDowell and Howe, Magnesite Refractories. Trans. Am. Ceram. Soc., Vol. 3, p. 226, 1920.

SPECIFIC HEAT

According to E. Heyn[1] the specific heat of magnesia brick is as follows:

ANALYSIS OF BRICK

MgO Per Cent	CaO Per Cent	SiO_2 Per Cent	Fe_2O_3 Per Cent	Al_2O_3 Per-Cent
88.85	0.35	0.20	9.31	0.17

Specific Heat

+ °C.	+ °F.	True Specific Heat at + °C. (+ °F.)	Mean Specific Heat Between 25° C. and + °C. (77 °F. and + °F.)
0	32	0.208	.....
100	212	.....	0.220
200	392	.253	.233
400	752	.275	.250
600	1112	.290	.260
800	1472	.316	.269
1000	1832	.324	.278
1100	2012	.332	.282
1200	2192	.340	.287
1300	2372	.349	.291

Steger[2] gives the mean specific heat between 20°C. and 200°C. (68°F. and 392°F.) of magnesia brick containing 84.5 per cent MgO as 0.225.

RESISTANCE TO ABRASION AND MECHANICAL STRENGTH

Magnesia bricks have a very low resistance to abrasion, the purer bricks being friable and the less pure ones soft at the very high temperatures at which they are used. The mechanical strength is somewhat higher than that of ordinary fire brick.[1]

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[1] E. Heyn, Thermal Conductivity of Refractory Building Materials, Mitteilungen a. d. kgl. Material prüfungsamt. Vol. 32, p. 185, 1914.

[2] W. Steger. The Specific Heat of Refractory Materials. Silikat-Z. Vol. 2, p. 203, 1914.

[3] Le Chatelier and Bogitch. The Refractory Properties of Magnesia, Trans. Ceram. Soc. (Eng.), Vol. 17, Part 1, p. 18, 1917-18; G. H. Brown, Load Tests on Magnesia, Chrome and Silica Brick, Trans. Am. Ceram. Soc., Vol. 14, p. 391, 1912; McDowell and Howe, Basic Refractories for the Open Hearth, Trans. Am. Inst. Mining Eng., Vol. 55, p. 291, 1919.

CHEMICAL REACTIONS

Magnesia bricks are essentially basic in character, though if well burned are so dense and hard that a short heating in contact with acids such as silica or clay will not seriously corrode them. They are not affected by heating in contact with basic slags. The material with the most corrosive effect on them is iron oxide which is more powerful in this respect than silica, alumina or phosphoric acid. They are not appreciably attacked by water or water containing carbon dioxide or other acids, but are soon reduced to powder by the action of steam as this slakes the magnesia.

MAGNESITE IN CEMENTS

GENERAL STATEMENT

When magnesite is subjected to caustic calcination so that it contains 3 to 8 per cent carbon dioxide it will react with a solution of magnesium chloride to give a product which, upon chemical analysis, shows a constitution believed to conform to the symbol $MgCl_2.5MgO.10H_2O$. This material, mixed with suitable inert fillers, hardens to give a strong cement, known as oxychloride or Sorel cement. Applied in plastic form it sets in a few hours as a tough seamless surface having a very great bonding power and holding firmly to wood, metal or concrete as a base.

This effect was noted about 65 years ago by a chemist named S. T. Sorel, when he observed a similar phenomenon upon the mixing of zinc oxide and zinc chloride. Although this latter mixture has not come into general use, the discoverer's name has clung to the magnesium oxychloride cement.

The temperature of calcination of the magnesite for use in cements is important and serves as the essential difference between the treatment of the raw material for this purpose and for refractories. If the mineral be calcined at a moderate temperature, say 1600°F. (871°C.), or considerably below the temperature of fusion, dissociation is not complete and the residual product is not inert but will recombine with carbon dioxide gas and moisture. As has been already shown, dead-burned magnesite is not chemically active in this manner. The caustic calcination in practice removes all but 3 to 8 per cent of the carbon dioxide so that the product not only reacts readily with the air but also with certain compounds like magnesium chloride and it is upon this reaction that its use in making oxychloride cements depends. To obtain the best results the tem-

perature of calcination is varied from 1300 to 1700°F. (704 to 927°C.) depending upon the quantity and nature of the impurities present. For instance, magnesite containing much iron oxide may be calcined at a lower temperature than when this ingredient is absent owing to the lower fusion point of this, one of the commonest impurities present.

The growth of the industry argues well for its future development. The manufacture of oxychloride cements began in the United States about 20 years ago but up to the last 6 or 8 years it was primarily in the experimental and development stages. Today the manufacture of this product consumes approximately 10 per cent of the crude magnesite used in this country. The number of manufacturers is close to 200 and it is claimed that they provide employment, under normal conditions, for from 5000 to 10,000 men. The volume of business transacted amounts to more than ten million dollars annually.

SOURCES OF RAW MATERIAL

The first magnesite used in caustic calcination was imported from the Grecian deposits. Later imports from Venezuela were found satisfactory, and in recent years the deposits of California and Canada have been drawn upon as sources of the raw material, while small quantities have been provided from the Washington field. These facts bring forcibly to the attention the preference that has been shown toward the pure amorphous magnesite, with limited use of the pure crystalline material in Washington, the high-iron crystalline Austrian ore having been generally disregarded for this purpose.

In choosing between domestic and imported magnesite, the relative costs were, before the war, the deciding factor, thus throwing the bulk of the business to the Greeks and Venezuelans. With the war, however, California provided the bulk of the trade. In regard to

the suitability of this domestic raw material for the purpose, Mr. T. G. Alvord, writing in the New York Herald of June 21, 1919, states that no complaints have been received by government representatives regarding the quality of the West Coast ore. On the other hand, John F. Shanley, president of the Special Service Flooring Corporation, in a letter to the Congressional Committee investigating the advisability of a protective tariff which would increase costs to consumers, wrote that at a meeting of a composition flooring association, without exception every member present had complaints to make of the quality of the West Coast material. Such conflicting opinions have caused investigation into this feature of the situation with the result that the trouble experienced with the domestic material has been practically traced to calcination methods.

CAUSTIC CALCINATION

But little has been known regarding whatever relation may exist between the quantity and nature of the impurities present in raw magnesite and the temperature and time of calcination so that regardless of composition, all raw material may be converted into a caustic calcine capable of giving a standard uniform cement. Believing this to explain the unsatisfactory results obtained from domestic magnesite, the Bureau of Mines at its experiment station at Berkley, California, is now proceeding with exhaustive research into this calcination problem and expects to establish the factors influencing the properties of the resultant cement so that it may become a standard product just as the refractory producers have been able to produce a magnesite brick by artificial treatment that is generally accepted as being as satisfactory as brick made from the Austrian ore. The results of this research are not yet public, but will be available as soon as completed in the reports of the

Bureau. It is expected that the report will do much toward giving impetus to use in the cement trade of domestic magnesite, from both California and Washington.

"In practice,[1] it has been common to conduct the calcination in (1) shaft kilns, particularly those gas-fired, (2) continuous chamber kilns, and (3) rotary kilns. In the shaft kilns, of course, the raw magnesite and coal are fed into the top, and caustic calcined magnesite is removed at the bottom. Inasmuch as magnesia may fall to powder if shaken during burning and, with careless firing, shows a tendency to bind into lumps, such agglutination being particularly marked with high silica, continuous acting shaft kilns are unsatisfactory unless especially modified for the purpose. Gas or oil firing is generally preferred to the use of coal. However, a shaft kiln designed by E. Schmatolla has proved excellent for burning Grecian magnesite. In this country two California operators offer examples of methods employed. The Western Magnesite Development Company, in Santa Clara County, employs two low vertical kilns, approximately 15 feet in diameter, tapering to a cone above the main part of the kiln. The raw ore is fed in at the top, falling gradually by gravity. It is thus gradually heated and calcined, falling finally into four compartments of which the main kiln is composed and where final calcination takes place. The fuel is distillate, which is sprayed into the kiln with air at four points, the flame impinging directly on the magnesite for about 2¼ hours. The product is sorted and screened, going not only into the plastic flooring trade but also to manufacturers of paper pulp and Epsom salts. At the Tulare Mining Company, calcination is accomplished in two low vertical kilns, wherein crude oil is atomized with steam into

[1] W. C. Phalen. The Present Situation in the Magnesite Industry. Bureau of Mines Separate, July, 1919.

each of the four compartments of each kiln. Raw lump ore is added every two hours and calcines are drawn every hour or three-quarters of an hour. After coming from the calcining plant, the calcines are carefully sorted, any unburned material being reburned. The product is graded, crushed, ground, and packed or barreled for the plastic flooring trade. This plant formerly furnished magnesite for use in the manufacture of paper. The operations at the plant are but a fraction of what they were during the war. Electric power obtained from Porterville is employed in the various mining and grinding operations."

It can be seen from this brief review of the practical operation of caustic calcining plants that the burning is not scientifically conducted, nor is it to any great extent, chemically controlled. However, when more knowledge is available as to just what takes place during calcination and upon just what factors a satisfactory product is dependent, undoubtedly this troublesome phase of the utilization of magnesite will have been removed.

PREPARATION OF OXYCHLORIDE CEMENT

"In general it may be said that in the preparation of oxychloride cement, the magnesium oxide (caustic calcined magnesite) is mixed with the other dry materials and magnesium chloride is added in the form of a solution. Almost any strength of magnesium chloride solution will produce the effect of setting but a solution of about 20° Baume (specific gravity 1.16) is usually employed. The magnesium oxide and chloride may be combined in dry form in any proportion desired and, to the resulting mixture, water and the remainder of the dry materials added. This latter method, however, is not

[1] W. C. Phalen. The Present Situation in the Magnesite Industry. Bureau of Mines Separate, July, 1919.

satisfactory and its use has been abandoned. Some manufacturers make a semi-fluid mix of cement and solution and then add the rest of the dry materials. The better way on the whole is to add the chloride in the form of a liquid in which form it may be purchased on the market and reduced to the density desired."

The preparation of the cement is not difficult and many satisfactory combinations have been patented.

OTHER MATERIALS FOR OXYCHLORIDE CEMENT

Aside from caustic calcined magnesite, magnesium chloride and fillers are required. The former was obtained principally from Germany before the war. Since, however, a satisfactory material has been obtainable from California and Michigan where the chloride is a by-product in the manufacture of salt and bromine. To offer substantiation of this last statement there is available the following extract from the letter of J. F. Stanley[1] to the Congressional Committee. "To cite the other material which is used in connection with magnesite in making oxychloride floors. This material is magnesium chloride and was formerly imported from Germany. A short time after the war broke out, the Dow Chemical Co. started making magnesium chloride. We feel sure that you will find every one connected with the use of magnesium chloride will have a good word for this company."

As fillers the following have found use: wood flour or cork, asbestos, ground quartz or silex, ground talc or soapstone, and various mineral pigments depending upon the desired color effect.

INDIVIDUAL PROCESSES

While it is undesirable to give here any detailed description of processes used or formulas followed in the

[1] Hearings before the Committee on Ways and Means, H. R. 5218, p. 216.

manufacture of oxychloride cements, as these are available in the patent literature, it may perhaps be valuable to present here a few of the compositions as patented in order that some general idea of the subject may be available.

1. U. S. Patent 1183446. Mix caustic calcined magnesite, cellulose, magnesium chloride and enough water to wet all before the fibre is added. Magnesium chloride added should be just sufficient to combine with the oxide as follows:

$$MgO + Mg\,Cl_2 + 2H_2O = 2\,Mg\,(OH)\,Cl + H_2O.$$

It is better to use too little than too much magnesium chloride. The cellulose is added as desired.

2. To 100 pounds of fibrous vegetable matter add 2 to 5 pounds linseed oil; mix; add ½ to 3 pounds caustic soda or caustic potash; mix; add 80 pounds caustic calcined magnesite; 40 pounds dry magnesium chloride, mix with water and lay.

3. To 100 pounds powdered sawdust, add 3 pounds raw linseed oil, 1 pound powdered caustic soda; mix; add 100 pounds caustic calcined magnesite, 250 pounds powdered marble or other hard material, 3 or more pounds of color, 2½ pounds of casein and 50 pounds dry magnesium chloride.

GENERAL PROPERTIES OF OXYCHLORIDE CEMENT[1]

"The cement may be finished with a very smooth, even surface which will take a good wax or oil polish. Its surface is described as warm and quiet, as a result of the elastic and non-conducting character of the composite material.

"The desirable qualities of any flooring material (cost not considered) are listed for purposes of analysis or comparison, under eighteen heads as follows: Cleanliness

[1] Fletcher Hamilton, Magnesite; Its Occurrence and Applications, Mineral Foote Notes, Foote Mineral Company, Inc., Phila., Pa., Jan., 1918.

(sanitary qualities), quietness, immunity from abrasion (surface wear), resilience, immunity from slipperiness, appearance, water proof character, plasticity, warmth (thermal insulation), life (immunity from deterioration with age), acid-proof character, fire-resistance, alkali-proof character, elasticity, crushing strength, structural strength (rupture), immunity from expansion and contraction and lightness. The importance of these several qualities varies with the varying requirements to be met. For instances, in some places, as in hospitals, cleanliness is one of the prime considerations; in other places, immunity from abrasion might be one of the principal requisites. As to most of these qualities the conclusion is reached that magnesia cement affords one of the most satisfactory flooring materials for use in kitchens, laundries, toilets and bathrooms, corridors, large rooms or halls in public or other buildings, including hospitals, factories, shops and restaurants.

"There is no doubt that the material is steadily coming into more general recognition and favor for these uses. For a few special uses, it is more or less disqualified, as an instance, it is not suited for construction of swimming tanks or for conditions of permanent wetness, since under constant immersion it gradually softens, although it is said to withstand intermittent wetting and drying and is recommended for shower baths. Naturally it is not acid proof and not wholly alkali-proof, which might be a disadvantage in its use for laboratory floors and tables, but these are rather special requirements. Its cost per square foot is estimated to be 25 to 33 cents, depending on area, which is said to be lower than marble, cork, rubber, clay or mosaic tile, slate or terrazzo, although more expensive than wood, asphalt, linoleum or Portland cement.

"When unsuccessfully used, the causes of failure are ascribable to uncertain climatic changes, lack of uniform-

ity in the mixture used, lack of care on the part of those handling the materials, possible deterioration of materials used through exposure (either before or after mixing), lack of proper preparation of foundations on which the material is to be laid, and, as a very important factor, experience or non-experience in the manipulation or actual laying or troweling of the material."

PHYSICAL PROPERTIES OF OXYCHLORIDE CEMENT[1]

"The physical properties of magnesia cement have been investigated by Raymond J. Roark,[2] and his results show what may be expected of magnesia cement when used for flooring purposes." Preliminary tests were made with neat cement, a 1 to 3 mortar of standard Ottawa sand, and a standard floor mix. The standard floor mix which gave good results consisted of the following proportions by weight:

Cement	49.3 per cent
Sawdust	29.2 per cent
Asbestos	13.4 per cent
Coloring matter	8.1 per cent

"Tests were also made omitting the coloring matter, but keeping the proportions of the other constituents the same. The results showed that the absence of coloring matter had no effect.

"At the suggestion of the manufacturer, the magnesium chloride solution was added to the standard mix in the proportion of 85 cubic centimeters to each 100 grams of solids, i.e., one gallon to 10 pounds of solid material. The specific gravity of the solution was about 1.22 (26° Baume).

"A sufficient number of tests was made on the three mixes, the neat, the 1 to 3 sand, and the standard floor

[1] Abstracted in part from an article in the American Architect, Vol. CXIV, nos. 2229-2231, Sept. 11-25, and Oct. 9, 1918, by W. C. Phalen, op. cit.

[2] Engineering Experiment Station, University of Wisconsin, Bulletin 879.

mix to ascertain whether the three were similarly affected by the different variables, and to ascertain which yielded the most uniform and consistent results. Three cements were used. The first tests were made for tensile strength. The second series of tests was made to check the first series and to compare the results obtained by different operators working simultaneously. Samples were made up of the same three mixes together with the same three cements that were used in the first experiments. A third series of tests was made in which the specimens were made at different times and the tests also to determine the effect of different temperatures and humidities at the time of preparing the specimens, during storage, and at the time of the test. It was found that very considerable differences exist between the results of tests made on different dates.

"The results of these three series of preliminary tests showed that, in general, all tests intended to show the effect of variables other than the amount of aggregate should be made on specimens of standard floor mix; that specimens should be stored in normal air; that tests should be made at any time after three days; and that all tests, the results of which are to be compared quantitatively, should be made at the same time on specimens made at the same time and by the same operator.

"A mineral like magnesite varies, and the calcined product from one mine may be different in composition from that of others. The calcined product, however, is a crude material, and to make it uniform it would have to be treated chemically, which would involve prohibitive expense. Up to the present time, and for this reason, no standard product has as yet been placed on the market, and for this reason again, the consulting architect can make no detailed specification as to the chemical composition of the material he wishes to use unless it is the product of a certain mine with which he is acquainted.

"The application of magnesia cement, therefore, is governed by the particular product used and the methods employed will vary with the nature of the cement, weather conditions, and other variables. The specifications are usually restricted to a statement of the results to be accomplished and to the fundamental factors common to all these cements.

"In order to gauge the effect of these variables, tests were made to determine the effect of:

1. The chemical constitution of the cement.
2. Variation in the amount of $MgCl_2$ solution; density constant.
3. Variation in the density of the $MgCl_2$ solution; amount constant.
4. Variation in both the amount and density of the $MgCl_2$ solution; amount of $MgCl_2$ constant.
5. Variation in the proportion of cement to aggregate.
6. Variation in the moisture content of the aggregate.

"To determine the effect of the variables listed, tests were made as follows:

1. Tension test.
2. Compression test.
3. Cross-breaking test.
4. Hardness test.
5. Expansion test.
6. Change in weight test.
7. Pat test.

"The results of these tests are summarized in part as follows:

1. The standard floor mix, gaged with a magnesium chloride solution having a density of 1.20 (24° Baume) in the proportion of 85 c.c. of solution to 100 g. of solid material (1 liquid gallon to 10 pounds) was found to have:

An average tensile strength of 593 pounds per sq. in.

An average compression strength of 2340 lbs. per sq. in. at seven days, and 4,000 lbs. per sq. in. at 28 days.

An average modulus of rupture of 1,200 lbs. per sq. in.

An average modulus of elasticity of 650,000 lbs. per sq. in.

An average Brinell hardness number of 7.3.

A coefficient of expansion of 0.0000126 per degree F.

2. Specimens made of this mix were found, in general, to increase in strength as time went on, and the increase in compressive strength was greater than the increase in tensile strength; but in some instances a decrease in tensile strength was noted.

3. Specimens of this mix were found to expand during setting, and for some time afterward. In a dry atmosphere, the maximum expansion varied from 0.10 per cent to 0.30 per cent and occurred in from 70 to 140 hours. After that time, the specimens began to shrink and the ultimate length of same was less than the original. In a moist atmosphere, the specimens expanded continuously during the period of observation. The rate of expansion varied.

4. The weight of specimens as a rule decreased during storage in a dry atmosphere, but increased during storage in a moist atmosphere.

5. It was found, in general, that the strongest mixtures were those made with cements having a high magnesium oxide content, and a low lime content. The addition of lime was found to produce a marked decrease in tensile strength. No consistent relation was found to exist between the strength and the amount of any other chemical constituent of the cements.

6. The tendency to shrink or expand was not found to bear any relation to the chemical constituents of the cement.

7. The maximum strength and hardness were obtained with that quantity of magnesium chloride solution necessary to give good working consistency, that is, with about 85 cubic centimeters of solution to 100 grams of solid material (one gallon per 10 pounds).

8. In a dry atmosphere, the per cent (percentage) of expansion of the specimens was found to increase with the quantity of solution used; in a moist atmosphere, the per cent (percentage) of expansion was found to decrease with the quantity of solution used.

9. In dry air, the per cent (percentage) of loss in weight of the specimen was found to increase with the quantity of solution used; in moist air, the per cent (percentage) of gain in weight was found to increase with the quantity of solution used.

10. The strength, stiffness, and hardness were found to increase with the density of the magnesium chloride solution used. A density of 1.15 appears to be the least that should be employed in any case.

11. In a dry atmosphere, the percentage of expansion of the specimens was found to increase with the density of the solution; in a moist atmosphere, it was found that the percentage of expansion varied at first inversely, and later on, directly, as the density of the solution. The relation between percentage of expansion and density of solution do not, however, appear to be clearly defined.

12. In dry air, the percentage of loss in weight of the specimens was found to vary as the density of the magnesium chloride used. In moist air, the percentage gain in weight was found to vary indirectly as the density of the solution.

13. The results of the tests on mixes in which different quantities of solutions had been used, but in which the quantity of magnesium chloride was practically the same, showed that strength and hardness increased with

the amount of solution so long as this amount was less than that required to give normal consistency. This shows that the physical properties of the mix are not dependent simply upon the ratio of magnesium chloride to magnesia, but depends also upon the quantity of water used.

14. Strength and hardness were found to increase with the ratio of cement to aggregate. This increase became less marked as the richness of mix was increased.

15. The tendency to expand was found to increase with the ratio of cement to aggregate.

16. Tests made on mixes in which the aggregate had been moistened before mixing, in order to secure normal consistency with less magnesium chloride solution, showed that the strength varied directly with the amount of solution used.

17. The time of set was found to be affected by the temperature and humidity, and also by the density of the magnesium chloride solution. High temperature, low humidity, and the use of a dense solution were found to produce quick setting of the cement."

USE IN INTERIOR WORK[1]

"Magnesia cement, or magnesium composition flooring has been compared with other flooring materials.[2]" It differs from other flooring materials with the exception of asphalt, concrete, and terrazzo in that it is installed in the plastic condition. Floors made of magnesia cement may cover quite a range of hardness which is accomplished by varying the character of the aggregate, for example, by using variable quantities of sand. The harder the floor, naturally the more noisy it will be as

[1] W. C. Phalen, Magnesite, Monthly Reports of Investigations, Bureau of Mines, Oct., 1919, p. 8.

[2] See American Architect, July 24, 1918, p. 116.

compared with a less dense and resilient floor made from such materials as wood fiber, saw-dust, or cork. The resilient floor is quiet, elastic, warm, and agreeable to the tread, and the wearing qualities of such floors is considered to be equal to that of the hard type, in which silica sand is largely used.

"Magnesia cement flooring may be planed, drilled, scraped, and burnished. The extent to which it may be thus treated depends naturally upon the character of the aggregate. The resilient floors are more easily worked. Such working qualities of magnesite cement are marked when compared with concrete which is brittle, and unelastic.

"Magnesite cement floors may be colored with mineral pigments. Such colors as red, buff, or black appear to give the best results, but gray shades may be made by mixing white and black. Other colors are apt to fade, and are not so desirable. Floors may be laid in two or more colors, the added cost depending on the design and arrangement.

"The foundation provided for the magnesite cement floors is of importance. Lime is detrimental and it is necessary that all traces of it be removed from the foundation. The floors should be laid in two layers, an under layer 3/16-inch thick, and a top layer 5/16-inch thick. In the case of wainscoting or closet floors, a thickness of ⅜-inch is ample. The surface should be brought to a true plane with a trowel, and should have a uniform color. Burnishing, rubbing or scraping should not be resorted to. The finished floor should be protected with ½-inch layer of sawdust or fine shavings. The temperature of the room where such a floor is being installed should not be less than 50° F. (10° C.). Such floors should be guaranteed for a period of at least two years.

USE IN EXTERIOR WORK

"The qualities of magnesia cement requisite for success in exterior finishing are resistance to abrasion, impact and structural stresses. Durability when subjected to the action of the elements and stability to minor disarrangements of the base on which it is placed are of importance. It must be relatively unaffected by changes in temperature, by the action of water and the elements in general, should adhere to the material on which it is placed, and should be free from shrinkage cracks due to setting up the material.

"The elasticity of such cement is the outstanding quality which makes it desirable for exterior work. It also possesses the ability to adhere to all materials in a marked degree. Its freedom from expansion and contraction after setting is one of the principal reasons for its adhesive quality. It may be applied to old brick or stone walls, even though they have been repeatedly covered with paint, and the quality of adhering to wood makes it possible to secure a weather-proof protection to the wooden casings and trim of exterior openings. The quality of adhesion and elasticity is easily proved by applying a ½-inch layer to a 1-inch board which has been first covered with metal lath. Such a board, about 8 feet long, may be repeatedly deflected about 3 inches in the center without breaking the bond to the board, or causing any cracks to appear in the magnesia cement. The ability to resist fire as well as the possession of insulating qualities are also desirable characteristics of magnesia cement stucco.

"Magnesite cement stucco should be applied in two coats, each ¼-inch thick, on various surfaces such as wood lath, metal lath, sheating board, brick, hollow tile, or stone; care being taken as regards the presence of lime, unless the same has been rendered, or become

inert as with very old walls. The first coat made up to a consistency that works easily under the trowel is applied in the usual manner. No water should be added to the liquid chloride as it would alter its density and injure the work. The second or finishing coat is then applied. The aggregates are different in each, and no other dry material should be added to them as they come to the trade. The cement may be applied in zero weather without damage. Setting is quite slow under such conditions, but the cement ultimately becomes hard. It should always be applied to a dry surface excepting that under certain conditions it is desirable to apply a solution of magnesium chloride before using the stucco.

"The temperature is of importance. If the temperature is over 50° F. (10° C.) only so much of the first coat should be applied in one day as can be covered with the second coat. In this way, the finishing coat is applied before the first coat has become hard. If the temperature is below 50° F. (10° C.) the finishing coat can be applied 24 hours after the first coat is applied.

"Magnesia cement stucco may be colored with any mineral color or combination of such colors. The factory-made product is produced in colors, and thus prepared, the shade is uniform."

ECONOMIC FEATURES OF THE MAGNESITE REFRACTORY SITUATION

QUALITY OF AMERICAN MAGNESITE

Leaving, for the moment, the geological, mining and industrial phases of magnesite, it will be well worth while to consider briefly some opinions on the value of American refractories made from domestic raw material. It must be borne in mind that the birth of the industry came at a time when the treatment received by its products was unusually severe. There can be no doubt that metallurgical furnaces were run at more than capacity in the universal endeavor to supply the world's war needs. Perhaps, the care that was formerly given to furnace linings slackened a bit; certainly these linings were taxed as never before.

It is true that the first grain and brick magnesite did not come up to expectations; over-capacity conditions could not explain their undoubted failure; it was due to lack of knowledge as to just how to artificially supply the iron which, naturally in the Austrian raw material, was lacking in that from the Pacific Coast. Later, though, it was a different story; tons of domestic refractory gave satisfactory results.

Lest there be doubt regarding the authenticity of this last statement, attention is directed to the many opinions as to the ability of American magnesite to do the work required of it, that came to light during the recent Congressional hearing.[1] Without going into detail inasmuch as this data is all a matter of record in the published report of the hearing, the summary of these opinions as set forth by Phalen[2] are herewith given.

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[1] Hearings before the Committee on Ways and Means, H. R. 5218.

[2] W. C. Phalen, Magnesite. Monthly Report of Investigations, Bureau of Mines, July, 1919.

"The Washington magnesite, according to Harbison-Walker Refractories Company (a very large manufacturer of magnesite brick) has been substituted for the Austrian for every purpose for which the Austrian formerly was used or sold, either in the manufacture of steel, copper, or other metals and no conclusive evidence

WASHINGTON GEOLOGICAL SURVEY BULLETIN NO. 25. PLATE XIII

Aerial tramway of the Northwest Magnesite Company extending across Colville Valley to the company's calcining plant.

has appeared that the Washington product is inferior to the foreign. As a matter of fact, the testimony of some of the largest consumers of magnesite is to the effect that the Washington mineral, as now produced, is as good as the Austrian. Brick manufactured by this firm have been made exclusively from the Washington magnesite since the middle of 1918, and during this period nearly 60,000 tons of magnesite in the form of dead-burned grain and brick have been use and marketed."

The general situation regarding the American magnesite refractories insofar as production and quality are concerned may be therefore briefly restated. First, the Austrian and Washington magnesite are both crystalline in character, and so suited for refractory use; second, the American reduction practice, though complicated through the necessity for the addition of iron ore, is more modern and efficient, there being less waste in quarrying and a greater recovery in calcining with about the same fuel consumption; third, the dead-burned grain resulting from both Austrian and domestic practice shows practically the same chemical analysis and seems to have undergone the same bonding action during sintering; and fourth, to the extent of 60,000 tons marketed and used complete satisfaction with the American product is expressed by a leading refractory brick manufacturer.

COSTS

Turning from the question of the quality of American magnesite with the belief that it is satisfactory as a refractory in metallurgical furnaces, attention may be directed to the relative costs of the imported and domestic product. Abundant sources of information on this subject are available because of the data recently presented at the Congressional hearing on the subject. For the sake of brevity the facts brought out in this hearing have been abstracted.

It is estimated that the total plant investment in California and in Washington for mining, handling and calcining magnesite is $3,500,000 to $4,000,000. The industry would normally employ more than 1,000 men, with 1,500 as maximum, although it is doubtful whether at present more than 25 per cent of this number are so engaged. These figures refer only to the actual producing and transporting end of the business and have no reference to the manufacture of magnesite brick.

Figures on the cost of producing dead-burned magnesite in the United States, freight rates to the eastern market and pre-war figures on the cost of Austrian magnesite at the same eastern points have been compiled as follows:[1]

Highest cost per ton U. S.	$28.43
Freight	16.07
Cost at eastern market	$44.51
Lowest cost per ton U. S.	$21.15
Freight	16.07
Cost at eastern market	$37.22
Average cost per ton U. S.	$25.13
Freight	16.07
Cost at eastern market	$41.20
Pre-war cost of Austrian, per ton	$16.15
Average differential per ton	25.05

It should be noted that the American costs include no profit for the producer, whereas the Austrian figures do. On the other hand, the Austrian costs are for pre-war conditions, no figures being available on quotations since the cessation of hostilities.

Insofar as the State of Washington is concerned, it is possible to give still further cost data as provided for the Congressional hearing.

[1] The following figures were taken at the time of the Congressional Hearing. The present (April 1, 1921) freight rate from Chewelah, Wash., to Pittsburgh, Pa., is $18.40 per ton and to Chester, Pa., $20.80 per ton, exclusive of war tax, which amounts to approximately $1.00 per ton. Domestic manufacturing costs have changed but little from those prevailing in 1919; what change has occurred, however, has been downward.

COST OF PRODUCNG CALCINED (DEAD BURNED SINTERED) MAGNESITE—NORTHWEST MAGNESITE CO.

June 1, 1918, to May 1, 1919.

	Amount	Per ton Dead-Burned
Mine Expense	$261,245.24	$6.16
Treatment Plant Expense	400,465.60	9.41
Tramway Expense	39,682.08	.93
Total direct operating expense	$701,392.92	$16.50
Administration and General	26,232.06	.61
Taxes, Insurance and Interest	56,457.54	1.32
	$784,082.52	$18.43
Depreciation	64,331.13	1.51
Depletion	48,917.55	1.15
Total Cost	$897,330.20	$21.09

COST TO KILNS—AMERICAN MINERAL PRODUCTION CO.

	Cost per Ton Dead-Burned	Cost per Ton Crude
Mining	$7.28	$2.60
R. R. to Valley	5.60	2.00
Freight to Cement Kiln	3.92	1.40
Totals	$15.80	$6.00

Assume 2.8 ton crude=1 ton dead-burned.

It is therefore apparent that the Northwest Magnesite Company shows a cost sheet which is apparently a minimum for dead-burned magnesite in the United States. An estimation of the calcining cost for the American Mineral Production Company, whether its calcination was accomplished at the kilns of the International Portland Cement Company or those of the Northwest Magnesite Company, would put its total production cost at about an average for the United States. In the former case, there would exist at the eastern market a differential in favor of the Austrian product of 1.05 cents per pound, and in the later case, 1.25 cents per pound, based upon the above mentioned conditions of no profit to the

American producer and pre-war production and ocean freight costs for the Austrian.

To meet this differential, Representative Hadley of Washington introduced into Congress in the form of H. R. 5218, a bill which when amended after hearing before the Ways and Means Committee provided the following protective tariffs:

1. A duty of ½-cent per pound on crude magnesite ore.
2. A duty of ¾-cent per pound on calcined, dead-burned grain magnesite.
3. A duty of ¾-cent per pound and 10 per cent ad valorem on magnesite brick.

There is much to be said on both sides of the question of the advisability of these tariffs, but such arguments have no place here since they are obtainable in the public document on the hearing. Suffice it to say that it was believed that these duties, because of increased Austrian producing costs since the war, would provide sufficient protection to enable American producers to compete with the imported refractory. In other words, it was the belief that in Austria labor and other operating costs, handling and transportation will have increased to the extent of ½-cent per pound on dead-burned grain, so that the differential of 1¼ cents per pound in favor of the pre-war imported product will have been eliminated by the imposition of a tariff of ¾-cent per pound. However, although the bill, as amended, passed the House of Representatives, it failed of passage in the Senate because of the 1920 adjournment and again in the 1920-21 session.

Under present conditions, therefore, the cost of calcined magnesite at Chewelah, Wash., for instance, will not vary much from the neighborhood of $35.00 per ton. Freight rates plus war tax to the East from California and Washington points are approximately $20.00

per ton. These figures offer no great hope for any appreciable change from the present quotations in technical journals of $55.00 to $60.00 per ton for dead-burned grain magnesite and $90.00 to $100.00 per ton or $450.00 to $500.00 per thousand for magnesite brick, these quotations being f.o.b. Chester, Pa.

A factor that must be taken into consideration, however, is the substitution for dead-burned magnesite, of much dead-burned dolomitic Canadian magnesite and dead-burned dolomite, of which data of the U. S. Geological Survey shows 340,000 tons were marketed in 1917. The freight rate on the Canadian magnesite to Pittsburg, Pa., is a little more than half of what it is from western points to that city.

As an example of just what the cost of magnesite really means in industry and the effect of increasing costs, it is interesting to consider the quantity and cost of the magnesite used per ton of steel.[1] Prior to the war between six and fourteen pounds of magnesite were used per ton of steel, according to estimates of several prominent eastern steel manufacturers. The quantity used was cut in half during the war owing to a greater measure of economy and the substitution for magnesite of dead-burned dolomite. About three to seven pounds, or an average of five pounds per ton of steel was used during 1917, which quantity may be considered approximately that used now. The cost of magnesite per ton of steel is small. With magnesite brick $450.00 per thousand and grain magnesite at $48.50 per ton f.o.b. Chester, Pa., the cost of magnesite per ton of steel on a basis of all brick, would be about 22½ cents, and on a basis of all grain, 12½ cents. With half brick and half grain the cost would not be far from 17 to 18 cents, with two-thirds brick and one third-grain, 19 cents.

[1] W. C. Phalen, The Present Situation in the Magnesite Industry. Bureau of Mines Separate, p. 5, July, 1919.

It is not difficult to see then, that, regardless of production costs, tariffs, and competition rates, the cost of the magnesite when it is considered in the final analysis as to its effect upon the price of a ton of steel will make very little difference whether the consumer uses the imported or domestic product, with or without protective tariffs.

PRODUCTION, CONSUMPTION, IMPORTS AND EXPORTS

With regard to supplies of magnesite available for use, but little can be added to the information contained in the early pages of this report. The foreign supply is vast, the domestic supply extensive and, were all of the California raw material to be devoted to other uses, there is a sufficient deposit in Stevens County, Washington, to provide for the metallurgical needs of the country for many years.

The consumption for all purposes of crude magnesite in the world is estimated at 500,000 tons annually, and of this, the United States consumes about 70 per cent or 350,000 tons. Before the war approximately 96 per cent of the material used in this country was imported, and of the material imported 95 per cent came from Austria. Pre-war production in the United States, all from California, was 10,000 tons crude annually. The total production in the United States during 1917 was 317,000 tons by at least 30 producers.

Today there are eight leading producers, six in California and two in Washington. These concerns have ample calcining capacity to supply the needs of the country. Of brick manufacturers, nine or ten supply most of the finished product, there being four large companies leading the field.

Only two states, Washington and California, produce magnesite. The entire Washington production comes from Stevens County. The first production from these deposits was made during December, 1916, when there began a feverish growth of the new industry in answer to incessant war demands. During 1917 Washington produced approximately one-half as many tons as California. The 1918 production was an increase of 40 per cent over the previous year and it placed Washington as the leading magnesite producer of the country, which position it has since maintained.

The production figures are as follows:

PRODUCTON OF CRUDE MAGNESITE.

YEAR	WASHINGTON		CALIFORNIA	
	Quantity Short Tons (a)	Value	Quantity Short Tons (a)	Value
1916	715	$783,188	154,259	$1,338,331
1917	105,175	1,050,790	211,663	2,116,630
1918	147,528	1,595,000	84,077	761,811
1919	106,206	743,442	50,020	504,973
1920	221,785	1,664,888	81,782	1,083,262

(a) Calculated to a crude basis.

CRUDE MAGNESITE PRODUCED IN THE UNITED STATES 1913-20.

YEAR	Quantity Short Tons	Value
1913	9,632	$77,056
1914	11,293	124,223
1915	30,499	274,491
1916	154,974	1,393,693
1917	316,838	2,899,818
1918	231,605	1,812,601
1919	156,226	1,248,415
1920	303,767	2,748,159

MAGNESITE IMPORTED FOR CONSUMPTION IN UNITED STATES 1909-19.

YEAR	CRUDE		CALCINED, NOT PURIFIED	
	Quantity (pounds)	Value	Quantity (pounds)	Value
1909	19,635,479	$46,005	208,947,602	$939,014
1910	52,002,557	162,069	297,652,901	1,380,731
1911	25,948,797	76,097	244,149,581	1,109,770
1912	35,810,752	104,326	250,503,372	1,265,339
1913	26,479,109	84,911	334,187,404	1,672,565
1914	26,708,381	54,677	243,633,205	1,323,194
1915	99,527,772	255,140	53,148,739	232,071
1916	150,689,445	634,447	18,539,704	204,183
1917	60,554,420	232,105	7,931,159	232,601
1918	10,864,000	103,233	38,038,815	824,022
1919	12,261,280	103,311	18,941,440	270,721

The following tables, taken from the Mineral Resources of U. S., Part 2, page 145, show by months the rapid increase and decrease of imports from Canada in 1918, and are of especial interest in showing the results of the competition of the Canadian and domestic magnesite. The imports from that country had already begun to decline before the armistice was signed.

MAGNESITE, CALCINED, NOT PURIFIED, IMPORTED INTO THE UNITED STATES 1918.

MONTH	Canada	Scotland
January	215	152
February	286	98
March	633	53
April	2,600	71
May	2,076	82
June	2,765	.....
July	2,660	.....
August	2,498	272
September	3,317	.....
October	1,129	63
November	1,254	24
December	576	52
Total Tons	20,003	867

The Bureau of Foreign and Domestic Commerce reports the following importation of magnesite during 1919 and 1920:

MAGNESITE IMPORTED INTO THE UNITED STATES.

	1919		1920	
	Short Tons	Value	Long Tons	Value
Austria	2,650	$64,933	.....	$4
Germany	34	2,023	713	28,566
Italy	2,416	62,753	21,185	241,220
Czecho-Slovakia	.....	.....	3,829	126,827
Greece	.....	.....	4,000	38,418
Turkey in Europe	.....	.....	3,528	70,540
Netherlands	.....	.....	819	54,891
England	29	4,849	28	3,511
Scotland	94	9,369	190	13,720
Canada	8,066	216,605	6,028	184,060
Mexico	2,563	13,500	500	6,300
Venezuela	.....	.....	2,300	11,500
Australia	.....	.....	34	417
Straits Settlements	.....	.....	.....	4
Totals	15,852	$374,032	43,154	$780,078

The imports for 1919 were extremely small in comparison with pre-war figures. This is largely due to the unsettled foreign conditions and it is only a question of time until European competition will be severely felt by the domestic producers of magnesite. Grecian magnesite was not entered in 1919, and the California material continued to supply the bulk of the magnesite used by the plastic trade. Likewise, the Stevens County magnesite continued until the close of 1920 as the principal source of magnesite used for refractory work. The several Washington producers closed down entirely during December, 1920, but this has apparently been caused more by the present lack of demand for refractories, rather than by a sudden increase in importations of foreign magnesite.

All of the material is now calcined or dead-burned before being shipped to the eastern markets. The carbon dioxide and moisture thus eliminated cuts the freight costs in half. The expansion of coastwise shipping tends

to encourage the belief that it may be found cheaper to ship the material by boat through the Panama Canal. At the present time there is no direct service from Seattle to New York by water, but it is highly probable that such service will be established in the near future and it is likely that the re-entrance of foreign competition will force some such shipping arrangement for magnesite. The deposits are 360 miles by rail from Seattle, and the fact that a part of the haul is over the Cascade Mountains would tend to make the freight rate still an important cost item.

RESEARCH CONDUCTED ALONG LINES OF PROPOSED NEW USES FOR MAGNESITE

INTRODUCTION

With a situation, such as has been described in the preceding paragraphs, facing the magnesite industry, research into the present and possible new uses for magnesite was undertaken in the belief that improved and more varied products would insure perpetuation of the industry regardless of the results of the foreign competition in the dead-burned refractories.

In outlining the field for possible development, it appeared that research might be undertaken along the following lines:

1. More complete geological investigation in an effort to determine extent of present domestic deposits and to locate any new ore bodies.
2. Improvement in refractory practice.
   a. Further study of the exact kiln reactions by means of metallographical and chemical research.
   b. Development of satisfactory mechanical methods for the concentration of magnesium oxide in crude magnesite.
   c. Utilization of more of the ore body.
   d. Manufacture of new refractories.
3. Study of caustic calcination, particularly in regard to the possible relationship between content of impurities and time and temperature of calcination.
4. Study of magnesia cement.
5. Reduction of magnesite to metallic magnesium.
6. Precipitation of light magnesia.
7. Development of magnesium alloys.
8. Utilization of magnesite as source for magnesium chloride.

9. Manufacture of anhydrous magnesium nitrate or basic nitrate for the fertilizer trade and as a carrier for nitric acid.

10. Investigation of minor possibilities with magnesite for raw material of which the following is but a brief list to indicate the trend of new uses.

a. Refining and drying of vegetable oils with magnesia or magnesium carbonate.
b. Improvement of utilization of magnesium salts in fire-proof paints.
c. Use in wood preservation.
d. Production of magnesium sulphite for paper manufacture.
e. Production of magnesium sulphate for textile industry and medicine.
f. Production of magnesium hydrate for sugar industry.
g. Production of magnesium perborate for bleaching purposes.
h. Use of hydrated calcined magnesia in the ammonia soda process.
i. Production of inorganic salts of magnesium, such as the fluoride, fluo-silicate, peroxide and silica fluoride and organic compounds containing magnesium.

Upon consideration of the foregoing field, the immediate possibilities of research were narrowed down to three general types: First, improved high temperature refractories, through metallographical and chemical investigation and new compositions capable of use in replacing fire-brick and other low temperature linings; second, improvement in the magnesia cements with particular reference to the calcination problem inasmuch as the many patented cement mixtures are apparently satisfactory; third, selected miscellaneous products that have never before been seriously commercially contem-

plated in connection with magnesite as the source. The first problem has been attacked by the magnesite interests themselves and, although results are not definitely known, it is understood that considerable progress has been made. The second problem was turned over to the Mines Experiment Station at Berkeley, California, and definitely favorable results are expected which will be available in publications of the Station; some phases of the third problem as dealt with at the University of Washington will be set forth in this chapter, while others were investigated by the Washington State College. The work of the latter institution was confined to precipitation of light magnesia and production of magnesium salts, on both of which favorable results were reported and the preservation of wood with magnesite for the raw material, on which the results were negative.

Three principal lines of attack were followed in the chemical laboratory of the University of Washington: First, attempts at concentration of the crude magnesite with elimination of sufficient lime and silica so that quarry run material might be available for refractories without the necessity for hand picking; second, a study of magnesium nitrates and basic nitrates to produce non-hygroscopic fertilizers and carriers of nitrate acid; third, the precipitation of light magnesia for use in heat insulators.

CONCENTRATION OF CRUDE MAGNESITE

But little work was done on this problem as all avenues of attack seemed on the face to lead to processes which, if commercially possible of achievement, would cost too much to offer any solution of the problem. The lines chosen for consideration were table concentration and the use of hydrofluoric acid with regeneration of the reagent. It was finally concluded to abandon the work, at least temporarily, and turn to the possibilities

of utilization of the waste raw material offered by a development of nitrate and basic nitrate of magnesium or light magnesia.

PROCESS FOR THE MANUFACTURE OF NON-HYGROSCOPIC MAGNESIUM NITRATE OR BASIC NITRATE

INTRODUCTION

At the present time in the United States, the question of sufficient nitrate fertilizers to satisfy the ever-increasing demand is becoming one which requires immediate attention. Nitrate from the Chile saltpeter deposits is quoted at $50.00 to $60.00 a ton laid down on the eastern seaboard. Calcium nitrate or basic nitrate, whether manufactured in the United States or imported from other countries, commands a like price and has the objectionable feature that the product, even the best obtainable, requires great care, with corresponding cost, in packing and shipping because of the hygroscopic nature of the material.

Moreover, concensus of opinion has selected the Pacific Northwest as the most favorable portion of the United States in which to develop a profitable arc process for the fixation of atmospheric nitrogen.

In view, then, of the demand for nitrate fertilizers, the necessity of utilizing magnesite in new and profitable products and the favorable location of nitrogen fixation plants, an attempt has been made to develop experimentally on a laboratory scale a process for the manufacture of a non-hygroscopic magnesium nitrate or basic nitrate which will undersell Chile saltpeter and calcium nitrate or basic nitrate, will permit of cheap and convenient handling, packing and shipping and will provide a market for two of the natural industries of the State of Washington.

A careful search through the literature failed to show that any attempt to manufacture magnesium nitrate or basic nitrate for fertilizer had ever been made. How-

ever, considerable work has been done in determining the effect of magnesium carbonate on plant life and it has been found to be much more injurious than calcium carbonate. Whether magnesium nitrate or basic nitrate would likewise be toxic could not be determined in the literature. However, at the present time, experiments are being conducted by the Department of Agriculture in an attempt to determine the fertilizing value of these salts and upon the results of this investigation will depend largely, of course, their availability as fertilizers.

It has been claimed that magnesium nitrate should offer a convenient and fairly cheap method of transporting nitric acid. It should be possible to make a non-hygroscopic magnesium nitrate from magnesite of sufficient purity to carry 15 per cent or 16 per cent nitrogen. But little care would be necessary in shipping and the freight rate should not be excessive inasmuch as the product could be classed as a fertilizer. In regenerating the nitric acid, the method used could be the same as that employed in the manufacture of the acid from Chile saltpeter inasmuch as the resultant magnesium sulphate or acid sulphate or mixture of the two, melts at a slightly lower temperature than the sodium acid sulphate resulting from the use of sodium nitrate. This would permit of the utilization of the excess niter pots and nitric acid condensors and towers at present in the United States as a result of the great increase in the production of nitric acid during the war. This apparatus would undoubtedly give a recovery of at least 98 per cent of the nitric acid.

The magnesium sulphate or acid sulphate released from the niter pots in a molten condition could be turned into a very profitable by-product by allowing it to harden, dissolving in water and precipitating light magnesia as discussed later under the work done on that problem.

Therefore, in connection with the laboratory work on a magnesium nitrate or basic nitrate for fertilizing purposes some additional laboratory work has been attempted in an effort to produce a purer non-hygroscopic magnesium nitrate than that suitable for fertilizer so that it might be used as a means of transporting nitric acid.

MAGNESIUM NITRATE OR BASIC NITRATE FOR USE AS FERTILIZER

EXPERIMENTAL WORK

All experiments were performed on a small laboratory scale, solution and evaporation being obtained in 12-inch evaporating dishes heated on a gas hot plate. Filtration was by means of a laboratory suction filter. The final product was allowed to solidify in small iron pans and the product was broken into small pieces by means of a hammer and small laboratory jaw crusher set for ¼-inch.

The tables and reactions on pages 152-155 are sufficiently complete to show the method of conducting experiments and the data obtained. The conclusions hereinafter set forth will be most readily understood by reference to these tables.

Analysis of solutions and final product for nitrogen was by means of titration with standard ferrous sulphate, the method having been developed by F. C. Bowman and W. W. Scott.

DISCUSSION OF RESULTS

Solution. Lump magnesite through a number 5 gyratory (2 inch-3 inch) reacts with least loss of HNO_3 when it is present in excess and the temperature is maintained between 40° C. and 50° C. (104° F. and 122° F.) The laboratory experiments were conducted with lump magnesite and 42 per cent HNO_3 because the magnesite is delivered from the quarry in this condition and the

HNO_3 from the arc process is of approximately this strength. However, other conditions were tried. Finer magnesite causes the reaction to proceed too fast so that the temperature is raised above the limit of 50° C. (122° F.) and there is undue loss of HNO_3 in the form of volatile oxides. HNO_3 of greater or less concentration does not apparently affect the rate of reaction but with too concentrated acid there is loss of volatile oxides. Therefore both of the original materials can be used in the condition in which they are most readily obtainable. A 98 per cent utilization of HNO_3 was obtained and is possible of attainment on a commercial scale. The remaining 2 per cent can be recovered in the final neutralization of this acid solution of $Mg(NO_3)_2$.

Purification. The principal impurities present in the magnesite are silica, iron, alumina and lime. The silica is insoluble as is whatever iron, aluminum and calcium present as silicate. The remaining iron and aluminum precipitate as hydroxide when the solution is neutralized with caustic calcined magnesite and all insoluble materials can be removed by filtration or decantation. The remaining lime is soluble as calcium nitrate and, in itself, a good fertilizer, it does no harm when present in the final product. Removal of the other impurities is necessary, however, because, although probably not harmful if added to the soil with the fertilizer, their presence necessitates a lowering of the nitrogen content of the final product below that necessary for successful competition with the calcium nitrate or basic nitrate already on the market. However, this purification can probably be realized by merely settling and decanting and is so inexpensive as to have practically no effect on the cost of the final product. Moreover, inasmuch as neutralization must be accomplished in any case, the purification can be readily carried on in conjunction with it so that its cost is reduced to practically nothing.

Neutralization. The greatest item of expense in the manufacture of the magnesium nitrate or basic nitrate, is the nitric acid. Therefore, less of this constituent, even so much as a fraction of a per cent must be avoided. To further this end, the magnesium nitrate solution is neutralized with caustic calcined magnesite, added in finely divided form (through 100 mesh). The neutralization should be with caustic calcined magnesite for two reasons, 1st, because this reaction gives least rise in temperature with consequent loss of nitrogen, and 2nd, because any excess added reacts with the magnesium nitrate solution to give soluble basic nitrate, whereas there would be no reaction with excess magnesium carbonate. Some form of agitation should be provided for the tank.

REACTION AND SOLUTION DATA—MAGNESIUM NITRATE OR BASIC NITRATE RESEARCH.

Experiment Number	DATE 1919	Magnesite Grams	H_2O c. c.	HNO_3 c. c. (1.42)	HNO_3 Grams	HNO_3 Per Cent	Excess Magnesite Per Cent	Excess HNO_3 Per Cent
1	July 30	100	125	142	141	43	.....	.....
2	July 31	25	30	36	35	43	.....	.....
3	July 31	25	40	36	35	39	.....	.....
4	July 31	25	33	40	39	43	.....	.....
5	July 31	25	0	36	35	70	.....	.....
6	July 31	25	300	36	35	10	.....	.....
7	July 31	25	30	36	35	43	.....	.....
8	July 31	25	0	36	35	70	.....	.....
9	July 31	25	300	36	35	10	.....	.....
10	July 31	25	33	40	39	43	.....	10
11	Aug. 1	1150	125	142	141	43	1050	.....
12	Aug. 4	2500	500	580	560	42	500	.....
13	Aug. 6	2500	500	580	560	42	500	.....

Experiment Number	TEMPERATURE °C.	TEMPERATURE °F.	Time Hours	Residue Grams
1	110-140	230-284	2	56
2	15- 18	59- 64.4	15	25
3	15- 18	59- 64.4	15	25
4	15- 18	59- 64.4	15	25
5	15- 18	59- 64.4	15	23
6	15- 18	59- 64.4	15	24
7	70- 80	158-176	3	18
8	70- 80	158-176	3	18
9	70- 80	158-176	3	20
10	70- 80	158-176	3	18
11	70- 80	158-176	3	1105
12	60- 64	140-147	1½	2150
13	45- 50	113-122	2½	2130

EXPERIMENTAL DATA IN FORMATION OF MAGNESIUM NITRATE AND BASIC NITRATE.

Experiment Number	DATE	Lump Magnesite Grams	HNO_3 c. c. (1.42)	HNO_3 Grams	H_2O Added at Start c. c.	HNO_3 Per Cent	H_2O in HNO_3 c. c.	Wash Water c. c.
12-A.....	Aug. 4	2500	580	560	500	42	260	240
B.....	Aug. 4	*	.....	.....	.....	.....	.....	.....
13-A.....	Aug. 6	2500	580	560	500	42	260	340
B.....	Aug. 6	*	.....	.....	.....	.....	.....	.....
14-A.....	Aug. 7	2500	580	560	500	42	260	240
B.....	Aug. 7	*	.....	.....	.....	.....	.....	.....
15.....	Aug. 8	1200	290	280	250	42	130	120
16.....	Aug. 11	1200	290	280	250	42	130	120
17.....	Aug. 12	1200	290	280	250	42	130	120
18.....	Aug. 13	1200	290	280	250	42	130	120
19-A.....	Aug. 14	2500	580	560	500	42	260	340
B.....	Aug. 15	*	.....	.....	.....	.....	.....	.....
20-A.....	Aug. 18	2500	580	560	500	42	260	240
B.....	Aug. 19	*	.....	.....	.....	.....	.....	.....
21-A.....	Aug. 20	2500	580	560	500	42	260	440
B.....	Aug. 21	*	.....	.....	.....	.....	.....	.....
22-A.....	Aug. 22	2500	580	560	500	42	260	440
B.....	Aug. 25	*	.....	.....	.....	.....	.....	.....

* A and B combined until $MGNO_3$ solution divided into two equal parts.

EXPERIMENT NUMBER	H_2O Due to Reaction c. c.	Temperature of Reaction $HNO_3 + MgCO_3$ °C.	Time of Reaction $HNO_3 + MgCO_3$	MgO for Neutralization Grams	Grams Caustic Calcined Mag'site for Neutralization
12-A.....	75	60-64	1.5	.....	.....
12-B.....	.....	.....	.....	.....	.....
13-A.....	75	45-50	2.5	.....	.....
13-B.....	.....	.....	.....	.....	.....
14-A.....	75	45-55	2.5	.....	.....
14-B.....	.....	.....	.....	.....	.....
15	38	45-50	3.0	80	.....
16	38	45-50	3.0	80	.....
17	38	45-50	3.0	50	.....
18	38	45-50	3.0	50	.....
19-A.....	75	45-50	3.0	.....	80
19-B.....	.....	.....	.....	50	.....
20-A.....	75	45-50	3.0	55	.....
20-B.....	.....	.....	.....	55	.....
21-A.....	75	40-45	4.0	.....	90
21-B.....	.....	.....	.....	.....	50
22-A.....	75	45-50	4.0	.....	80
22-B.....	.....	.....	.....	.....	80

Experiment No.	Residue Grams	Solution c. c.	Utilization HNO_3 in Reaction $HNO_3 + MgCO_3$ Per Cent	Temperature of Evaporation °C.	Time of Evaporation Hours	C. c. of Solution When Excess Oxide Added
12-A	2150	1300	90	100-125	3.5	200
12-B	.....	*	.....	100-125	3.5	200
13-A	2130	1400	98	100-125	4.0	200
13-B	.....	*	.....	100-125	4.0	200
14-A	2250	1300	66	100-150	4.0	200
14-B	.....	.....	.....	100-150	4.0	200
15	1167	.....	98	100-150	3.5	.....
16	1167	.....	98	100-150	3.5	250
17	1130	.....	98	100-150	3.5	250
18	1130	.....	98	100-150	3.5	250
19-A	2350	1400	99	100-150	3.5	200
19-B	.....	*	99	100-150	3.5	200
20-A	2370	1300	99	100-150	3.5	200
20-B	.....	.....	99	100-150	3.5	200
21-A	2290	1500	98	100-150	3.5	250
21-B	.....	*	98	100-150	3.5	250
22-A	2400	1500	98	100-150	3.5	250
22-B	.....	*	98	100-150	3.5	250

* A and B combined until $MgNO_3$ solution divided into two equal parts.

Experiment Number	Grams MgO Added to Give Mg (OH) (NO_3)	Grams Caustic Calcined Magnesite Added for Mg (OH) NO_3)	Loss HNO_3 in Evaporation Per Cent	Final Product Grams	Nitrogen in Final Product Per Cent
12-A	.....	70	10	495	10
12-B	.....	70	12	**410	11
13-A	.....	50	12	540	10
13-B	.....	50	12	530	10
14-A	50	.....	10	400	9
14-B	50	.....	12	**350	10
15	.....	.....	2	390	15
16	25	.....	2	540	11
17	50	.....	1	510	12
18	75	.....	1	525	11.5
19-A	.....	75	1	530	11.5
19-B	.....	75	1	510	12
20-A	.....	60	0	485	12.5
20-B	.....	***55	0	500	12
21-A	.....	50	0	**440	13.8
21-A	.....	40	0	**435	13.9
22-A	.....	50	0	**460	13.4
21-B	.....	None	0	**400	15.0

** Impurities filtered out.
*** Dead-burned magnesite added.

EXPERIMENT NUMBER	Per Cent Over All Loss of Nitrogen	Non-Hygroscopic Properties of Final Product Aug. 25, 1919	Non-Hygroscopic Properties of Final Product July 1, 1920
12-A	20	Fair	No good
12-B	22	Poor	No good
13-A	14	Fair	No good
13-B	14	Fair	No good
14-A	44	Fair	No good
14-B	46	Poor	No good
15	4	Good	Good
16	4	No good	No good
17	3	Fair	No good
18	3	Good	Good
19-A	2	Good	Good
19-B	2	Good	Good
20-A	1	Good	Good
20-B	1	No good	No good
21-A	2	Good	Good
21-B	2	Good	Good
22-A	2	Good	Good
22-B	2	Good	Good

The final product resulting from experiments where there was complete neutralization showed better non-hygroscopic characteristics than where an acid solution was evaporated and allowed to solidify.

Evaporation. Evaporation after neutralization proceeds at 100°C. (212°F.) until all water in excess of that necessary to give a solution of $Mg(NO_3)_2 . 2H_2O$ is driven off. When this point is reached, the temperature begins to rise. If now approximately half the theoretical amount of caustic calcined magnesite necessary to completely convert the magnesium nitrate to the basic nitrate, is added in finely divided form (through 100 mesh) and the temperature allowed to rise until it reaches another stationary point (145 to 150°C.—293 to 302°F.) the material may be poured and allowed to set giving, finally, a product that shows good non-hygroscopic properties. Many methods of conducting this evaporation were tried and discarded in favor of the one outlined here. Variations in temperature only served to emphasize the fact that the method outlined here was most easily controlled, permitted of simplest methods of mechanical handling and gave the most consistently non-hygroscopic product.

No matter what the subsequent method of evaporation it is self-evident that the first step is to eliminate the water in excess of that necessary to give $Mg(NO_3)_2 . 2H_2O$. This point is easily detected for when it is reached the temperature begins to rise above 100°C. The point at which to add the caustic calcined magnesite was more difficultly determined. However, it was found best to convert the nitrate to the basic nitrate as soon as possible after the temperature started to rise because otherwise there seemed to be decomposition of the nitrate with consequent loss of nitrogen. This decomposition is not evident with the basic nitrate nor with the nitrate in the presence of basic nitrate until a temperature of 145°C. —150°C. is reached. At this temperature, however, there is evidence of decomposition and the temperature remains stationary. If now the solution is poured it is found that the product is very satisfactory. The question of how much caustic calcined magnesite to add offered difficulties. Over half the theoretical amount caused crystallization of nitrate and basic nitrate from the solution before the time to pour. The resulting final product was poor as a non-hygroscopic material and moreover was removed from the evaporating dish with great difficulty because of its semi-solid character. Less than half the theoretical amount of caustic calcined magnesite converted too small a part of the two molecules of water of crystallization in the $Mg(NO_3)_2 . 2H_2O$ into the hydroxyl radical of the basic nitrate so that the final product was unnecessarily high in nitrogen content for successful competition with other nitrate fertilizers. The result of repeated experiments showed it to be best to add approximately one-half of the theoretical amount of caustic calcined magnesite necessary for complete conversion to basic nitrate. The resulting product is an intimate mixture of practically one part of nitrate to one part of basic nitrate bound together with whatever im-

purities the caustic calcined magnesite contained and what water remains unconverted to the hydroxyl radical of the basic nitrate. This product is completely fluid when poured at the beginning of decomposition at 145° C.(293°F.) so is easily handled from the evaporation. The product on solidifying is sufficiently non-hygroscopic for the uses to which it would be put. The nitrogen content would be a little better than 13 per cent or practically the same as that of the calcium nitrate or basic nitrate now on the market.

By-product. Although no experimental work has been done on the utilization of the impurities settled out from solution in the settling tank, it is possible that the material so obtained might be used for the manufacture of fire brick of some sort. After heating, the material would be essentially oxides of iron and aluminum and magnesium, silicates of iron and aluminum and possible silicate of magnesium if the brick were treated to sufficient temperature during manufacture. Such a combination suggests itself as a possible source of refractory brick.

Costs. It is with difficulty that any cost estimate is attempted with the data at hand and the following is merely a suggestion subject to great modification if more detailed study of the subject is pursued. It is based on a tonnage of thirty tons of finished product per day and an investment of $250,000.

ESTIMATE OF COSTS IN MANUFACTURE OF MAGNESIUM NITRATE OR BASIC NITRATE

Original Material:	
13 tons magnesite at $6.00 per ton	$78.00
17.4 tons of HNO_3 (100 per cent) at $55.75 per ton	870.00
3.5 tons caustic calcined magnesite at $15	52.00
Total for material per day	$1,000.00

Cost of Operation:	
Power	$8.00
Labor (12 operators) at $5.00	60.00
Repairs (5 per cent per annum)	33.00
Overhead (5 per cent per annum)	33.00
Interest (10 per cent per annum)	66.00
Total for operation per day	$ 200.00
Total cost 30 tons final product	$1,200.00
Total cost 1 ton final product	40.00
Total cost 1 pound final product	.02

The above figures are based on a final product running 13 per cent nitrogen. 30 tons such final product would contain 3.9 tons nitrogen which would be provided by 17.5 tons of 100 per cent HNO_3. This amount of HNO_3 would require 13 tons of magnesite running 90 per cent $MgCO_3$ for neutralization and 3.5 tons of caustic calcined magnesite for a suitable final product. It is assumed that no HNO_3 is lost. The HNO_3 is provided at 30-40 per cent concentration, at which strength it is estimated to cost $55.75* per ton of 100 per cent HNO_3. The only power required is for pumps and agitation inasmuch as all heat is provided as waste from the nitrogen fixation plant. The labor provided at $5.00 per day is sufficient. The estimate for repairs is high as is also the overhead especially if the process is incorporated into the nitrogen fixation process. The interest is 10 per cent on $250,000.

The cost of Chile saltpeter on the Atlantic coast at the time of the above estimate was made was $57.50 per ton or 2.875 cents per pound. The freight on either Chile saltpeter or magnesium nitrate or basic nitrate from coast to coast would be about 1.00 cent per pound.

CONCLUSIONS FROM THE EXPERIMENTAL WORK ON THE PREPARATION OF MAGNESIUM NITRATE OR BASIC NITRATE FOR USE AS FERTILIZER

1. A non-hygroscopic magnesium nitrate, basic nitrate or combination of the two which carries thirteen to

* See Final Report of Nitrogen Products Committee of Great Britain, p. 237.

thirteen and one-half per cent of nitrogen can be made at what appears to be a cost low enough to meet competition.

2. The substance does not noticeably take on water after eleven months' exposure to many variations of atmospheric conditions and could easily be shipped in box cars without packing other than paper or similar protection from rain.

3. The substance will absorb water if subjected to treatment as severe as exposure for periods of time exceeding one month in an ice-filled refrigerator.

4. A process, each point of which has been fully developed has been evolved whereby this non-hygroscopic substance may be manufactured.

5. The toxicity of the substance when used as a fertilizer has not been determined but is being worked upon by the Department of Agriculture.

MAGNESIUM NITRATE AS A MEANS OF TRANSPORTING NITRIC ACID

EXPERIMENTAL WORK

Experiments 15 and 22B were performed with the object of obtaining magnesium nitrate which would be as pure as possible and contain as great a percentage of nitrogen as possible. The first requirement is easily obtained simply by use of the process outlined for the manufacture of magnesium nitrate or basic nitrate for fertlizer, omitting, however, the addition of caustic calcined magnesite to the solution in the evaporator. The resulting product would be free from all impurities except calcium nitrate. The possible necessity for an additional step in the process to remove this impurity will be discussed later. The second requirement seems to be limited to about 15 per cent nitrogen which would give a nitrate of magnesium corresponding to the formula $Mg(NO_3)_2.2H_2O$. A further concentration of the nitro-

gen content is possible by heating of the solution being evaporated beyond 145°C. (293°F.) but such concentration is accompanied by a decomposition and loss of nitrogen in the form of volatile oxides and so is prohibited inasmuch as loss of nitrogen must be limited to the smallest possible amount.

DISCUSSION OF RESULTS

Advantages. Consequently it is possible to convert the nitric acid from an arc nitrogen fixation process, possible only in the northwestern portion of the United States, into a pure, high-nitrogen content carrier. There can be little doubt as to the great advantage in shipping non-hygroscopic magnesium nitrate rather than nitric acid. To ship nitric acid in tank cars would require concentration, at great expense, to an acid much stronger than the 30-40 per cent product coming from the final tower of the fixation product. Furthermore, sulphuric acid and oleum would have to be added to the concentrated nitric acid to prevent attack upon the iron of the tank car and these additions would render the nitric acid unfit for certain uses. Finally, if the nitric acid is not shipped in tank cars it must be transported in expensive drums, carboys, or other acid-proof containers. In any case the handling costs, interest on invested capital and freight rates are high. With magnesium nitrate, there would be no need for concentration of the nitric acid beyond 42 per cent and, provided always that the nitrate proves to be sufficiently non-hygroscopic, it could be shipped in box cars as fertilizer with a correspondingly low freight rate.

Regeneration. In consideration of the regeneration of the nitric acid from the magnesium nitrate many favorable features are found. In the manufacture of nitric acid from sodium nitrate the niter pots, of which there are an abundance in the United States today, are de-

signed to allow the removal of the resultant sodium sulphate and acid sulphate in the molten form inasmuch as this is the physical condition of these products at the temperature used for the reaction between sodium nitrate and sulphuric acid. In like manner, magnesium sulphate which, with nitric acid, would result from the reaction between magnesium nitrate and sulphuric acid, would be in the molten condition at the temperature of the reaction and so would afford utilization of the niter pots already manufactured. It is in this connection, however, that some consideration of the calcium nitrate present as an impurity in the magnesium nitrate must be taken. The reaction in the niter pots would transform this calcium nitrate into calcium sulphate and nitric acid and calcium sulphate is not molten at the temperature of the reaction. The calcium sulphate would constitute about 3% of the total sulphate present. Only experiment would determine whether the construction of the niter pots and the conditions present therein would permit of the 97 molten parts carrying with them from the pots the 3 solid parts without clogging which would necessitate subsequent shut-downs for cleaning out the solid calicum sulphate. It seems very possible, however, that the calcium sulphate would be so carried out. If not, however, some steps as previously mentioned in this discussion, would have to be taken to purify the magnesium nitrate solution of calcium nitrate before evaporation.

Hygroscopicity. The material made has non-hygroscopic properties sufficient to permit of easy transportation in box cars as shown through observation over a period of eleven months.

By-product. So far no consideration of the utilization of the magnesium sulphate coming molten from the niter pots has been made. Suffice to say that this ma-

terial can be made into the light magesnia which forms 85 per cent of the 85 per cent magnesia pipe covering so widely advertised. A description of product will be undertaken in the following discussion where the possibilities of its manufacture from magnesite will be outlined. Attention here is called to the fact that its utilization as a by-product in the transportation of nitric acid commences at that point in the process of its manufacture from magnesite where the magnesium is present in the form of the sulphate in dilute solution.

CONCLUSIONS FROM THE EXPERIMENTAL WORK ON THE PREPARATION OF MAGNESIUM NITRATE AS A MEANS OF TRANSPORTNG NITRIC ACID.

1. A non-hygroscopic magnesium nitrate free from all impurities except calcium nitrate, conforming to the formula $Mg(NO_3)_2.2H_2O$ and carrying from 15 to 16 per cent nitrogen can be made from magnesite.

2. This product has remained non-hygroscopic through eleven months of exposure without protection other than paper to all kinds of atmospheric conditions; it will absorb water, however, if submitted for longer than one month to the atmosphere in an ice-filled refrigerator.

3. It could be shipped in box cars, eliminating many of the objections to other nitrates.

4. The arc nitrogen fixation process and the magnesite deposits are located in close proximity in the Pacific Northwest.

5. The nitric acid can be regenerated in apparatus now available for use with sodium nitrate.

6. The molten magnesium sulphate resulting from the regeneration is available as a source of light magnesia.

PREPARATION OF LIGHT MAGNESIA FROM MAGNESITE

COMPOSITION OF LIGHT MAGNESIA

The exact chemical composition of the so-called light magnesia, as it finds use in "85% Magnesia" products, is not definitely known. However, authorities have nearly agreed in the belief that when it is precipitated at room temperature it conforms to the formula $3MgCO_3Mg(OH)_2 3H_2O$ and when precipitated from a boiling solution to the formula $Mg_3(OH)_2(CO_3)_2$. In either case it is not known whether the precipitate is a basic salt of either of the above compositions, or merely mixtures of the hydroxide and carbonate in the proper proportions to give these compositions. Moreover, if precipitated at temperatures other than these two, there seems to be evidence of still other compositions. The final product must be very bulky and practically free from all impurities, the principal among which are apt to be silica and salts of calcium, iron and aluminum.

TYPICAL METHODS OF PREPARATION FROM DOLOMITE

At the present time dolomite is used generally as the original material in the preparation of such light magnesia. But very little is known concerning the methods employed in the manufacture of this product. One of the principal methods used is described by Capt. F. W. Bartlett.[1] He says, in part:

"The works are generally located at the deposit, to save freight, and a cheap method of quarrying and conveying the rock is devised. The native rock is a mixture of calcium and magnesium carbonates. Since the calcium must be removed, the rock is first calcined, using charcoal as fuel. The carbonic acid produced is used later. The calcined rock is next mixed with water in special rotating vessels where the lime is slaked. All impurities remain in the vessel, and all the lime is

[1] F. W. Bartlett, Power, Vol. 42, p. 426, 1915.

carried away by the overflowing water during the operation. The oxides are now in a state of suspension in the water, the percentage of the soluble material being very small. The later processes consist in a juggling of 'states of suspension' and 'of solution' to separate the calcium and the magnesia.

"The liquid is pumped into vertical metal cylinders about 5 feet in diameter and 15 feet high. These have pipes leading from the top head to near the bottom for the entrance of the carbon dioxide, derived from the calcining. This gas is pumped from the calcining kilns and returned to these cylinders under a pressure of about 70 pounds. It rises through the liquid, being absorbed by the oxides in suspension in the water, and reconverts them into carbonates. But this operation produces an important difference in the condition of the two carbonates—after the operation the calcium carbonate is in suspension and the magnesium carbonate is in solution. The next step, the separation of the material, is achieved by a system of filtration. The liquid enters the interior of a series of wood cells perforated by small holes and lined with cotton canvas or cloth, which act as filters. The water passes out, carrying with it the magnesium carbonate while the calcium carbonate in suspension is caught in the meshes of the cloth as a paste. This is the end of the calcium carbonate as far as this process is concerned.

"The water containing the weak solution of magnesium carbonate is next put into other vertical cylinders of about the same size as the corbonating cylinder and is there heated by steam to about 190°F. At this temperature the magnesium carbonate goes again into suspension instead of into solution. The liquid is then pumped to open vats lined with thin cloth, and most of the water is drained off, just enough remaining to allow the mixture to be pumped to the molds.

"The molds are like the filtering cells, with the same size of holes and kind of cloth. A number of cells are placed beside one another and pressed together firmly, and the liquid is allowed to enter them all at once. When all are filled so that no more liquid flows from the openings, the cells are opened. The material that was in suspension has been retained by the filtering process, and the mold is filled with magnesium carbonate.

"The magnesium carbonate used for pipe or boiler covering is mixed with asbestos fiber so that the resulting mixture may not be so brittle. The covering is formed in molds that resemble the kilns previously described, except that cores are made as in foundry work and the outside corresponds to the shape desired. After the molds are made they are dried for six days in extensive ovens, and later are finished just as if they were made of wood."

Another clue to a method of manufacture is contained in the following quotation: "Minerals containing magnesium are finely powdered and treated with sulphuric acid, the heat of the reaction being allowed to rise high enough to prevent formation of gelatinous silica; less sulphuric acid is used than is necessary to combine with all the magnesium. The magnesium compound thus produced is recovered."

POSSIBLE METHODS OF PREPARATION FROM MAGNESITE

Three possible methods for the manufacture of light magnesia from magnesite are suggested by the foregoing excerpts from the literature. First, the application to magnesite of the treatment described by Capt. Bartlett, where dolomite is the original material. There is no apparent reason why any change should be necessary in the process in order that the resulting product should be as satisfactory as that obtained from dolomite. On

the other hand, there is every reason to believe that the cost of the product would be reduced, due to the higher percentage of magnesia in magnesite with consequent lessening of the amount of impurities which would have to be handled.

The second method would be a modification of that described by Capt. Bartlett. The magnesite, suspended in a finely divided state in water, might be treated directly with carbon dioxide gas under pressure when, because of the greatly increased surface of magnesium carbonate exposed to the action of the carbon dioxide, it is believed that the basic carbonate would go directly into solution, the carbonate of lime, silica, sulphates and other impurities remaining in suspension to be later removed by filtration. From this point on the process would be unchanged. The gain in such a modification would be that calcination would be eliminated and there would be a decided decrease in the quantity of impurities handled so that the cost of manufacture might be materially lessened.

The third method, in brief, would be as follows: The material would be treated with sulphuric acid and the procedure so regulated that it results in an alkaline solution of magnesium and calcium sulphates. Silica and silicates, iron and aluminum hydroxides and other impurities are insoluble. The magnesium sulphate solution is freed of impurities by filtration and, after dilution, the light magnesia is precipitated by means of sodium carbonate, sodium acid carbonate, carbon dioxide gas, or some combination of the three.

The experimental work and the results described in this paper are limited to those obtained by application of this third method.

EXPERIMENTAL

Analysis of Magnesite obtained from the Northwest Magnesite Co.:

	Crude Per Cent	Calcined Per Cent
Silica (SiO_2)	1.51	7.01
Iron and Aluminum	3.95	7.43
Lime (CaO)	1.29	2.40
Magnesia	44.6	38.3
Loss on ignition	48.65	48.86
	100.00	100.00

The above analysis was performed according to the method described by H. P. Talbot.[1]

The problem resolves itself into three parts: First, the determination of conditions producing maximum completeness of the reaction between magnesite and sulphuric acid; second, the determination of the most favorable dilution, temperature and the precipitant for giving high grade light magnesia, and, third the testing of the resulting product to determine its thermal conductivity when mixed with asbestos as a binder.

Solution of Magnesite in Sulphuric Acid. At the start the experiments were conducted in 12 inch evaporating dishes, heated over a gas hot plate, in an effort to determine the concentration of sulphuric acid and the temperature which would most readily and completely promote solution. However, no satisfactory results were obtained, due to the fact that the reaction did not proceed without agitation. After some preliminary small-scale operations, which were highly encouraging, one liter beakers were substituted for the evaporating dishes and the mixture kept agitated by means of stirrers propelled by water turbines. This arrangement proved to be satisfactory. Starting out with the same known weight of magnesite in each case, it was treated with different amounts of sulphuric acid of varying dilution and the number of hours required for the solution to become alkaline was determined, methyl orange being

[1] H. P. Talbot, Quantitative Chemical Analysis, p. 44.

employed as the indicator. The following results were obtained:

(Solution of Magnesite in Sulphuric Acid)

Run No.	I	II	III	IV	V
Magnesite used	200gr	200gr	200gr	200gr	200gr
Sulphuric acid	60cc	60cc	30cc	31.5cc	30cc
Water	600cc	1200cc	300cc	600 cc	600cc
Temperature	70°C	70°C	70°C	75°C	45°C
Hours required for the completion of the reaction	14	13.5	8	6	9.5

Discussion of Solubility Tests. Apparently, then, it is best to have the magnesite ground to pass through 100 mesh; the strength of the acid should be one part of

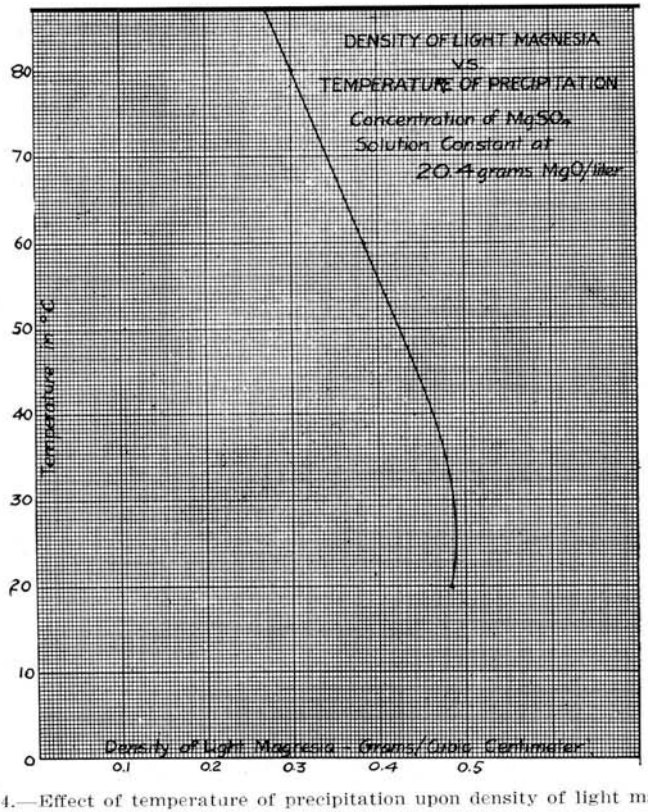

FIG. 4.—Effect of temperature of precipitation upon density of light magnesia —Concentration of MgSO, solution constant at 20.4 grams MgO per liter.

sulphuric acid (1.82 sp. gr.) to 20 parts of water by volume; the temperature should be in the neighborhood of 70° Centigrade; there should be a 75% excess of magnesite present; and finally, the reaction should be accompanied by constant agitation.

Utilization of Sulphuric Acid. Having obtained the product of the reaction between magnesite and sulphuric acid, the per cent utilization of the acid was next determined by precipitating the magnesium with sodium hydrogen phosphate and weighing it as magnesium pyrophospate. The weight of magnesium thus obtained divided by the theoretical value indicates the utilization

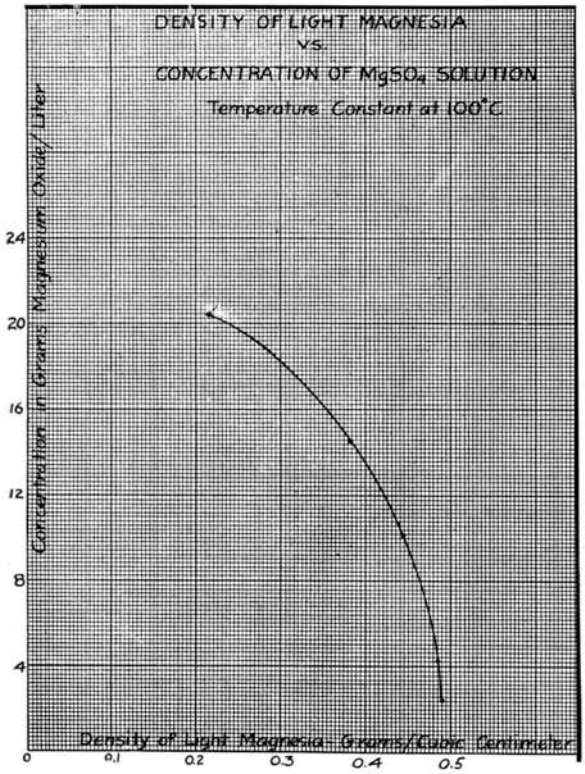

FIG. 5.—Effect of concentration of $MgSO_4$ solution upon density of light magnesia. Temperature of precipitation constant at 100°C.

of the acid. Results obtained averaged 96% and would probably range higher on a commercial scale.

Precipitation of Light Magnesia. The next step was the precipitation of light magnesia. Extensive work has been carried on in an effort to determine the best conditions for this phase of the work. The results are tabulated according to the following table and curves have been drawn to further emphasize important characteristics.

PRECIPITATION OF LIGHT MAGNESIA

RUN	Volume $MgSO_4$ Solution	Concentrat'n $MgSO_4$ Solution	Weight MgO in Solution	Temperature of Precipitation	Weight Na_2CO_3 Added
NUMBER	c. c.	Grams MgO/liter	Grams	°C.	Grams
1	50	34.2	1.71	20	8.0
2	100	17.1	1.71	20	8.0
3	150	11.4	1.71	20	8.0
4	200	8.55	1.71	20	8.0
5	25	20.6	0.515	20	3.0
6	50	10.3	0.515	20	3.0
7	75	6.86	0.515	20	3.0
8	50	10.3	0.515	60	3.0
9	50	10.3	0.515	80	3.0
10	50	10.3	0.515	100	3.0
11	50	10.3	0.515	100	3.0
12	50	10.3	0.515	100	2.4
13	75	6.86	0.515	100	2.4
14	25	20.6	0.515	60	2.4
15	35	14.7	0.515	100	1.7
16	35	14.7	0.515	100	1.7
17	125	4.22	0.515	100	2.4
18	175	2.94	0.515	100	2.4
19	15	44.7	0.515	100	2.4
20	105	19.53	2.05	100	7.0
21	95	21.6	2.05	100	7.0
22	95	21.6	2.05	100	7.0
23	100	20.6	2.06	80	7.0
24	50	20.4	1.02	100	4.8
25	50	20.4	1.02	100	4.8
26	50	20.4	1.02	100	4.8
27	50	20.4	1.02	100	4.8

RUN	Concentrat'n Na_2CO_3 Solution	Weight $NaHCO_3$ Added	Weight $NaHCO_3$ Per Gram of MgO	Other Reagents	Weight of Light Magnesia Obtained
NUMBER	Grams Na_2O Per Liter	Grams	Grams		Grams
1	150	.....	.....	.....	6.6420
2	150	.....	.....	.....	7.9168
3	150	.....	.....	.....	8.7850
4	150	.....	.....	.....	6.7380
5	175	.....	.....	.....	1.6900
6	175	.....	.....	.....	1.5600
7	175	.....	.....	.....	1.3800
8	175	.....	.....	.....	3.5160
9	175	.....	.....	.....	1.8700
10	175	.....	.....	.....	2.9640
11	175	.....	.....	.....	1.4190
12	140	.....	.....	.....	1.3716
13	140	.....	.....	.....	1.3524
14	140	.....	.....	.....	1.3766
15	98	0.2	0.388	.....	1.2300
16	98	0.4	0.776	.....	1.2952
17	140	0.4	.....	.....	1.5004
18	140	.....	.....	.....	1.5122
19	140	.....	.....	.....	1.1520
20	137	3.2	1.560	.....	4.1854
21	137	2.5	1.220	.....	5.1220
22	137	1.0	0.486	.....	5.0020
23	137	3.2	1.550	.....	5.5600
24	140	1.6	1.570	CO_2	1.6250
25	140	1.4	1.372	CO_2	1.3860
26	140	1.6	1.570	CO_2	1.8130
27	140	1.5	1.470	CO_2	1.5740

Note.—Solid sodium bicarbonate was added.

RUN	Volume obtained	Weight lee light Magnesia	MgO in light Magnesia	Recovery of MgO
No.	c. c.	Grams	Grams	%
1	7.6	0.876	.....	.....
2	8.5	0.980	.....	.....
3	9.9	0.886	.....	.....
4	8.0	0.835	.....	.....
5	3.5	0.483	.....	.....
6	.....	.....	.....	.....
7	.....	.....	.....	.....
8	4.2	0.838	.....	.....
9	.....	.....	.....	.....
10	.....	.....	.....	.....
11	3.2	0.445	0.438	85.3
12	3.6	0.382	0.458	89.1
13	3.4	0.398	0.463	90.0
14	3.6	0.383	.....	.....
15	3.2	0.385	.....	.....
16	3.1	0.418	.....	.....
17	3.1	0.485	.....	.....
18	3.1	0.489	.....	.....
19	3.2	0.362	.....	.....
20	14.5	0.289	.....	.....
21	17.6	0.291	1.970	95.9
22	15.4	0.347	.....	.....
23	18.0	0.298	.....	.....
24	7.6	0.214	0.989	97.0
25	6.1	0.227	0.994	97.3
26	7.8	0.233	0.982	96.4
27	6.9	0.229	0.990	97.0

Note: A reflux condenser was used in the last five runs in order to keep the volume the same in each case, thus carrying the precipitation out under the same conditions every time.

Discussion of Precipitates. The results obtained in runs 24, 25, 26 and 27 are very satisfactory since the weight of one cubic centimeter of the light magnesia compares favorably with the density of a sample obtained from Johns-Manville Co. and determined as 0.21 gr./cc. Moreover these results can be duplicated and the overall recovery of magnesium oxide is sufficiently high to permit of commercial operation. The concentration of the magnesium sulphate solution and the temperature existing at the time of precipitation are very important factors. Degree of completeness of precipitation together with lightness of the precipitant increase with increased dilution to 20.4 grams magnesium oxide per liter and with increased temperature to 100° Centigrade.

Thermal Conductivity Test. The third part of the procedure was the testing of the light magnesia obtained by runs 24, 25, 26, and 27 for thermal conductivity. Mixed with asbestos fiber in the ratio of 85 to 15 the light magnesia was placed under a pressure of about 2500 pounds, after which it was dried in an oven for about three days.

Description of Apparatus. The heat conductivity test was carried out according to the method described by Frederick A. Osborn.[1] The apparatus used consisted of a double walled vessel with a heavy copper bottom, 4mm. thick, projecting 0.5cm. beyond the walls. The diameter of the bottom was 16cm. The areas of the two cylinders were the same, a cover had openings for two stirrers, one in each compartment and for two thermometers. The heater consisted of a cylinder 15cm. in diameter and about 1 cm. thick. The upper face of the heater was made of the same heavy copper used in the calorimeter.

[1] F. A. Osborn, School Science and Mathematics, Vol. 19, May, 1919.

Two 0.5cm. tubes project from opposite sides of the heater for the inlet and outlet of the steam.

Method of Testing. The method of operation was as follows: Five hundred grams of water 5 or 6 degrees below the room temperature were put into each compartment, the test piece of "85% Magnesia" was placed on the heater and the calorimeter set on it. Steam was admitted into the heater and the stirrers started. If the room temperature was 20°C., the first reading of the temperature in the inner compartment was taken when the temperature was 17°C., the time being noted. The second reading was taken at 23°C., time again being read.

Results. The thickness of the material used was obtained with a vernier caliper, several readings with different degrees of compression giving the probable thickness.

THERMAL CONDUCTIVITY TESTS

Area of the inner compartment (A)c	79.25 sq. cm.
Water equivalent of calorimeter (W')	26.25 grams
Mass of water heated (W)	500 grams
Room temperature (t')	21.°2 C.
Steam temperature (t)	100°C.
Temperature of water at the start (t')	21°2 C.
Temperature of water at the end (t'')	23°:2 C.
Time at the start 4- 4-50 ⎫	
Time at the end 4-14-20 ⎭	570 seconds
Thickness of the sample (D)	0.635 cm.

The coefficient of conductivity of (K) of "85% Magnesia," as prepared from magnesite, in calories per centimeter cube per degree Centigrade temperature diffierence per second is caluculated as follows:

$$K = \frac{(W' + W)\ (t''-t')\ (D)}{(A)\ (t-t')\ (T)} = \frac{(526.25)\ (2)\ (0.635)}{(79.29)\ (78.8)\ (570)} = 0.000189$$

Discussion of Results. The result obtained compares favorably with the thermal conductivity of white magnesia[1] which is given as 0.000170, but no data in C. G. S. units is available in order that it may be compared with that of commercial "85% magnesia."

[1] Chem. Ab., Vol. 11, p. 3403. 1917.

CONCLUSIONS FROM THE EXPERIMENTAL WORK ON THE PREPARATION OF LIGHT MAGNESIA FROM MAGNESITE

I. A maximum completeness of the reaction between magnesite and sulphuric acid is obtained when:

1. The magnesite is ground to pass through 100 mesh.
2. The strength of the acid is one part of sulphuric acid (sp.gr.1.82) to 20 parts of water by volume.
3. The temperature is in the neighborhood of 70° Centigrade.
4. There is a 75% excess of magnesite present.
5. The reaction is accompanied by constant agitation.

II. The utilization of sulphuric acid averaged 96% throughout the experimental work but would probably range higher in commercial operation.

III. High grade light magnesia is obtained when:

1. The concentration of the magnesium sulphate solution is 20.4 grams magnesium oxide per liter.
2. The precipitants used are a 2.32 normal solution of sodium carbonate, solid sodium bicarbonate and gaseous carbon dioxide.
3. The weight of precipitants per each gram magnesium oxide in solution is 4.7 grams sodium carbonate and 1.47 grams sodium bicarbonate.
4. The precipitants are added with agitation in the following order, the magnesium sulphate solution being at room temperature; sodium bicarbonate, sodium carbonate, carbon dioxide.
5. The temperature is raised to 100° Centigrade after addition of the precipitants and the solution boiled until the reaction is complete.

IV. The thermal conductivity of a sample of "85% Magnesia" prepared from magnesite is 189×10^{-6} calories per centimeter cube per degree Centigrade temperature difference per second and indicates satisfactory heat insulation were the material to have commercial use.

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This bibliography is divided into two parts. Part one includes the references which describe chiefly the geology and occurrences of magnesite, while part two refers to articles on the preparation and utilization of magnesite. For convenience of reference the citations are arranged in chronological order; the articles under each yearly division are arranged alphabetically according to the authors name. Many new references were secured from the excellent bibliography prepared by McDowell and Howe for the March, 1920, Journal of the American Ceramic Society.

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