LIME AND MAGNESIA.

SOME MAGNESITE DEPOSITS OF CALIFORNIA.

By Frank L. Hess.

INTRODUCTION.

Magnesite, while not a common mineral, is found at a considerable number of places in different parts of the world where there are large areas of serpentine, peridotites, and pyroxenites. The principal foreign deposits now worked are in Germany, Austria, Greece, Italy,[a] and India.[b] Unworked deposits are known in Lapland, Sweden, Russia, Africa, Quebec,[c] near Atlin Lake, British Columbia, and in Mexico, of which the deposits in Quebec may be altered sedimentary rocks.

In the United States the most important occurrences are in California, with lesser ones in Southern Oregon, Nevada, Pennsylvania,[d] Maryland,[e] and Massachusetts.

The Pennsylvania and Maryland deposits were at one time worked in a small way and the product used for making Epsom salts and other chemicals, but magnesite from Austria and Greece can now be imported so cheaply that they no longer pay to operate.

In California there are many deposits scattered along the Coast Range from the Oregon line to below Los Angeles, with a few along the foothills of the Sierras. Deposits are worked near Livermore and Porterville, and mines were formerly operated at Chiles Valley, Pope Valley, and in a desultory way at other points. The four places mentioned were visited by the writer in November, 1905.

COMPOSITION AND USES.

Magnesite, as it occurs in the California deposits, is a beautiful white fine-grained rock with a conochoidal fracture that looks like a break in fine china. It is magnesium carbonate, $MgCO_3$, and is about one-third harder and heavier than calcite. It contains 52.4 per cent of carbon dioxide (CO_2) and 47.6 per cent of magnesia (MgO). Like limestone, it gives off carbon dioxide on burning, and it is used for producing this gas, as the proportion contained is much greater than in limestone, which carries but 44 per cent. The residual magnesia left on burning is also more valuable than the lime left on burning limestone, and the amount of heat required to drive off the CO_2 is less. The burned magnesia (MgO) is used for making refractory brick for use with basic slags, as in copper smelting and some steel making, as an adulterant in paint, and medicinally. After being changed to the sulphite it is used in the digestion of wood pulp for paper. The light carbonate, known also as magnesia alba levis, is employed for medicinal and toilet purposes, and with varying

[a] D'Achiardi, Giovanni, La formazione della magnesite all' Isola d'Elba: Atti della Società toscana di scienze naturale, residente in Pisa; Memorie, vol. 20, 1904, pp. 86–134, 3 pls.

[b] Eckel, Edwin C., Cements, Limes, and Plasters, their materials, manufacture, and properties, New York, John Wiley & Sons, 1905, p. 150.

[c] Hoffman, G. C., Rept. section of chemistry and mineralogy: Ann. Rept. Canadian Geol. Survey, Ottawa, vol. 13, 1905, pp. 14–19.

[d] Frazier, P., jr., Lancaster County: Second Geol. Survey Pennsylvania, vol. CCC., 1880, pp. 89, 97, 176–179, 196.

[e] Bascom, F., The geology of the crystalline rocks of Cecil County: Cecil County report, Maryland Geol. Survey, 1902, pp. 96–97.

amounts of asbestos (15 to 50 per cent of the whole) for pipe coverings and boiler lagging, As the sulphate, it is known as Epsom salts, large amounts of which are consumed in warp sizing or weighting in cotton mills and smaller amounts in medicine. The chloride is used as a cement and the hydrate in sugar making.

The low price of magnesite—about $6 per ton landed at New York City—makes its mining on the Pacific coast profitable only for the local demands unless manufactured into more valuable forms. The Rose Brick Company, a subsidiary company of the American Magnesite Company, has recently established a factory at Oakland with the intention of making brick for shipment to the steel mills of the East, and other products will be manufactured by allied companies. The magnesite intended for brick will be burned in long, sloping, brick-lined steel cylinders, somewhat similar to those used for pyritic roasting. Crude oil will be used for fuel.

DESCRIPTION OF DEPOSITS.

GENERAL STATEMENT.

The California magnesite deposits, so far as known, all occur as veins in serpentine or similar magnesian rocks. By far the larger part are in the Coast Range in the serpentines that stretch from southern California into Oregon. These serpentines are probably Lower Cretaceous in age [a] and cover large areas, Becker [b] estimating that between Clear Lake and New Idria, a distance of about 200 miles, there are over 1,000 square miles of serpentine. Through a large part of this area magnesite veins of varying sizes are found. Those large enough to be more or less workable are reported from many places in Mendocino, Napa, Placer, Sonoma, Alameda, Stanislaus, Santa Clara, Fresno, Tulare, Kern, and Riverside counties. Of these the deposits in Placer, Tulare, and Fresno counties are in the foothills of the Sierras.

The serpentines of the Coast Range are ordinarily green or bluish, greatly broken and faulted, a solid block a foot in diameter being a rarity in many localities. They are derived from olivine-pyroxene rocks, in which the amounts of the minerals have varying ratios at different localities. At Porterville, the only place along the Sierra Nevada at which the serpentines were seen, they seem, from a preliminary examination, to be derived from an olivine-pyroxene rock. Instead of the usual green color, the serpentine is here brown, and as compared with the others described is remarkably solid.

Magnesite is formed from the breaking down of the serpentine, a hydrous magnesium silicate. The magnesia is dissolved by percolating waters carrying carbon dioxide, changed to the carbonate, magnesite, and precipitated in cracks and crevices as veins. The silica is carried away by the water and is often deposited in other veins as opal or quartz.

The magnesite frequently stands out prominently from the surrounding serpentine, from the fact that it seems to weather less readily than the serpentine and also that the existence of a magnesite vein generally indicates that the surrounding serpentine is considerably decomposed and so erodes rather easily. The boldness of outcrop makes the veins readily noticeable, so that their occurrence is generally known.

In the larger veins there is often a central portion of comparatively pure magnesite, while on one or both sides there may be many inclusions of serpentine. This mixed condition of the magnesite and serpentine in the veins is common among the large veins seen along the Coast Range. Small inclusions of serpentine are apt to extend well into the vein. As the side is neared the inclusions form a gradually larger proportion of the mass until the magnesite appears only as a great number of small veins in the broken serpentine. Or if the main mass is approached from the side, as along a tunnel, a stockwork of small veins of magnesite first appears, growing thicker toward the large vein, until the larger part of the mass is magnesite and the pieces of the serpentine are so separated as to become inclusions in the magnesite. Near the veins the serpentine has almost always lost its normal color and is badly rotted and

---

[a] Fairbanks, Harold W., Description of the San Luis quadrangle: Geologic Atlas U. S., folio 101, U. S. Geol. Survey, 1904, p. 6.

[b] Becker, Geo. F., Geology of the quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888, p. 103.

porous as the result of its decomposition by percolating surface waters. The rock shrinks through the gradual removal of its components and the magnesite fills the enlarging spaces between the fragments. The magnesite formed through the decomposition of serpentine occupies about four-fifths of the space of the original rock, so that a magnesite vein may be and probably is formed very largely from the serpentine which formerly occupied the space filled by the vein, the remainder coming from the rock in a comparatively narrow zone on each side. The large width of some of the veins is thus easily explained by supposing that they occupy spaces made by the disintegrating serpentine almost as fast as they are left rather than natural fissures or cracks in the rocks. The veins are thus, in a sense, partly residual from the serpentine. Such belts of disintegration are naturally along the channels with greatest circulation of water, generally coincident with the larger faults. Every crack and joint along the line makes a feeder for the trunk channels. Among these reticulations the same process of deposition is going on, and in places sudden enlargements of the veins occur, making so-called "bowlders" of magnesite, which may be 2 or 3 feet in diameter and nearly equidimensional. This lack of linear extension in small deposits, together with the number of faults known to cross the Coast Range serpentines in every direction, makes the following of veins by widely separated outcrops very uncertain, for there is no reason to believe that sudden terminations do not occur in the large deposits as in the smaller ones.

Little is known of the depth to which the veins extend. If it is considered that they are formed through the influence of percolating surface water, it seems fair to assume that the deposits may extend down to the limit of circulation of these waters, their size being modified by the time through which such circulation has existed, any difference in the hardness or composition of the rock, etc.; and faulting is as likely to cut the veins off in depth as in length.

Cinnabar and chromite are frequently found accompanying the serpentines in the neighborhood of the magnesite deposits.

LIVERMORE DEPOSITS.

Near Livermore, a town 48 miles southeast of San Francisco, are a number of magnesite deposits, of which the only one being worked is located 32 miles southeast of Livermore and belongs to the American Magnesite Company.

An excellent road follows up Arroyo Mocho, crossing into and running down Arroyo Colorado. The maximum grade for the haul from the mine is said to be 3 per cent. At the mines the company has erected good buildings and roads, and an aerial tram 2,500 feet long, with a capacity of 100 tons per ten-hour day, delivers the magnesite to bunkers, from which it is loaded into iron wagons for hauling to Livermore. The wagons carry 17½ tons each, and two are hauled by an oil-burning traction engine. The magnesite is shipped to Oakland, where the company's factories for brick, carbon dioxide, and other products are situated. The mine offices and other buildings are located near springs that give sufficient water for the needs of the engines, the mine, and other purposes.

The magnesite veins stand out prominently in the bright sunshine of the valley and are almost dazzlingly white, so that they can be seen from the higher hills, miles away. One of the veins, called the "Mammoth," stands fully 10 feet above the hillside. Many of the veins, however, are largely covered by débris. The magnesite shows many peculiarities in weathering. Some of the surfaces weather into a pattern that looks like sun cracks in mud, with flatly oval surfaces from one-eighth to three-fourths of an inch wide between the cracks. In places there are fluted surfaces such as occur on exposed limestones, but in narrower lines, and at times the weathered surface is thickly studded with sharp points. At this place surfaces frequently are covered with a white powder which has been supposed to be magnesium oxide or hydromagnesite, but which has been determined by W. T. Schaller, of the chemical laboratory of the United States Geological Survey, to be another form of the magnesite.

Underground, nodules or portions of veins of magnesite will turn to this almost impalpable powder, leaving a core of solid material. Mr. C. H. Spinks, the superintendent of the mines, told the writer that certain other veins belonging to the company, a few miles distant, carried several feet of this powder. Why it should take this form, breaking down from the solid state without apparent chemical change, is unknown. One of the veins shows an outcrop 40 feet broad and traceable through a distance of several hundred feet. Others show lesser outcrops, but the amount exposed is large. However, in such outcrops but two dimensions are known, and an estimate of the amount of magnesite available is merest guesswork.

Although these deposits have been known for a long time, they have not been worked until the past year owing to their distance from a railroad. There are a number of veins in a group around a small valley, so arranged as to be excellently located for working by adits and an aerial tram. The first magnesite was shipped from the mine in November. The vein that is being mined strikes about N. 30° W., dipping steeply southwestward. It is pierced by several adits on different levels, and a crosscut at one place entered the vein for 35 feet without going through it. A drill hole 8 feet long at the end of the crosscut was said not to have reached the other side. The vein had been developed through a length of between 250 and 300 feet. The magnesite is pure and white, the crosscut looking as if freshly whitewashed. As is to be expected in a serpentine area, faults have occurred, cutting the vein in a number of places, both hanging and foot walls being fault planes.

Mining is carried on by means of an open cut in which the magnesite is quarried and allowed to fall through an upraise to an adit below, whence it is moved in cars to the aerial tram. The tram drops 600 feet in the 2,500 feet to the bunkers. The skips are placed 500 feet apart and each carries 1,000 pounds of magnesite.

Close to the magnesite veins are small impregnation veins of chromite, about 250 yards southeast of the present workings. The chromite occurs in grains from the size of a pea downward and can be clearly seen to spread from joints in the serpentine. The chromite is accompanied by a pale lilac-colored chlorite, probably either kotschubeite or kammererite. A small amount of work has been done on the veins, but the prospects do not seem to have been encouraging.

A little cinnabar is said to have been found in the neighborhood, and two mercury mines are being developed within a radius of 4 or 5 miles.

CHILES VALLEY.

Chiles Valley is situated in Napa County and its nearest shipping point, Rutherford, is 84 miles by rail north of San Francisco. Magnesite was mined in the valley at a point about 10 miles from the railroad by Stanley & Bartlett for twelve years, but the mines have not been operated for the last five years, being too far from the railroad to compete with points having better shipping facilities. During the time that the mines were worked many thousands of tons of magnesite were mined and burned at this place. As pure magnesite loses more than half its weight by being burned, a large saving could be made in haulage by getting rid of the carbon dioxide, if the material was to be used as magnesia. Manzanita, a hard-wooded shrub making a hot fire, was largely used for fuel.

The country rock is here also the Coast Range serpentine, somewhat more inclined to a blue-black color than at the Livermore deposits. The deposits are on the west side of the valley in a small serpentine hill skirted by a public road, and consist of a number of veins which vary in thickness from 1 foot to 6 feet and are said to have been as much as 12 feet wide. Where seen, however, the larger veins were much mixed with serpentine and other impurities. Much faulting occurs with the veins, and both the hanging and foot walls are generally fault planes. The serpentine is much broken in the neighborhood of the veins, the interstices being filled by smaller veins of magnesite.

On the foot wall of several of the veins extensive silicification has taken place, the serpentine being hardened through 2 or 3 feet. The veins are often brecciated and cemented with less pure material of yellowish color, while the original magnesite is a clear white. Frequently in the brecciated portions each fragment is covered by magnesite in radial crystals, forming a coating up to half an inch thick and varying in color from crystalline clearness to delicate green and yellowish green. Cracks in the serpentine are also filled with the same crystalline magnesite. This form is strikingly different from the ordinary magnesite, which in these deposits shows no crystal form to the unaided eye. In places crevices in the vein have a velvety black coating of pyrolusite (manganese dioxide), making the rock look as if it were coated with lampblack. A small amount of chromite has been found in the neighborhood, but not in paying quantities. An analysis of magnesite from this mine is given on the next page.

POPE VALLEY.

What is usually known as the Walters magnesite mine is located on the east side of Pope Valley, 22 miles northeast of Rutherford. The distance of the mine from the railroad makes hauling expensive, and the mine has never been worked on a large scale and has had no production for several years. A proposed electric road from San Francisco to Lake County will pass, if built, within 4 miles or less of the mine, in which case it will be in an excellent position to ship magnesite.

The deposits are situated in a serpentine hill, about 400 feet (barometric measurement) above the valley. They are composed of a large number of veins whose exposures vary in width from a fraction of an inch to 12 feet, and lie on both sides of a small ravine which forms an amphitheater, with an easy, straight southward grade to the valley, making an almost ideal place to work with an aerial tram.

The deposits are in three principal groups, two of which lie on the east side of the ravine and the other on the west. In the main group on the east side are three large veins of magnesite which can be definitely traced for distances of about 140, 250, and 230 feet respectively, with strikes of N. 28°, 30°, and 45° W. At their north end the western and eastern veins are but 30 feet apart, with the middle vein probably converging with the eastern one. The dip of the western vein is shown by a shallow shaft to be 50° E. The veins stand up boldly and can be seen from any part of the valley not hidden by hills. Longitudinal faults occur in both of the outer veins. Between the large ones are many smaller veins having a general parallelism to the main bodies. At its widest exposure the western vein is about 10 feet thick, of which about 5 feet on the foot wall are solid white magnesite, while the upper 5 feet (on the hanging-wall side) contain many inclusions of serpentine. The structure of the eastern vein is similar and in places the magnesite may be seen grading into the country rock. It is about 12 feet wide where exposed in a shallow crosscut. In the middle vein a width of 18 inches to 5 feet of clear white magnesite is exposed.

There has been some crushing of the magnesite and the broken particles have been cemented with yellowish, less pure material. Part of the magnesite has formed in yellowish botryoidal masses that are rather impure. Some crystalline magnesite, similar to that of Chiles Valley, is found in the crevices. But a small amount has been mined, and that was simply broken from the exposed faces of the veins.

A second group of veins with a more northerly strike occurs 100 feet or more above the veins just described. The veins forming this second group are smaller, running from 2 inches to 2 feet in width, and the larger ones are impure. There are also many scattered veins in the intervening space.

On the west side of the ravine is a third group of veins 200 to 250 feet from those first described, with a strike between north and northwest. The largest is a vein 4 to 6 feet wide and seven others from 1 to 2 feet wide occur within a space of 125 feet. All are of excellent quality. It would seem possible to blast out the whole of the rock through this distance and hand pick it, should the deposits again be worked.

PORTERVILLE DEPOSITS.

The Willamette Pulp and Paper Company is working a large group of magnesite veins 4 miles northeast of Porterville, in the outer range of foothills of the Sierra Nevada. The veins occur in a brown serpentine, derived from peridotite and having an apparent bedding structure. The serpentine forms part of a metamorphic complex of amphibolite-schist, serpentine, and other magnesian rocks, some talcose and mica bearing, and a small amount of fine-grained quartzite. The rocks have a general northerly strike, with a high (60°) easterly dip. They are cut off by a granitic mass on the south, a few hundred feet from the deposits, and several granitic dikes cut the serpentine and other rocks. Basic dikes of several varieties cut both the country rock and the veins and are occasionally squeezed to a schist.

Faulting is frequent, but the serpentine is not divided into the small irregular blocks usual in the Coast Range and many other serpentines, due to the swelling of the rock as it changes its chemical form. Internal movement is evident and the magnesite is invariably crushed in the larger veins. In one vertical 2-foot vein a couple of hundred feet southeast of the kiln the magnesite has been so squeezed that it has taken a modified cone-in-cone structure and is left in irregular fragments whose sides are covered with abrasion lines, the whole looking as if at the time of crushing it had been in a semiplastic state. In other veins the planes along which the magnesite has moved on itself are smooth and shaped so as to somewhat resemble the curve of a highly arched shell. Along these planes is often a bright-red stain of iron oxide, although the surrounding magnesite is pure white. At the north end of the deposits are several "blanket" or flat veins. The largest one is practically horizontal in the middle part and somewhat uptilted at both ends. It extends through the hill a distance of 362 feet, and is probably twice as long, and from 2 to 4 or more feet thick. A basic dike flattens and spreads under a large part of the vein in a thin sheet 1 to 2 feet thick; then, breaking through, it overlies the remainder of the vein.

There is nothing to show that the vein has been tilted from a more upright position to its present place and it was evidently formed as it lies, flat and cutting across the vertical structure of the serpentine. This is accounted for by supposing that there was a slow movement in the rocks along this plane at the time of the vein's deposition, the magnesite filling uneven, open spaces along the horizontal fault, and that when there was another movement these depositions would hold the mass apart and make room for contiguous deposits. The crushed condition of the whole mass and inclusions of serpentine in lines approximately parallel to the sides of the vein give this hypothesis some color. The other "blanket" veins lie at rather low angles and will probably be found to run into this one. At the north end of the deposits is a stockwork of small veins 2 to 6 inches thick, and it is thought that it may pay to blast the whole mass and hand pick it.

With the exception of magnesite shipped to the Western Carbonic Acid Gas Company, of San Francisco, for making gas, all the magnesite mined here is burned before being shipped. Crude oil is used for fuel, and the magnesite is fed into the top of a kiln, gradually rising in temperature until it reaches the flame from the burners. It is then raised to a white heat and kept there for from twenty to twenty-five minutes, when it is withdrawn. Shipments are made from Hilo, a spur on the Southern Pacific Railroad, 1 mile north of Porterville.

Analyses of magnesite and magnesia.

	1.	2.	3.	4.	5.	6.	7.	8.
Silica (SiO_2)	0.10	0.50	1.10	3.30	2.48	[a]1.81	[a]6.68	[a]0.90
Iron oxide (Fe_2O_3)	.25	.30	.47	7.25	6.02	.08	15.10	.49
Alumina (Al_2O_3)	....	....	.76	.84	1.18			
Lime (CaO)	.62	.70	....	2.48	4.34	Trace.	....	1.49
Magnesia (MgO)	47.10	46.90	97.35	84.72	84.56	46.55	37.23	44.39
Carbon dioxide (CO_2)	51.98	51.60	....	....	....	51.25	40.98	50.06
Water and undetermined	....	....	.32	1.40	1.33	.32	....	2.57
	100.05	100.00	100.00	99.99	99.91	100.00	99.99	99.90

[a]Insoluble.

1, 2. Alameda claim, American Magnesite Company, 32 miles southeast of Livermore, Cal.
3–5. Same, calcined.
6. Chiles Valley.
7. Same, poor; not shipped.
8. Porterville.

Analyst, Nos. 1-5, unknown; 6–8, Abbot A. Hanks, 531 California street, San Francisco, Cal., October 1, 1903.

THE BURNING OF MAGNESITE.

Among men engaged in the burning of magnesite a difference of opinion has existed as to the temperature at which the carbon dioxide can be driven off. In recent experiments Herr Otto Brill[a] has determined this point, and made a number of interesting discoveries as to the behavior of magnesite when heated. His experiments were carried on with carefully prepared and purified materials, so that his results are not exactly analogous to those that would be obtained by using the raw natural material. He showed that, while calcium carbonate (as ordinary limestone) gives up all of its carbon dioxide at 825° C. (1,517° F.), when magnesium carbonate (magnesite) is burned it begins to give off carbon dioxide at about 235° C. (455° F.); little if any more carbon dioxide seems to be given off while the material is held at 255° C., but on raising the temperature the gas is again given off. Other such stages were marked at various points, and these were considered to show the successive formation and breaking up of various basic carbonates. The last of the carbon dioxide is given off at 510° C. (950° F.), a temperature much below that needed to burn lime. Herr Brill's table showing the different carbonates is given below. The fifth column, the reduction to the Fahrenheit measurement of temperature, is added by the writer of this paper.

Basic carbonates formed in burning magnesite.

	Calculated MgO.	Obtained. MgO.	Dissociation temperature.	
	Per cent.	*Per cent.*	*° C.*	*° F.*
$10MgO.9CO_2$	50.64	50.58	265	509
$9MgO.8CO_2$	50.79	50.98	295	563
$8MgO.7CO_2$	51.20	51.37	325	617
$7MgO.6CO_2$	51.51	51.69	340	644
$6MgO.5CO_2$	52.36	52.35	380	716
$5MgO.4CO_2$	53.41	53.03	405	761
$7MgO.CO_2$	86.53	86.31	510	950

The temperature at which magnesite gives up the last of its carbon dioxide, 510° C., is below a red heat, but the time required to drive off all of the gas is not given, and this, of course, would vary with the size of the material used. The important point, however, is that at this temperature all of the carbon dioxide may be driven off, so that, although higher heating will undoubtedly remove the gas more quickly, it ordinarily means a waste of fuel.

MANUFACTURE OF LIQUID CARBON DIOXIDE.

At the time of the writer's visit the Western Carbonic Acid Gas Company of San Francisco, with works across the bay at Sedan or Emeryville, was the only maunfacturer of carbonic-acid gas from magnesite, although one of the subsidiary companies of the American Magnesite Company was erecting a plant at East Oakland (Clinton).

The magnesite is burned in a kiln with one-tenth its weight of coke, and the gas is pumped into scrubbers, of which there are three, filled with broken limestone to counteract any sulphuric acid formed, and washed with sea water. The gas then passes to an absorption tower, where it comes in contact with a sprayed solution of potassium carbonate, by which it is absorbed. The "loaded solution" is then pumped into boilers, where it is raised to a temperature just below the boiling point of water. The solution gives up its gas and is

[a] Ueber die Dissoziation der Karbonate der Erdalkalien und des Magnesiumkarbonates: Zeitschrift für Anorganische Chemie, Band 45, Heft 3, June, 1905, pp. 277-292.

sent back to the absorption tower, while the gas is pumped through cleansing tanks to a gasometer. It is then compressed in a three-step compressor to the liquid state and is shipped in steel cylinders holding 25 to 60 pounds. In this process the weight of gas obtained is about 50 per cent of the weight of the magnesite used. The gas is shipped all over the Pacific coast and the Southwestern States. It is used in refrigeration and in making soda water and other aerated beverages.

This same company is preparing to make light magnesia alba, by the Pattinson process, to be used as an absorbent for nitroglycerin in the manufacture of dynamite. It is said to make a very superior absorbent for the best grades of dynamite.

THE LIME INDUSTRY OF KNOX COUNTY, ME.

By Edson S. Bastin.

DISTRIBUTION OF THE LIMESTONES.

The limestones of Maine which are utilized commercially in the production of lime are confined to Knox County. The limestone areas form, in general, long, narrow, somewhat irregular strips trending northeast and southwest and surrounded by quartz rocks and schists. The largest continuous area extends from Chickawaka Pond, 2 miles north of Rockland, in a southwesterly direction, somewhat over 5 miles, to Thomaston, where its

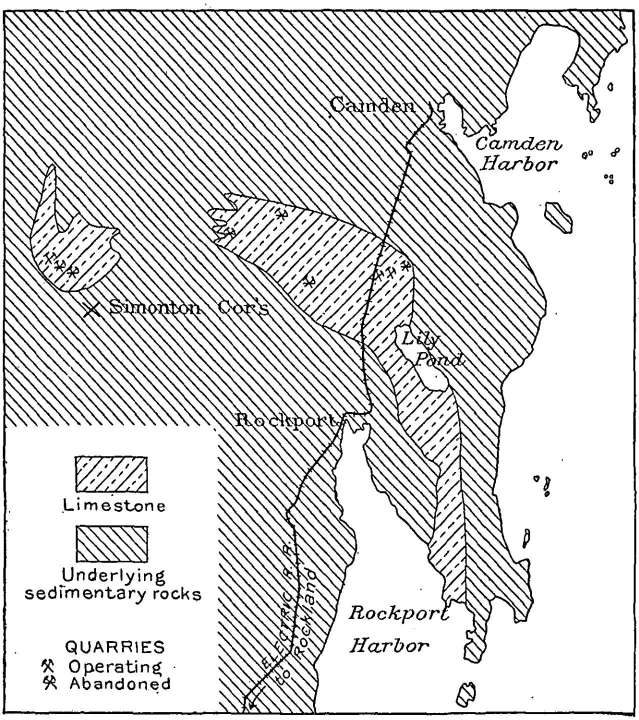

Fig. 13.—Map showing distribution of limestone and location of quarries in the vicinity of Rockport, Me.

southernmost exposures are seen in the yard of the State prison. In some places this belt has a width of nearly a mile, although all of the rock is not of commercial quality. The second largest deposit extends from the east shore of Rockport Harbor, near the Henry Cottage, northward to Lily Pond and thence assumes a more westerly trend; it takes in the Jacobs quarry on the trolley road between Rockport and Camden and extends to the west of this road for a little over a mile. After a short interruption the same belt appears again just west of Simontons Corners, where it includes the Eells quarry. (See fig. 13.) Next in commercial importance is the deposit occurring 2 miles northwest of the village of

Warren; this deposit was not mapped in detail, but enough was learned of it to show that it was relatively small and that its trend was similar to that of most of the other areas. Several narrow belts occur between the Warren deposits and Alford Lake, but none of these are now worked. Southwest of Rockland there are, as shown on the map forming fig. 14,

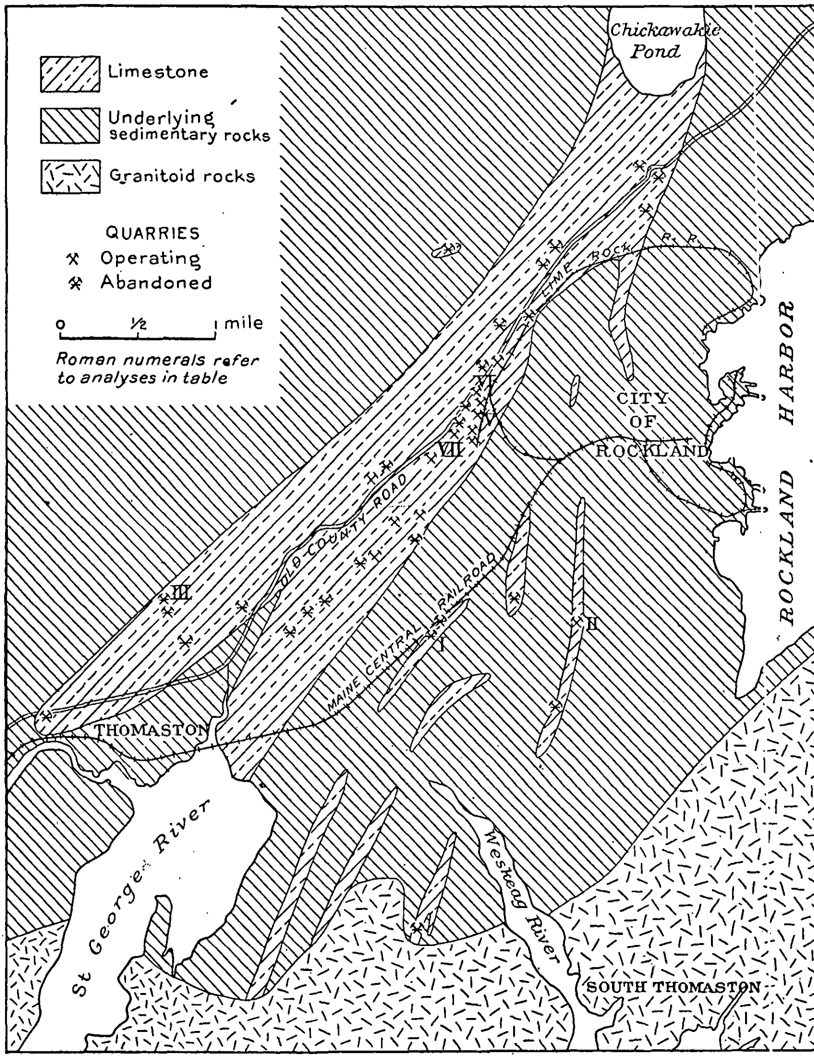

FIG. 14.—Map showing distribution of limestone and locations of quarries in the vicinity of Rockland and Thomaston, Me.

several narrow belts nearly parallel to the main limestone belt. On the easternmost of these belts is located the pulp-rock quarry now being operated by Mr. S. P. Dunton for the McLoon & Stover Lime Company.

PRESENT UTILIZATION.

Within the district under consideration limestone is now quarried (1905) at nineteen quarries, operated by ten different companies and employing an average of 250 quarrymen. The great bulk of the rock is burned for common lime, but a small amount is shipped unburned for use in pulp mills or as flux,[a] and some is used in the production of a hydrated lime, to be discussed later more fully. The rock is not suitable for building purposes. The production in this region of common lime, hydrated lime, and limestone for pulp and flux purposes since the year 1898 is given in the following table:

Production of lime, etc., in Knox County.[b]

Year.	Common lime.	Hydrated.	Lime for pulp-making purposes (mainly magnesian).[c]	Limestone for flux and pulp-making purposes.
	Casks.[d]	*Tons.*	*Casks.*[d]	*Casks.*[e]
1898	1,610,178	....	(*f*)	(*f*)
1899	1,939,427	....	(*f*)	(*f*)
1900	1,728,134	....	(*f*)	(*f*)
1901	1,962,717	....	94,133	(*f*)
1902	1,589,982	....	78,157	(*f*)
1903	1,817,787	10,000	72,001	(*f*)
1904	1.792,559	12,500	52,909	21,000

[b] Compiled from records of lime inspectors at the various ports and from the records of private companies.
[c] All from quarries at West Warren.
[d] Of 200 pounds.
[e] Of 400 pounds.
[f] Statistics not available.

About two-thirds of the common lime produced goes to the New York market, where for many years it has had the highest reputation. Nearly all of this is shipped by water, the largest of the companies maintaining a fleet of six barges, each capable of carrying 15,000 casks (200 pounds each) of lime and of bringing on the return voyage 1,500 tons of coal. The remainder of the product goes to Boston and other New England markets. In spite of the fact that freight rates are lower by rail, most of the lime shipped to Boston goes by water, as the Boston building contractors have good docking facilities but in few cases have railroad yards. For the rest of New England the shipments are usually by rail. From one-fourth to one-third of the lime is of finishing grade.

Of recent years a process has been taken up by the Rockland-Rockport Lime Company which has not only proved a great success here and elsewhere, but which seems to point out an important line of future development in the lime industry. This process consists in a complete hydration of the lime before it is placed on the market. It has been carried on successfully in other parts of the country under a variety of patents, the product being variously known as "new-process lime," "hydrated lime," "limoid," etc. The Rockland product goes under the name of "prepared pure white lime." While differing in details, the various processes are identical in principle. The lime after burning is crushed or ground until no lumps larger than 1 inch in size remain. It is then transferred to a mixer, where it is thoroughly mixed with about 25 per cent of its weight of water, the chemical change produced being represented by the equation—

$$CaO+H_2O=Ca\ (OH)_2$$
Lime+water=lime hydrate.

A description of the effects produced by this hydration and of the subsequent steps in the process of manufacture may be quoted from one of the prospectuses of the Rockland-Rockport Lime Company. The lime "undergoes a radical change, its heating and expanding qualities being entirely removed; it is then conveyed to bins where it is allowed to age, the same result being obtained as when slaking lime several months before it is used; it is then bolted to the varying degrees of fineness according to the different purposes for which it is

[a] Only a very small amount is used for flux.

used and drawn into bags or barrels for the market." This process of manufacture has several decided advantages over the ordinary process: (1) Crushed and crumbled lime can be used in this way which can not be barreled for shipment as "lump" lime, although its quality may be equally good; (2) coarse-grained limestone which does not retain the lump well on burning can be utilized in this process; (3) the hydrated lime "will not absorb moisture, in other words it will not air slake, hence will keep in good condition until used;" this fact much decreases the risk in shipment by water and leads to a proportional reduction in insurance rates; lime thus prepared may be shipped in bulk and for long distances, the Rockland-Rockport Lime Company having recently made shipments to Panama for disinfecting purposes; (4) "as the lime has been reduced to a powder, there is absolutely no liability of its pitting on the walls." Finally, it is believed that this process of manufacture is not greatly more expensive than the manufacture of common lime; the machinery needed is not complex; savings in the matter of materials utilized and of insurance have already been mentioned; and there is an additional saving when shipments are made in cloth bags. These are much cheaper than casks, which cost 16 to 17 cents each, and being light can be shipped back after emptying and used again and again.

GENERAL CHARACTER AND MODE OF OCCURRENCE.

The limestones of Knox County have all been completely recrystallized since their original deposition. They are now virtually marbles, although either too coarse, too dark colored, or too much fractured to be used for ornamental or building purposes. In color the rock used varies from dark purplish-gray to pure white, the commonest colors being light gray and dark blue-gray. In the Rockland quarries a variety showing alternate bands of grayish white and dark blue-gray is very common. In the bulk of the rock quarried the grains are under one-sixteenth inch in diameter, and in some occurrences they are so small as to be unrecognizable with the naked eye, but in other cases may reach a diameter of one-fourth of an inch.

The general form of the limestone belts has already been described, and is shown on figs. 13 and 14; it remains now to discuss briefly the structural relations of which this distribution is an expression. All the sedimentary rocks of this region were deposited in a nearly horizontal position, as muds, sands, and marls, upon the ocean bottom, where they gradually consolidated to form, respectively, shales, sandstones, and limestones. At a later period these sediments were thrown into a series of long, narrow folds commonly trending 20° to 30° east of north, or about parallel to the general trend of this part of the coast. As in most regions where folding of this kind has taken place, the larger folds were themselves thrown into a series of smaller folds, which trend parallel to the larger ones—a relation which may be illustrated by the curved surface of a crimping iron, which is itself fluted with minor folds.

The minor folds in this region are closely compressed, so much so that when seen in cross section opposite sides of a fold are often nearly parallel. As a result of this, the beds are now for the most part steeply inclined, as may be observed in the easternmost series of quarries of the Rockland-Rockport Lime Company, west of Rockland. Here the bedding is indicated by a very distinct banding, which is almost vertical. The relations are complicated by the presence of cross folds, which trend about at right angles to the main folds. They influence the form of the limestone belts in various ways; for example, the narrowing of the Rockport belt about one-half mile south of Lily Pond is due to a cross fold, which in this case is an up fold or anticline, while in the region southwest of Rockland the interrupted character of the narrow limestone belts is also due to the presence of cross folds. Within the main limestone belt the crookedness observed in the trend of some of the limestone "veins" is due to folds which cross the main folds diagonally.

During this process of severe folding, the various types of sediments were intensely altered, the shales being changed to schists, the sandstones to quartzite, and the limestones to marble. The schists are well exposed at Bear Hill, Ingrahams Hill, and many other places, and are commonly known as "land ledge." The muds from which they were derived were deposited on the ocean bottom somewhat earlier than the limestones, which in most places they immediately underlie. In the region southwest of Rockland, however, there is a local development between the schists and the limestone of a considerable thickness of quartzite and a thin bed of talcose limestone. Fig. 15, which shows a section from northwest to southeast across the limestone belts southwest of Rockland, is intended to illustrate the general relations outlined above; it is not drawn to scale and is purely diagrammatic, the folding being in places even closer than shown. The sedimentary rocks underlying the limestone are represented by A in the figure, the locally developed quartzite and talcose limestone beds not being separately shown. Among the limestones several varieties are indicated, B=magnesian limestone or dolomite, C=the so-called "hard rock" of the quarrymen, D=impure limestone, and E=the "soft rock" of the quarrymen. These limestones form a broad down fold (synclinorium), which is itself divided into a number of smaller folds, both up folds (anticlines) and down folds (synclines). A comparison of this cross section with fig. 14 shows that, considered as a whole, the limestone occurs as a broad trough made up of numerous smaller folds. The main large fold is not perfectly symmetrical, its western side being relatively steep; as a result, the limestone terminates abruptly on the west. To the southeast, however, we have a number of small outlying limestone troughs (see fig. 14), which represent the minor foldings of the main trough and show that its eastern side has a much gentler slope. One of these outlying troughs is shown in fig. 15 at B′.

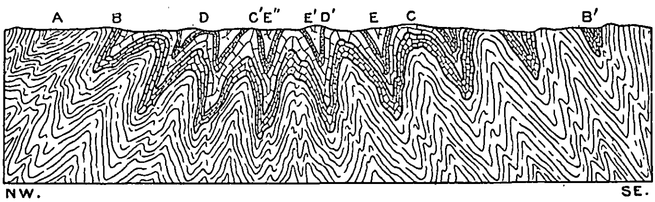

FIG. 15.—Diagrammatic geologic section across the principal limestone belt southwest of Rockland, Me.

The position of the magnesian limestone at the base of the limestone series is definitely determined by field studies, but the relative position and thickness of the "hard rock," the impure limestone, and the "soft rock" are not known, the relations having been obscured by the folding and its attendant alteration of the rocks. The reader is therefore especially cautioned against drawing any inferences from the diagram in regard to the sequence or relative thickness of these three types of rock.

MAGNESIAN LIMESTONE OR DOLOMITE.

The presence of magnesian limestone below the other varieties is shown particularly from a study of the limestone belts lying southeast of the large Rockland belt (see fig. 14). These outlying belts are usually only 100 to 200 feet in width and manifestly can represent only the lower part of the limestone series, as is brought out in fig. 15 at B′. In each of these outlying areas the bulk of the rock is found to be a magnesian limestone, a characteristic which may be recognized in the field from the fact that the rock effervesces feebly or not at all when dilute muriatic acid is applied. This rock is usually light gray to pure white in color and very fine grained. It has been quarried at a number of places and is usually used for pulp purposes. At the Gay farm, about 2 miles southwest of Rockland along the railroad, one of these small troughs of magnesian limestone was formerly worked by the Rockland-Rockport Lime Company. Analysis No. I of the table (p. —) is of a limestone from this quarry. The rock was of uneven grain and apt to be high in silica and silicates. The quarry was abandoned, although the supply along the trend of the deposit was by no means exhausted.

The quarry 1 mile southwest of Rockland, on the east side of "the Marsh," now being operated by Mr. S. P. Dunton for the McLoon & Stover Lime Company, is located on the southeasternmost of these outlying strips of magnesian limestone. It was opened in June, 1905, and the output to November 17, 1905, was 6,000 casks. The rock is similar in appearance to that from the Gay Farm quarry. At present it is all burned for pulp-making purposes. Its analysis is No. II of the table (p. —) and shows nearly 43 per cent of magnesia. A quarry formerly operated by Mr. Geo. W. Barry, on the Butler farm, about half a mile south of the quarry above mentioned, is located on the same strip of limestone; the rock is identical in appearance and gives an almost identical analysis. At the Dunton quarry a considerable amount of rock is rendered worthless because of the abundant development of talc (a silicate of magnesium), but it remains to be seen whether the quantity is sufficient to prohibit profitable development.

In general, the exploitation of the isolated strips of limestone southeast of the main belt should proceed in a most cautious manner, and the following facts should be kept constantly in mind: First, the rock is a magnesian limestone which at present finds a market only with the pulp mills; second, a certain proportion of the rock is likely to be talcose, and therefore commercially valueless; third, the amount of rock is relatively small, the belts seldom exceeding 200 feet in width and often being less. They may be expected to narrow rather than to widen with depth. The installation of expensive machinery is therefore not warranted.

Within the broad Thomaston-Rockland limestone belt magnesian limestone was found only at one locality. Its absence throughout most of the belt is readily understood from the diagram (fig. 15); it is buried beneath the other members of the limestone series. Theoretically, as is seen from the diagram, it should come to the surface on the eastern border of the belt, but this border is covered up by clays throughout its whole length. On the western border of the limestone area, at the locality marked III on the map, we do however, find a magnesian rock. This is at the Levensaler quarry about 1 mile north of Thomaston. Its approximate situation with respect to the rest of the limestone belt is indicated by the letter B in fig. 15. The analysis is No. III of the table (p. —) and shows 21 per cent of magnesia. Besides carrying this lower magnesia percentage the rock is coarser and of a bluer color than that of the outlying areas east of the main belt.

The most important deposits commercially of magnesian rock are those 2 miles northwest of the village of Warren. Here there is a down-folded belt of limestone similar in origin to the magnesian belts southwest of Rockland, but considerably wider and probably deeper. The principal difference is in the fact that the schists which surround (underlie) the limestone have been permeated with granite, dikes of which occasionally cut the limestone. The presence of this granite has resulted in a greater amount of recrystallization and purification of the limestone than in the Rockland region, but it has also resulted in the development, near the granite, of silicate minerals in good-sized crystals, which render some of the rock worthless. For years this rock has found a ready market for pulp-mill use, about five-sixths being shipped as lime and one-sixth as raw rock.

During the past year the Warren Company has placed on the market about 20,000 casks of this magnesian lime for building purposes. On the relative merits of the calcium and magnesian limes for building purposes the following may be quoted from Eckel: [a]

> The relative merits of these two classes have been frequently discussed in the text-books and technical journals and are still subjects of controversy. The facts of the case, however, seem to be simple enough and may be summarized as follows:
>
> High-calcium limes slake rapidly on the addition of water and evolve much heat during slaking. They also expand greatly, giving a large bulk of slaked lime. Magnesian limes slake very slowly and evolve very little heat during the process. Their expansion is also less, so that, taking equal weights they give less bulk of slaked lime.
>
> Owing to the slowness and coolness with which the magnesian limes slake, there is some danger that the average mortar mixer will not give them sufficient time to slake thoroughly. Owing to the fact that they make less bulk of slaked product than do high-calcium limes, the average contractor or builder thinks they are too expensive; but, on the other hand, they are very much stronger in long-time tests than the high-calcium limes, and will therefore carry much more sand.

[a] Eckel, E. C., Cements, Limes, and Plasters, 1905, p. 115.

On the whole, the shipment of magnesian limes for building purposes is to be encouraged, but it is a question whether a product of more merit can not be secured by the hydration of this lime before it is placed upon the market. The process of hydration would not be greatly slower than in the case of calcium limes and the danger from imperfect slaking at the hands of the mortar mixer would be completely avoided. The result should be a lime which is superior in strength to the calcium limes.

Recently there has been considerable complaint from pulp-mill operators because there has often been much dirt mixed with the raw magnesia rock and with the magnesian lime which was shipped to them, and some custom has been lost for this reason. Owing to the clay covering which usually overlies the limestone here, it is difficult to keep the rock perfectly clean. Probably this trouble could be remedied in part by keeping the stripping of the clays further in advance of the quarrying, but it is worth considering whether the rock could not be washed before shipment or burning at little or no extra expense by utilizing the water which is pumped from the quarry, but which usually serves no useful purpose.

THE MAIN ROCKLAND-THOMASTON BELT.

The diagram (fig. 15) brings out certain features of importance in regard to the distribution of the different kinds of limestone within the main belt. These may be enumerated as follows, always bearing in mind the caution already given, that the diagram is not intended to show actual thicknesses or sequence, but to bring out correctly the principles involved.

(1) *Repetition of beds.*—The character of the folding is such that the same bed is likely to be repeated several times in the width of the belt. Thus the bed E (fig. 15) appears again at E′ and E″, and the bed C is repeated at C′. As a result we may have within the broad limestone area several nearly parallel belts of almost identical rock, separated by belts of poor rock or of good rock of a different kind. This principle finds an immediate application in the prospecting for new deposits. This search should be conducted by test troughs or ditches dug through the surface clays and gravels at a right angle to the general trend of the limestone belts. Such prospect ditches are likely to disclose, beyond the walls of poor rock which bound the pits now worked, a repetition of the same profitable bed or the presence of a bed of good rock of a different kind—that is, "hard" instead of "soft" rock, or vice versa.

(2) *Width of surface outcrops.*—The surface width of the bands of "hard rock," "soft rock," and impure limestone depend not only on the original thickness of these various beds, but also on the character of the folding and the position of the present surface with respect to these folds. Thus the "hard rock" as it outcrops at C is a broad band, while at C′ its outcrop is narrow. The same is true of the impure limestone, which, as represented at D, has a broad outcrop, but at D′ a very narrow one.

(3) *Depth of the folds.*—As already stated, the folds which are developed in these rocks are more compressed even than is shown in the diagram. Their depth is greater than their width; in many cases it is probably two or three times as great. As a consequence it may be expected that in most cases a "vein" of a valuable rock can be worked to a depth which is at least equal to its width and which may be twice its width. In only a few cases, as at locality C (fig. 15), is the depth likely to be less than the surface width.

(4) *Prospecting outside the limestone area.*—In the past considerable time and money has been expended in sinking drill holes and prospecting in other ways for limestone in the schist ("land ledge") areas outside the limestone belts. Since the schists lie beneath the limestones, it is manifestly useless to expect to find limestone by drilling through the schists. In nearly every case, if limestone is present at all, it will be present at the surface.[a]

The field studies within this region indicate that the supply of valuable rock does not remotely approach exhaustion, and that intelligent prospecting following the methods already outlined will disclose large deposits whose presence is not now suspected. The suc-

[a] Some limestone does occur locally below the schists, but it is older than the limestone here discussed and is not of economic importance.

cessful utilization of these deposits will depend very largely on the depth of clay which must be stripped off before the limestone is exposed; in general this thickness will be greater than in the case of most of the "veins" now worked. In prospecting, the thickness of the covering material can be tested readily with an auger before digging is attempted; if too great to warrant its removal the prospect may be abandoned in favor of a locality where the covering is not so deep. In general this thickness is least in the highlands and greatest in the lowlands; hence the former offer the most promising field for prospecting.

PORTLAND CEMENT.

The possibility of utilizing the clays which are abundantly developed in the Rockland region and which in some places directly overlie the limestone, in the manufacture of Portland cement has already received some attention from quarry operators in this region. The matter is rather fully discussed by the writer in another part of this bulletin, in an article on "Clays of the Penobscot Bay region" (pp. 428–431). In this article the abundance and availability of the clays are brought out. It may be stated here, however, that the clays have a composition which suits them to this purpose, and that if the clays obtained from stripping could be utilized in this way limestone beds could be profitably worked, which otherwise it would not pay to uncover. For cement-making purposes in the utilization of the clay the magnesian limestones are not serviceable, for when mixed with clay they do not form so strong a cement as the calcium limes.

Analyses of limestone and limes from Knox County, Me.

	I.	II.	III.	IV.	V.	VI.	VII.
Carbonate of lime	....	53.13	74.36	53.52	....	....	98.17
Carbonate of magnesium	....	42.94	21.62	45.13	....	....	.09
Calcium oxide	55.10	....	....	....	96.31	85.51	....
Magnesium oxide	38.70	....	....	....	1.13	9.25	....
Silica and insoluble matter	4.59	2.87	1.85	.90	1.42	2.74	1.08
Iron and alumina	1.61	1.06	1.04		1.08	1.61	.15
	100.00	100.00	98.87	[a]100.00	99.94	[b]100.00	[c]99.77

[a] Total includes moisture, etc., 0.45 per cent.
[b] Total includes 0.89 per cent loss on ignition.
[c] Total includes 0.28 per cent of organic matter.

I. Magnesian lime from Gay Farm quarry, 2 miles southwest of Rockland along the railroad. R. S. Edwards, analyst.

II. Magnesian limestone from quarry operated by S. P. Dunton, 1 mile southwest of Rockland. Specimen taken at depth of 18 feet. F. C. Robinson, analyst, Brunswick, Me.

III. Magnesian limestone from Levensaler quarry, 1 mile north of Thomaston. Deficiency in total may indicate error in figures.

IV. Magnesian limestone from quarries at West Warren. S. P. Sharples, analyst, Boston, Mass.

V. "Soft-rock" lime from eastern pit of Rockland-Rockport Lime Company, near Rockland. R. S. Edwards, analyst.

VI. "Hard-rock" lime from Fred Ulmer "hard-rock" quarry, west of Rockland. R. S. Edwards, analyst.

VII. "Soft-rock" from McNamara quarry, Rockland. F. C. Robinson, analyst, Brunswick, Me.