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THE TECHNOLOGY OF SLATE

BY

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A thesis submitted to the faculty of George Washington University in part fulfillment of the requirement for the degree of Doctor of Philosophy

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THE TECHNOLOGY OF SLATE.

By Oliver Bowles.

INTRODUCTION.

Under a cooperative agreement between the Bureau of Mines, the United States Geological Survey, and the United States Bureau of Standards, a study of the stone-quarrying industries of the country was begun in 1914. The results of investigations made have been published from time to time.[1] During the World War the Bureau of Mines centered its attention on problems relating to national defense, and detailed studies of stone-quarry problems were not undertaken except for an investigation of labor saving at limestone quarries, reported in Technical Paper 203, which related to a question of military importance. Since the return of peace, the high cost of materials and labor has made more imperative than in prewar times the conduct of investigations for aiding the quarrying industries in every way possible to adopt more economical methods and to utilize the most efficient labor-saving equipment. The publications already issued have had a wide demand, and in the interest of the quarry industries the bureau proposes to issue additions to the series as rapidly as funds are available.

In an endeavor to promote economy and the reduction of waste in the slate industry, a study of slate quarrying was begun in 1920 and covered a period of about two years. Sixty-five active quarries were visited, and a detailed study made of all problems bearing on their successful operation. Field study was supplemented by a study of all information available in books or published articles on slate quarrying.

High-grade slate, such as occurs in various parts of this country, is an excellent roofing and structural material, and because of its

[1] Bowles, Oliver, Safety in stone quarrying, Tech. Paper 111, Bureau of Mines, 1915, 48 pp.; The technology of marble quarrying, Bull. 106, Bureau of Mines, 1916, 174 pp.; Sandstone quarrying in the United States, Bull. 124, Bureau of Mines, 1917, 143 pp.; Rock quarrying for cement manufacture, Bull. 160, Bureau of Mines, 1918, 312 pp.; Labor saving at limestone quarries, Tech. Paper 203, Bureau of Mines, 1919, 26 pp.; Kessler, D. W., Physical and chemical tests on the commercial marbles of the United States, U. S. Bureau of Standards Technol. Paper 123, 1919, 54 pp.

excellence is worthy of much wider use. A great many other roofing materials are now on the market, and although some of them are good and well adapted for certain types of buildings, many low-priced inferior types of roofing are also given wide publicity, with the result that the slate industry suffers and the general public is eventually the loser. Slate has many other structural uses, such as steps and baseboards, where its strength, nonabsorption, and insolubility make it valuable. Employed for school slates and blackboards, it establishes a standard to which no substitute materials can attain. Slate is also widely used for electrical switchboards. During the war, switchboard manufacture was the most important branch of the industry.

The purpose of this bulletin is to point out the most efficient methods and equipment now in use in slate quarries, to describe methods of utilizing the quarried material to best advantage, and to outline means of reducing the proportion of waste, which is now excessive. Briefly, the purpose is to enable the slate quarryman to reduce his production costs, and to improve the quality, and increase the variety of his products that he may compete more favorably with producers of substitute materials.

An important phase of the problem, to which the author devoted many months, is the utilization of waste slate, which up to the present time has been practically unused in this country. The new uses discovered, and the encouragement given to wider application, are believed to have fostered enterprises for such utilization that fully justify the time and effort expended. Tangible evidence of this is the fact that due to the bureau's activity, one of the largest producers of slate in Pennsylvania built, during 1921, a well-equipped grinding plant for the manufacture of granules and slate flour from quarry and mill waste.

ACKNOWLEDGMENTS.

The Bureau of Mines desires to express appreciation of the cordial cooperation of all slate producers in giving the bureau's representative access to their quarries and mills, and in supplying information to be used in the preparation of this report. Service of special value was rendered by Mr. William H. Kitto and Mr. N. M. Male of Pen Argyl, Pa., Mr. William H. Smith, of Bangor, Pa., and Mr. E. R. Roberts, of Granville, N. Y.; Mr. H. M. Milburn of the Bureau of Public Roads, Department of Agriculture, supplied the information on asphalt mixtures. Acknowledgement is also made of the cordial cooperation of many manufacturers of asphalt, rubber, linoleum, and other products in making tests to determine new uses for waste slate.

PROPERTIES OF SLATE AND FEATURES OF DEPOSITS.

SCOPE OF BULLETIN.

A detailed discussion of the chemical composition, physical properties, and geologic relations of slate has been given by Dale[2] in a bulletin of the United States Geological Survey. To repeat the data contained in that bulletin is unnecessary. The general discussion of the geology of slate in the present bulletin is confined to those features that are of greatest economic significance and have a definite relation to quarrying and to utilization.

DEFINITION OF SLATE.

The term "slate" is applied to fine-grained rock that has a more or less perfect cleavage, permitting it to be readily split into thin, smooth sheets. The term includes materials differing widely in color and having a considerable range in chemical and mineralogical composition.

ORIGIN OF SLATE.

Excepting certain rare slates of igneous origin formed from volcanic ash or igneous dikes, slates have originated from sedimentary deposits consisting largely of clay. Other minerals originally present with the clay in limited quantities include quartz, mica, zircon, compounds of iron, lime, and magnesia, carbonaceous matter and feldspars, and other silicates. Such materials were deposited in bodies of water, and through changing conditions of erosion and deposition successive beds may have differed considerably in composition. Other materials, such as lime carbonate or sand and gravel, may have been deposited over the clays, and the pressure of the superimposed materials may have gradually consolidated the clays into bedded deposits of shale such as are found in many places. A shale is a laminated rock consisting essentially of clay, but it does not possess the splitting properties of slate.

Many shales, however, have been subjected to intense metamorphism. The mountain-building forces ever at work in the earth's crust may crumple and fold the shales under the influence of intense pressure and high temperature. By such processes shales are transformed into slates. The intense pressure changes the orientation of the mineral grains, which normally lie parallel to the bedding, causing them to assume parallel positions and lie at a more or less definite angle to the direction of pressure. At the same time, high temperature acting with the pressure tends to alter the constituent minerals, changing them to new minerals, such as mica, quartz,

[2] Dale, N. T., and others, Slate in the United States: U. S. Geol. Survey Bull. 586, 1914, 220 pp.

chlorite, magnetite, graphite, tourmaline, and various others, the mica, quartz, and chlorite usually predominating. The parallelism of the mineral grains results in that tendency to split with ease in one direction which has been termed slaty cleavage. When the metamorphic process has reached such a stage that slaty cleavage is pronounced, the rock is termed a true slate. The rock is usually folded and contorted, and in consequence the slaty cleavage may intersect the bedding planes at various angles.

The process of alteration of the original minerals may be only partial, resulting in a slate having as its chief constituents clay, mica, and chlorite. Such a slate is termed "clay slate." The process may, however, be carried further, until little or no clay remains, the chief constituents being mica, quartz, and chlorite. As chlorite is also flaky and mica-like in character, such a rock is termed "mica slate." Mica slates are more resistant to absorption, and, therefore, more enduring than clay slates. They constitute the chief supply of commercial slate in the United States.

Continued intensive metamorphism of a mica slate produces more complete recrystallization in coarser grains, and develops in the rock a schistosity that is commonly wavy and irregular. Such highly metamorphosed rocks are termed "phyllites" or "mica schists."

COMPOSITION OF SLATE.

MINERALOGICAL COMPOSITION.

One of the most abundant minerals in mica slate is white mica, which being secondary in character is termed "sericite." Sericite is a hydrous silicate of potash and aluminum. It is present in very minute flakes, their outlines being recognizable only under a microscope with high magnification. Small grains of quartz are also abundant and are regularly distributed among the mica flakes. The micalike mineral chlorite is usually present in considerable amount. Chlorites are of various kinds, the more common being hydrous silicates of aluminum and iron or magnesium. Clay or kaolin is usually present in small amounts in mica slates and may be quite abundant in clay slates. Minerals of minor importance are rutile, hematite, pyrite, carbonaceous matter, graphite, feldspar, zircon, tourmaline, calcite, dolomite, siderite; very small quantities of many other minerals are commonly identified. According to Dale[3] the mineral composition of average mica slate is as follows:

[3] Dale, T. Nelson, and others. Work cited, p. 19.

Mineral composition of average slate.

	Per cent.
Mica (sericite)	38–40
Chlorite	6–18
Quartz	31–45
Hematite	3–6
Rutile	1–1½

CHEMICAL COMPOSITION.

Results of many analyses indicate that clays, shales, and slates differ little in chemical composition, the changes that take place during metamorphism being confined largely to rearrangement of the chemical elements into new minerals and changes in such physical characteristics as hardness and cleavage. The summary of 15 analyses of prominent slates in the United States as given by Dale[4] (Table 1) is a fair representation of the chemical composition of slates in general.

TABLE 1.—*Summarized analyses of roofing slates from New York, Vermont, and Pennsylvania.*

	New York.		Vermont.					Lehigh County, Pa.	General average.
	Bright green (1).[a]	Red (4).	Sea-green (3).	Unfading green (2).	Variegated (Eureka) (1).	Purple (2).	Black (1).	Black (1).	
Silica (SiO_2)	67.89	63.89	63.33	59.37	60.24	61.29	59.70	56.38	61.51
Titanium dioxide (TiO_2)	.49	.52	.73	1.00	.92	.77	.79	.78	.75
Alumina (Al_2O_3)	11.03	11.80	14.86	18.51	18.46	16.24	16.98	15.27	15.39
Ferric oxide (Fe_2O_3)	1.47	4.56	1.12	1.18	2.56	4.63	.52	[b] 1.67	2.21
Ferrous oxide (FeO)	3.81	1.33	4.93	6.69	5.18	2.62	4.88	[b] 3.23	4.08
Lime (CaO)	1.43	2.25	1.20	.49	.33	.60	1.27	4.23	1.47
Magnesia (MgO)	4.57	4.57	2.98	2.36	2.33	2.99	3.23	2.84	3.23
Potassa (K_2O)	2.82	3.95	4.06	3.78	4.09	5.27	3.77	3.51	3.90
Soda (Na_2O)	.77	.50	1.22	1.71	1.57	1.38	1.35	1.30	1.22
Carbon dioxide (CO_2)	1.89	3.15	1.41	.30	.08	.54	1.40	3.67	1.55
Pyrite (FeS_2)	.04	.02	.11	.14	.16	.04	1.18	1.72	.42
Water above 110° C. (H_2O)	3.21	2.82	3.37	4.01	3.81	3.16	3.82	4.09	3.53
Carbon (C)	....	....	Trace.	....	....	....	.46	.59	....
Sundry others and water present below 110° C.	.66	.77	.69	.51	.39	.56	.70	1.11	.67
Total	100.08	100.13	100.01	100.05	100.12	100.09	100.05	100.39	....
Specific gravity [b]	2.717	2.796	2.776	2.795	2.805	2.806	2.774	2.783	2.783

[a] Figures in parentheses indicate the number of analyses averaged.
[b] Approximate.

[4] Dale, T. Nelson, and others. Work cited, p. 51.

In this connection Dale gives the following range in composition of ordinary slates, the less important constituents being omitted:

Range of composition of slate.

Silica	55–67	Soda	0.50–3.97
Alumina	11–23	Magnesia	0.88–4.57
Ferric oxide	0.52–7	Lime	0.33–5.20
Ferrous oxide	0.46–9	Water above 110° C	2.82–4.09
Potash	1.76–5.27		

COLOR OF SLATE.

The more common colors in slates are gray, bluish gray, and black. The reds, various shades of green, and variegated slates are less common, and purple is rare. Yellow brown and buff colors are occasionally found in deposits, but usually they have resulted from weathering, and slates of such colors are not marketable. Chemical and mineralogical composition determine the color of a slate, the colors other than gray and bluish gray being due chiefly to the presence of iron compounds and carbonaceous material. Slates containing considerable proportions of finely divided carbonaceous matter are black. Regarding the more brightly colored slates, Dale[5] has pointed out that the percentage of ferric oxide, Fe_2O_3, in the colored slates steadily increases from the variegated to the purple and to the red, whereas the proportion of ferrous oxide, FeO, markedly decreases in passing from the unfading green to the variegated, sea-green, bright green, purple, and red. He attributes this decrease to the smaller amount of chlorite present in the latter varieties.

Color is of great economic importance. Slates of certain colors are in demand and command high prices, whereas those of other colors are difficult to sell. Permanence of color is probably of most economic importance, for although some slates maintain their original colors for many years, others fade rapidly. According to Dale[6] and Hillebrand, the fading of slate is due to the presence of small quantities of iron-lime-magnesia carbonates, which decompose readily with the formation of the yellow, hydrous iron oxide, limonite.

RESULTS OF PHYSICAL TESTS.

Comprehensive tests of electrical slate from the soft-vein slate belt of Pennsylvania were recently conducted at the Fritz Engineering Laboratory of Lehigh University. The mean results of a series of physical tests are given below.

[5] Dale, T. Nelson, and others. Work cited, p. 51.
[6] Dale, T. Nelson, and others. Work cited, pp. 55–59.

Mean results of physical tests of Pennsylvania slate.

Specific gravity		2.81
Porosity, per cent		0.196
Tensile strength	pounds per square inch	3,625
Compressive strength	do	10,250
Mod. of rupture for ½-inch depth	do	7,760
Mod. of rupture for 1-inch depth	do	7,940
Mod. of rupture for 1½-inch depth	do	10,250
Mod. of elasticity for 1-inch depth	do	9,600,000
Mod. of elasticity of 2½-inch depth	do	8,050,000
Abrasion, per cent of wear		5.12
Abrasion, French coefficient		7.81
Toughness		11.5
Hardness coefficient		11.0
Coefficient of expansion per ° C		0.00001034

DURABILITY OF SLATE.

Slates consist essentially of stable silicate minerals that are very resistant to weathering, and consequently high-grade mica slate is one of the most durable of building materials. Ferguson[7] says, that slates mined near Delta in 1734 were, at the time of writing (1910), still in use covering the seventh building on which they had been placed, showing no indication of change in color or deterioration in quality. In European countries slates have been used for centuries, and consequently better evidence of their durability is obtainable from that side of the Atlantic. Reference may be made to a slate-roofed Saxon chapel which stands in Bradford-on-Avon, Wiltshire, England. It was built in the eighth century, and after 1,200 years of constant exposure to climatic changes, it is moss covered but still in good condition.

The fact is significant that during the latter part of the World War the British Government expressed a much greater preference for slate than for the cheaper and more temporary forms of roofing. This attitude was due partly to the coal shortage, for composition roofing manufacture required larger coal supplies than did slate manufacture, but the chief reason was recognition of the durability of slate and its ultimate economy as compared with temporary roofing materials that had soon to be repaired or replaced. Consequently, slates were used widely for both temporary and permanent structures, such as engineering works, grain warehouses, airdromes, shell factories, and offices. Many composition roofs were stripped from buildings and replaced with slate.

[7] Ferguson, E. G. W., Peach Bottom slate deposits, Pennsylvania; Min. World, vol. 33, 1910, p. 183.

SLATE STRUCTURES.

BEDDING.

The shales from which slates originated were primarily deposited as clay beds. Variation in conditions of deposition may have resulted in such variations in color or texture that distinct bedding planes were formed. These bedding planes, at first horizontal, may have become tilted by subsequent earth movements, and the intense metamorphism that converted the shales into slates has greatly folded and contorted many of the beds. The variation in color of the successive beds commonly makes possible the tracing of folds and contortions on the quarry wall. Bands representing beds of darker colored slate are known among quarrymen as ribbons. In many deposits, the original bedding has been obliterated so that it is extremely difficult to trace. Although the original shale splits most readily parallel with the bedding, this tendency may be destroyed through recrystallization and pressure and a new direction of easy splitting developed quite independent of the direction of bedding.

Dale[8] fully describes the characteristics of beds, and the various means of identifying the direction of bedding in slate deposits. This is of considerable importance, for the slate in any one bed tends to be uniform for considerable areas, but one bed may differ greatly from another. Consequently for the proper development of a deposit of desirable slate, it is necessary to follow the original bedding, which he must be able to trace. Thus, in the Pen Argyl district of Pennsylvania, the quarries are situated on the "Albion" vein, the "Diamond" vein, the "United States" vein, or the "Pennsylvania" vein, all of which are of limited thickness. These veins or beds are vertical or dip at a steep angle, and their direction may change with depth. Thus, folds or the inclination of beds have a direct bearing on the location of the quarry opening and on the plan of development.

SLATY CLEAVAGE.

Slaty cleavage is the structure which above all others differentiates slate from other rocks and gives it economic value. By virtue of it the rock splits much more easily in one direction than in others. A true slate may be split into thin sheets having comparatively smooth and even surfaces. Some of the Pennsylvania slates can be split as thin as one-thirty-second of an inch, but such sheets are too thin for practical use. In the manufacture of blackboard slates, uniform, smooth slabs 4 by 6 feet or larger may be readily split to a thickness of three-eighths inch. As already noted under

[8] Dale, T. Nelson, and others. Work cited, pp. 27–33.

"Origin of Slate" on page 3, the slaty cleavage is caused by recrystallization and rearrangement of the constituent minerals of the original shale by intense metamorphism. The direction of the cleavage planes thus formed is governed by the direction of pressure.

Most writers agree that only exceptionally does the slaty cleavage have the same direction as the bedding, but Eckel[9] claims that in his experience the cleavage of most of the commercial slates in the United States is either absolutely parallel with the bedding or else diverges from it at a small angle. The writer's observations do not justify this claim, for in practically all the quarries of Pennsylvania, the most important slate-producing State, the slaty cleavage rarely coincides with bedding, and commonly crosses it nearly at right angles. Where slaty cleavage and bedding coincide, the split surface is usually more uneven than where they intersect, and such slates are, therefore, more suitable for mill stock than for roofing. Shearer[10] claims that slates with a very smooth and perfect cleavage tend to be weaker than those having a rougher cleavage surface. Weathered slates have poorer cleavage and are less durable than those quarried at considerable depth. Quarrymen know that the best splitting can be obtained from freshly quarried rock, for slates can not be split readily after they have dried out. The slates of Monson, Me., seem to be an exception to this rule for they are said to split readily after they have dried on the bank for a long time. Repeated freezing and thawing also destroys the splitting quality. Many American slates have remarkably perfect and true cleavage, permitting the production of uniformly thin slabs of large size.

GRAIN.

Although slates split with greatest ease in the direction of slaty cleavage, many slates have a second direction of splitting that although less pronounced than the slaty cleave is of economic significance. This second direction of splitting is termed the "grain." It is approximately at right angles to the slaty cleavage, usually follows a direction nearly parallel to the cleavage dip, and may commonly be recognized by lines or striations on the cleavage surface. It seems to result from mineral orientation, for the fact has been noted that many minerals lie with their flat faces parallel with the direction of the slaty cleavage and their long axes parallel with the grain. In some slate deposits the grain is distinct, whereas in others there is practically no grain.

The grain may be utilized to obtain a uniform fracture in separating the larger blocks of slate in the quarry and in reducing them to

[9] Eckel, E. C., Building stones and clays. 1912, p. 110.

[10] Shearer, H. K., The slate deposits of Georgia: Geol. Survey of Ga. Bull. 34, 1918, p. 13.

convenient sizes. In the manufacture of roofing slates, the grain should always be parallel with the long sides so that breakage will be in the direction of the dip of the roof.

JOINTS.

Joints may be defined as more or less regular parallel systems of cracks or fractures in rocks, such fractures being caused by rock strains or movements. In an earlier publication[11] the author has discussed the origin of joints in detail, and has pointed out that as the direction of fracture bears a definite relation to the direction of strain, joints tend to occur in parallel series. In slate beds the joints are classified according to their directions. Those parallel with the strike of the beds are termed "strike joints," those parallel with the direction of dip, "dip joints," and those that intersect both strike and dip, "diagonal joints." There are also horizontal joints, sometimes termed bottom or flat joints. In some Pennsylvania deposits there is a tendency for joints to parallel intrusive dikes. In some deposits curved or undulating joints have been noted.

Uniform joints spaced several feet apart, and occurring in two systems approximately at right angles, are of great assistance in quarrying, but if they are closely spaced, or meet at acute angles, they cause a large proportion of waste.

IMPERFECTIONS IN SLATE.

CURVED OR IRREGULAR CLEAVAGE.

Curvature of cleavage has been noted in various slate deposits. Curved slates resulting from such cleavage have been used to some extent for roofing round towers, but aside from this, curvature or any form of irregularity in cleavage is undesirable, for it causes the production of irregular slates and thus increases waste. A moderate curvature may not preclude utilization as small roofing slates, though it would probably prevent blackboard manufacture.

SLIP OR FALSE CLEAVAGE.

As defined by Shearer,[12] false cleavage or slip cleavage is "a capacity to part along parallel incipient joints, although there is usually no actual fracturing of the mass." Such incipient joints appear in certain zones only, and do not pervade the entire mass. The presence of slip cleavage detracts from the value of a slate deposit, and microscopic search for evidences of slip cleavage should be made before

[11] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1916, pp. 23–29.

[12] Shearer, H. K. Work cited, p. 14.

commercial development is attempted. As an indication of how serious this defect may become, Dale[13] refers to a Vermont quarry which proved a failure on account of the presence of slip cleavage.

SHEAR ZONES.

Shear zones are described as angular plications or series of plications due to shearing pressure on somewhat rigid material. Such zones usually intersect cleavage planes diagonally, and thus result in the production of angular blocks, with consequent waste of material. Usually they do not affect any large mass of slate, and are to be regarded as structures of minor importance from the economic standpoint. "Post" is a quarryman's term for shear-zone structures.

RIBBONS.

"Ribbons" is a term applied to comparatively narrow bands crossing slants at various angles. They represent minor beds having somewhat different composition from the main body of the slate. Some ribbons are not objectionable for they may contain no injurious constituents and may not have undesirable colors. In some of the Pennsylvania deposits, however, the ribbons are rich in carbonates that weather more readily than the siliceous constituents. Such ribbons in roofing slates can be permitted only on those parts of the slates that are not directly exposed to the weather. Much of the ribboned slate can be used to advantage for structural purposes or blackboards. Conspicuous color of the ribbon may render it undesirable to use the slate.

When exposed to the weather the ribbons in the "soft-vein" slate of Pennsylvania decompose more readily than the clear stock. In sidewalks, made of ribboned slate, deep grooves have commonly resulted from the weathering of the ribbons. The ribbons in the "hard-vein" slate of Pennsylvania resist weathering.

FAULTS.

The relative displacement of adjacent rock masses along a fracture is termed a "fault." Many minor faults are visible in slate deposits, but faulting has had little economic significance in slate quarrying up to the present time. A major fault may bring an undesirable rock mass into the line of a desirable slate bed, and the determination of the faulting would then be of great economic importance.

VEINS.

Veins are common in slate quarries. They may follow bedding planes or cleavage planes, may intersect such planes at various

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[13] Dale, T. Nelson, and others. Work cited, p. 37.

angles, or may be very irregular. The vein material is commonly quartz, and such veins are termed "flints" by quarrymen. Calcite or "spar" veins are common, and also veins filled with a mixture of quartz, calcite, dolomite, and possibly chlorite and biotite. The filling material has been derived from the surrounding slates or associated rocks and deposited from solution.

DIKES.

Dikes which may be defined as volcanic intrusions of igneous rock solidifying in fractures are common in slate deposits. Dikes and joints are usually in parallel arrangement. They are not as common as veins, but in proportion to their occurrence they are as detrimental.

Intersecting dikes naturally cause considerable waste; furthermore, they constitute planes of weakness and may cause dangerous rock slides.

NODULES.

In some Vermont quarries lenslike nodules consisting of quartz, calcite, pyrite, and muscovite occur along the bedding planes. In some places they may be concretions, the pyrite quartz and other grains originally scattered throughout the slate being concentrated in nodular form.

Some quarrymen term quartz lenses or nodules slate "purifiers," for they claim that slate in the vicinity of such nodules is very pure and uniform. If the quartz masses are concretions of siliceous impurities derived from the surrounding rock, there is evidently a logical basis for this claim.

COLOR EFFECTS.

Slates differ in color, and some colors are much more in demand than others, the preference being based more on tradition than on artistic taste or actual qualities of the slates. A wider market for colors not now in demand depends, therefore, on the cultivation of public taste. Architects and builders can widen the field of utilization of roofing slate by judicious efforts to popularize new colors or combinations of colors.

Slates are classed as fading or unfading according to their color stability. The fading of green slates is probably due to the presence of iron carbonate which seems to be present not as pure siderite, $FeCO_3$, but as an isomorphous mixture of the carbonates of iron, lime, magnesium, and possibly manganese. The hydrous iron oxide formed by decomposition of the carbonate through action of certain solvents carried in rain water destroys the green color and causes fading. According to Eckel[14], the black and gray slates usually contain small amounts of such constituents and are therefore nearly permanent in color. Bluish slates commonly turn grayish, and red slates may turn brown. The green slates are the most uncertain, some are practically permanent in color, but others fade and discolor badly.

A moderate and uniform fading may not be detrimental, but may produce a more pleasing effect, though in replacing broken slates it may be difficult or impossible to match the colors. Nonuniform fading results in spots or streaks and is undesirable. The formation of some spots is due to the weathering of grains of the iron sulphides, pyrite, or marcasite.

Spots and blotches are very objectionable in slates. Many of the red and purple slates contain pale green spots, some bordered with purple. The spots range in size from minute specks to spots 2 inches or more across, some are circular or oval and others are irregular. In places the spots form bands or ribbons.

From microscopical and chemical work done by Dale[15] and Hillebrand it appears that the pale green spots in the red and purple slates are due to chemical changes caused by the decay of organisms embedded in the clays from which the slates were formed.

IMPURITIES.

Most of the minerals composing slates are stable silicates that withstand weathering remarkably well. A slate free from impurities is, therefore, a very durable rock. The injurious constituents have already been discussed, and a brief review of them is all that is necessary at present.

Nodules of quartz, calcite, and muscovite occurring along bedding planes are to be avoided. Carbonates are undesirable, as they decompose readily compared with the chief constituents of the slate; iron carbonate is the most detrimental, for it not only decomposes but causes stains. Iron sulphides by oxidation may form spots and stains. Marcasite is more injurious than pyrite, as it decomposes more easily. Mixtures of pyrite and marcasite or porous forms of either may decompose with comparative rapidity, whereas pure crystallized pyrite may be fairly stable. Howe[16] states that crystals of pyrite have been observed still retaining their brilliant luster in roofing slates in Glasgow, where they have been exposed over 100 years. The stability of iron sulphides when exposed to the weather is discussed in detail in a previous publication.[17] Reference has

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[14] Eckel, E. C. Work cited, p. 109.

[15] Dale, T. Nelson, and others. Work cited, pp. 23–27.

[16] Howe, J. Allen, The geology of building stones. London, 1910, pp. 301, 302.

[17] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1916, pp. 29–33.

already been made to slates being invaded by foreign minerals in veins or dikes.

Clay slates are not as durable as mica slates; they are more porous and disintegrate more readily. If a high-grade mica slate is placed on edge in water, the moisture will not rise perceptibly above the water line even in 24 hours; whereas if a poor grade of clay slate is used, the moisture may rise as much as 2 inches in 10 minutes because of the capillarity of the porous clay.

TESTING OF SLATES.

The testing of slates is described in considerable detail by Dale.[18]

The following simple tests will enable one to judge the quality of a slate with reasonable certainty:

SONOROUSNESS.

If a good-sized fragment of slate is suspended and struck with a hard object, the nature of the sound given forth is a fair indication of the quality of the slate. A high-grade mica slate will yield a semivitreous ring, whereas clay slates or mica slates containing considerable chlorite or talc are much less sonorous.

CLEAVABILITY.

A freshly-quarried unfrozen block in a moist condition should be tested for cleavability with a regular slate-splitting chisel in the hands of an experienced workman. The test indicates not only the ease of splitting but also the smoothness of the surfaces obtained. Examination of the cleavage surface with a hand lens will reveal the grain, false cleavage, ribbons, and surface irregularities.

SCULP.

Sculping is a technical term applied to splitting in the grain direction. A thick block should be employed and the test made with a stout chisel and a long-handled heavy mallet. It can be done properly only by an experienced workman.

LIME.

The presence of lime carbonate can best be detected by applying dilute hydrochloric acid to the edge of a slate fragment or to powdered slate, and noting whether effervescence or bubbling results. To test for dolomite (carbonate of lime and magnesia) stronger acid must be used or heat applied.

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[18] Dale, T. Nelson. Work cited, pp. 172–181.

PERMANENCE OF COLOR.

The permanence of the original color, or the changes that are likely to ensue from exposure to the weather, can best be determined by comparison of a fresh piece of slate with slate from the same deposit long in use in an exposed place. If slate roofs are not available for comparison, slate taken at a considerable depth below the surface may be compared with exposed parts of the ledge.

CLAY.

By breathing upon the surface of a freshly quarried fragment of slate, the presence of clay may be detected by an argillaceous odor. The best slates give little evidence of the presence of clay.

SULPHIDES.

Grains of iron sulphide may be recognized by their yellow metallic appearance. Pure pyrite in crystallized form, commonly occurring in cubes or octahedrons, may not be detrimental as it may resist weathering for many years, but marcasite, mixture of pyrite and marcasite, or porous, spongy forms of either are undesirable; they decompose readily and give yellow stains. Careful examination should therefore be made of all sulphide grains to determine their shape and character.

MAGNETITE.

Slate to be used where low conductivity is required, as for electric switchboards, must contain a very small percentage of magnetite. The percentage of magnetite can best be determined by pulverizing a given quantity of slate, separating the magnetite with a powerful magnet, and weighing it.

COMPOSITION AND PHYSICAL PROPERTIES.

In accordance with the cooperative agreement (page 1), tests of electric resistance, strength, elasticity, density, porosity, hardness, corrodibility, with chemical analyses of American slates are being made by the Bureau of Standards, and a report will be issued in due time.

USES OF SLATE.

ROOFING.

Slate makes such durable and attractive roofing that its use should be greatly encouraged. Furthermore, its noninflammability as compared with wood adds to its value, for the most frequent cause of dwelling-house fires in the United States is said to be sparks from a chimney alighting on a wood-shingle roof.

The essentials of slate for roofing are straight, uniform, and smooth cleavage, a uniform and attractive color, unfading or fading uniformly, and absence of mineral constituents that dissolve with relative ease. Roofing is a very important use and formerly it was, with minor exceptions, the only use made of slates.

In the United States slates are sold by the "square"—enough slate to cover 100 square feet with a 3-inch lap. In France and England the unit is a "mille," 1,200 slates of any given size and 60 additional to cover loss by breakage. Slates range in size from 7 by 9 to 16 by 24 inches, and the number of slates required for a square ranges from 85 to 686, according to the size. Ordinary slates are from one-eighth to one-fourth inch thick, and although the cost of transportation and the weight on the roof supports is less for the thinner slates, the liability to breakage is greater. The weight of a square of average roofing slates is about 650 pounds.

MILL STOCK.

BLACKBOARDS AND SCHOOL SLATES.

Slate suitable for blackboards must be soft and fine-grained. Such slate is obtained from what is known as the "soft-vein" region of Lehigh and Northampton Counties, Pa. The soft vein is the northern slate belt which includes the region in and about Bangor, East Bangor, Pen Argyl, Danielsville, Slatington, and Slatedale. This comparatively small area, not over 22 miles long, comprises the best if not the only good blackboard slate deposits in the world. Because of their smoothness, uniformity, permanence, and attractiveness, slate blackboards are superior to all other types of blackboards now in use.

A tendency exists among users of slate blackboards to specify clear stock only. A high quality in finished products is, of course, desirable, but in demanding clear stock the consumer is hedging the producer about with conditions that he is often powerless to meet. Clear stock, by estimate, constitutes only about 10 per cent of what is commonly regarded as the commercial slate of the soft-vein belt, or approximately 1 per cent of the gross tonnage mined. If, therefore, the majority of consumers specify clear stock, such hardship is laid on producers that the very existence of their industry is threatened, for a tendency to accept only selected stock may raise specifications to a point where no slate blackboards will be produced.

Manufacturers claim that a moderately banded or ribboned slate is equal to clear stock for blackboard manufacture except possibly in appearance, and efforts are being made to so modify specifications that more ribbon stock may be used. Blackboard users will help the industry by endeavoring to appreciate the manufacturer's contentions, and frame specifications in a way that will permit a wider use of stock that is not clear.

School slates were once common in America, but their use has greatly declined. Foreign demand is considerable, and most school slates now manufactured are exported. As school slates are small, their manufacture permits the utilization of the smaller pieces, many of which would be otherwise wasted. School slate is similar to blackboard slate, and the deposits are largely confined to the same area.

STRUCTURAL SLATE.

Although roofing is ordinarily regarded as structural material, a distinction is made in speaking of slate, the term "structural slate" being employed for slate products used chiefly for interior structural and sanitary purposes. The chief structural slate products are mantels, floor tiles, steps, risers, flagging, skirting board, window sills, lavatory slabs, billiard and other table tops, wainscoting, hearths, well caps, vats, sinks, laundry tubs, grave vaults, sanitary ware, refrigerator shelves, flour bins, and dough troughs. A soft, even-grained slate, preferably not highly fissile, is required for such purposes.

The need for a better standardization of structural slate, and wider publicity as to its superior qualities led the Structural Service Bureau of Philadelphia in cooperation with the Structural Slate Co., of Pen Argyl, Pa., to issue a series of pamphlets on structural slate, the first of which appeared in 1919. The object of these pamphlets is to encourage the use of standard sizes, shapes, and patterns, to minimize calculations, and to provide for architects a series of standard specifications that will greatly facilitate the placing of orders. Such a movement is of great benefit to the industry, not only by tending to reduce the cost of manufacture, but by permitting producers to carry standard sizes in stock and thus fill orders with little delay.

ELECTRICAL SLATE.

Slate is used widely for purposes where low electric conductivity and mechanical strength are required. As a rule it has a lower dielectric strength than marble, but from its toughness, easy workability, low cost, and ease of matching when switchboards are enlarged, it is more generally employed. Electrical slate should be strong, and of such quality that it can be cut and drilled without scaling; it must be free of magnetite and of veins of low-resistance minerals.

Definite information as to the requisite qualities of electrical slate until recently has been notably lacking. To meet this deficiency a series of tests of electrical slate were conducted in the Fritz Engineering Laboratory, Lehigh University, under the direction of Robert Notvest, and the information obtained was used as a basis for establishing standard specifications for electrical slate. The Structural Service Bureau of Philadelphia took the initiative in the matter and called a conference to discuss and perfect the specifications. The tentative specifications as agreed upon at the conference read as follows:

1. Natural slate to be used for electrical purposes shall be of clear mill stock, of uniform color and free from veins, spots, and cracks.

2. The slate shall be of uniform dense texture and have a specific gravity of about 2.8.

3. The porosity or factor of absorption shall not be in excess of 0.3 per cent. The tensile strength shall be about 3,500 pounds per square inch; compressive strength not less than 10,000 pounds per square inch.

4. The modulus of rupture shall not be less than 8,000 pounds per square inch; the modulus of elasticity should show about 8,000,000 pounds per square inch.

5. The slate shall be relatively soft and easy to drill, hardness as tested on a Dorry machine should show about 6 per cent wear or if abrasion is determined relative to the French coefficient it should show about 10 per cent.

6. The slate shall be rather tough; when tested on a Riehle impact machine to determine toughness—that is, resistance to fracture under impact under the method as advocated by the American Society for Testing Materials, it shall show not less than a factor of 12.

7. The coefficient of expansion shall be less than 0.00002.

8. The slate shall be able to withstand a temperature of 200° C. without showing cracks, such temperature as in actual practice might be caused by a circuit breaker or switch stud carrying an overload of current. The slate also shall not crack if any heat-radiating resistance unit was mounted within 3 inches of the surface of the slate, provided that such radiation of heat would not cause on the surface of the slate a temperature in excess of 175° C.

9. The ohmic resistance of 1 cubic inch of such slate shall not be less than 400,000 ohms; also the resistance measured lateral to the cleavage of the slate by means of clamping metallic studs through the slate, the nearest metallic parts to be 1 inch apart on the surface, should show not less than 300,000 ohms.

10. The slate shall not be used for electrical purposes until after three months from the date of quarrying the same.

11. The face and edges of panels shall have even, true surfaces, accurately cut to dimensions given, and shall not vary more than one-sixteenth of an inch. Any adjoining edges or sides shall not deviate from a right angle by more than one thirty-second inch per linear foot. Bevels shall be cut true entirely around panels and shall be measured by the projected width and depth. Backs of panels shall be free of lumps or depressions.

12. Finish upon all edges, bevels, and exposed faces shall be honed finish, true to a line. Backs shall have sand-rubbed finish, but need not be trued.

13. Holes drilled in the slate for the purpose of securing it to the supporting angle-iron or pipe framework, shall be from 15 per cent to 20 per cent larger in diameter than the screws, bolts, cap screws, or studs used for this

purpose; also between the surface of the slate and the points of contact on the supporting framework, there shall be interposed compressible washers of suitable size of such material as rubber, leather, felt, etc., to compensate for the irregularities of the surface of the framework.

14. Slate slabs over 4 square feet in area, mounted on framework shall rest on an angle-iron support so that whenever possible, the fastening bolts, screws, or studs do not carry the weight of the slate but only hold the same in place. In case of large switchboard assemblies, all panels shall rest on a substantial channel iron base, preferably cushioned with a strip of the above mentioned compressible materials between the slate and the base.

HISTORY.

EARLY HISTORY IN EUROPE.

The earliest reference to the use of slate for roofing probably is the construction of a chapel roof at Bradford-on-Avon, England, in the eighth century. (See page 7.) According to Davies,[19] slates were used to cover old catsles at Carnarvon and Conway in North Wales during the twelfth century. Such slates were thick and rough, the workers not having attained the skill in splitting and trimming which characterized later practice.

One of the earliest references in literature to slate quarrying is the mention of the Penrhyn quarries by a Welsh poet in 1570. The physical characteristics of the slates of Cornwall were described by Carew in 1602. After the latter part of the eighteenth century, the industry attained considerable importance. During those early years, the methods were crude and wasteful. The rock was quarried by small groups of men or even by single operators, each having his own quarry opening. The waste material was thrown in the most convenient place, and usually covered good slate. The rock was broken with hammers and much of it wasted. Transportation was most primitive, the rock being hauled by horses, conveyed in wheelbarrows, or carried in bags on men's backs. At the Llangynog quarries in Wales, the slates were loaded on sledges and guided in a precarious manner on the steep slopes down which they slid. After about 1850, the growth of the Welsh slate industry was rapid. Large villages grew up around the quarries, and seaports were developed for transportation of the product. The rapid growth during this period is attributed by Davies[20] to railway extensions affording more easy transportation and thus widening the market, the growth of new towns, and improvement in rural dwellings, the removal of restrictive tariffs, and increased foreign demand.

A slate-roofed castle at Angers, in France, a famous modern slate-mining center, dates to about the twelfth century. As in Wales, the rapid development of the slate industry in France began about

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[19] Davies, D. C., A treatise on slate and slate quarrying. London, 2d ed., 1890, p. 161.
[20] Davies, D. C. Work cited, p. 174.

1850. According to Watrin,[21] mining and transportation methods were greatly improved subsequent to 1842, chiefly by the substitution of mechanical equipment for hand methods.

EARLY HISTORY IN AMERICA.

Probably the oldest slate quarry in the United States is in the Peach Bottom district at the Pennsylvania-Maryland line, from which slate was taken in 1734. In Virginia the first quarry was opened to provide slate for the roof of the State capitol about 1787. According to Shearer, slate was first quarried in Georgia in 1850. From these early beginnings, slate quarrying spread and became an established industry. It is generally admitted that slate quarrying in America was really established by Welsh slate workers. Davies[22] refers to the fact that not long before 1877, 150 skilled slate workers went from the Bethesda district to work in American quarries. Long prior to that, practically at the beginning of the industry, Welsh slate workers were employed, for a number of places in the slate region, as Pen Argyl and Bangor, were named after Welsh towns.

SLOW DEVELOPMENT OF INDUSTRY.

As may be observed from Table 2, the industry for 10 years prior to the World War was practically stationary, and during the war its nonessential status except for electrical switchboards caused a decided decrease of output. Postwar recovery is now evident, and the amount of building that must be done to supply the needs resulting from restricted construction during the war offer fair prospect of a more rapid growth.

As slate is a superior roofing and structural material, the reasons for the slow growth of the industry require some explanation. Evidently several factors are concerned, as pointed out below.

CAUSES CONTRIBUTING TO SLOW DEVELOPMENT.

EXPENSE OF QUARRYING.

High-grade slate usually occurs in narrow beds inclined at steep angles and the working of such beds results in deep quarries. Commonly slate quarries are over 400 feet deep, and such deep quarrying is more expensive than the working of comparatively shallow pits.

In order to obtain sound blocks of slate, slow and careful methods are used, which involve a great deal of hand labor and are costly.

[21] Watrin, N., Les ardoisières des Ardennes. Charleville, 1897, p. 10.
[22] Davies, D. C. Work cited, p. 176.

HIGH PERCENTAGE OF WASTE.

In quarrying comparatively narrow inclined beds, much adjacent barren material must be removed. Moreover, imperfections in the slate require the removal of considerable waste from the slate bed. In many quarries, particularly where blasting is employed, methods are very wasteful, though the introduction of channeling machines has somewhat lessened waste from this cause. A total waste of 75 to 90 per cent of the gross production is common, however, and as the cost of removing waste must be added to the cost of the finished product, the price must be raised to a point that makes competition with other materials more difficult.

TABLE 2. *Quantity and value of roofing slate and millstock produced in the United States, 1887–1920.*[a]

Year.	Roofing slate.			Millstock.			Other uses (value).	Total value.
	Number of squares.	Value.	Average price per square.	Quantity (square feet).	Value.	Average price per square foot.		
1887	573,439	$1,720,317	$3.00					$1,720,317
1888	662,400	2,053,440	3.10					2,053,440
1889	835,625	2,797,904	3.35		$684,609			3,482,513
1891	893,312	3,125,410	3.50		700,336			3,825,746
1892	953,000	3,396,625	3.56		720,500			4,117,125
1893	621,939	2,209,049	3.55		314,124			2,523,173
1894	738,222	2,301,138	3.12		489,186			2,790,324
1895	729,927	2,351,509	3.22		347,191			2,698,700
1896	673,304	2,263,748	3.36		482,457			2,746,205
1897	1,001,448	3,097,452	3.09		427,162			3,524,614
1898	916,239	3,129,390	3.42		594,150			3,723,540
1899	1,100,513	3,454,817	3.14		507,916			3,962,733
1900	1,194,048	3,596,182	3.01		644,284			4,240,466
1901	1,304,379	4,114,410	3.15		673,115			4,787,525
1902	1,435,168	4,950,428	3.45		745,623			5,696,051
1903	1,378,194	5,345,078	3.88		911,807			6,256,885
1904	1,233,757	4,669,289	3.78		947,906			5,617,195
1905	1,241,227	4,574,550	3.69		921,657			5,496,207
1906	1,214,742	4,448,786	3.66		1,219,560			5,668,346
1907	1,277,554	4,817,769	3.77	5,979,624	943,409	$0.157	$258,042	6,019,220
1908	1,333,171	5,186,167	3.89	4,793,812	793,304	.165	337,346	6,316,817
1909	1,133,713	4,394,597	3.87	5,112,894	876,089	.171	170,732	5,441,418
1910	1,260,621	4,844,664	3.84	5,181,498	999,098	.192	392,997	6,236,759
1911	1,124,677	4,348,571	3.87	5,744,577	1,027,605	.178	351,843	5,728,019
1912	1,197,288	4,636,185	3.87	5,765,273	1,013,220	.176	393,913	6,043,318
1913	1,113,944	4,461,062	4.00	6,312,011	1,233,838	.195	480,576	6,175,476
1914	1,019,553	4,160,832	4.08	5,361,925	977,930	.182	568,025	5,706,787
1915	967,880	3,746,334	3.87	4,576,112	819,672	.179	392,909	4,958,915
1916	835,873	3,408,934	4.08	5,782,842	1,177,260	.20	752,643	5,338,837
1917	703,667	3,411,740	4.85	5,478,151	1,277,249	.23	1,060,977	5,749,966
1918	379,817	2,219,131	5.84	4,841,133	1,498,164	.31	1,123,825	4,841,120
1919	454,337	3,085,957	6.79	7,466,000	1,782,793	.24	1,161,898	6,030,648
1920	396,230	3,524,658	8.90	9,910,000	3,147,281	.32	2,054,503	8,726,442

[a] Compiled from Mineral Resources, U. S. Geol. Survey.

ENCROACHMENT OF SUBSTITUTES.

Wooden shingles, tile, sheet metal, asbestos shingles, and composition roofing of various types are used extensively. In particular various forms of composition roofing have been given wide publicity during recent years, and have encroached on the field formerly occupied by slate. This has not been due primarily to the superior qualities of the substitute materials, many of them being far inferior to average slate in attractiveness and permanence, but to their low cost and to extensive advertising. The latter cause is to be regarded as the most important, for composition roofing manufacturers have advertised very widely and slate manufacturers have advertised little, with the result that their industry has suffered.

DISTRIBUTION OF SLATE.

SLATE DEPOSITS OF THE UNITED STATES.

Active slate quarrying in 1921 was confined to the States of Maine, Maryland, New York, Pennsylvania, Vermont, and Virginia. The chief production was from the Lehigh district of Pennsylvania, including parts of Northampton and Lehigh Counties. The Peach Bottom district, which extends from York and Lancaster Counties across the line into Harford County, Md., has produced considerable slate. The active Vermont district lies in Bennington and Rutland Counties and extends into Washington County, New York. The Maine slate deposits occur in Piscataquis County about the center of the State. Slate occurs in several distinct deposits in Virginia, but operations are now conducted only on the Arvonia belt of Buckingham and Fluvanna Counties.

Active quarrying, therefore, is conducted in five distinct areas. A number of other deposits have been worked in the past and may be worked again, but are now idle; others have not yet been developed. An adequate description of deposits not now worked is given by Dale.[23]

FOREIGN SLATE DEPOSITS.

Howe [24] has reviewed foreign slate deposits.

In Canada slate has been quarried chiefly in Richmond County, Quebec, though some slate has been produced in Nova Scotia and in British Columbia. Slates have been obtained from the shores of the Bay of Islands and Trinity Bay, Newfoundland.

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[23] Dale, T. Nelson, Slate in the United States: U. S. Geol. Survey Bull. 586, 1914, 220 pp.
[24] Howe, J. Allen, The geology of building stones. London, 1910, pp. 291–314.

In the British Isles, the Welsh slates, particularly those of Carnarvonshire and Merionethshire, are the best known, though slates are also produced from Cornwall, England, from Argyle, Perth, and Dumbarton, Scotland, and from Tipperary and Cork Counties, Ireland. The Welsh deposits constitute the main supply for export trade.

The chief slate mines of France are in the Ardennes and the Angers districts. Great quantities of slates have been taken from these regions and much of the product has been exported. Slates have been quarried in Bohemia and near Olmutz in what was formerly the Austrian Empire, and along the Valley of the Moselle and in Westphalia, Germany.

A limited production of slate has been noted from Norway, Portugal, India, Italy, New Zealand, and Tasmania.

PLAN OF QUARRYING.

OPEN-PIT METHODS.

Slate is usually obtained from open quarries. In planning the quarry layout, careful consideration must be given to rock structures. The attitude of the original bedding, which is commonly marked out by the so-called "ribbons," must be carefully traced. In this connection a knowledge of the geology and origin of slate is of great advantage to the operator. As pointed out on page 3, most slate deposits represent clays originally deposited in strata or beds, which were afterwards folded and compressed enough to develop the characteristic structure and mineral composition of slate. The materials that formed an original bed and were deposited simultaneously and under constant conditions evidently must have been of fairly uniform composition over large areas; hence, if particularly good slate occurs in a certain bed the operator must plan his quarry in such a way as to follow this bed and thus obtain a maximum of high-grade rock.

In the Pennsylvania slate region the beds are clearly marked by "ribbons" or "bands," so that tracing the direction of the original bedding is comparatively easy. In many deposits the bedding is more difficult to recognize. In some slate quarries in Pennsylvania the slate beds are nearly vertical, but curve back and forth at steep angles. In the New York-Vermont slate area near Granville, Poultney, and Fair Haven, the bedding dips at an average angle of about 40° or 45°, ranging in different quarries from 15° to 60°. As the beds are inclined at a lower angle in this region the plan of work is somewhat different from that followed in Pennsylvania. In the Vermont-New York area the low angle of the beds necessitates wide openings, for with vertical descent the quarry pit may pass entirely through the desirable bed, and further development demands an extension of the quarry opening along the strike. If the cost of removal of the overlying material is not prohibitive, the pit may be extended in the direction of the dip. In any case the tendency is toward the development of wide and comparatively shallow quarries, where the beds are flat-lying or inclined at low angles. Where the beds are nearly vertical, as in Pennsylvania, a quarry having a small surface opening may be worked to a great depth and consequently may be operated for many years without any further expense for removal of overburden, but deep quarrying has its special dangers and inconveniences. Rock fragments may fall from the walls or the surface or from hoisted blocks or loaded pans, and hoisting takes more time than at shallow

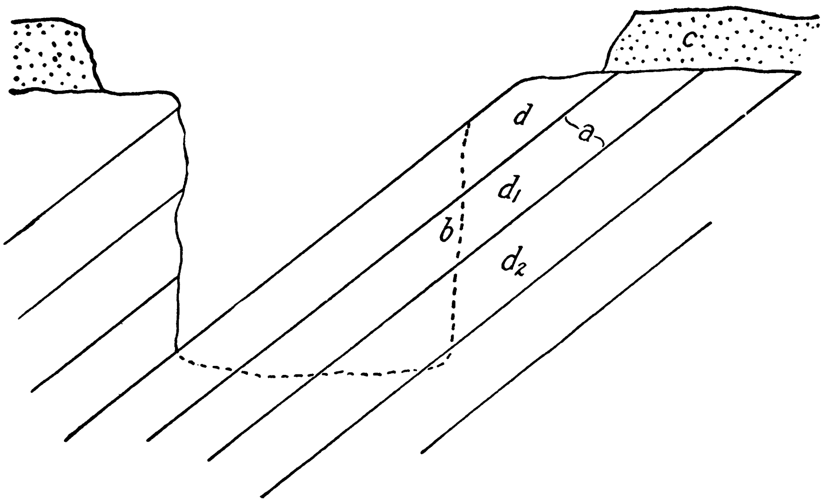

FIGURE 1.—Rock slides caused by steeply inclined open joints: *a*, Open joints; *b*, boundary of proposed quarry opening; *c*, overburden; *d*, slate beds.

excavations. At shallow pits, however, the stripping necessary may entail the removal of great quantities of waste rock or earth. Thus it may be seen that the inclination of the beds has a direct bearing on the plan of quarrying to be followed, the necessary equipment, and the probable cost.

In planning a quarry opening careful attention must be given to rock structures. Steeply inclined open joints or open beds may endanger operations because of slides of rock masses left without support. In one quarry observed an additional area had to be stripped and the quarry opening widened in order to remove rock masses that were in danger in sliding into the pit. Thus, as shown in Figure 1, the inclined open joints *a* might cause rock slides into the pit if the latter were projected downward as indicated by the dotted line b. To avoid such a danger the overburden c may be stripped back, and the rock masses d, d_1, d_2, et cetera, removed in succession from the surface downward. The advantages of such a plan of development are obvious. The projection of the pit as indicated by the dotted line b would result sooner or later in slides of unsupported rock into the pit, including surface weathered rock and possibly the soil overburden. Aside from the danger involved in such slides the resulting confused mass of rock and soil would be difficult to handle and would require hoisting from the bottom of the pit. According to the suggested improved plan of development the stripping is first removed, and as the rock ledges can then be worked from the surface little hoisting is required. When good rock is reached a clean floor may be maintained having no obstruction from waste rock and soil.

Failure to observe the menace of steep open joints, or inability to secure operations against distaster, has resulted in a number of quarries being closed because of rock slides. The operator should plan his quarry as a permanent industry, and at the very beginning map out a plan of development that will permit untrammeled operation for an indefinite period. Lack of capital has been the chief excuse given for improper quarry planning. Although it is undoubtedly true that ample capital would favor a comprehensive scheme of development, nevertheless in many quarries a much better plan could have been devised at little more expense. A careful study of the dip and strike of beds and of the occurrence of open joints would determine the operator in making a deep and narrow pit or a wide and relatively shallow opening. Such observations should also serve as a guide in determining the probable direction in which the pit should be extended for future wider development or for protection against rock slides.

If slate of good quality is available over a considerable area, and there is a choice of several places for a quarry opening, an important factor governing such location is a suitable disposal area for quarry waste and stripping. The most obvious error observable in all slate districts is insufficient removal of waste. In some places the waste is so disposed that it covers valuable slate deposits and thus retards development; in others the waste dumps are so close to quarry openings that lateral expansion is prevented; and in several quarries rock slides into the excavations have undermined the spoil banks and precipitated them into the pits. Where this has happened the cost of removal was usually prohibitive and the pit was abandoned. Plate I, *A*, shows a waste pile partly fallen into the quarry pit. The quarry is practically ruined through lack of foresight during the early stage of development. At another quarry, shown in Plate IV

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(p. 50), the retention of a waste pile accumulated during the early period of development has required the construction of an elaborate and costly timber barrier.

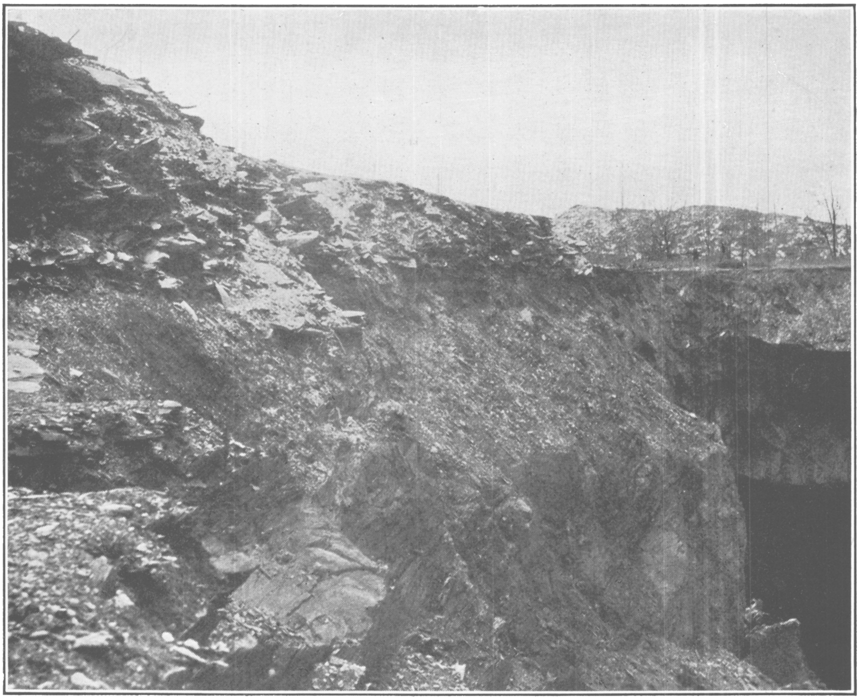
Insufficient removal of overburden is not always due to lack of foresight; it has often resulted from lack of capital. The slate industry has always been remarkably deficient in capital investment. Thousands of enterprises less deserving than slate quarrying have been provided with ample capital, but for some reason the slate industry has not attracted investors. The industry could be made more attractive if more comprehensive plans of development were carried out. Thus, if a mass of workable slate were blocked out in such a way that prospective investors had definite assurance of a large supply of raw material readily available, the assurance of success would encourage investment.

Availability to transportation lines is another factor that must be given consideration in planning the location of a quarry opening. The rehandling of material should be avoided wherever possible. Convenient trunk lines, with sidings, are greatly to be desired.

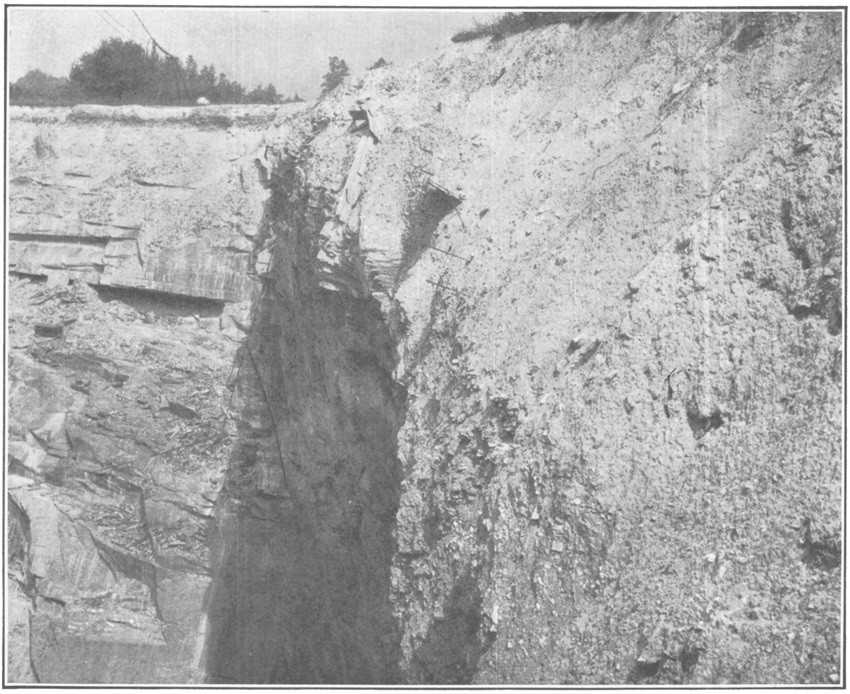
What has been said in the preceding paragraphs regarding quarries that have been improperly developed is presented chiefly for the guidance of the prospective operator. The owners of quarries that have been improperly worked should, however, receive equal consideration, for many of them are producing in the face of great difficulty. To plan a new operation is a much easier matter than to outline methods of rehabilitating a quarry that has reached an undesirable condition through many years of improper development. As such rehabilitation is largely nonproductive work, it probably requires considerable capital. Waste piles, too close to allow further development, may be removed with a steam shovel. If slides of rock or waste have partly filled the pit the opening of a new quarry on the slate bed may be advisable. Removal of a waste heap on comparatively level ground by means of a steam shovel and cars is comparatively simple, but such equipment can rarely be used in the bottom of a pit, and hand loading into a pan hoisted by derrick or cableway is slow and costly. If the chief difficulty is lack of adequate transportation facilities the only remedy is to build sidings, inclines, or cableways, or to devise some cheap method of motor transport.

UNDERGROUND METHODS.

Mining slate by shafts and drifts is done only where the vein is narrow and is vertical or nearly so, thus necessitating quarrying at considerable depth. Active slate mines are confined to the Monson district of Maine, and a complete description of operations there is given on page 55.



A. WASTE HEAP PARTLY FALLEN INTO THE QUARRY.



B. STRIPPING FACE LYING AT A STEEP ANGLE WITH ITS LOWER EDGE AT THE BRINK OF THE QUARRY.

QUARRY OPERATIONS.

STRIPPING.

IMPORTANCE OF STRIPPING.

Stripping is the process of removing the overburden of soil on the rock surface. The extent of the stripping required depends greatly on the method of quarrying. Some deep quarries on nearly vertical veins have been worked constantly for 40 or 50 years without enlarging the original opening, and thus have had no stripping problems since they were opened. Where slate is mined the same conditions of minimum stripping prevail. Generally, however, even in districts where deep quarrying is done the development of new deposits or enlargement of present quarries demands removal of overlying soil. In districts where slate is taken from wide and shallow pits, stripping becomes more important, and may constitute a considerable share of the quarry expense.

NATURE AND DEPTH OF STRIPPING.

Clay, sand, and gravel, with broken and decayed rock are the common overburden constitutents. In a few slate areas the rock is bare and no stripping is required, but in most regions there is more or less overburden, its thickness in different places varying from a few inches to 40 or 50 feet.

Although the term "overburden" properly applies only to the covering of soil, the upper part of the rock, decayed by water action or shattered by frosts, is closely related to it in that it also consists of a waste material that must be removed. Where this is loose and incoherent it is naturally classed with stripping, but where relatively firm it is removed by regular quarry processes. Therefore, the removal of the upper ledges of waste rock will not be considered as a stripping process, but will be taken up as a quarry problem for it involves processes similar to those used in the removal of any other waste rock in the quarry.

REMOVAL OF OVERBURDEN.

A great variety of stripping methods are used at mines and quarries. Earlier publications [25] of the Bureau of Mines, on marble, sandstone, and cement rock, describe the following types of stripping equipment: Hand shovel and dump cart, hand shovel and derrick or cableway pan, hand shovel and dump cars, teams and scrapers,

[25] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1916, pp. 46–48; Sandstone quarrying in the United States, Bull. 124, Bureau of Mines, 1917, pp. 27–30; Rock quarrying for cement manufacture, Bull. 160, Bureau of Mines, 1918, pp. 36–42.

teams and wheel scrapers, drag-line scraper, clam-shell bucket and traveling crane, steam shovel, and hydraulic equipment. Hand methods are the least efficient and the drag-line scraper, steam shovel, and hydraulic equipment the most economical where much stripping is to be done.

The great majority of the slate quarries visited use hand methods for loading overburden, though a few use steam shovels. In some quarries the overburden is so thin that the use of expensive equipment is not justified, and hand methods are probably the best. Where any considerable amount of soil must be removed, hand methods can not be too strongly condemned. At one quarry the writer saw 4 to 6 feet of clay being removed by a gang of men with picks and shovels, who loaded the clay into a 4 by 5 foot pan supported on a small car that was pushed by hand to a position beneath an overhead cableway by means of which the pan was hoisted. At another quarry, where 6 to 10 feet of clay soil was being removed, a pan was loaded by two men using picks and shovels, the loading pan being removed by an overhead cableway. Obviously, the engineer of the hoist connected with this cableway was idle at least 95 per cent of the time. For such a depth of soil this process is much too slow and costly under present wage conditions.

A still more costly method observed is to throw down the soil and débris from the margin to the bottom of the quarry by means of shovel, pick, and bar, and thereafter load it into pans by hand and remove by cableway. Such rehandling combined with hand labor renders stripping an exceedingly high item in total quarry expense.

One objection raised against more efficient methods is that a small stripped area is sufficient to provide for operation for several years, and that the extent of such stripping is insufficient to justify the purchase of a steam shovel or other expensive equipment. However, a small tractor shovel probably would soon pay for itself through the lower cost per yard of overburden removal.

As a rule a number of slate quarries are grouped within a small area, and as the stripping required for new development at each is usually small, one shovel would probably serve the whole group. The work could be done by an independent company under contract, or the slate producers might jointly purchase the required equipment and use it in turn. Certainly there is room for vast improvement in stripping methods at slate quarries. As a whole they are less efficient than methods observed in the majority of other types of quarrying in the United States.

INSUFFICIENT STRIPPING.

At a number of quarries the overburden has not been stripped far enough back from the quarry face; in fact, in some places the overburden face is almost if not quite continuous with the quarry face. Plate I, *B* (p. 26) shows a stripping face lying at a steep angle and with its lower edge at the brink of the quarry. Any rock or soil dislodged on such a face must fall into the pit. One great disadvantage resulting from this condition is that overburden falling into the pit must be removed slowly by hand, whereas if removed from its original position at the surface a more efficient method could be used. In the second place, danger of accident from falling débris is ever present. A timber or plank barrier to hold back loose material is never entirely satisfactory and is costly. Removal of the overburden far enough from the face to provide a level shelf where all débris may collect without risk of falling into the quarry is much more satisfactory. At one quarry in Pennsylvania a steam shovel has been used to strip back and provide a shelf of considerable width to reduce the danger and inconvenience from falls of overburden.

DISPOSAL OF OVERBURDEN.

Attention has been directed to the serious condition that exists in many quarries where waste heaps are placed too close to excavations (p. 25). Overburden material commonly forms the nucleus of such heaps, showing that insufficient removal of overburden is responsible for them. The overburden should be transported in the proper direction and far enough to permit untrammeled development of a slate deposit for an indefinite period.

DRILLING.

TYPES OF DRILLS USED.

Compressed-air hammer drills of the nonreciprocating, automatic rotation, hollow steel type are the most popular and are widely used. In a few quarries, where no air compressor has been provided, steam tripod drills are used. Small drills struck with hand hammers have been seen, but, fortunately, such primitive methods have disappeared from most quarries. The excessive cost of hand drilling is so well known as to require no comment. Churn drills are used occasionally where there is a depth of 20 to 50 feet of waste rock that requires heavy blasting for its removal.

RATE OF DRILLING.

Slate is a relatively soft rock, and where free of flint it drills rapidly. A maximum of 240 feet of drill hole per man during an eight-hour shift has been noted. To avoid damage to the good slate drilling in the country rock adjacent to the slate is sometimes necessary, and if such rock is highly siliceous, as in the Maine deposits, drilling may be much slower than in pure slate.

DEPTH AND ARRANGEMENT OF DRILL HOLES.

The depth and arrangement of drill holes has to do chiefly with methods of blasting or wedging for which the drill holes are provided, and consequently such phases of drilling can best be discussed in connection with blasting and wedging.

BLASTING.

BLASTING WASTE ROCK.

Commonly 10 to 40 or even 50 feet of the slate nearest the surface is defective and must be removed to reach the good slate beneath. Occasionally for making blast holes in such material, churn drills are employed, but usually hammer or tripod drills are used. The usual explosive is straight nitroglycerin dynamite, of 40 per cent strength, in a single hole or a series of holes. As the purpose is to break the rock into small fragments heavy charges may be used.

BLASTING COMMERCIAL SLATE.

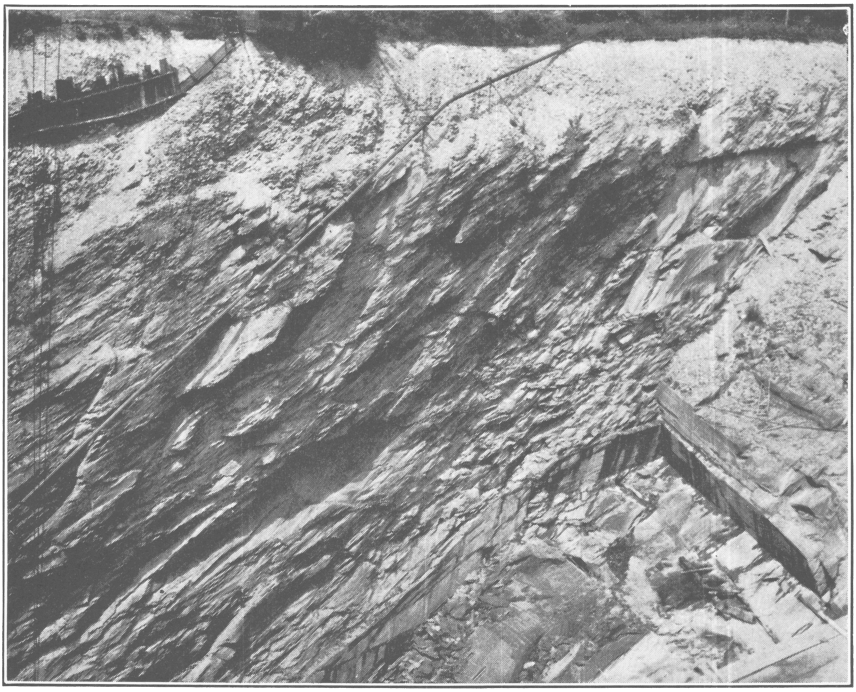
The use of explosives in commercial slate is one of the chief causes of excessive waste characteristic of the industry. Very small charges of black blasting powder may be used to advantage in making cross fractures or floor breaks, but in best practice the drill holes for such shots are only three-eighths to five-eighths inch in diameter, and it is customary, even when firing with electricity, to place a length of fuse in the hole merely to take up space and to distribute the minimum charge throughout the length of the hole. The shots may be fired with a fuse or by electricity.

The use of explosives for making primary cuts along the walls of a quarry is to be condemned except under extraordinary circumstances. The shattering of the rock results in excessive waste. Plate II, *A*, shows the shattering of a quarry wall where the slate has been removed by blasting. In the lower right corner of the illustration the work of a channeling machine may be noted, and the smooth, even surface is in sharp contrast with the rough and irregular wall that results from blasting. The blocks obtained by blasting are commonly shattered, and furthermore, they usually terminate in long points or are otherwise angular and thus cut to poor advantage in preparing the finished products.

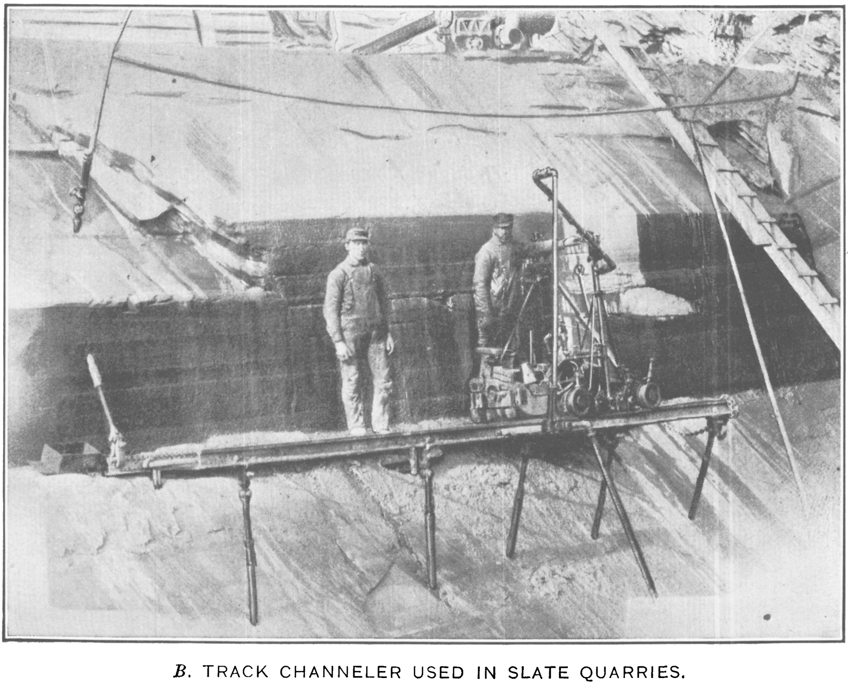
Blasting for the primary separation of blocks is used to a limited extent in the Pennsylvania slate district in Northampton and Lehigh Counties and in Maine and is used almost exclusively in all other slate regions in the United States. The great waste that results from the use of explosives suggests the need for better methods.

WEDGING.

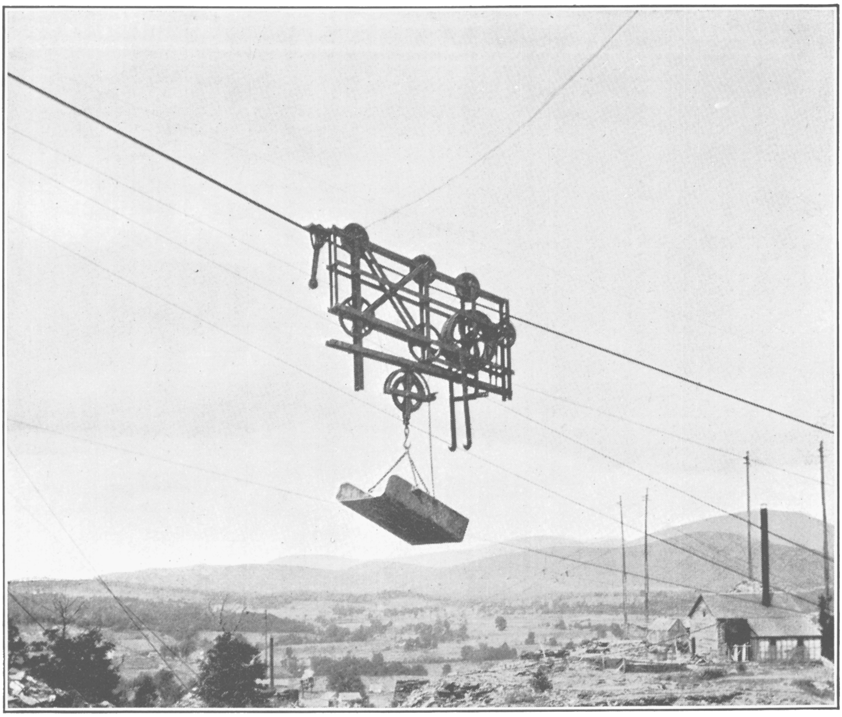
Wedges of the plug and feather type driven into shallow drill holes are commonly used for making cross fractures.



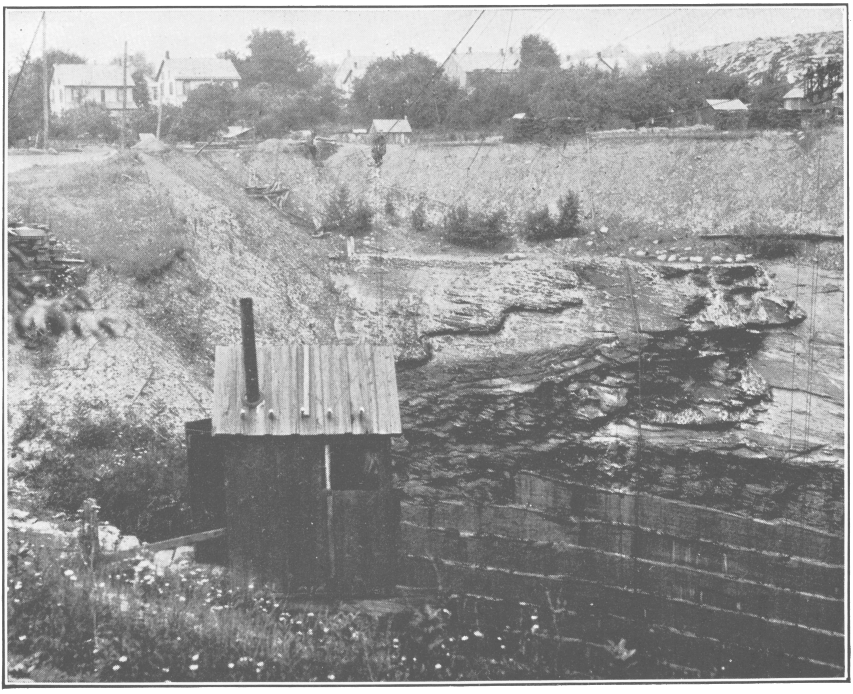
A. ROUGH, SHATTERED QUARRY WALL WHERE SLATE HAS BEEN REMOVED BY BLASTING.



B. TRACK CHANNELER USED IN SLATE QUARRIES.



A. TYPICAL AERIAL CARRIER USED WITH CABLEWAYS AT MOST SLATE QUARRIES. (COURTESY OF THE GRAY FOUNDRY, INC., POULTNEY, VT.)



B. MOTION SHANTY FROM WHICH HOISTING SIGNALS ARE TRANSMITTED.

The best type of "feathers" have one rounded surface to fit the wall of the drill hole and the other surface flat to fit the wedge or "plug." The feathers should be larger at the bottom and gradually taper toward the upper end so that as the plug, which is larger at the top and smaller at the bottom, is driven between the feathers, the pressure is exerted throughout its full length. If short feathers are used and no provision is thus made for obtaining a uniform pressure, the force exerted by the wedge is concentrated near the surface; then the plugs and feathers are much less efficient and require harder driving, which tends to chip or fracture the rock near the wedge holes.

An improved type of feather used in some marble quarries is to be highly recommended for slate. In place of two feathers a single folded feather is used. As indicated in Figure 2, the two arms are comparatively thin at the top and gradually increase in thickness toward the loop or fold. They are curved on the outside to fit the drill hole. The advantage of such a feather is that it may be easily forced to the bottom, or to any intermediate point in a drill hole, and the wedge pressure adjusted at any point desired. Such adjustment is extremely difficult, if not impossible, with separate short feathers, as they can not be kept in place except in the upper part of the drill hole.

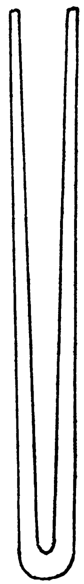


FIGURE 2. — An improved type of feather for use in wedging slate.

CHANNELING.

Channeling machines are now common, particularly in the Pennsylvania slate belt, and their introduction has marked a very great advance. The early method of blasting with black powder not only produced an excessive amount of shattered-rock waste material, but the slate blocks obtained were usually angular and irregular. The channeling machine gives a smooth surface, does not shatter the rock, and provides a ready means of obtaining regular rectangular blocks. The machines may be run by steam or by compressed air; the latter is preferable, particularly in deep pits or in underground workings.

The bar channeler, which was first introduced in slate quarries about 1887, consisted of a bar about 12 feet long supported by four iron legs. Drills were mounted on this bar, and by moving the drills to different positions on the bar closely spaced holes were projected in line. By broaching out the intervening rock a channel was formed. The process was so slow that it was not widely used.

About 10 years later the track channeler was designed. This is the modern type of channeling machine (Plate II, *B*), which travels back and forth on a track and cuts out a channel much more rapidly than the primitive bar machines.

In few slate quarries do the rock structures permit the maintenance of a level quarry floor, consequently much of the channeling must be conducted on floors inclined at an angle of 5° to 30° from the horizontal. To permit work on grades the inner edge of one rail is commonly provided with a rack that engages heavy gears cast on the trucks of the machine. This mechanism is fairly satisfactory on moderate grades.

For the operation of channeling machines on heavy grades the geared machine has been superseded in many places by the "balance car," which is placed on a track parallel with that of the channeling machine, and is attached to the latter by means of a cable running over a sheave. The car is loaded with rock to exactly counterbalance the channeling machine, and the latter will then work with equal ease up or down the grade.

Ordinarily in slate quarrying a channeling machine may be driven to full capacity, but in some slate beds the striking of heavy blows by the channeler bars may fracture the rock adjacent to the channel cut. Such fracturing is common in sandstone quarries and is termed "stunning" by quarrymen. It may be avoided by so adjusting the machine that light and rapid blows will be delivered rather than slow and heavy ones.

The advantage of channeling machines is so great that their wider use is greatly to be desired. Many slate quarries are run by primitive methods, and strong objection is made to the introduction of any new devices. In many organizations no one has ever seen a channeling machine in operation, and this lack of familiarity with it has discouraged its introduction.

Channeling machines are not used in the Peach Bottom slate district at the Maryland-Pennsylvania border, the chief reason being the belief that such machines are not advantageous where the slaty cleavage is vertical. It may be of interest to such operators to know that channeling machines are successful at Monson, Me., where the slaty cleavage is also vertical. The average cutting rate at Monson is 40 to 100 square feet a day for each machine, which is probably a somewhat lower rate than could be attained if the channel cut crossed the slaty cleavage.

In some quarries where the proportion of inferior rock is high, objection is made to channeling machines on the basis that their use is too expensive in waste rock. This objection may be valid before the best of the rock is reached, but it is doubtful if any deposit having so high a proportion of waste rock as to discourage the use of a channeling machine would be long profitable under any mode of operation.

Quarrymen in all localities where channeling machines have not yet been introduced are urged to visit quarries where such machines are in use, and to study carefully the improved product obtained and the lessened proportion of waste. It is believed that a wider use of such equipment would be of lasting benefit to the slate industry.

USE OF THE WIRE SAW.

The wire saw has been used with success in marble quarries both in America and abroad. It usually consists of a three-strand endless wire rope about one-fourth inch in diameter. The wire passes around a driving wheel and is carried on pulleys to the place in the rock where a cut is desired. An abrasive, such as steel shot, with water, is fed to the rope at the point where it enters the rock. To prevent too rapid abrasion of the wire, a length, sometimes exceeding a mile, of wire rope is used. The wire saw may be used for making cuts in the quarry or to saw blocks on the bank. This type of equipment has never been used in slate quarries in the United States, nor, from information available, does it appear to have been used in slate quarries abroad. One slate producer in the Slatington District of Pennsylvania contemplates its introduction, and the results obtained will certainly interest all slate workers. A more complete description of the wire saw is to be found in another publication[26] of the Bureau of Mines.

FLOOR BREAKS.

The slate-quarrying industry has no general term for the separation of large masses of slate from the quarry floor. In marble and sandstone quarrying the term "bed lifting" is used, as such separations commonly parallel the bedding. In slate quarrying, however, the bedding is parallel with the quarry floor only in a very few quarries, largely in the New York-Vermont area. At Arvonia, Va., Monson, Me., and in the Peach Bottom District of Pennsylvania and Maryland the bedding is vertical or nearly so and seams or joints are commonly utilized for open floors. In other slate districts the bedding or ribbon may be vertical or inclined at various angles. In such quarries the floor most commonly parallels the slaty cleavage, and the process of making floor breaks, where nature has not provided open seams, is locally termed "split-hole" blasting or "driving up splits."

For split-hole blasting, approximately horizontal drill holes are projected at the floor of the bench to parallel the slaty cleavage. By means of small charges of black blasting powder a fracture is made separating the mass from the quarry floor. Where the mass of rock is light or where the slate splits very readily, notches may be cut in the face and wedges driven into them. This process, known as "driving up splits," is usually confined to the separation of smaller masses.

[26] Bowles, Oliver, The technology of marble quarrying: Bull. 106, Bureau of Mines, 1916, pp. 71–74.

Floor breaks are sometimes made by discharging small charges of black blasting powder in the bottoms of holes drilled to a depth corresponding with the desired thickness of the block.

REDUCTION OF LARGER MASSES.

When the large mass is set free it is subdivided into slabs small enough to be hoisted to the surface. Notches are cut in the bench face in a line parallel with the slaty cleavage about 18 inches or 2 feet from the top of the bench, and a split is made by driving wedges into the notches. Vertical holes are then drilled in line with the grain direction and a fracture made with plug and feather. Breaks across the grain are made in the same manner.

BLOCK ELEVATION.

When a block of the desired size is broken loose, it is raised by means of heavy bars with curved ends. Several men use the bars simultaneously as levers, and thus gradually raise the block from the floor. Freeing the rock is sometimes slow and difficult, not only because of its weight but because of many interlocking corners that must be actually broken. The most effective work results when the energies of all the men are applied to their bars at exactly the same moment. To obtain such unanimity the foreman frequently leads in a sing-song rhyme, the men joining and keeping perfect time with their crowbars. When the block is raised enough a fragment of rock or a wedge is dropped in the crack, the bars are placed in more advantageous positions, and the process continued until the hoist chain can be passed under the block.

Where vertical breaks are made by blasting, block raising is more difficult than where channeling machines are used, for the channel cut provides space for lateral movement and relieves the block from much of the interlocking which otherwise hinders free movement.

HOISTING.

Wooden derricks and compressed-air hoisting engines are used in the Monson, Me., district, but in practically all other districts overhead cableway hoists are used. Derricks may be advantageous where the quarry or the mine opening is small, or where, as in Maine, narrow beds are worked by deep pits. In most regions, however, the pits are so wide that a derrick boom can not reach all parts. For large pits three to six parallel cableways are commonly required in order to serve properly all parts cf the excavation. Supplementary derricks are used at some quarries for hoisting from the pit or for yard service. The main cables range in diameter from $1\frac{1}{2}$ to $2\frac{1}{4}$ inches, and the draw cables from $\frac{1}{4}$ to $\frac{3}{4}$ inch. In general, the cableways are designed to carry 3 to 5 tons. Plate III, *A*, (p. 31), shows the typical aerial carrier for cableways; it is readily adjustable either to dump in the air or to lower the loaded pan to the ground. The shorter cables are usually run on an incline of about 1 foot in 15 feet; the longer ones have a higher incline in order to overcome the sag. Spans of cables range from 500 or 600 to 1,600 or 1,800 feet between supports. Ordinarily one engineer is needed for each cable hoist, but by using a three-drum engine one engineer can control three cableways. One advantage of the cableway system at many places is that the waste rock may be conveyed to the spoil bank by a single handling.

Cables are usually supported by single masts held in position with wire-rope guys. If single masts are not high enough, two or more are spliced end to end, and intermediate supporting guys are needed. Thousands of feet or even several miles of cable may be required to support a single tall mast. Two-leg masts are used in some places. Where the quarry is on a side hill one end of the cable may be attached to a buried timber or other hold fast and no mast may be needed.

In hoisting out blocks of slate, both care and skill are required to make proper attachment of the chain sling. The rock must be properly balanced in the chain, and when free of the floor it must be steadied to prevent the cable swinging or twisting before the rock is hoisted.

HOIST SIGNALING.

Efficiency and safety in hoisting depend greatly on the signaling system and on the care and alertness of the signal man. Signaling is usually done from a small house overhanging the brink of the pit so that the signal man has a clear view of the entire quarry floor. This little house is known locally as a "motion shanty." In best practice it is connected by wires with the engine houses where the hoist engineers are stationed. Plate III, *B*, shows a typical motion shanty at the brink of a 400-foot pit in Pennsylvania. The five wires leading back from the shanty indicate that the quarry has five cableways. The signal man has five electric buttons before him, one corresponding with each cableway, and he is thus able to control all hoisting in the quarry. The desire for such action as slackening the cable, taking up slack, hoisting, or holding steady is conveyed to the signal man by arm motion by the quarry foreman who has charge of work on the quarry floor, and the signal man notifies the hoist engineer by pushing a button. In some very deep quarries signals are transmitted from the quarry floor to the motion shanty by striking a saw blade with a hammer. After the block is properly started on its way from the quarry floor its movements are controlled by the signal man until it reaches the bank.

At some quarries, particularly in the Vermont-New York district, a board arm is used in place of electric devices. A board about 2½ feet long and 5 or 6 inches wide, pivoted near one end is attached to the roof of the motion shanty and moved by a wire leading into the shanty. The signal code is based on the motions of the board.

Sometimes, particularly in the early stages of development, all work may be in full view of the hoist engineer and no intermediate signal man is required, but usually in long established quarries direct observation becomes impossible.

QUARRY METHODS.

INFLUENCE OF PHYSICAL PROPERTIES.

The physical properties of slate have a direct influence on quarry methods. The ease of splitting, the direction of slaty cleavage, the direction of grain, the position of joints, and the dip of the beds are all factors in quarry problems. Slate can not be successfully quarried without a detailed knowledge of these physical properties, and familiarity with them is gained only by actually working with the slate for some time. The quarryman learns to know his rock, and this knowledge guides him in his choice of methods. If, therefore, the reader is unfamiliar with the physical properties of slate, careful study of the discussion of such properties as are presented in the introductory part of this bulletin is essential before attempting to trace the quarry methods outlined in the following pages.

Quarrymen as a rule are thoroughly familiar with the properties of the rock that they have to handle and they are skilled and careful workmen, but, unfortunately, many of them are so conservative that they are loath to introduce new machines or methods. Thus in some important districts slate quarrying has failed to keep pace with the progress attained in many other mineral industries.

PHYSICAL PROPERTIES OF SLATE, BY REGIONS.

The physical properties of slate have been discussed in some detail (p. 3), but without direct deference to individual localities. As quarry methods are so closely related to the physical properties and geologic structures of the rock, it seems desirable to outline these features in a general way for each slate region where active quarrying was in progress at the time this bulletin was prepared. The groups of quarries or districts discussed are Pen Argyl-Bangor, Slatington, Chapman's Quarries and Belfast, Granville-Fair Haven, Peach Bottom, Arvonia, and Monson.

PEN ARGYL-BANGOR DISTRICT.

The Pen Argyl-Bangor district includes the quarries of eastern Northampton County, Pa., in and about Windgap, Pen Argyl, Bangor, North Bangor, and East Bangor. The output of this region exceeds that of any other slate district in the United States.

The strike of the rock is, in general, east and west, but differs considerably in different quarries. The structural feature that has the greatest effect on the plan of quarry is the steep dip of the beds, the bedding being indicated by distinct ribbons. In several of the deep quarries the ribbon is vertical, or curves back and forth from north to south in gentle sweeping folds, usually at steep angles, though in some quarries at East Bangor it dips only 30° to 40°. In general, however, the beds are so nearly vertical that the region is characterized by deep quarries with vertical or nearly vertical walls. Loose ribbons and open joints may commonly be utilized to take the place of channel cuts or fractures made by blasting. Joints are generally spaced so as to permit the removal of large blocks. The quarry floors are maintained parallel with the slaty cleavage which dips from 5° to 30°.

SLATINGTON DISTRICT.

The Slatington district comprises the quarries of western Northampton County and those of Lehigh County, Pa. This district and the Pen Argyl-Bangor comprise the "soft-vein" slate belt of Pennsylvania. It is the only slate belt in America, and probably in the world, that provides material suitable for blackboard manufacture.

The Slatington district is characterized by a series of close folds with east and west axes that pitch east. The ribbon is distinct, and many loose ribbons or open bedding planes greatly facilitate quarrying. Because of the close and repeated folding quarrying is a complex process, and the operator must have a clear idea of the rock folds in and about his quarry in order to develop the slate to best advantage. A succession of folds may cause a bed of high-grade slate to reach or approach the surface in several places, and a clear understanding of the nature and position of the folds will enable the operator to quarry the servicable slate with minimum excavation. Probably in some quarries what has been regarded as a succession of good beds is merely a single bed brought to the surface by repeated folding. Some quarries are on synclines, others on anticlines, and others are worked on single limbs of large folds.

A remarkable feature of the Slatington district is the constancy of dip of the slaty cleavage. With few exceptions the dip is 60° to 75° south, irrespective of the folding of the beds. The "sculp" or grain is also remarkably constant, crossing the rock generally a little east of south, and dipping to the east at a steep angle, approximately 85° to 88° from the horizontal. Hence following the sculp tends to make the east walls of quarries slightly undercut.

CHAPMAN'S QUARRIES AND BELFAST DISTRICT.

The Chapman's and Belfast quarries comprise the "hard-vein slate belt" of Pennsylvania. Because of its hardness the rock is not used for structural purposes but for roofing slate only. In 1921, the only active operations in the district were at Chapman's quarries.

The rock is folded into synclines and anticlines. Ribbons are numerous, but are so hard and durable that they do not detract from the value of the slate. The quarry floor is maintained parallel with the slaty cleavage which dips 5° to 15° south-southeast. The grain runs northwest and is vertical.

GRANVILLE-FAIR HAVEN DISTRICT.

The Granville-Fair Haven district includes the quarries of Washington County, N. Y., and Rutland County, Vt. In many places the geologic structure is complex, the rock lying in close folds more or less overturned to the west. In general, however, the beds dip at a lower angle than in the Pen Argyl-Bangor district which largely influences quarry methods. As most of the beds of good slate are relatively thin, a quarry projected downward would soon pass entirely through such a bed. Evidently a quarryman must follow a bed down the dip until the cost of removing overburden becomes prohibitive, and must then extend the quarry opening in the direction of strike of the beds. The tendency is, therefore, for wide and comparatively shallow quarries. In some quarries, however, as for example those near West Pawlet, the bedding dips steeply and quarries are deep.

In general, the slaty cleavage dips at low angles, in most places 10° to 30° to the east; in some quarries it is parallel with the bedding, and in many others it crosses the bedding at a small angle. Closely spaced jointing in the direction of dip occurs in some quarries, and results in the production of undesirably small blocks of slate. Usually, however, the joints are far enough apart to permit advantageous quarrying.

PEACH BOTTOM DISTRICT.

The Peach Bottom district includes the quarries situated in York and Lancaster Counties, Pa., and Harford County, Md. The bedding of the rock is obscure and difficult to trace. The slaty cleavage is vertical, or nearly so, and strikes approximately northeast. A structural feature having a pronounced effect on quarry methods is the occurrence of steeply inclined open joints, which permit unsupported masses of rock to slide into the quarry pits. These joints have resulted in several disastrous rock slides.

ARVONIA DISTRICT.

The Arvonia district includes the quarries of Buckingham and Fluvanna Counties, Va. The beds strike north 30° to 40° east, and stand nearly vertical, dipping about 85° southeast. The slaty cleavage is parallel with the bedding. Major joints occur in systems paralleling in a general way the dip and strike of the cleavage. Diagonal joints dipping at various angles complicate quarrying and increase the proportion of waste.

MONSON DISTRICT.

The only active quarries in Maine in 1920 were those in Piscataquis County in the vicinity of Monson. There the slate beds stand vertical or dip at a steep angle, 80° to 85° southeast. The slaty cleavage is vertical and crosses the strike of the beds at an angle of 5° to 10°. The grain is vertical and crosses the slaty cleavage at right angles. The chief workable beds are 9 to 10 feet thick. Because of the beds being relatively thin and standing nearly vertical deep and narrow quarries or underground workings are necessary. In one locality a succession of serviceable beds permits open quarrying.

Vertical and horizontal open joints spaced at intervals of 8 to 15 feet are of very great assistance in projecting tunnels and in overhead stoping, as such joints are commonly utilized to form the walls and ceilings of the drifts.

COMBINATIONS OF PROCESSES.

An adequate understanding of the slate-quarrying industry can be gained only by a detailed study of the conditions under which the various methods are best used and the ways in which they are combined. No general method can be given because of the wide differences in conditions. The combinations of processes employed in a number of typical quarries will, therefore, be described individually in the hope that the reader will get a clear idea of the controlling factors that must be taken into account in developing the most efficient methods. No attempt is made to discuss the methods used in all quarries, but certain quarries are selected as typical of present practice. Quarries that are not described in these pages may be quite as important as those described. Certain quarries have been selected because they represent particular types, or because they illustrate extraordinary conditions.

METHODS IN INDIVIDUAL QUARRIES.

ALBION BANGOR SLATE CO. QUARRY.

As the grain in the Albion Bangor slate quarry is diagonal to the ribbon the quarry is not square, for one wall is maintained parallel to the ribbon and the contiguous wall parallel to the grain. By paralleling the ribbon a larger proportion of clear stock is obtained than by having the ribbons cross the blocks diagonally. Similarly, as the rock must be split on the grain, blocks of more uniform shape are obtained when all cross cuts are made parallel with the grain. Wall cuts are made with channeling machines and occasional channel cuts are made in other parts of the quarry parallel with the ribbon as shown in Figure 3.

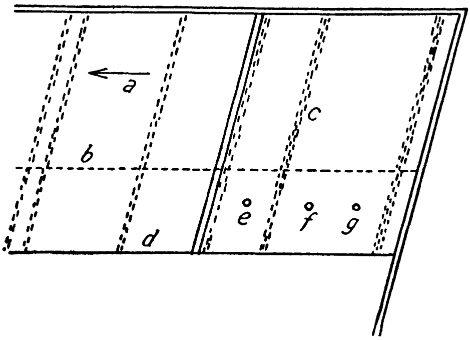


FIGURE 3.—Rock structures and quarry plan at Albion Bangor Slate Co. quarry, Pen Argyl, Pa.: *a*, Direction of dip; *b*, direction of grain; *c*, ribbon; *d*, face of bench; *e*, *f*, *g*, drill holes for small blasts to make floor breaks.

The quarry floor dips about 30° to parallel the slaty cleavage. Channel cuts are made about 10 feet deep, and when they are completed a floor break is made by blasting. A small charge of black blasting powder discharged in the bottom of a 10-foot hole, as shown at *e* in the figure, is sufficient to start a fracture for a distance of about 20 feet from the hole. By discharging blasts in a series of holes such as *f* and *g*, the floor break may be extended to the wall cut. The floor must be freed, before making cross breaks, by the use of plugs and feathers in shallow drill holes. The slate breaks readily in the grain direction.

ALBION VEIN SLATE CO. QUARRY.

The following method is used in a 450-foot quarry of the Albion Vein Slate Co. at Pen Argyl, Pa. The ribbon that marks the direction of the original bedding planes is nearly vertical where quarrying is now in progress, and crosses the quarry floor in a northeast direction; the slaty cleavage dips about 25° south and the quarry floor is kept parallel with it. The grain is vertical and runs northwest. A few open joints seem nearly vertical and at right angles to the grain. The contiguous walls of the rectangular quarry are parallel to the grain and ribbon, respectively, and the floor noticeably dips toward the corner at the south, where a sink hole is maintained as a drainage sump.

The rock is worked down first along the southeast wall as shown in *a* in Figure 4, which gives a free face represented by the line *b*; subsequently the rock is worked back from this face. A cut, *c*, 9 to 11 feet deep and parallel with the grain, indicated by the dotted line *d*, is made with a channeling machine run by compressed air. The cut terminates at an open joint *e*, which in the place observed was about 30 feet back from the face. Thus it may be seen that the bench face *b*, the channel cut *c*, and the joint *e* constitute three free faces. The fourth face to be set free is beneath the bottom of the block, that is, the floor face. This fracture is made by drilling a hole, *f*, the same depth as the channel cut, and firing therein a small charge of black blasting powder. As the rock splits readily on the slaty cleavage, a very small charge is sufficient to form a floor break. The final break is made by firing small charges of black blasting powder in holes *g* and *h* drilled exactly in line with the grain.

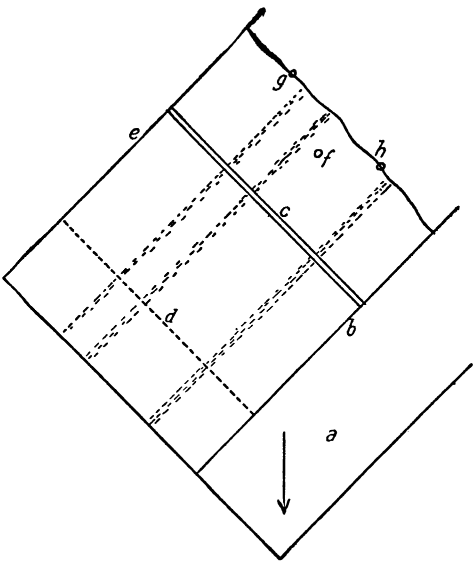


FIGURE 4.—Rock structures and quarry plan at the Albion Vein Slate Co. quarry, Pen Argyl, Pa.: *a*, Lower bench level; *b*, face of upper bench; *c*, channel cut; *d*, grain direction; *e*, open joint; *f*, drill hole for floor break; *g*, *h*, drill holes for break on grain.

The block thus set free is too large to be removed whole; to reduce it to blocks of convenient size it is split on the cleavage from the face *b*, and cross breaks in the ribbon direction are made with plug and feather. The channel cut allows a little lateral movement that tends to prevent the blocks from binding as they are raised from the floor. If the rock still binds even when moved laterally all that the channel cut will allow, a hole is drilled and a piece of rock wedged off the side. The removal of this key strip permits free raising of the block, which is barred up by several men to allow a chain to pass beneath it; then the overhead cableway hoist lifts it.

BANNER SLATE CO. QUARRY.

The Banner Slate Co. leases the Montgomery Slate Co. quarry, which is about 4 miles east of Slatington, Pa. As shown in Figure 5, the slate lies in a syncline. Some of the beds are well adapted for roofing and others, nearly black in color, are of good quality for school slates. Two series of very small beds, about a dozen beds in each series, known locally as "wrappers," appear at various levels; these beds are worked up into the smaller sizes of roofing slate. Starting with a heavy bed of roofing slate which at the time of observation was near the surface at the north side of the quarry, the following succession of beds was noted: Big bed, roofing; small bed, roofing; school-slate bed; roofing bed; hard black bed for roofing; 7 "wrappers"; 7-foot school-slate bed; a succession of 13 beds, two of which are for school slates, several are thin roofing beds, and the remainder wrappers; big bed, roofing and blackboards; a series of roofing and school slate beds. The aggregate thickness of this whole series of beds now opened is about 145 feet. Core drill holes show excellent big beds and school beds to a depth of 300 feet below the present quarry bottom.

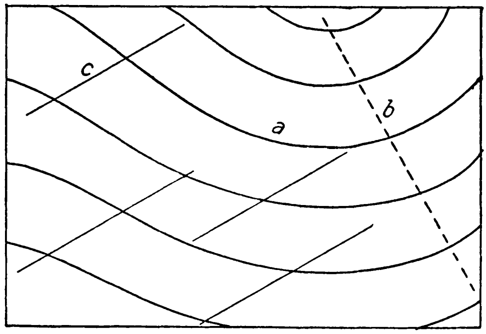


FIGURE 5.—Rock structures as they appear on the east wall of the Banner Slate Co. quarry near Slatington, Pa.: *a*, Curved bedding planes (ribbons); *b*, direction of slaty cleavage; *c*, joints.

The slaty cleavage dips 65° to 75° south, and a series of major joints, as shown at *c*, Figure 5, dip about 30° north. The grain or sculp is nearly vertical and crosses both ribbons and slaty cleavage approximately at right angles. Joints and loose ribbons are utilized for floor breaks wherever possible. The rock is split by wedging on the slaty cleavage, and breaks in the direction of grain are made by discharging light charges of black blasting powder in drill holes.

BLUE MOUNTAIN SLATE MANUFACTURING CO. QUARRY.

The east wall of the quarry of the Blue Mountain Slate Manufacturing Co., near Slatington, Pa., presents a remarkable example of a synclinal fold. The slaty cleavage dips 60° to 70° south and is practically parallel with the axis of the fold. Figure 6 shows the rock structures and their relation to quarry methods.

The top of the bench is an inclined joint dipping north about 30°; the east side of the bench *a* is parallel with the sculp and dips 80° to 85° east. The front of the bench *b* is parallel with the slaty cleavage and dips about 70° south. The inclinations of these three faces are indicated in the figure. The ribbons *c* and *d* dip about 30° south. A back split is first made in line with the slaty cleavage and about 2 feet back from the face by driving wedges in shallow holes, as shown at *e*. A loose ribbon, *d*, makes an open floor. A hole one-half inch in diameter and 2 feet deep is then drilled at right angles to the front face, as shown at *f*. The hole is nearly filled with black blasting powder and tamped with about 1 inch of soft slate. The charge is fired with a fuse and the blast fractures the rock along the sculp, as shown by the dotted line *g*.

If for any reason a split can not be made in the direction of the slaty cleavage by wedging, blasting is done in a drill hole like the one at *f*. This is known as "split-hole" blasting; a small charge of black blasting powder is put in the bottom of the hole and most of

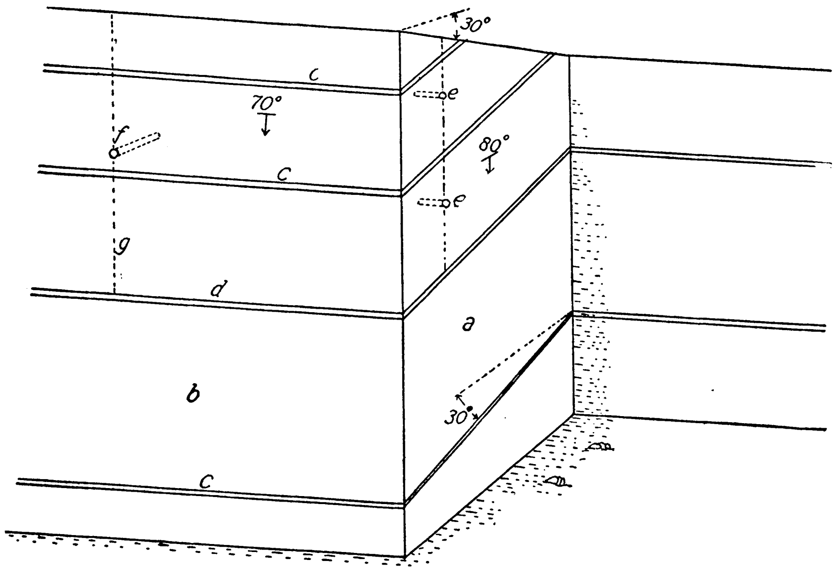


FIGURE 6.—Rock structures and method of block removal at the Blue Mountain Slate Co. quarry near Slatington, Pa.: *a*, east wall of bench; *b*, south wall of bench; *c*, *d*, ribbons; *e*, wedge holes; *f*, drill hole for sculp blast; *g*, break parallel with grain or sculp.

the hole is filled with powdered slate. When used as a "sculp hole" almost the entire hole is filled with explosive. If through absence of joints or loose ribbons, two breaks approximately at right angles must be made, this is sometimes accomplished by firing a charge in a single triangular hole, the rock breaking from the corner. Such holes are drilled by hand.

As the syncline pitches east and the grain of the rock dips east the slate blocks tend to have sharp angles rather than right angles. For this reason there is considerable waste, particularly in the thin beds. Structural slate can be cut from thin beds to better advantage than roofing slate, and of late years the increasing demand for structural slate has resulted in more advantageous work with a lower percentage of waste.

BLUE VEIN SLATE CO. AND ROYAL BLUE SLATE CO. QUARRIES.

The Blue Vein Slate Co. and the Royal Blue Slate Co. quarries are at Slatedale, Lehigh County, Pa., in what is generally recognized as the Slatington district. The quarries are working the Big Lock bed, which lies in an east-west synclinal fold or trough that pitches east. The slate appears in sweeping folds, the beds being nearly vertical at the south side and nearly horizontal at the north. The dip of the slaty cleavage is about 75° south, and is fairly constant irrespective of the dip of the beds. The grain, or sculp, crosses both ribbon and slaty cleavage nearly at right angles, and dips east 80° to 85° from the horizontal.

Vertical or steeply inclined loose ribbons are utilized to form the north and south walls of a quarry wherever possible, but where the ribbons are horizontal or inclined at low angles joint planes may be utilized, or the rock may be broken with explosives. The east and west walls of a quarry usually follow the grain or sculp of the rock. As the slate trough or syncline pitches east, the drainage sump is usually maintained at the east end of the excavation and the rock is worked back from there. When the east end of a mass of rock is set free by blasting out rock fragments along the sculp direction, a bench face is formed from which subsequent quarrying is done. Working from this free end or bench the slate is first split on the slaty cleavage, usually by wedging. Holes are then drilled on the cleavage face in line with the sculp and masses of slate are loosened by blasting with light charges of black blasting powder. A joint plane or a loose ribbon is commonly utilized to form the floor of the bench. One bed of high-grade slate about 30 feet thick constitutes the chief source of supply in these quarries.

DIAMOND SLATE CO. QUARRY.

The ribbon in the Diamond Slate Co. quarry at Pen Argyl, Pa., dips 75° to 80° south near the surface, but toward the bottom of the 200 feet pit it becomes more nearly vertical. The south wall of the quarry is channeled parallel with the ribbon and thus is undercut. The north wall of the quarry requires no channeling, as a loose ribbon permits easy separation, "loose ribbon" being a local term for an open bedding plane. In this particular quarry the loose ribbon provides a wall almost as smooth and uniform as a channel cut, saving the operator much of the heavy expense of channeling. Loose ribbons or joints do not always free the quarrymen from the necessity of channeling, for channel cuts may be needed to provide clearance for removal of key blocks.

The relation of slaty cleavage and ribbon and grain directions to quarry walls is shown in Figure 7. The quarry floor is kept parallel with the slaty cleavage and hence dips toward the southwest corner at an angle of about 2°. An important feature is the maintenance of a sink hole or sump for drainage in this corner as shown at *e*. The sump provides a working face, and the slate is worked back from it. The dip of the floor toward the sump insures ready drainage from all points where quarrying is done.

A mass of slate as indicated by *f* is blocked out by channel cuts, open joints, or loose ribbons. It is noteworthy that the channel cut is made to coincide with a ribbon, thus conserving the high-grade slate. If some natural plane of division such as a joint does not provide an open floor, horizontal "split holes" are drilled paralleling the slaty cleavage and a split is made by blasting. Vertical holes as indicated by *g* and *h* are then drilled 8 to 9 feet back from the face, 20 or 30 feet apart, and to the full depth of the rock mass, which is about 10 to 15 feet thick. Such holes are made as small as they can be conveniently drilled, about one-half or three-eighths inch in diameter. Small charges of black blasting powder are discharged in these holes to make a fracture in the grain direction. Such a process is known locally as "scallop" blasting. In order to take up space so that a very small charge will be evenly distributed throughout the length of the holes, two pieces of fuse are placed in each hole. The charges are fired with electricity. The object is merely to crack the rock and not shatter it. The next process is known as "driving up splits." Notches are cut on the open face about 2 feet from the top and the driving of wedges into the notches splits the rock on the slaty cleavage. If the mass of rock thus loosened is too heavy for the hoist, it is broken on the grain or across the grain by means of plug and feather.

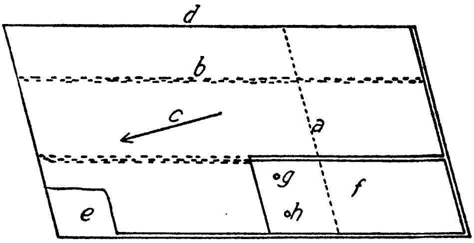


FIGURE 7.—Rock structures and quarry plan at the Diamond Slate Co. quarry, Pen Argyl, Pa. Lines in parallel pairs represent channel cuts. *a*, Direction of grain; *b*, ribbon; *c*, direction of dip of slaty cleavage; *d*, "loose ribbon;" *e*, drainage sump; *f*, mass of slate ready for floor break; *g*, *h*, drill holes for "scallop" blasting.

GENUINE WASHINGTON SLATE CO. QUARRY.

The Genuine Washington Slate Co. quarry, about 2 miles east of Slatington, is worked chiefly to secure the slate of the Upper and Lower Washington beds, totaling about 60 feet thick, and consisting of high-grade slate suitable for roofing, structural, electrical, and switchboard purposes. Figure 8 shows the rock structure in this quarry. The curvature of the beds indicates that their folding is synclinal. As is general throughout the district, the syncline pitches east. The curved, open bedding plane, or loose ribbon, shown at *a*, constitutes both the south wall and the floor of the quarry. The slaty cleavage indicated at *g* in the figure dips 60° to 70° south. The sculp or grain has a northwest direction and is nearly vertical. As shown at *f*, the chief joints dip 50° to 70° north, and strike approximately parallel with the axis of the syncline. North and south joints that cut across the slaty cleavage help greatly in the removal of blocks. By driving wedges in holes parallel to the slaty cleavage a mass of rock is split free; then a light charge of black blasting powder fired in a hole drilled perpendicular to the cleavage face forms a fracture in line with the grain.

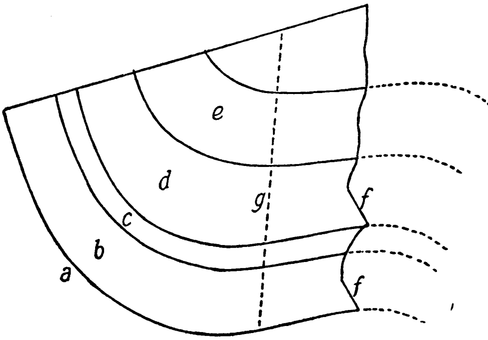


FIGURE 8.—West wall of Genuine Washington Slate Co. quarry near Slatington, Pa. Curved lines represent bedding planes (ribbons): *a*, Loose ribbon; *b*, lower Washington bed; *c*, small beds, school slates, and roofing; *d*, upper Washington bed; *e*, small beds; *f*, joints; *g*, direction of slaty cleavage.

KEENAN STRUCTURAL SLATE CO. QUARRY.

The ribbon that marks the bedding in the Keenan Structural Slate Co. quarry dips about 45° near the surface, but with increasing depth becomes vertical, and at the present floor level passes the vertical position and dips in the opposite direction. The slaty cleavage cuts across the ribbon at an angle of 60° to 80°, and as the ribbon curves the slaty cleavage also changes its direction as shown in Figure 9.

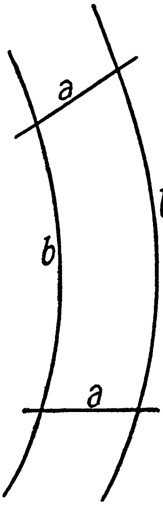


FIGURE 9.—Change in direction of slaty cleavage with change in dip of beds as shown in the Keenan Structural Slate Co. quarry, Pen Argyl, Pa.: *a*, Slaty cleavage; *b*, bedding.

The method of quarrying and the relation of quarry methods to rock structures are shown in Figure 10. The grain direction *a* is vertical and at right angles to the ribbon. Open joints parallel the ribbon and are far apart. When open joints are not available the walls are channeled with compressed-air channeling machines. Channel cuts, as represented by *b*, are also made at convenient intervals parallel with the ribbon *c*, except where open joints may be utilized. When a free face is obtained, as shown in the figure, the rock is worked out from the edge. It is broken with the grain, either by firing a light charge of black blasting powder in the hole *d*, or by driving plugs and feathers in a series of holes drilled in line with the grain. Wedging is employed wherever possible to avoid the shattering that results from blasting. The next step is to wedge up the floor at *e;* this is readily done, as the floor parallels the slaty cleavage. When the block is raised enough a chain is placed beneath and the hoist is used.

MAHARS BROS. SLATE CO. QUARRY.

What is known as the Eastern quarry worked by Mahars Bros. is situated between Fairhaven and Poultney, Vt. A large mass of rock is blocked out at the southeast corner of the quarry and is in ex-

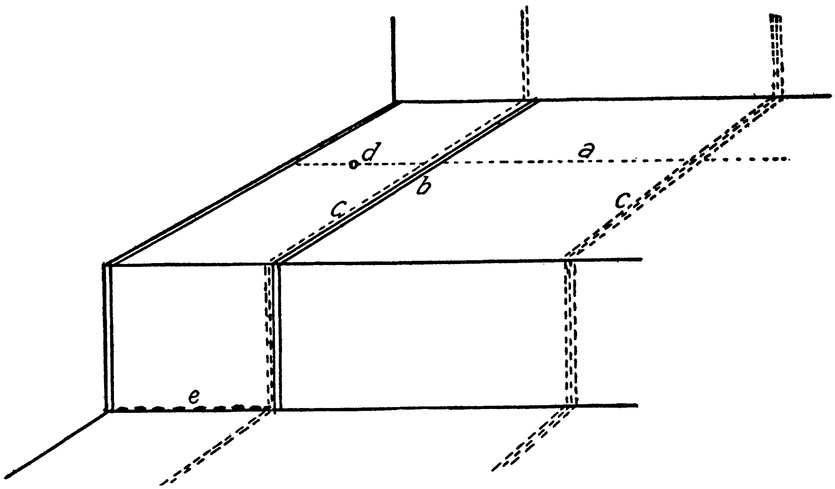


FIGURE 10.—Method of block removal at the Keenan Structural Slate Co. quarry: *a*, Direction of grain; *b*, channel cut; *c*, ribbon; *d*, drill hole; *e*, wedge holes for floor break.

cellent condition for economic working. The bedding dips 20° to 25° east and is practically parallel to the slaty cleavage. The grain is vertical and runs about 5° south of east. The relation of the various rock structures to each other is shown in Figure 11.

Open beds as indicated at *c* commonly occur at intervals of 5 to 7 feet and are thus conveniently spaced for bench floors. If the floor is tight, holes are drilled along the bed from the open side, as shown at *d*, and very light charges of black blasting powder are fired in them to jar the rock and set the bed free. When the floor is free, a break is made on the grain by blasting in holes drilled to the full depth of the bed. One hole is made for about each 15 feet of the desired break. "Foot joints," or "headers," are commonly utilized to form the third free face, but if they are not available, blasting is used. Large masses are thus set free, and further subdivision is made first by driving wedges in notches cut in the face as shown at *e*, and then by using plugs and feathers in drill holes parallel with and across the grain as shown at *f* and *g*.

NORTH BANGOR SLATE CO. QUARRY.

The strike of the bedding as marked out by the ribbon in the North Bangor Slate Co. quarry is N. 60° E. and the grain direction crosses. the ribbon approximately at right angles. The dip of the slaty cleavage is 5° to 15° southwest. The contiguous quarry walls are

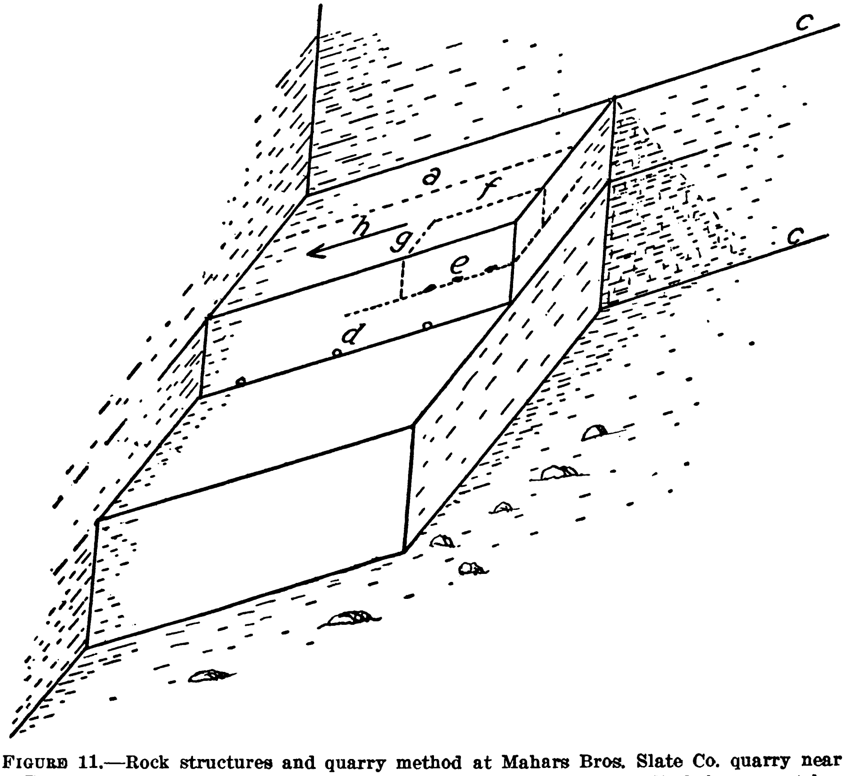


FIGURE 11.—Rock structures and quarry method at Mahars Bros. Slate Co. quarry near Fair Haven, Vt.: *a*, Grain direction; *c*, open bedding planes; *d*, split holes; *e*, notches for wedging; *f*, break on grain; *g*, break across grain; *h*, dip of beds and slaty cleavage.

Open beds as indicated at *c* commonly occur at intervals of 5 to 7 kept parallel with the ribbon and grain, respectively, and the quarry floor parallels the slaty cleavage. Channel cuts are made along the quarry walls, and as open joints are far apart, other channel cuts are made at intervals. After channel cuts have been made at the two ends of the bench, as shown at *a*, Figure 12, "split holes," 9 feet deep and 15 feet apart, are drilled parallel with the slaty cleavage at points about 12 feet below the top of the bench. Shots of black blasting powder in these holes split the mass free at the floor. About 12 feet back from the bench face *e* a series of vertical scallop holes *f* is then drilled in line with the grain; they are 10 to 12 feet apart and the full depth of the bench. Small shots of black blasting powder in these holes make a break on the grain. In this way a mass of rock about 12 feet thick, 12 feet wide, and 40 to 60 feet long is set free. This mass is reduced by "raising splits" on the slaty cleavage and by breaks made across the grain and along the grain with plug and feather. Blocks of suitable sizes for hoisting out of the quarry are thus obtained.

Plate IV shows the admirable method adopted by this company of blocking out a mass of slate in such a way as to permit a well-defined plan of development. The mass of rock blocked out in the corner of the quarry, as shown in the plate, is large enough to keep the quarry normally active for one year.

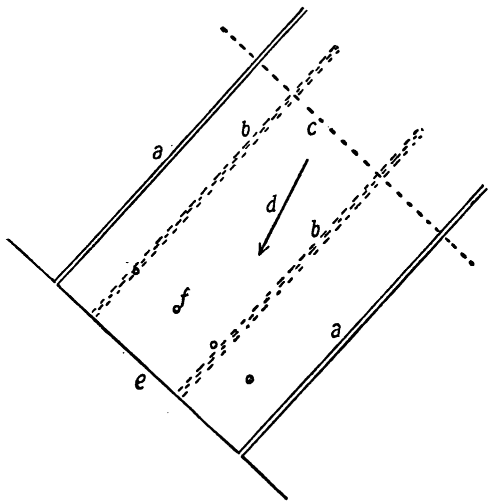


FIGURE 12.—Rock structures and method of rock removal at the North Bangor Slate Co. quarry: *a*, Channel cuts; *b*, ribbons; *c*, direction of grain; *d*, direction of dip; *e*, bench face; *f*, scallop holes.

PARSONS BROS. SLATE CO. QUARRY.

Parsons Bros. slate quarry operates on what is known as the Diamond Vein at Pen Argyl, Pa. The ribbon or bedding of the rock is so nearly vertical that the quarry may be carried to great depth. In 1921 it had been projected to a depth of about 550 feet, and is the deepest slate quarry in America. The ribbon is almost vertical at the surface, curves slightly to the south with increasing depth, and at a depth of about 520 feet it begins to curve back toward the north. The ribbons are far enough apart to permit the separation of many blocks of clear stock suitable for blackboard manufacture. The slate is also used for structural, electrical, and roofing purposes. The quarry floor is parallel with the slaty cleavage, which is more nearly flat than in most quarries of the region, for it dips only about 5° in a direction a little west of south. The draining is, therefore, toward the southwest corner. The grain of the rock is vertical and runs a little east of south. The quarry walls are maintained approximately parallel to ribbon and grain. The relative directions of ribbon, slaty cleavage, and grain are shown in Figure 13.

Channeling machines are so much used that the pit closely resembles a marble quarry. Not only are the wall cuts channeled, but the rock mass is channeled into strips about 12 feet wide, which are later subdivided by wedging.

The process of starting and extending a new floor or bench is as follows: When the wall cuts are made a channel is cut about 2½ feet from the east wall, providing a key strip *d*, the removal of which gives access to the bench floor. A channel cut *e*, about 8 feet deep, is made about 12 feet from the south wall. An open end to the strip thus separated is provided by removing the southern part of the key strip. At this open face a horizontal hole 10 or 12 feet deep is drilled parallel with the slaty cleavage, as shown at *f*, and is level with the bottom of the channel cuts. It is known as a "split hole," as it is made for the purpose of obtaining a split on the slaty cleavage. A very small charge, not more than one-fourth pound, of black blasting powder is put in the hole, the remainder of the hole is filled with slate cuttings, and the charge fired by electricity. In this way a floor break is made. Notches are then cut in the open face at intervals of 1 foot or 18 inches from the top of the rock mass, and by driving wedges into these notches relatively thin masses of slate are raised. To break the rocks on the grain, holes are drilled with a compressed-air hammer drill, as shown at *g*. Two feathers, thicker at the bottom than at the top, are put in each hole, and thin soft-iron shims are placed on their inner surfaces to give an even bearing for the wedge, which is greased and inserted between the feathers. Driving the wedge splits the rock on the grain. The blocks made are 12 feet long, and being too heavy to be hoisted out whole are broken across. This is done by wedging in a drill hole which is closer to one side of the block, as shown at *h*. If the hole were drilled in the center of the block the tendency of the rock to split along the grain would result in a fracture that might follow the grain. When, however, the hole is near one side of the block the break occurs in the shortest direction to that side and thus results in a fracture straight across the block. A mass thus separated is raised with bars, a chain passed beneath it, and it is hoisted out.

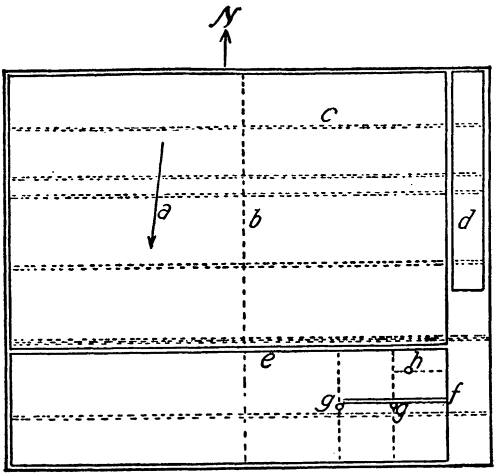
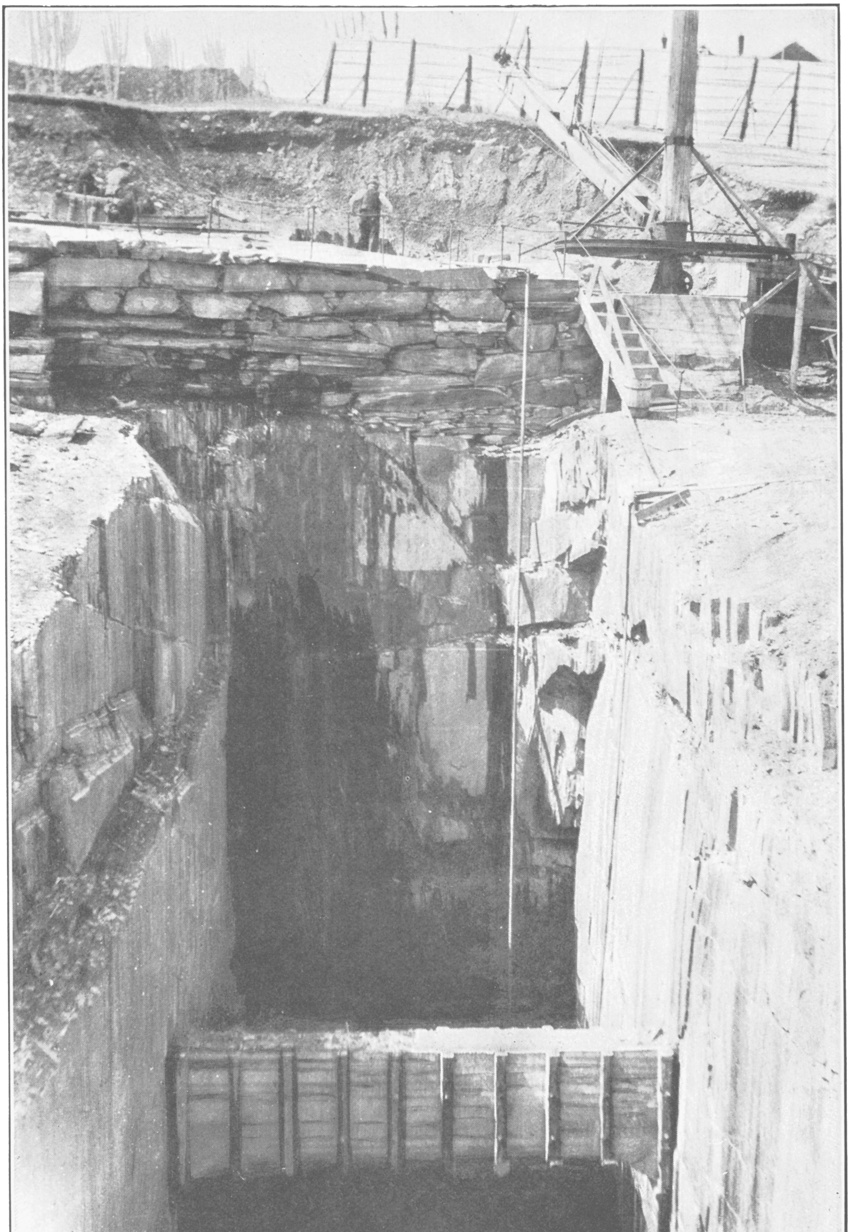


FIGURE 13.—Floor plan of Parsons Bros. Slate Co. quarry, Pen Argyl, Pa., showing rock structures and plan of work. Parallel lines indicate channel cuts: *a*, Direction of dip; *b*, direction of grain; *c*, ribbons; *d*, key strip; *e*, channel cut for 12-foot strip; *f*, split hole; *g*, drill hole for split on grain; *h*, drill hole for break across grain.

QUARRY SHOWING A MASS OF SLATE BLOCKED OUT FOR ONE YEAR'S OPERATION.
(COURTESY OF NORTH BANGOR SLATE CO.)



STEEL AND CONCRETE SUPPORT FOR WALLS OF NARROW CUT AT MONSON, ME.

PENRHYN SLATE CO. QUARRY.

The Penrhyn Slate Co. quarry between Fair Haven and Poultney, Vt., is in the unfading green slate belt and shows some unusual structural features. The beds dip about 40° to 50° north, and the slaty cleavage cuts across them at a steeper angle. Figure 14 shows the relation of bedding to slaty cleavage as seen on the east wall of the quarry, the solid lines representing bedding and the broken lines slaty cleavage. The grain crosses 5° to 10° east of north, and thus makes a small angle with the direction of dip. Large masses are set free by blasting on the grain and perpendicular to it. An unusual feature is a series of joints inclined at an angle of 20° to 30° to the grain direction. In some parts of the quarry they are spaced 2 to 3 feet apart and on this account the blocks must be removed with their long axes parallel with the joint system; thus, the direction of grain is inclined 20° to 30° to their long axes. As in making roofing slates the grain must be always parallel with their long direction, the blocks must be sculped parallel with the grain as at *c*, Figure 15, and sawed at right angles to the grain as at *d*. This results in the production of triangular fragments that must be thrown away. High loss in such fragments, of course, applies only to parts of the quarry where the inclined seams are relatively close together.

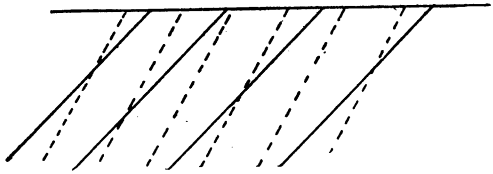


FIGURE 14.—Relation of bedding to slaty cleavage in Penrhyn Slate Co. quarry near Fair Haven, Vt. Solid lines indicate bedding and broken lines slaty cleavage.

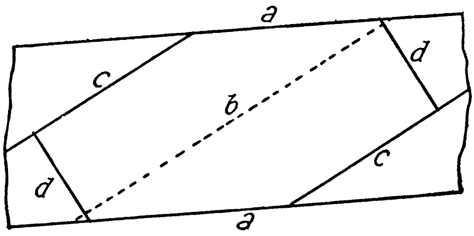


FIGURE 15.—Method of sawing and splitting blocks where the grain direction is inclined at an angle to the long axis of the block : *a*, Joint planes ; *b*, direction of grain ; *c*, splits made in grain direction ; *d*, saw cuts across grain.

PHOENIX SLATE CO. QUARRY.

Considerable trouble is met in quarrying rock in the Phoenix Slate Co. quarry near Wind Gap, Pa., because of the complexities of rock structure. The ribbon, which is nearly vertical at the surface, curves with depth, dipping 60° to 70° about 250 feet below the surface where quarrying is now in progress. The grain is vertical and crosses the ribbon at an angle of about 60°. The quarry floor parallels the slaty cleavage, which dips about 5° to 10° at right angles to the grain direction. The rock structures and the plan of operation are shown in Figure 16. Loose ribbons at intervals necessitate quarrying parallel with them. As the rock must be broken in the grain direction, which crosses the ribbon at about 60°, the contiguous quarry walls meet at angles of 60° and 120° rather than at right angles, as in most quarries. Many irregular joints add to the difficulty of quarrying. The channel cut, as indicated by double lines near the center of the figure, was cut irregularly to conform with joints and thus to separate blocks with a minimum of waste. More channeling is done in this quarry than in most slate quarries, because the rock is so easily fractured that blasting is avoided as much as possible. This tendency to fracture is so marked that it has been found advisable to adjust the channeling machine so that it strikes light blows. Although this physical property of easy fracture has a pronounced influence on quarry methods, it in no way detracts from the value of the finished products. The acute angle between grain and ribbon, the dip of the ribbon, and the presence of irregular joints make quarrying very complex, and removal of blocks demands extreme care in order to prevent excessive waste.

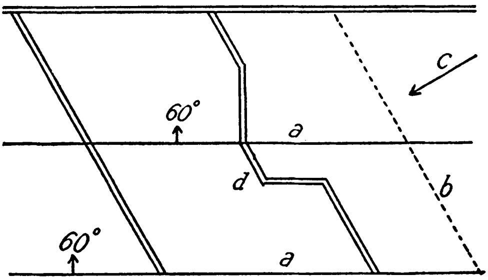


FIGURE 16.—Rock structures and plan of work at the Phoenix Slate Co. quarry near Wind Gap, Pa. Double lines represent channel cuts: *a*, Loose ribbons; *b*, direction of grain; *c*, direction of dip of slaty cleavage; *d*, channel cut conforming with various rock structures.

F. C. SHELDON SLATE CO. QUARRY.

The F. C. Sheldon Slate Co. quarries sea green slate in South Poultney, Vt. The slaty cleavage dips about 45° south. The grain is vertical and runs a little south of east. North and south joints are vertical or are inclined at right angles with the cleavage dip. Open seams are utilized for bench floors. Usually large masses are set free in this quarry by blasting in a series of deep drill holes. The holes are drilled to the full depth of the bench, which may reach 12 feet. They are placed 8 to 10 feet apart and directly in line with the grain. Eight or nine holes may be fired at one time. To insure straight splitting a flanged reamer is driven into the holes, cutting grooves on opposite sides of the holes and directly in line with the grain. A depth of about 2½ feet of black blasting powder is placed in each hole, and 4 or 5 inches of stemming at the top, the remainder of the hole being left as an air space. This identical method is used in granite quarrying and is known as the "Knox system." The air space permits the explosive gases to enter the grooves in the drill hole, and thus exerts a tremendous pressure in a direction perpendicular to that in which the break is to be made.

SLATINGTON SLATE CO. QUARRY.

The Slatington Slate Co. operates chiefly in the Franklin quarry, which has been worked since 1852. The Franklin bed consists of a high grade of nonfading blue-black roofing slate. The rock structure at the east side of the quarry, as shown in Figure 17, consists of low undulating folds, the beds assuming a dip of about 45° at the north side of the quarry. The slaty cleavage dips 60° to 70° south, a feature which is constant for most of the quarries in the Slatington district. As in the other quarries of this region already described the grain runs approximately north and south and dips east at a very steep angle. The major joints parallel the strike of the beds, but dip at a steep angle to the north. They are utilized as open floor seams to facilitate removal of rock. The lowest levels in the quarry are maintained along the south and east walls, and by splitting on the slaty cleavage and breaking on the grain the benches are gradually worked out toward the north and west.

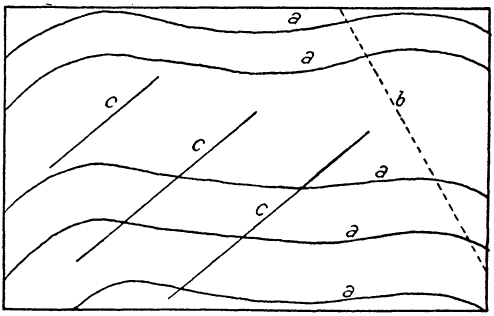


FIGURE 17.—Rock structures as shown on the east wall of Franklin quarry near Emerald, Pa.: *a*, Ribbons (bedding planes) ; *b*, direction of slaty cleavage ; *c*, joints.

A new quarry was opened by this company in 1920, about 1½ miles north of Slatington on what is known as the Mountain Bangor Vein. The quarry opening is on an anticline, as indicated in Figure 18, which shows the east wall of the quarry and part of the floor. The slaty cleavage dips about 60° south, and the grain approximately parallels the east wall with a steep eastward dip. Loose ribbons, which were nearly vertical at the main place of quarrying in 1921, and joints which are commonly nearly horizontal, greatly assist in the removal of blocks. The first step in quarrying is to set free the east end of the rock mass by blasting out an opening. The slate is then split out in thick masses by wedging on the slaty cleavage. Sculp holes perpendicular to the cleavage face are drilled with compressed-air hammer drills in line with the grain, as shown at *b*, Figure 18. Wedging with plug and feather is preferred to blasting in making breaks on the grain, as the latter causes excessive waste through shattering.

THOMAS SLATE CO. QUARRY.

The rock structures in the Thomas Slate Co. quarry at Slatedale, Pa., are shown in Figure 19. The ribbons which mark out the bedding planes are nearly vertical at the surface, curve with a gentle sweep to the south, and then curve back to the north, so that at a depth of about 240 feet they stand at an agle of about 45° north. The slaty cleavage dips at an angle of 65° to 75° south. The grain or sculp does not parallel the dip of the slaty cleavage, but is inclined to it at an angle of 10° to 15° toward the south, as shown in Figure 20.

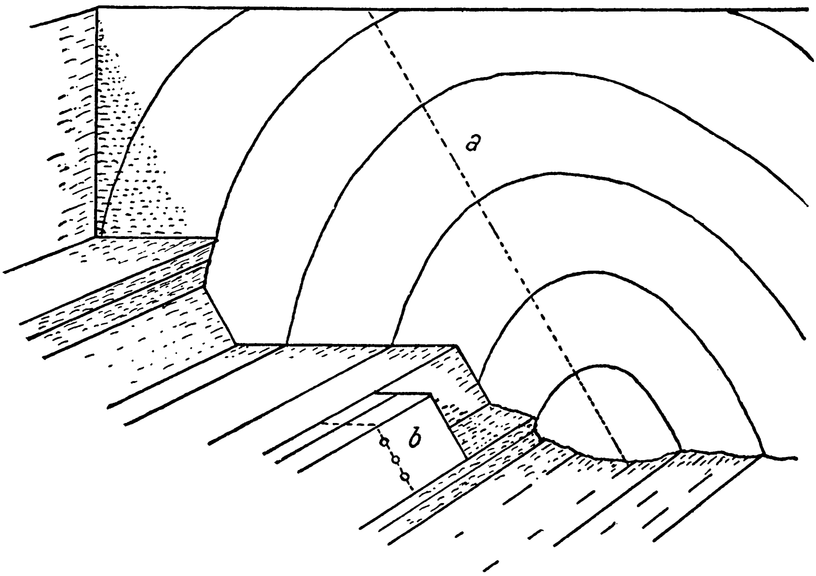


FIGURE 18.—East wall and some of the benches of the Mountain Bangor Vein quarry operated by the Slatington Slate Co. near Slatington, Pa. Curved lines represent bedding planes. *a*, Direction of slaty cleavage; *b*, sculp holes.

It also dips at a steep angle to the east. The rock is worked out much the same as in other quarries at Slatedale.

MINING FOR SLATE.

Although open-pit quarrying is the most common method for obtaining slate, underground mining is followed under certain conditions. Underground methods are now used at Monson and have been followed near Delta, Pa., and West Pawlet, Vt. The mine at Delta was abandoned some years ago, and work was suspended at West Pawlet during the recent war. Underground methods have been used more extensively in foreign countries, both in Wales and on the Continent, a famous example being the slate mines at Angers in France, where an overhead stoping method has been used successfully for many years. The French mines are probably the most widely known on account of their unusual methods, but Briggs[26] claims that the Oakeley quarry in North Wales is the largest underground slate operation in the world; slate has been removed from 26 levels. It has 50 miles of railroads, 4 miles of pump mains, and 12 miles of compressed-air mains.

Only under special conditions can underground methods be successfully used. If the deposit is wide and relatively thin, or if the material is too unsound to form a safe roof, open-pit methods must be used, for slate is too low priced a commodity to justify the heavy expense of timbering. Only where the deposit is relatively narrow, of great depth, and sufficiently sound to afford a strong roof can ordinary mining be followed.

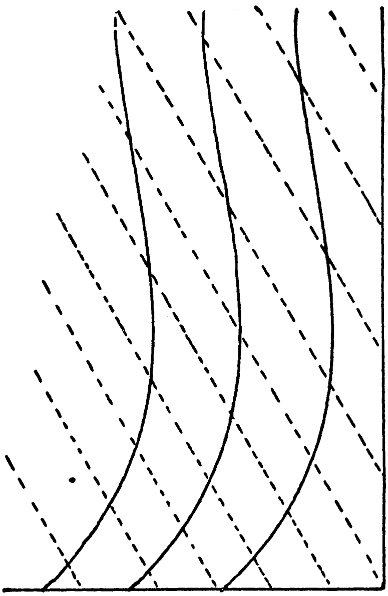


FIGURE 19.—Rock structures as shown on the east wall of the Thomas Slate Co. quarry, Slatedale, Pa. Curved lines represent ribbons, broken lines direction of slaty cleavage.

SLATE MINING IN MAINE.

The best slate beds in two of the three quarries at Monson, Me., are now worked by underground methods.

The chief bed worked by the Portland Monson Slate Co. is 10 feet thick, stands vertical, and strikes north 63° east. The slaty cleavage is vertical and crosses the strike of the beds at an angle of 5° to 10°. The grain or second direction of splitting is vertical and perpendicular to the cleavage. In addition to the 10-foot bed, two 2-foot beds and one 5-foot bed are available, but are not now utilized. In the Monson Maine Slate Co. quarry (the old Pond quarry) a greater number of beds are available, but at present quarrying is confined to a single bed about 9 feet thick which dips 80° southeast and strikes north 47° east. The slaty cleavage is vertical and strikes north 45° east, and the grain strikes north 43° to 50° west and is also vertical.

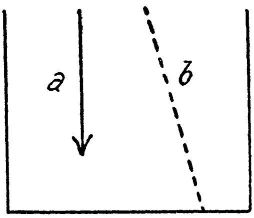


FIGURE 20. — Relation of direction of grain to direction of dip of slaty cleavage in the Thomas Slate Co. quarry, Slatedale, Pa.: *a*, Direction of dip; *b*, direction of grain.

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[26] Briggs, Roland H., Slate quarrying in North Wales: Compressed Air Magazine, October, 1921, p. 10247.

DISADVANTAGES OF OPEN-PIT QUARRYING.

The method originally followed by the Portland Monson Slate Co. was open-pit quarrying, with openings 75 to 225 feet long on the 10-foot vertical bed. No difficulty was encountered in this method until a considerable depth was attained. The vertical attitude of the beds, however, renders deep quarrying difficult, as the walls may scale and the rock become weakened by freezing of water in vertical bedding seams. Furthermore, the vertical beds tend to bulge inward through pressure of the rock when considerable depth is attained. For a time bulging was prevented by constructing heavy cross supports consisting of 20-inch steel I-beams in groups of three or four, set 2 feet in the walls and inclosed in concrete as shown in Plate V. (p. 51). Several such massive supports were placed at 30-foot intervals and at different levels, and by this means it was found possible to work with fair convenience to a depth of 300 feet or more. However, when a depth of 300 or 350 feet was reached even such supports were insufficient, and the walls would bulge inward between the supports.

Another factor that renders open-pit quarrying at great depth impractical is the presence of open joints inclined at a steep angle and meeting the slate bed obliquely. As the quarry is deepened a wedge-shaped mass of rock, bounded on one side by the inclined joint face and on the other by the vertical quarry opening, is left with no base for support. This greatly increases the danger of the walls collapsing, in fact one quarry in the Monson district has been reported completely closed by a slipping of the wall rock on an inclined open joint. In other words, the pit was closed by a fault initiated by artificial means.

TUNNEL DRIVING.

The heavy expense of constructing cross supports, and their evident inadequacy at depth, led the company a few years ago to devise a new plan of quarrying. The first step was to join the deep open pits by drifts (or tunnels) at the quarry floor. The drifts are 80 to 100 feet long, and about 300 feet below the surface, and with these as starting points, a system of overhead stoping was begun.

The drift is so placed that an open seam constitutes one wall of the excavation, and spacing of the seams may permit the use of another seam as the second wall. In the face, two horizontal holes are drilled, one above the other, about 10 feet deep and inclined toward the open seam, which it may be assumed forms the left wall of the drift. About four sticks of 40 per cent straight nitroglycerin dynamite are fired in these holes, and a wedge-shaped mass of rock is thus thrown out. The shooting of a second pair of holes removes another mass to the right of that thrown out by the first shot, and a third pair clears out the rock to the right-hand wall. This process is used only where two open horizontal seams are conveniently situated to form the floor and the roof, or ceiling. If the upper and lower seams are not clear and open, the first step is to throw out a V-shaped mass of rock with blasts in two pairs of converging holes.

OVERHEAD STOPING.

When the drift is completed the process of mining the rock from the roof is begun. The method of procedure is shown in Figure 21. At the northwest side of the drift, or at the left, as shown in the figure, a 2-foot slate bed, *c*, is separated by a few inches of quartzite *d* from the 10-foot slate bed *b*. Good slate could be obtained from the 2-foot bed, but as the slate drills much more easily and rapidly than the quartzite, the holes are drilled in the 2-foot slate bed. The drills are mounted on scaffolds and the holes laid out on 16-inch centers and staggered, as shown at *g* in Figure 21. The depth of the holes is governed by the position of the back seam, but it averages about 12 feet. The holes are loaded with light charges of black blasting powder, and are fired singly, beginning at the lowest. The purpose of staggering them is to prevent the discharge of the explosive in one hole from shattering the rock surrounding the succeeding hole. The narrow band of quartzite serves as a cushion and prevents shattering of the good slate in the 10-foot bed. A mass of rock is worked down in this way until an upper seam is reached, as shown at *f* in the figure. Then a final shot is discharged in a vertical hole drilled in the back corner at the southeast side in order to clear down all the slate to the open seam at that side. Fortunately side seams are commonly found in the quartzite several inches beyond the boundary of the slate. This condition is welcomed, for the slaty cleavage, as shown by the broken lines in Figure 22 is inclined at a small angle to the strike of the beds, and less waste is produced if a band of quartzite is included with the slate.

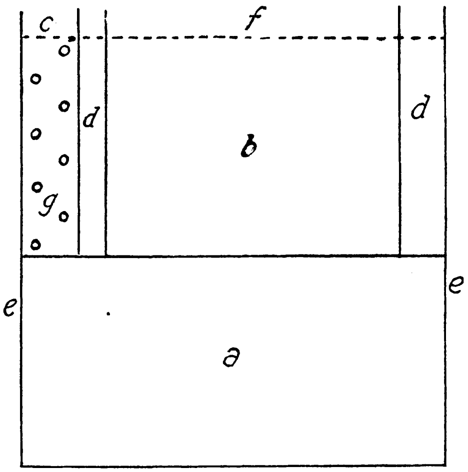

FIGURE 21.—Vertical section of Portland Monson Slate Co. drift for overhead stoping, Monson, Me.: *a*, Drift; *b*, 10-foot slate bed; *c*, 2-foot slate bed; *d*, quartzite beds; *e*, open vertical seams; *f*, horizontal roof seam; *g*, drill holes for blasting.

From the mass of rock thus thrown down all the good material is selected, hauled to the drift entrance by cable, and lifted to the surface by means of derrick hoists. The waste slate is left on the floor, and thus the heavy cost of waste removal is saved. The floor is thus constantly built up with waste, and for ideal operation it should keep pace with the upward progress of stoping from the roof.

Waste has been found to constitute approximately 50 per cent of the total rock moved. Although the waste in its loose and fragmentary form occupies much more than 50 per cent of the space obtained in mining the rock, there is not enough of it to build up the floor as rapidly as the roof is elevated. Thus the distance between floor and roof gradually increases. This is undesirable because of the increased cost for the erection of high scaffolding, also because of danger from roof falls. One remedy is to shoot in the walls and thus obtain more waste, but to do this the quartzite must be drilled. If some process to obtain additional waste is advisable, it would seem better to widen the primary excavation and drill in the quartzite in the first place, which would preserve a proportion, at least, of the good slate in the 2-foot bed. To gage properly the width of the excavation is difficult, for the proportion of waste varies from point to point, and a very important factor governing the width of the excavation is the position of the natural seams that may be utilized to form the walls.

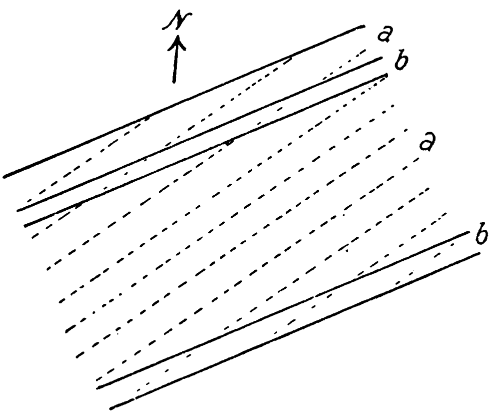

FIGURE 22.—Parallel beds of slate and quartzite at Monson, Me., showing direction of strike of beds and direction of slaty cleavage: *a*, Slate beds; *b*, quartzite beds. Broken lines indicate direction of slaty cleavage.

The advantages of stoping over open-pit operation or underground mining by sinking the floor are, 1, the great saving occasioned by leaving the waste rock in the pit; 2, reduction in hazard from roof falls, the floor being at all times only a short distance below the roof; 3, reduction in hazard from falling rock fragments in hoisting or from falls of rock from walls or upper edge of excavation; 4, no impediment to operation from snow, ice, or inclement weather; 5, absence of danger from walls collapsing, and, incidentally, saving of the cost of constructing wall supports.

EXTENSION OF DRIFTS.

One of the drifts had in June, 1920, been stoped to a height of 100 feet and another to a height of 150 feet. Evidently if operations of the present magnitude are continued, in a very few years the present stopes will be exhausted. Serious consideration is being given to a comprehensive plan for future development. The success of the stoping method encourages the sinking of deep shafts on the slate bed from which to work new stopes. If the slate bed is found to continue in its vertical attitude and to maintain its quality at depth, sinking of a shaft 800 to 1,000 feet and extension of drifts from the bottom of the shaft might be advisable. Although the first cost of sinking the shaft would be high, some good slate could be recovered during the process and thus somewhat reduce the mining cost. After the shaft and drifts were completed, past experience indicates that subsequent mining costs would be low as compared with other types of quarrying or mining.

SINKING THE DRIFT FLOOR.

The Monson Maine Slate Co. operates workings adjoining the old Pond quarry, a very large abandoned pit. This pit is approximately 500 feet long, 100 feet wide, and 250 to 400 feet deep. A series of slate beds alternate with beds of quartzite. The present workings extend underground from the southwest end of the old quarry. One drift is now nearly 700 feet long. This company also uses overhead stoping and has spent large sums of money in developing the process in order to attain the highest efficiency. In addition, it uses a system of working downward from the drift floor. The bed of slate is about 9 feet thick and dips at an angle of about 80° from the horizontal.

A drift was driven in the bed, and slate is mined from the floor of the drift, which is wide enough to include 2 or 3 feet of waste on either side of the commercial slate. A duplex channeling machine is used to cut a channel along one wall. As the cleavage is vertical the machine channels on what might be termed "edge grain," and consequently cuts slower than in a direction transverse to the cleavage. A single unit machine averages about 40 square feet a day, whereas a duplex cuts somewhat more. As the cleavage is vertical, only one wall cut is necessary, for the rock may be readily split at the other wall or an open seam may render splitting unnecessary. However, a seam can not be made to take the place of a channel cut, as some space must be provided to accommodate the block and prevent jamming during its removal. The depth of the channel cut, which averages 10 or 12 feet, is governed by the position of the bedding seam. Back seams are also utilized to avoid cross breaks. Thus, advantage is taken of rock structures to form five of the six faces on each block, the sixth face being cut with a channeling machine. The blocks are reduced to a convenient size for handling, are hauled to the entrance by cable, and raised to the surface by means of a derrick hoist run by a compressed-air engine. The hoisting equipment has a maximum capacity of 5 tons.

Sinking the drift floor has the same limitations as the open-pit method, for wall supports will be necessary before great depth can be attained. Foreseeing this contingency, the company has opened a new pit about 3 miles northwest which includes the 9-foot bed and several parallel beds. It will be worked for some time at least as an open pit.

The Portland Monson Slate Co. has recently sunk two new shafts from which drifts have been extended. The method of mining is similar to that already described for the Monson Maine Slate Co. at the Pond quarry. The drifts are wide enough to include the 10-foot bed and 2 feet of waste rock on either side. One wall cut is made with a channeling machine. A horizontal seam makes a remarkably smooth and safe roof.

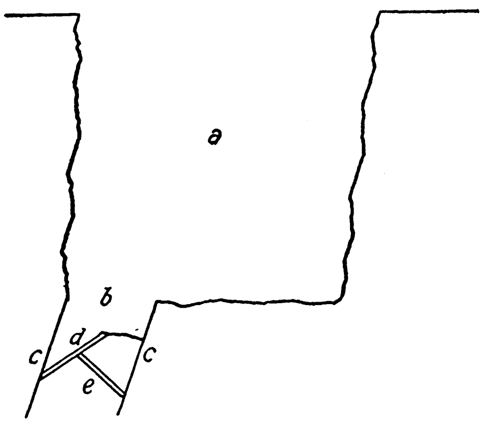

FIGURE 23.—Vertical section of quarry and shaft of Rising and Nelson at West Pawlet, Vt.: *a*, Open pit; *b*, shaft; *c*, open bed seams; *d*, *e*, drill holes.

The slate deposits of Monson are unique and demand special quarrying methods. It is to be hoped that a comprehensive scheme for future development will be successfully worked out, for the quality of the slate justifies a mining policy established on a permanent basis.

SHAFT SINKING AT WEST PAWLET, VT.

A quarry operated by Rising and Nelson at West Pawlet, Vt., used a method of shaft sinking that proved to be quite successful. The quarry was an open pit to a depth of over 100 feet, but as the bed of good slate dipped at an angle of about 70° the removal of the excessive overburden in order to follow the bed and maintain approximately vertical walls involved too great an expense.

To avoid the necessity of removing waste a series of six inclined shafts were sunk from the bottom of the quarry to a depth of about 200 feet. Each shaft is about 40 by 40 feet wide, and supporting pillars 25 to 30 feet wide were left between the shafts. The relation of shafts to open pit is shown in Figure 23. Fortunately, open seams as shown at *c* occur in such positions that they may be used for hanging wall and foot wall. Seams are also utilized for side walls wherever possible. The presence of such seams greatly facilitates the removal of the serviceable slate. Inclined holes are drilled as shown at *d* for removal of a mass of rock at the hanging wall. Inclined holes are then drilled as shown at *e* and the shoulder is removed to the foot wall. By removing alternate masses in this manner the shaft is projected downward.

Mining ceased during the recent war, but the shafts will be pumped out when business conditions justify resuming work.

OPERATIONS OUTSIDE THE QUARRY.

After methods of quarrying slate and of hoisting the blocks to the bank, the next step to be considered is the various processes involved in manufacturing the slate into its finished products. This includes transportation of blocks, manufacture of roofing and school slate, and the various steps in the manufacture of blackboards, switchboards, billiard tables, and other forms of structural slate.

YARD TRANSPORTATION.

As pointed out on page 34 the quarry blocks are, in nearly all slate districts, hoisted to the surface by means of overhead cableways. The blocks thus hoisted are usually placed on small 4-wheel cars and conveyed by hand where tracks are nearly level, or by cableway on hills to splitting sheds or mills for subsequent treatment. A small locomotive is used at one quarry in the Peach Bottom district of Maryland. Some of the mills for finishing the slate are in towns, and the quarries may be several miles distant; therefore the rough blocks must be transported by teams and wagons or by motor trucks.

At one quarry in the Granville, New York, district, cableways crossing the quarry pit place the blocks on the bank, whence they are hoisted and conveyed to the splitting shanties by the lateral cableway on the bank paralleling the quarry face.

An important part of yard transportation is involved in the disposal of waste rock. Tracks from the quarry bank lead usually by a moderate to steep incline over the waste heap which gradually increases in height and in lateral extent. A hoist engine is the usual motive power, with a cable and drum. Waste from the splitting shanties and from the mill must likewise be conveyed to a dump. Solid blocks of inferior rock 1 to 3 or 4 tons in weight are hoisted by chain and deposited on cars for transportation to the dump. Four-wheel side-dump cars are most commonly used. Smaller sized waste fragments are placed in metal pans about 5 or 6 feet square and having three sides each 1½ to 2 feet high. One side is open, and the pan is placed on the car with the open side toward the direction in which the car top tilts. The pan is held with an iron hook to prevent it sliding from the car when its contents are dumped. If the dumping of waste is fairly continuous, one or more men may be constantly employed at the upper end of the incline to dump cars and extend the track. Where the process is intermittent, a workman commonly rides up the incline on the car, dumps it, and returns on the empty. This is dangerous and not to be recommended.

Transportation also involves the conveyance of the finished product to railway sidings or storage yards. As roofing slates are commonly split at shanties situated on high waste heaps, the slates are conveyed down to the normal ground level by cable cars. Long 8-wheel cars are commonly used. In many places where transportation lines are not immediately available the slates are hauled by teams and wagons or by motor trucks for distances of a few hundred yards to several miles. In some parts of the Vermont-New York area the first part of the rail transportation is by trolley line.

A unique method of transportating slate from quarry to railway is an aerial tramway employed by the Auld & Conger Co. from their quarries in the South Poultney district of Vermont to Raceville on the Delaware & Hudson Railway. The tramway is nearly 2 miles long and carries about 400 buckets. It is electrically driven and has a capacity of about 200 squares of slate a day. Two men load the buckets and three unload them. In 1921 it had been successfully used for 26 years. It is divided into two parts. The first part, about one-half mile in length, connects the company's two quarries. The longer section of 1⅜ miles conveys the roofing slates from both quarries to the railroad. The main cable is three-fourths inch in diameter.

Haulage systems can still be greatly improved. At some quarries the difficulty and expense of projecting railway sidings necessitate the use of some laborious method of primary haulage, but much of the present slow haulage is believed to be needless. The location of finishing plants at towns and the quarries scattered about the surrounding country may have some advantages in housing for labor and in conducting business, but if such advantages will outweigh the disadvantages involved in conveying all the raw materials over the intervening distances is doubtful. Much waste always results in the finishing process, and the expense of transporting the waste could be saved if the slate was finished at the quarry. Where road haulage is necessary the motor truck is gradually superseding horses and wagons.

Track haulage is not always used even when available. At one quarry observed a railway siding was overgrown with trees and bushes and the slate was conveyed by teams and wagons over a road paralleling the track.

MANUFACTURE OF ROOFING SLATES.

SLATE-SPLITTING MACHINERY.

About 1913 an attempt was made to split slate with a machine invented by Vincent F. Lake. Dale[28] has described it in some detail. It has split slate successfully but has only been used experimentally. It is claimed to split seasoned slate as well as freshly quarried material, and observations as recorded in following paragraphs bear out this claim. No thorough test has ever been made to determine the possibilities of the machine on a commercial scale, due partly at least to prejudice and conservatism of operators. Such an attitude is regrettable, for the introduction of a slate-splitting machine that would even approximate in actual service the claims made for the Lake machine would do more than any other single factor to place the slate industry on a more profitable basis.

In February, 1922, the author observed the work of a small model of the Lake slate-splitting machine designed to split slates 8 by 16 inches. The flexible steel splitting blade is 8 inches wide, moves back and forth horizontally, and splits in a vertical plane. It may be advanced at any desired speed merely by pushing by hand a handle resembling that of a handsaw. The splitting is accomplished by rapid impact of the blade. By means of knobs on a rotating disk impulses are transmitted at the rate of 9,500 a minute. The intensity of impulse is regulated by pressure of the thumb on a trigger.

A piece of Maine slate, dried for 10 months, was split without difficulty. A piece of Bangor, Pa., slate dried for six weeks at the ordinary room temperature of the office was split perfectly to the remarkable thinness of one-fiftieth inch. The purpose of such splitting is to obtain thin uniform slabs for the manufacture of slate veneer products such as are discussed in some detail on page 105.

REDUCTION OF THE LARGER BLOCKS.

Slate that splits easily into thin and uniform sheets and that resists weathering and discoloration is suitable for roofing. The quarry blocks may be conveyed directly to the splitting shanties, where they are split and broken into convenient sizes. A compressed-air hammer drill is used to advantage in making the plug holes for scalloping the blocks in line with the grain. Sometimes the hammer drill is unsatisfactory, for as it nears the lower surface of the block the force of its repeated blows shatters and breaks out pieces of slate from around the hole. To overcome this difficulty in some soft slates, workers use hand rotary boring machines similar to those used by carpenters.

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[28] Dale, T. Nelson, Slate in the United States: U. S. Geol. Survey Bull. 586, 1914, p. 190; also Plate VI *B*.

An intimate knowledge of the physical properties of slate is essential in properly breaking and splitting the blocks. A skilled slate worker will drive a wedge, or plug, into a plug hole until a strain is placed on the rock, and he then procures a straight break by striking a blow at a particular point on the rock with a wooden sledge. Thus he can within certain limits force a fracture where desired. The slate is split on the grain into masses about 14 to 24 inches wide, and these masses are then broken across into the desired sizes for splitting into roofing slates. Various methods are used to subdivide the slate masses across the grain. Where they do not break readily or where the surfaces are very uneven when broken, they may be placed on a saw bed and cut across with a circular saw. If this method is used the blocks as they come from the quarry are sawed across and are later scalloped in the grain. Sawed blocks present smooth even ends that facilitate rapid splitting.

Some slates, however, break very readily and give a smooth uniform surface. Under such conditions breaking by hand is considered more economical than sawing. At one quarry observed the block is notched on two corners with a chisel and a cut made in the bottom of each notch with a small saw. The block is then turned and the opposite edge is cut smooth with a chisel. It is then struck one or two heavy blows with a large wooden mallet at a point exactly opposite the notches, with the result that a smooth even break is obtained. To cushion the blow and thus preserve the slate from damage, a thin flake of slate or a handful of fine slate rubbish is usually placed on the rock surface at the point where the mallet strikes. At one quarry where the rock breaks readily the corners are not notched but are cut with a small handsaw. The surface is then simply marked with a chisel which is struck repeated blows with a hand hammer. The slab is then turned over and sledged with a wooden mallet, or "beetle," on the opposite edge in the usual fashion.

FINAL SPLITTING.

When broken across, the slate masses are split with hammer and special chisel, known as a splitter, into thicknesses sufficient for eight slates each. The thickness of the slab is always measured with the splitter. Thus if a thickness of three-sixteenths inch is required for the finished slate, the splitter blade is eight times three-sixteenths or $1\frac{1}{2}$ inches wide. If the thickness of the slates is to be slightly increased, the blacksmith is instructed to make the splitters a little wider. The blocks are not allowed to dry out until finally made into roofing slates, as they split with much greater ease if the quarry sap is not allowed to evaporate. The Maine slates are said to be an exception to this rule as they split readily when dry.

The slate splitter then splits the slabs into the desired thickness for roofing slates, usually about three-sixteenths inch. He uses a wide flexible splitting chisel and a wooden mallet. The slab is always split in the center and subdivided until slates of the required thickness are obtained. It is customary in some places to lubricate the splitting chisel in order to decrease friction and thus reduce labor.

TRIMMING.

The trimmer takes the slabs from the splitter and cuts them to rectangular shape. The most common trimming equipment in Pennsylvania is a straight blade about 3 feet in length run by a foot treadle. The outer end of the blade is attached to an overhead spring pole so that the blade strikes repeated blows when once set in motion with the treadle. The use of man-power machines undoubtedly diverts much of the energy that could be used in handling the slates, and obviously mechanical cutting blades would result in a considerably greater production of slate per man with a much smaller expenditure of human energy. The operators in the soft-vein slate belt of Pennsylvania are aware of the increased production that might result from the use of mechanical trimmers, but attempts to introduce them have been unsuccessful. This lack of success is said to be due to inability to increase or decrease the speed of the trimmer for different grades of slate. With the foot-treadle machine the trimmer runs the machine at a slower speed for the weaker slates. The mechanically driven machines, running at constant speed, so greatly increased the percentage of slate breakage that they were abandoned in favor of the foot-treadle machines.

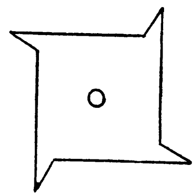


FIGURE 24.—Type of rotary saw used for trimming school slates.

In the Fair Haven and Granville districts of New York and Vermont the trimming machines are rotary, each having a curved blade similar to the cutting blade of a lawn mower. Most of them are run by foot treadles, though at some plants they are belt driven from a countershaft. It is claimed that slates can be trimmed much more rapidly where the operator is not required to supply the motive power of the trimming machine but may devote his entire attention and energy to handling slates. The mechanically operated machines do not appear to cause excessive breakage in the Vermont district.

The North Bangor Slate Co., at Bangor, Pa., early in 1922 undertook the mechanical trimming of roofing slates using the 4-toothed school-slate saw shown in Figure 24. The slates are placed on movable tables which are moved back and forth by hand thereby bringing the edge of the slate against the revolving saws. Gages regulate the length of the slates from 6 to 24 inches, the usual commercial widths. When slates are trimmed by this new method there is little splintering back from the edges, and the slates, therefore, exhibit their full thickness right to the edge. This is a great advantage, as knife-trimmed slates are usually splintered back from the edge on the lower surface so that they appear to be much thinner than they really are. A larger proportion of clear slates may also be produced by the sawing method, for the ribbons may be cut out and discarded. Furthermore, the saws produce slates absolutely uniform in size and with four square corners. At the present stage of development, however, speed of operation is a disadvantage, for a trimmer using a rotary saw is able to trim only 30 to 40 per cent as many slates as in the same time on a regular machine. On this account the cost of production by the new method is relatively high. Whether sufficient improvement in quality results to justify the additional cost has not yet been determined. This is a fruitful field for further investigation for the development of some successful mechanical means of trimming slate is very desirable.

For trimming by the knife method the steel guage bar on which the slates rest is provided with a series of notches each of which serves as a guide in trimming the slate to any standard size. Considerable skill is required to determine quickly the sizes to which slates will cut to best advantage. Slates are marketed in many sizes, dimensions in inches, the general run being as follows:

Sizes of school slates.

24 x 14	22 x 12	22 x 11	16 x 10	14 x 9	14 x 7
22 x 14	20 x 12	20 x 11	14 x 10	12 x 9	12 x 7
20 x 14	18 x 12	18 x 11	12 x 10		
14 x 14	16 x 12			16 x 8	12 x 6
	14 x 12	20 x 10	18 x 9	14 x 8	
24 x 12	12 x 12	18 x 10	16 x 9	12 x 8	

Other sizes may be had by special order.

IMPORTANCE OF MILL PLAN.

Racks on which the slates are piled are provided within easy reach of the trimmer. Slates are sorted according to size and quality as made, a section being reserved for each class. Once a day, either just before closing time, or first in the morning, the slates are loaded on cars and taken to the piling yards. At one plant in Vermont the racks are provided with small wheels which run on tracks; this reduces the labor in handling slates, for it permits the loaded racks to travel from the mill to a position close beside the car. The handling of finished slates is very heavy and tiresome labor, and any mechanical equipment designed to reduce the labor involved is highly desirable.

For rapid work the splitter and trimmer should be so located that the slate can be handled with as little waste effort as possible. At one plant observed the trimmer stood at the side of the trimming machine opposite to that at which the splitter worked. On this account he could not reach the slates as they were piled by the splitter, but was obliged to carry them to a more convenient place. This needless motion could have been avoided had the machines been more conveniently arranged.

One of the most efficiently planned slate mills observed is that of the Auld & Conger Co., between Poultney, Vt., and Granville, N. Y. The plan of the mill is shown in Figure 25, which represents but three of the 10 units of the plant. The blocks are unloaded beside the track *a*, where they are reduced to proper size for the slate splitters. One skilled operator marks the position of drill holes on the blocks and supervises drilling and wedging, which may, therefore, be done by relatively unskilled men. The slabs when prepared for the splitters are piled on the arms of rotating racks, *d*, which occupy spaces in the wall of the closed shed. In cold weather cold-air currents through the spaces thus opened in the wall may be shut out by means of canvas flaps. The splitter working at *e* in the closed shed rotates the rack until the loaded arms are inside the shed within convenient reach. While he is occupied in splitting, a further supply of slabs is being prepared and loaded on the outer arms. The split slates are likewise placed on the arms of the rotating rack *f*, and by a half revolution they are brought within convenient reach of the trimmer at *g*. One great advantage of the rotating rack is that the trimmer is freed from the danger of accident to his fingers, a danger which is ever present where the splitter is throwing slates on the pile from which the trimmer is taking them. Belt conveyors *h* beneath the floor carry the waste from trimmers and splitters to dump carts

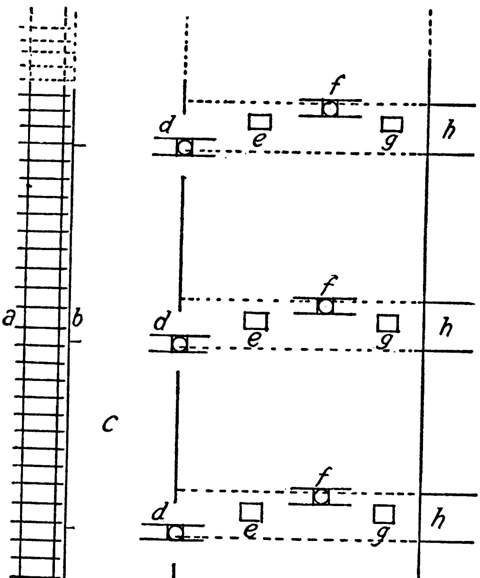


FIGURE 25.—Plan of Auld & Conger Co. roofing slate mill: *a*, Track for bringing blocks of slate; *b*, compressed-air line; *c*, space for block makers; *d*, rotating racks for slate blocks; *e*, splitters; *f*, rotating rack for split roofing; *g*, trimmers; *h*, belt conveyor for waste.

on a depressed roadway at the side of the mill. Finished slates are piled on rack cars. In the morning the loaded cars are run out to the yards, and empty cars back to the trimmers for their day's work.

A roofing-slate unit may consist of two men, a trimmer and splitter, who prepare their own slabs from the larger blocks. At most plants the slabs are prepared for the splitters so that splitting and trimming are uninterrupted. Skilled slate workers having the slabs prepared for them may finish a maximum of a square an hour, though six to eight squares a day is an average accomplishment. A square is the amount of slate required to cover 100 square feet of roof.

ROUGH AND HEAVY ROOFING SLATES.

Large and heavy roofing slates, with a maximum thickness of 2 inches and weighing 75 to 200 pounds each, have recently been much in demand. Such slates are used for roofing large residences. Popular demand calls for rough, uneven surfaces, and great variation in size and color. The red and mottled slates of Vermont and New York are used extensively, the highly colored ones from the weathered zone being most popular. Special heavy types of trimming machines are used in the manufacture of heavy slates. In one respect their manufacture is an advantage to the quarryman in that it permits the utilization of material that would not split readily into thin slates and would otherwise be wasted.

WASTE FROM SPLITTING SHANTIES.

The waste material from the splitting and trimming is commonly thrown into a slide which conveys it over the edge of the waste heap. The waste heap thus gradually increases in size, and disposal of the débris becomes more and more difficult. At one plant in Pennsylvania the waste is thrown into wheelbarrows and wheeled and dumped over the edge of the waste heap. The latter is thus gradually extended, and to avoid constantly increasing labor the splitting shanties are moved toward the edge of the bank at one to two year periods. At one plant observed, where the waste could not be so conveniently disposed, a tunnel was provided beneath the trimming machines and the waste was conducted from hoppers into cars and hauled by cableway to the waste heap.

At one quarry in Vermont five splitting units occupy a long shed. From each trimming machine a belt conveyor having transverse metal bands carries the waste to a depressed track beside the mill, where it is dumped into cars and hauled to the waste heap with horses.

STORAGE AND SHIPMENT.

Finished slates are piled on edge in storage yards, each pile being made up of slates of the same size. Most slate producers know how to pile slates properly, but many dealers and roofers are less familiar with approved methods. It is very important in piling slates to place them on edge and as nearly vertical as possible. When piled in a slanting position there is danger of breakage from overlying slates. Slates should not be piled more than three tiers in height.

Sometimes slates are punched before shipment. The punching machine is operated by a foot treadle and punches the two holes simultaneously. The side which is uppermost in punching should be placed downward on the roof, for the punch makes an inverted conical hole, the larger part of which provides a ready means of countersinking the nail head. Slates too thick to punch and some thin slates on special orders are drilled and countersunk, usually with motor-driven rotary drills. Some storage yards are readily available to railway sidings, but commonly they are situated on waste heaps, and the slates must under such conditions be transferred to the railway by cable cars.

IMPROVEMENTS IN CLASSIFICATION.

Slates should be graded and classified in such a way that the consumer will not be deceived by their characteristics. The most obvious error is, of course, the wholly dishonest practice of some manufacturers in designating slates with names that definitely misrepresent their qualities. Purchasers requesting and expecting an unfading slate have sometimes been supplied with fading slates simply because the producer could not supply the desired quality and did not wish to lose the sale. Such operators commonly meet with failure after a brief and inglorious period of deception, but during the short span of their activities much harm has been done to the reputation of slate.

Aside from such practices, which are universally condemned by the trade, it is believed that a truer classification of the established grades would render slate more popular. For example, the professional roofer knows the changing effect of "sea-green" slate, but the purchaser commonly does not know that the original color alters to various shades. Such variability in color is by no means undesirable, for it gives many beautiful effects, and such slates are much in demand. If the inexperienced purchaser, however, buys "sea-green" slate with the object of obtaining a green roof, he will find that he has made a mistake. It would be better, therefore, to employ a more descriptive term for "sea-green," such as "weathering green variegated." As the term "sea-green" is long established, it might be bracketed after the new term until the latter had become well known.

The term "variegated" when used alone also leads to confusion. It commonly relates to an unfading, but it may be applied to a fading slate. The experienced dealer knows that "variegated" is a mottled green and purple, but there is nothing in the term to convey this impression to the public. Trade names should briefly and definitely describe the slates, and give the purchaser reliable information as to whether the colors are fast or changing.

Slates from some localties are much weaker than from others. Weakness in the material results in excessive waste from breakage in punching, and in the frequent appearance of broken slates in the finished roof. To classify slates according to strength is difficult, for the slate of a given bed commonly varies greatly from point to point along its course, or at different levels beneath the surface. As a protection to the public, and to maintain a high reputation for slate, to conduct frequent tests of transverse strength seem advisable; also the rejection of all slates that fall below a certain standard. Many products, such as cement, are sampled and tested frequently, and continued purchases are made only if the product conforms with certain fixed specifications. The slate dealer would do much to popularize his product if the same rigid tests were applied, and all slates that failed were summarily rejected. Some slate-selling organizations now classify slates according to strength, and adjust prices in conformity with their relative qualities.

IMPROVEMENTS IN MANUFACTURE.

Aside from improvements in classification as suggested above, the Bureau of Mines has been led to believe that there are various other ways in which the slate producer could modify his operations so as to render slate more popular and widen his market. In the first place he should endeavor to cater to the demands of the consuming trade in so far as such demands do not impair the quality of the product. One of these demands is for a thickness sufficient to prevent excessive breakage. In certain regions slate splits with great freedom, giving thin uniform slabs. As slate is sold on the basis of surface area, a slate maker obviously can obtain greater returns from a block split into thin slabs than he can obtain from the same block split into thick ones. Moreover, the weight of a square is less, which lowers charges for haulage. Consequently there is a tendency to make thin slates from free-splitting rock. If slates fall below three-sixteenths inch in thickness they are likely to be so weakened that undue losses occur from breakage during punching and laying.

Besides, the staging that supports the workmen while they place the upper courses of a roof must rest on the lower courses already finished, and its supports may break weak slates in those lower courses. Furthermore, painters, window cleaners, and other workers may at various times find occasion to stand on the roof, with resulting breakage of weak slates. Such breakages involve replacement of broken slates on the finished roof, which is somewhat difficult, and replaced slates are never as satisfactory as the original ones. The annoyance and expense involved in the use of weak slates has been detrimental to the use of slate, and it is believed that if slate producers would maintain a thickness a little greater than three-sixteenths inch rather than less, the advantage gained from this better service to the consumer would be ample to offset the slight saving in material or in the freight charges gained in making the thinner slates. Rejections of orders have resulted from deficiency in thickness of slates; it is much better to keep to a standard or even to excel it, for a satisfied customer brings repeated orders, and a satisfactory roof is the very best advertisement.

Another way in which the manufacturer can render his products more salable is to specialize on popular sizes. A slate maker can manufacture more squares of the larger sizes in a month than he can of the smaller ones, and a tendency exists to regard volume of production as an item of more importance than the manufacture of sizes that the trade demands. This is a mistake, however, for the producer finally has a surplus of large sizes and a shortage of moderate sizes in stock, and his customer seeks other sources of supply. If the customer is by any means persuaded to take the larger sizes, he will probably be unsatisfied, and may not only cease to purchase from this particular producer, but may even turn to other types of roofing manufactured in standard popular sizes. Specialization on slates in lengths from 14 to 20 inches is preferable, even though the material is suitable for larger sizes.

THE ROOFER'S RESPONSIBILITY.

Some slate roofs have not given satisfactory service, and it is important to point out the chief reasons for the failure of such roofs to fulfill the expectations of the purchaser. To obtain a roof of high quality, part of the responsibility rests on the roofing contractor. The contractor's duty is to lay the slate on the roof in accordance with the most approved practice. That any carpenter can lay slate is a common statement, and many roofs are laid by inexperienced workmen. Slate roofs give much better service when placed by men who specialize in such work. For example, most carpenters in placing slates drive the nails "home," just as they would in securing wooden shingles, with the result that when the sheeting dries and shrinks the slates are cracked. A skilled slate roofer does not drive the nail to its full depth, but allows the slate to hang loosely.

Another common error is due to mistaken economy or even dishonesty on the part of the roofer, who in order to save slates my give a head lap less than the regulation requirement of 3 inches. As a result the roof may leak, not through any fault of the material, but through improper workmanship. The law in some States renders it illegal to place slate with less than a 3-inch head lap.

Occasionally the nail holes in slates are punched by the manufacturer before shipment. However, the practical roofer usually punches the slates at the place where they are to be used, and during the punching process he sorts them into three grades—thin, medium, and thick. The heaviest slates are then placed near the eaves, those of medium thickness midway, and the lightest at the ridge, which gives a very uniform roof.

The art of laying slates involves many other important features, but the points referred to above are sufficient to indicate that a grave responsibility rests on the roofing contractor. Upon him, to a great extent, the reputation of slate depends, and his efficient and honest service is reflected in the satisfaction of all those who may be sheltered by the roof of his construction.

THE ENDURING QUALITIES OF ROOFING SLATE.

Every householder knows that a leaky roof not only is a source of continual annoyance, but that it seriously impairs the walls and ceiling, and probably the contents of the structure that it is designed to protect. Properly manufactured slates laid according to established practice on uniform and strong supports of moderately steep pitch will provide a roof that will not leak. Furthermore, as pointed out in earlier paragraphs, a roof so constructed will maintain its quality for very many years without any repairs or treatment other than the occasional replacement of a broken slate. A more general recognition of the inherent qualities of slate would no doubt lead to its wider use, for although the first cost is greater than that of many types of roofing, the low maintenance and replacement costs under long service render it inexpensive.

With the many available convincing records of the durability of slate roofs, the fact is somewhat surprising that so many permanent homes and other structures have less enduring roofing materials. This is no doubt due in part to the lower cost of the more temporary types, and in part to the aggressive advertising of competitors.

The modern tendency toward speculative building has a similar influence, for structures built to sell are commonly covered with the cheaper and less durable types of roofing. A wider knowledge of the excellence of slate on the part of the purchasing public, and a growing demand for roofs of standard quality would tend to discourage the use of roofing that from time to time must be repaired or even completely renewed.

The Bureau of Mines makes no claim that slate is the only permanent roofing material. There are various other types of mineral roofing that are enduring and satisfactory, but the bureau has not yet been able to undertake a special study of them.

IMPORTANCE OF BUSINESS STANDARDS.

Efficient and painstaking workmanship is one of the surest roads to success in any slate-manufacturing enterprise. The sacrifice of quality for volume of output may give larger returns for a limited period, but excellence in the product is a fundamental requirement of a permanent business. Throughout the slate regions of the United States the selling agencies are constantly receiving orders with the proviso attached that they must be filled only by certain reliable companies who have given dependable service in the past. Careful workmanship and true classification of products by the manufacturer, together with honest and efficient service on the part of the roofer, would go far toward establishing slate in its rightful place as an attractive and permanent roofing material adapted for universal use.

MANUFACTURE OF SCHOOL SLATES.

Slate suitable for the manufacture of school slates is found in soft black beds free of all hard streaks or knots of flinty material. Such slates may be used also for roofing, but they commonly fade rapidly when exposed to the weather. They are split in the same manner as roofing slates, but the trimming is done with small saws that rotate at high speed. The shape of the saw is shown in Figure 24 (page 65). When trimmed to size, they are delivered to the school-slate factories. Here the edges are first beveled and then the slate is placed on edge between two knives and a descending bar forces it down so that the knives scrape off all rough projections. A second pair of knives gives the slate a smoother surface. The slates are then polished between sanded drums, thoroughly washed in hot water, and carried on a belt conveyor through a heated chamber to dry them before piling. The slates are then ready for framing. Slates broken in the framing process are unframed and recut to smaller sizes. Several million school slates are manufactured in the United States every year and about 90 per cent of them are exported.

STRUCTURAL SLATE MANUFACTURE.

DETAIL OF PROCESSES.

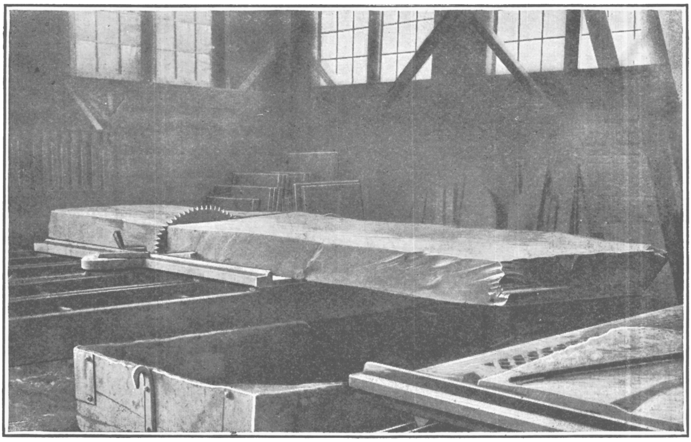
In the discussion of milling processes blackboards and switchboards are included with structural slate, as the processes of manufacture are similar.

The rough blocks from the quarry are usually conveyed to the mill by cars on tracks and unloaded with derricks. To keep blocks moist until finished is thought advisable, and this is easily done if the blocks are kept under cover. Consequently some operators have a storage space within the mill.

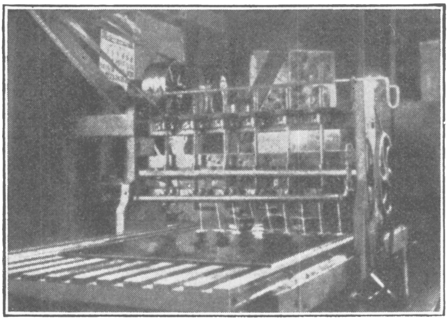
SAWING.

Slate-finishing mills are usually in the form of long closed sheds with one or more sets of tracks running through their length. The mills are equipped with sawing machines, planers, rubbing beds, buffers, and certain other types of machines. The blocks are measured and marked according to the size for which they are best adapted. The marked block is then placed on a saw bed. In some mills a series of wooden derricks are used for handling heavy blocks within the mill. Triplex block hoists are convenient for moving blocks on the saw bed. Some of the better equipped mills have overhead traveling cranes. Electricity, which is the most convenient motive power for all mill machinery, is gradually replacing all other forms of power.

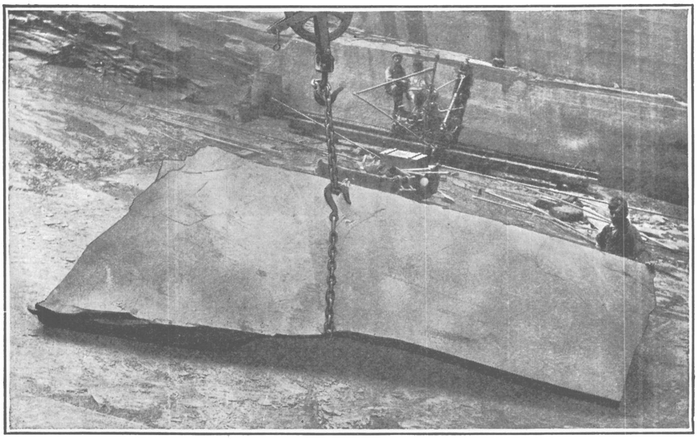
A typical slate-sawing equipment is shown in Plate VI, *C*. The bed on which the block of slate rests is propelled back and forth by a pinion working in a rack of cogs. Different rates of travel are made possible by a system of gears. The slow speed may be not more than 3 inches and the fast speed 9 inches a minute. Where thinner or softer slate is cut, the bed may travel 20 inches a minute or faster. The belt which drives the saw runs on a cone of pulleys, and thus different rates of rotation may be obtained, the desired speed being governed by the nature of the slate block. An average rate is about six or seven revolutions a minute. The saws vary from 24 to 48 inches in diameter and are about three-eighths inch thick. The saw makes a cut about three-fourths inch wide. Ordinarily the saw tooth is part of the blade, but an inserted tooth saw is used in Vermont. Each tooth is held in place with an iron wedge. When the slate contains knots of flint there is the ever-present danger of breaking out a tooth from the saw, and the advantage of the inserted tooth saw is that in such an event a broken tooth may be readily replaced. There is, however, some difference of opinion as to the advantage to be gained from using such equipment.



A. A BLOCK OF SLATE ON THE SAW BED.



B. MULTIPLE-HEAD POLISHING MACHINE.



C. BLOCK OF SLATE SHOWN IN *A* AS IT APPEARED WHEN HOISTED FROM THE QUARRY.

Plate VI, *A*, shows the block on the saw bed in Plate VI, *C*, as it appeared when hoisted from the quarry.

SURFACE FINISHING.

When the sawing process is completed the blocks are conveyed to a planer where the surfaces are finished. The planer bed travels back and forth in the same manner as the saw bed. The tool consists of a heavy blade set horizontally and adjustable laterally and vertically. As the block is carried on the traveling bed the sharp tool planes the surface of the slate. With each motion the tool is moved laterally until it has passed over the entire surface. If all irregularities are not removed, the tool is set at a lower level and the block replaned. The block of slate is then turned over so that the smooth surface rests on the bed. The opposite side is planed in the same manner, but special care must be taken to obtain the desired thickness for the finished product. The block is not reduced to its final thickness in the planer, for some allowance must be made for removal of slate during subsequent processes, such as rubbing or honing.

When the slabs of slate are taken from the planer, if a smoother surface is desired, they are placed on the rubbing bed. This is the same type as is used in marble and sandstone finishing plants and consists of a cast-iron disk about 12 or 14 feet in diameter. This disk rotates and the slabs of slate are placed on the upper surface. A stream of water is constantly supplied and sand is used as an abrasive. The rubbing bed is not only used to obtain a smooth surface but also to grind rectangular blocks to size. The operator uses a gage and square and thus is able to turn out blocks true to size and having right angles. The rubbing bed is also used for making beveled edges on switchboards and other products, though the bevel is often cut with a coarse file, a pneumatic tool, or a carborundum wheel. For certain thin products, such as blackboards, the blocks as they come from the saw table must be split into thin sheets. In a good splitting slate the surface is so smooth that no planing is required. The thin slabs are placed on the rubbing bed without any preliminary smoothing process.

Certain products, such as blackboards and switchboards, require a much smoother finish than can be obtained on a rubbing bed. This fine polish may be obtained with a carborundum cloth belt, a buffer, some other form of polishing machine, or by hand. The carborundum cloth belt is about 15 or 20 feet long, double, and passes over a table on which the slab of slate is placed. This table is moved back and forth very easily and the operator holds the traveling belt down upon the slate with a wooden block. It is a very rapid and efficient means of obtaining a smooth finish. The smoothness of the finish depends upon the size of carborundum grains contained in the belt; No. 100 D is a popular grade for a fairly smooth finish. A No. 80 grit is sometimes used for "roughing," and a No. 120 for finishing. No definite rule may be given, however, for some experimental work is always necessary to determine the grit which is best suited to the type of slate used and the particular result desired. A belt sender with a coarse-grained abrasive may be used to surface masses of slate that are too large to be placed on a rubbing bed.

The buffer is the ordinary polishing machine used in granite and slate plants. It consists of two movable arms, one attached to the end of the other and holding a rotating buffer head. The latter is belt driven. There is one belt for each arm, and the belt pulleys are so adjusted that their axes are coincident wtih the axes of rotation of the arms. Thus the rotating head may be moved about to any desired position without interfering in any way with the movement of the belts. The rotating head is provided with a set of six or seven blocks set in plaster of Paris. These blocks consist of polishing materials made up in accordance with various formulas worked out by mill operators. Fine-grained carborundum blocks are also commonly used. A stream of water is directed on the surface, and the rotating head is moved back and forth until a fine polish is obtained.

A special type of multiple-head polishing machine (Plate VI, *B*, p. 74) has lately been devised and is in use in a few mills. It consists of a series of six arms, each provided with a polishing block and rotating in small circles. The circles overlap and the arms are so adjusted that the blocks follow each other over the same ground with no interference. The slab of slate to be polished is placed on a traveling bed which conveys it back and forth beneath the rotating arms. Surface honing by hand methods is now confined almost entirely to the polishing of edges or other irregularities which can not be polished by machines.

Carborundum machines are now used in some mills to cut bevels or grooves or to recut slabs to smaller sizes. A carbonundum wheel rotating at high speed cuts slate very rapidly, but a stream of water must be constantly directed upon it. Unlike most other slate machines, the bed is stationary and the rotating wheel travels back and forth. The advantages of the carborundum machine are speed, accuracy, and a finished polishing, as the wheel leaves a true and smooth surface.

DRILLING HOLES.

Switchboards are commonly drilled for wiring by the electrical companies using them, but sometimes the drilling is done at the slate mills. Extreme accuracy is demanded both as to position of holes and workmanship, and only well-equipped mills should attempt such drilling. One mill in Maine uses a spindle drill capable of drilling 16 holes at one time. The spindles that hold the drills are flexible and so may be adjusted to position. A pattern or template is used through which the drills mark the new block. The template is then removed and the drills are guided accurately by the depressions thus formed.

The rigid requirements as to size and shape demanded for switchboards has resulted in a high degree of refinement in slate-mill operation. Producers who have manufactured blackboards and structural materials only have found that the manufacture of switchboards requires much greater accuracy and care.

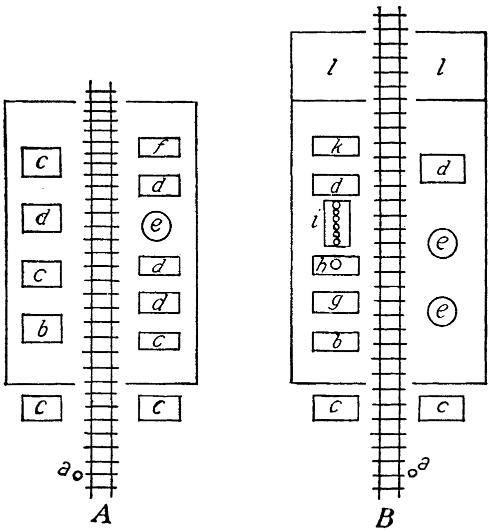


FIGURE 26.—Plan of mills of Albion Vein Slate Co. at Pen Argyl, Pa.: Mill *A*, rough cutting; mill *B*, finishing; *a*, derricks; *b*, derrick hoists; *c*, saws; *d*, planers; *e*, rubbing beds; *f*, saw sharpener; *g*, carborundum beveler; *h*, buffer; *i*, multiple-head polisher; *k*, carborundum recutter; *l*, crating and storage space.

STORAGE.

Blackboards, switchboards, panels, steps, and other structural slate are usually stored at the finishing end of the mill. Racks are commonly provided where all slabs may be placed on edge. Piling in a horizontal position or in any manner such that one block rests against another is bad practice, for the piece desired may not be available without moving others. The ideal storage plan provides a series of racks where each slab of slate stands in its own space and any piece may be removed without touching any other piece.

PLANS OF SLATE MILLS.

The various machines in a slate mill should be so arranged that the slate passes in the most direct manner from one machine to another. Much time and labor are saved if the machines are in logical order, and if efficient equipment for handling the blocks is provided. In order that an adequate idea may be gained of the manner in which machines are arranged, the plans of several typical slate mills are shown and described.

Figure 26 gives the plans of the mills of the Albion Vein Slate Co. at Pen Argyl, Pa. Mill *A* is devoted chiefly to sawing rough blocks as they come from the quarry, and planing the sawed slabs to uniform surfaces; in mill *B* they are finished. Attention may be directed to the use of a carborundum machine for edge beveling. Exceedingly true work may be accomplished with such a machine, and the time required is much shorter than when a hand file is used. The carborundum recutter in mill *B* has the advantage over an edging saw in that it leaves a smooth surface, requiring no polishing. It may be noted also that both an ordinary buffer and a multiple-head polishing machine are used.

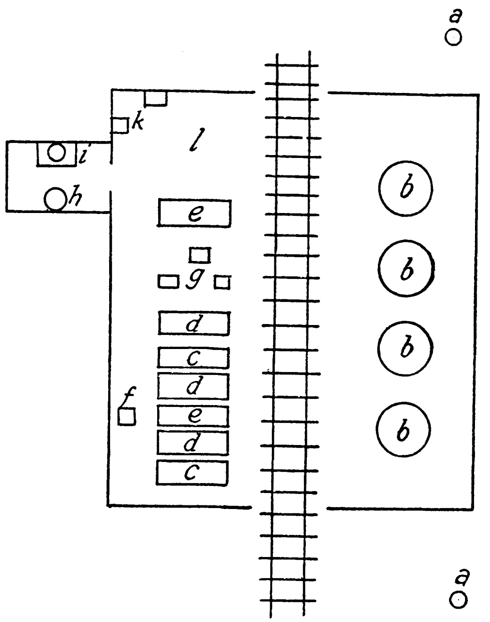


FIGURE 27.—Plan of finishing mill of Penrhyn Slate Co. at Hydeville, Vt.: *a*, Derricks; *b*, rubbing beds; *c*, saws; *d*, planers; *e*, carborundum machines; *f*, band saw; *g*, drills; *h*, small rubbing bed; *i*, buffer; *k*, benches for trimming and corner filing; *l*, space for crating and storage.

Figure 27 is a plan of the Penrhyn Slate Co. finishing mill on the shore of Lake Bomoseen at Hydeville, Vt. The quarry supplying the stock is about 3 miles distant by water. The rough blocks are sawed and split at the quarry, and the slabs transported by scows to the finishing mill. The slab is rubbed smooth on one side on a rubbing bed, then placed on the planer bed with the smooth side down and planed to the desired thickness. The edges are then finished on a rubbing bed. The band saw shown at *f* in the figure is used for corner trimming.

Figure 28 is a plan of the Jackson Bangor Slate Co. mill at Pen Argyl, Pa. The mill is adapted for the manufacture of blackboards, switchboards, and all kinds of structural slate. It is run by electricity in several units so that a breakdown in a motor will not cripple the entire mill. The mill foundation is of heavy concrete so that the machinery can not be thrown out of adjustment by settling. The line shafting is all provided with ball bearings. The equipment is so arranged that the mill may be readily extended in a direction toward the top of the figure, as shown. The smaller products are carried directly to the storage shed and heavier products are loaded on cars and conducted to storage or loading platforms by the switch. A notable feature of the equipment is a belt-rubbing machine, as represented at *h* in the figure.

Figure 29 is a plan of the mill of the Diamond Slate Co. at Pen Argyl, Pa. Mill stock enters from the track at the end, and waste is taken out on the track at the side, as indicated by the arrow. The capacity of the mill at first was comparatively small, and when it had to be greatly increased, additions were built and other machines were added. Consequently the machines are not arranged for efficient operation. The positions of planers and rubbing beds *c* and *d* in the figure show a lack of system.

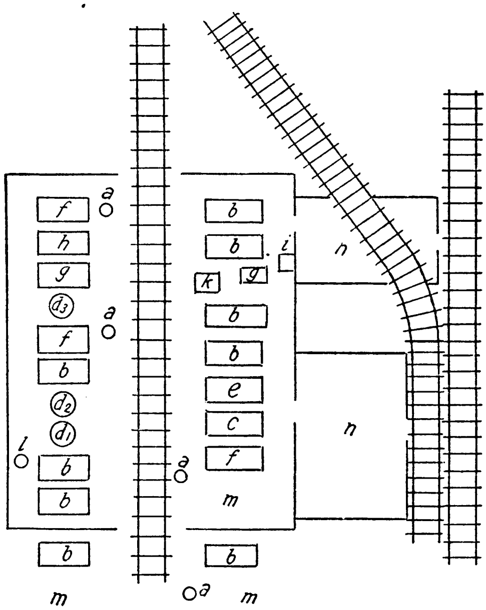


FIGURE 28.—Plan of Jackson Bangor Slate Co. mill at Pen Argyl, Pa.: *a*, Derricks; *b*, saws; *c*, small edging saw; d_1, rubbing bed, blackboards; d_2, rubbing bed, structural; d_3, rubbing bed, electrical; *e*, polishing machine; *f*, planers; *g*, carborundum machines; *h*, belt; *i*, drill; *k*, bench for edge fitting and beveling; *l*, emery wheel; *m*, block storage; *n*, finished-stock storage.

The experience gained from construction and operation of this mill supplied the owners with valuable information which was later put to practical use. The Doney Slate Co. was incorporated in 1919 under practically the same management as the Diamond Slate Co., and when plans were made for a new slate mill the company included all improvements suggested by their former experience. The plans of the new mill are shown in Figure 30. Slate blocks are brought from the quarry into the mill on track *a*, track *b* being used for the removal of waste. The blocks are handled by derrick between the tracks. The saws *d* are arranged down one side of the mill and planers *e* down the other side. After the preliminary stages of sawing and planing, the slabs are finished in the three wings, as shown at the left. Each wing has a rubbing bed near its entrance followed by a series of finishing machines such as carborundum bevelers, recutters, and polishing machines, as shown at *g* and *h*. The wings were not fully equipped in 1921, but one was intended for producing structural slate and the other two for manufacturing blackboards. Room for storage and crating is shown at *i*. A railway siding at the ends of the wings provides a ready means of shipping the product. An important feature of the mill is the facility with which it permits expansion. If increased capacity is demanded the mill may be extended and one or more additional wings added, as indicated by the dotted lines in the figure, without in any way interfering with the logical order of machine arrangement.

FLOW SHEET FOR A SLATE MILL.

A mill plan that will conform with all local conditions is difficult to devise, but in making such a plan the logical sequence of operations should be kept definitely in mind. The first step, therefore, is to outline a flow sheet showing the course of a block of slate as it travels through a mill. Although various modifications may be necessary, such as the addition or omission of certain machines, the following flow sheet (Figure 31) will at least form a basis for logically planning and equipping a slate mill.

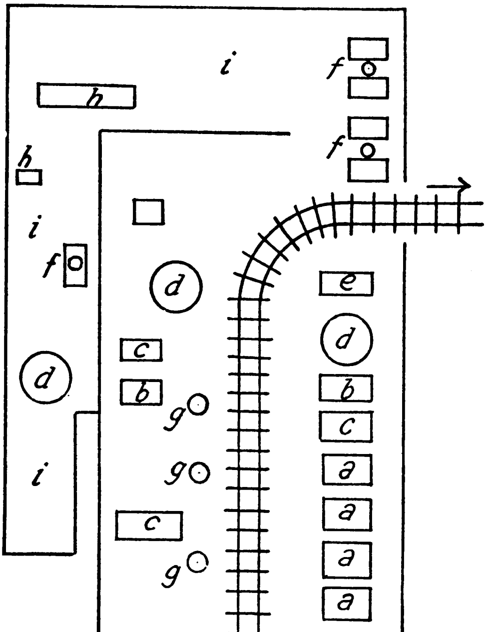


FIGURE 29.—Plan of Diamond Slate Co. mill, Pen Argyl, Pa.: *a*, Saws; *b*, small edging saws; *c*, planers; *d*, rubbing beds; *e*, carborundum machines; *f*, buffers; *g*, derricks; *h*, benches for edge fitting; *i*, finished-stock storage.

SLATE MARBLEIZING.

For ornamental switchboards, mantels, and certain other interior decorative uses, architectural taste sometimes demands a finish other than the natural slate surface. The process of finishing slate to resemble verde antique, bloodstone, or well-known marbles is known as marbleizing. Briefly, the process consists of repeated painting and baking. The following is a typical marbleizing process. The slabs are first painted black, then baked several hours in a chamber heated to a temperature of 175° F. They are then dipped in a trough of water having red, white, and green paint floating on the surface. A skilled operator can stir the water in such a manner as to obtain the various patterns with the floating paint. When the slab of slate is brought into contact with the surface the paint adheres and reproduces the pattern. It is then baked a second time, varnished, baked a third time, polished with pumice, and finally baked a fourth time. This gives a "bloodstone" finish. If no green paint is used a "Venetian" finish results. Checker boards, flags, and various other designs may be made in the same manner. Many striking and beautiful patterns may be obtained by the marbleizing process.

THE PROBLEM OF WASTE.

PROPORTION OF WASTE.

A remarkable feature of the slate-quarrying industry is the high percentage of waste. It has been stated that in one quarry in Vermont an average of 16 tons of rock is removed for each ton of good slate. In most regions the waste averages 70 to 90 per cent of gross production. In other places, particularly in underground mining, the waste may be as low as 50 or 60 per cent. In Wales 1 ton of slate is said to be produced for every 8 tons of waste rock quarried. In view of the high percentage of inferior rock associated with the slate, the problem of waste is of unusual importance.

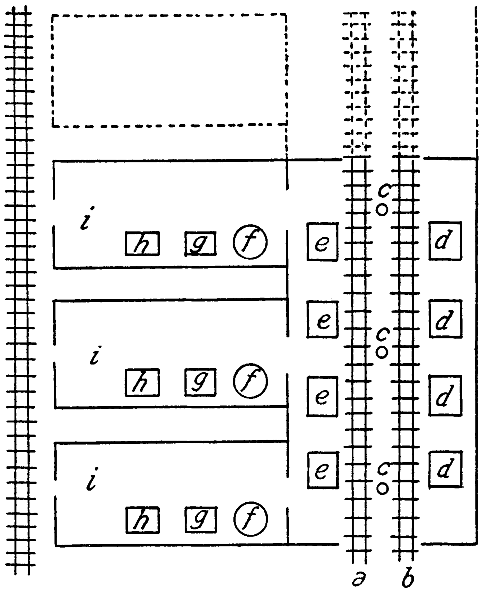


FIGURE 30.—Plan of a mill designed by the Doney Slate Co., Pen Argyl, Pa.: *a*, *b*, Mill-car tracks; *c*, derricks; *d*, saws; *e*, planers; *f*, rubbing beds; *g*, *h*, carborundum machines, polishing machines; *i*, space for storage and crating.

CAUSES OF WASTE.

Slate occurs in beds which are commonly termed "veins" by quarrymen, though they are not veins in the sense in which the term is used geologically. Beds of inferior rock alternate with the good beds, and owing to their intimate association the former must often be removed to secure the latter. Furthermore, only a part of the good beds may be used, for much of the slate in the good beds must be discarded because of such imperfections as siliceous knots, ribbons, and cracks. A considerable percentage is also lost in the process of removal; blasting may shatter it, or irregular fractures caused by wedging may result in the loss of angular fragments. During the process of manufacture a heavy percentage of waste occurs in the trimming shanties where roofing slates are made, and great quantities of refuse must be removed from beneath the saws and planers of a structural slate mill.

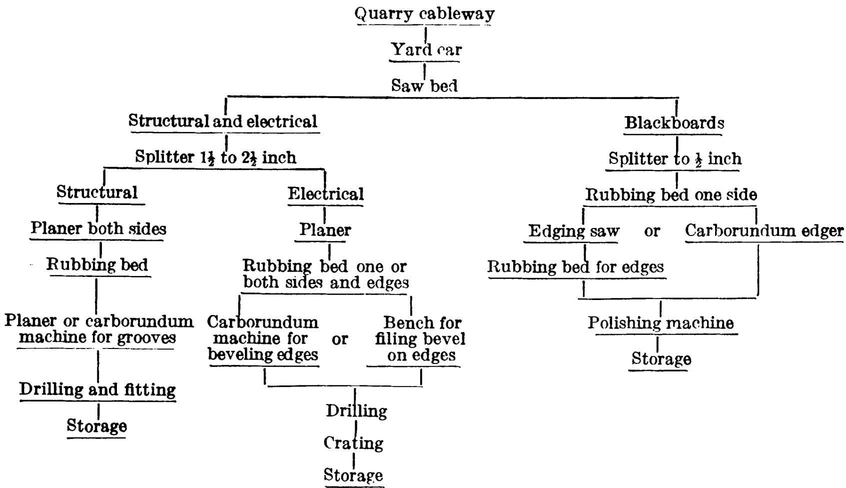


FIGURE 31.—Flow sheet of mill for manufacture of structural and electrical slate.

MODES OF PREVENTING WASTE.

Two possible lines of inquiry may be pursued in any effort to arrive at a solution of this complex problem of waste. The first has to do with modifications of methods of quarrying and manufacture, having in view a substantial reduction in the percentage of waste handled. This process has certain limitations, for although some waste is preventable, much is due to natural defects in the stone over which man has no control. The second line of inquiry has to do with the various ways in which waste may be utilized as a by-product of the industry.

The inquiries conducted by the Bureau of Mines relate to both these fields of investigation. Every quarryman should likewise consider his waste problem from this two-fold standpoint, for even the most efficient operation possible is still hampered by heavy percentage of waste for which some field of utilizaton should be sought.

REDUCTION OF WASTE.

IMPORTANCE OF WASTE REDUCTION.

After a careful study of the waste problem from all angles the conclusion has been reached that the efforts of the quarryman should be devoted to waste elimination rather than to waste utilization problems. Although many new uses are being found for waste slate, the problem is surrounded by many difficulties, the greatest of which is transportation expense. On this account the quarryman is wiser to reduce his percentage of waste to a minimum and then to consider waste utilization as a problem of secondary importance. As waste elimination is, therefore, the primary problem, ways and means by which such elimination may be effected are considered in detail.

PREVENTABLE WASTE.

Obviously slate is subject to many natural imperfections over which the quarryman has no control. If only 40 per cent of the mass of rock blocked out in the quarry is of a grade that can be used, then 60 per cent is the lowest minimum to which waste may be reduced even in theory. In actual practice the proportion of waste must exceed 60 per cent by a varying amount depending on the efficiency of quarrying and manufacture. If the final product constitutes only 15 per cent of gross production and 85 per cent is waste, obviously 25 of the 40 per cent or five-eighths of the good slate is wasted in quarrying and manufacture. A certain percentage of the good rock must of necessity be lost in quarrying and manufacture, but whatever share of this five-eighths may be saved by improved processes or equipment may be termed "preventable waste."

Perhaps the mass of rock referred to above was not blocked out in the most judicious manner. By paralleling the beds, inclining the quarry walls, or modifying in some other way the general plan of quarrying, the rock can often be removed in such a way that a large proportion of the good rock may be included and much of the waste left undisturbed in the earth. From observation of many quarries the conclusion has been reached that the proportion of preventable waste is sufficiently high to demand a careful investigation of waste reduction methods.

SYSTEMATIC QUARRY PLANS.

Rock structures and imperfections are unalterable qualities of slate, and the quarryman must modify his plans so as to minimize their effects. The walls of the quarry opening should parallel the beds or "veins" of good slate. If narrow beds of good material are flanked by wide beds of waste, a careful estimate may prove that the wiser policy is to abandon the narrow beds and to work only those parts of the deposit where the proportion of waste is smaller.

If the slate beds are steeply inclined, the walls of the excavation should also be inclined so as to follow the beds, provided, of course, that the overhang is not dangerous. Where the walls can not be undercut safely, a great volume of waste must be removed in order to follow the inclined bed and at the same time maintain safe walls. As shown in Figure 32, the mass of waste *a*, as marked out by dotted lines, must be removed to insure safety in an open pit. As the quarry is projected to greater depths ever increasing masses of waste must be removed, as shown at *b*. As the proportion of waste soon reaches a point rendering working unprofitable, the plan of quarrying must be modified. One method of meeting the difficulty is to extend the quarry laterally on the bed and to work only to moderate depth. Another method is to project inclined shafts, as shown on page 60. One great advantage in the mining method is that it allows much of the waste to remain undisturbed.

The proportion of waste during the entire life of the quarry is so dependent on the original layout that very careful attention should be given to this problem by every prospective operator.

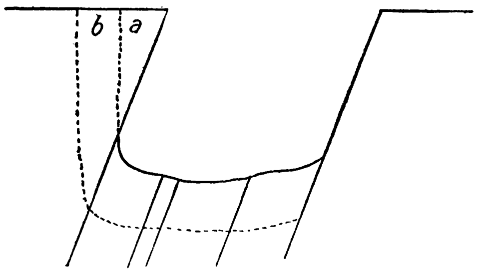


FIGURE 32.—Masses of waste, *a* and *b*, that must be removed at successive depths in deep open-pit quarrying on inclined beds.

QUARRYING IN CONFORMITY WITH ROCK STRUCTURES.

The chief rock structures that concern the quarryman are bedding planes which are commonly marked out by ribbons or bands, slaty cleavage, and grain. In some quarries, particularly in the Pen Argyl district of Pennsylvania, these three structures follow three chief planes which are approximately at right angles to each other. In many quarries the ribbon is nearly vertical, the slaty cleavage dips only a few degrees from the horizontal and the grain crosses the rock in a vertical direction nearly at right angles to that of the ribbon. Such an arrangement of rock structures permits economical quarrying, for if the quarry walls are maintained parallel with ribbon and grain, respectively, and the quarry floor parallel with the slaty cleavage, right-angled masses of slate may be produced with a minimum of waste.

Conditions are commonly less favorable, for the slaty cleavage may cross the beds at an acute angle, or the grain may also cross the ribbon obliquely, resulting in the removal of many angular fragments that can not be used.

Joints greatly influence quarry methods. If joints are not too closely spaced, and are parallel with one or more of the three chief structures referred to above, they are of great advantage to the quarryman. A joint may take the place of a channel cut, or may provide an open face without the necessity of blasting or wedging. In many quarries an open-joint plane may constitute a quarry wall. Joints parallel with the beds or ribbon are termed "loose ribbons," and their presence is of great advantage to the quarryman. Joints may, however, cross the rock in a direction oblique to that of the grain, ribbon, or slaty cleavage and cause excessive waste. Figure 15 (p. 51) shows the result when many joints cross the grain obliquely.

In whatever manner the rock structures occur in nature the general principal should be followed that channel cuts or fractures made by blasting or wedging should wherever possible be made in directions paralleling the chief rock structures, for thereby the proportion of waste is reduced to a minimum. If this principle is not followed the blocks of slate produced may be greatly marred by diagonal ribbons or joints. A good example of quarrying in accordance with rock structures is shown in Figure 16, page 52, for the channel cut indicated near the center of the figure parallels in its different parts grain, ribbon, and joints.

MINIMUM USE OF EXPLOSIVES.

Much of the waste in slate quarrying is due to the excessive use of explosives. Black blasting powder is very widely used for fracturing the rock, and often it not only makes the desired fracture but also shatters the rock so that much of it must be thrown away.

There are certain conditions under which the use of explosives is justified. In projecting a sump, or in the removal of a key strip to open up a new bench, explosives must be used. Explosives are also found to be the most effective means of making floor breaks under heavy masses, or in making long fractures on the grain. With proper care, black blasting powder may also be used to advantage in making many of the secondary fractures. Wherever explosives are used to make fractures in good slate, the greatest care should be taken to use the minimum charge that will simply fracture and not shatter the rock. The danger of shattering is so great that in most quarries the use of explosives for minor fractures should be abandoned, and wedging or channeling substituted.

Waste not only results from shattering, but also from uneven fractures that result from blasting. Blocks produced by blasting may have irregular surfaces or angular points which cause great waste.

USE OF CHANNELING MACHINES.

Channeling machines are used quite generally in the soft-vein slate belt of Northampton County, Pa., and in Maine. Channeling tends greatly to reduce the proportion of waste, for it preserves the rock intact from fractures such as commonly result from blasting, and at the same time gives a smooth, uniform surface. In many quarries where much blasting is now done, the use of channeling machines would undoubtedly greatly reduce the proportion of waste. Operators who formerly used blasting and wedging methods only and who later introduced channeling machines into their quarries, are almost without exception enthusiastic in their approval of channeling machines as types of equipment that assist greatly in keeping waste to a minimum.

INCREASED VARIETY OF PRODUCTS.

Where slate is quarried for the manufacture of one type of products only, the waste is as a rule greater than where a variety of products is made. Blocks of slate may, through peculiarities of their structures, cut to better advantage for structural uses than for roofing slates. In the Slatington district of Pennsylvania certain of the beds are unsuitable for roofing-slate manufacture but can be used for structural slate and for blackboards. Of late years products other than roofing slates are manufactured extensively in the district, and the proportion of waste has been thereby considerably reduced. Of course, such varieties of products can not be manufactured at every quarry. The "hard vein" slate of Pennsylvania was at one time used for structural purposes, all sawing being done with diamond saws, but the high cost of manufacture made the industry unprofitable, and the product of the quarry now consists of roofing slates only. On the other hand, the slate near Wind Gap, Pa., is suitable chiefly for structural purposes and very few roofing slates are made. Where the slate is of such a character that it may be used for several different purposes, a variety of products can be made with smaller waste through better utilization of raw material.

CUTTING TO STANDARD SIZES.

Producers of electrical slate usually quarry and manufacture only on definite orders. Thus, when an order is received for a certain number of switchboards of certain sizes, the blocks are quarried, brought to the mill, and cut to the sizes ordered, irrespective of the fact that the material quarried would often cut to better advantage to other sizes, and might even cut to sizes much more valuable than those ordered. One manufacturer of electrical slate has found that of all the orders he received 80 per cent of the switchboards are of standard sizes established by the larger electrical companies. The claim is made, therefore, that 80 per cent of the total production could be cut to standard size and the orders filled chiefly from stock.

This would enable the operator to cut his blocks to the best advantage. Small blocks could be cut to the smaller standard size, and large clear blocks could be cut to the larger and higher-priced sizes.

Electrical slate manufacturers should try, by concerted action, to standardize switchboard sizes. This would enable them to carry in stock the required sizes, blocks could be cut to better advantage, and orders could be filled more quickly from stock than when every piece must be manufactured after the order is received.

Structural slate has in the past also been manufactured largely on special orders. The disadvantages were so obvious that steps have recently been taken to establish definite standards for various structures. This subject is covered in greater detail on page 17.

WASTE UTILIZATION.

NEED FOR WASTE OUTLETS.

Owing to rock imperfections a large percentage of the gross production of slate quarries must be considered as waste, even under the most efficient quarrying methods. Waste utilization is, therefore, a matter of very great importance to the slate industry at the present time. Slate is forced to meet very keen competition from other types of roofing, structural and switchboard materials, and it is felt that any small salvage from waste, even though it merely covers the cost of handling, would better enable slate manufacturers to meet competition.

The need of some useful outlet for waste slate has been felt for many years. Various investigators have given more or less attention to the problem, but the results have been of little practical value. Slate consists of various silicates that have few uses as compared with some other rock types. For example, limestone may be used for lime and cement manufacture, for agricultural purposes, and furnace flux, for all of which uses slate is unsuitable. Its adaptability commercially is, therefore, greatly restricted, and on this account all but a very small fraction of the waste accumulation since slate was first quarried is still lying in veritable mountains waiting for the discovery of fields for its utilization.

PROGRESS MADE IN WALES.

Considerable interest has been directed for the past two years toward the activities of the North Wales Development Co. at Bethesda, Wales, incorporated in July, 1919, for the purpose of manufacturing useful products from the tremendous waste heaps of the Pantdreiniog, Penrhyn, and Deniorwic slate quarries. A plant of about 300 tons capacity a week was built at a cost of £20,000. The waste dumps controlled by the company are estimated to contain 200,000,000 tons of slate. Claims have been made that waste slate may be used in the manufacture of brick, pottery, roofing tile, glass, paint, distempers, putty, metal polish, abrasive soap, insulators, molded rubber goods, asphalt, and Portland cement. It is claimed that the finest powders collected in dust chambers may be used for toilet and tooth powders. Considerable quantities are sold for dusting coal mines to prevent explosions of coal dust. Pulverized slate varying in fineness from 120 to 240 mesh and finer are sold under the trade name of "myrtox." The material is supplied in red, gray, and green. In October, 1919, the output of pulverized slate was about 100 tons a week. The total production for the first year after incorporation of the company was 2,070 tons, and the total price received was £2,025, which is an average of about £1 a ton.

Several other quarry companies in Wales have built small plants to crush waste slate.

RELATION OF EUROPEAN ACTIVITIES TO AMERICAN PROBLEMS.

The activities of the North Wales Development Co. offer many suggestions for the utilization of waste slate in the United States. It is not to be assumed, however, that all slates are alike, nor that American slate may be used in exactly the same ways as Welsh slate. A careful comparison of pulverized slate from Wales with that obtained from Northampton County, Pa., indicates that the Welsh slate is much more micaceous and less harsh and gritty than the American product. Finely pulverized Welsh slate has a soft and greasy feel similar to that of talc. It is on this account that the very finest products may be used for toilet and tooth powders. On account of grittiness it is improbable that American slate dust could be used for such purposes. It is well to keep in mind, therefore, that the results obtained by investigators in Wales are not to be regarded as conclusive in their application to American slate, but simply as suggestions for independent investigation.

THE IMPORTANCE OF DISCOVERING ADVANTAGEOUS USES.

In some products slate may be substituted as a filler for materials now in use without any marked effect on the quality of the products. A wider use of slate in such products could result only from a definite price advantage as compared with other fillers. Although waste slate may probably be placed on the market at prices which will encourage its wider use, evidently utilization of waste slate can never attain sufficient magnitude definitely to assist the slate producers unless it is demonstrated that some definite advantage in quality may be gained when slate is substituted for fillers now in use. It is important, therefore, in conducting any inquiry as to wider uses for waste slate that special effort be made to find advantageous uses in order that both producer and consumer may be benefited.

FORMS IN WHICH WASTE SLATE MAY BE USED.

Slate waste may be used for certain purposes in its massive form. Thus small rectangles cut from waste pieces are used for the manufacture of inlaid slate and other forms of flat slate roofing, and larger masses may be used for flagging, for fence posts, or for wall rock. The most promising use, however, is in pulverized slate. Many products such as paper, rubber, road asphalt, floor coverings, and paints, require as one of their important constituents a considerable percentage of finely pulverized inert mineral matter to give "body," to obtain the desired consistency, or to supply the necessary wearing or other qualities demanded. Such materials are known as "fillers." As indicated in the following pages, slate dust proves to be a satisfactory filler in many of these products.

BUREAU OF MINES INVESTIGATION.

The great need that exists for waste slate disposal led the Bureau of Mines to undertake an extended inquiry into new and wider uses for the product. The results of inquiries conducted by various investigators were supplemented by special investigations under the bureau's direction. The Bureau of Mines has no equipment or facilities for conducting exhaustive tests of this character. Consequently, the cooperation of a number of manufacturing companies was enlisted, for it was felt that tests made under actual working conditions would be of great practical value. The utilization of slate flour as a filler had, prior to the present inquiry, received little attention by investigators. The desirability of enlarging this outlet for waste slate induced the bureau to seek the aid of industrial laboratories to determine the adaptability of slate as a filler in a number of important products. Requests for cooperative tests were sent to 135 companies. Many of those companies through lack of laboratory facilities or for some other reason would not undertake any experimental work. However, 45 companies requested material for testing. The bureau procured pulverized slate and shipped samples varying in amount from 3 to 100 pounds as desired. The companies that agreed to make tests were distributed among the various industries as follows: Rubber, 27; ceramics, 7; linoleum and oilcloth, 5; road asphalt, 4; plastic roofing, 2. Many other companies that did not actually conduct tests furnished information of great value in the inquiry. The results of the tests, combined with other information obtained, are given in the following paragraphs:

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RUBBER FILLER.

Most of the pulverized slate submitted for testing as a rubber filler was of such a fineness that 80 per cent would pass through a 200-mesh screen. Samples varying in weight from 3 to 10 pounds were submitted to 27 rubber companies. Several companies who obtained favorable results from the small samples, and desired to make tests on a larger scale, were provided with 100 to 200 pound samples.

Eighteen reports have been received from manufacturers of various classes of mechanical rubber goods. Of these reports 7 were unfavorable and 11 favorable. It was claimed by those reporting unfavorably that the resulting rubber was inferior in tensile strength, stretch, and wearing quality. One manufacturer claimed that slate flour made the product dry and hard with a tendency to crack. Several reports were received to the effect that the slate submitted was insufficiently ground and that finer-grained filler would give better results. Only one manufacturer expressed a preference for coarse-grained filler.

Details of one of the tests are given below. Slate flour was tested as a filler in comparison with soapstone. A physical examination revealed that the slate flour was coarser and less uniform than the soapstone used. The ingredients of the two compounds are shown as follows:

Ingredients.	Sample No. 1.	Sample No. 2.
	Per cent.	*Per cent.*
Smoked sheets	40.0	40.0
Magnesium oxide	2.0	2.0
Sulphur	3.5	3.5
Soapstone	54.5	....
Slate flour	....	54.5
Total	100.0	100.0

One-tenth inch slabs were press-cured for 75 minutes under 50-pound pressure. Stock containing the slate flour was very dark in color. The products were tested with the following results:

Results of tests on samples.

Sample.	Tensile strength.	Elongation.
	Pounds.	*Per cent.*
No. 1	1,315	525
No. 2	774	270

These results indicate that slate flour is inferior to soapstone as a filler, though the coarseness of grain may have had some influence on the results obtained.

Eleven manufacturers of mechanical rubber goods found that slate flour was a satisfactory filler for such products as disks, sheet packings, molded shoe heels and soles, hard-rubber battery jars, carriage tires, garden hose, clutch facings, and similar products. Slate flour was used successfully as a substitute for whiting, clay, ground barytes, and aluminum flake. A manufacturer of rubber footwear found that products in which slate was used compared favorably with those made from regular compounds in tensile strength, elongation, and accelerated or natural aging, but repeated stretching caused the rubber to break more readily than when regular compounds were used. The chemist in charge of the tests concluded that this latter quality was due to the coarseness of the slate filler, and suggested that finer grinding would overcome the difficulty.

Detailed tests conducted by one manufacturer may be of interest. For comparative tests three rubbers were compounded, one containing 40 per cent whiting, a second 40 per cent clay, and a third 40 per cent slate flour. The results of tests made on the rubbers thus compounded are as follows:

	Thickness.	Elongation.	Break.	Tensile strength.
			Pounds.	*Pounds.*
Whiting as filler	136	9	58	850
Do	136	8	46	680
Clay as filler	188	6½	80	850
Do	188	6½	80	850
Slate flour as filler	160	9½	68	850
Do	140	9½	56	800

The comment of the chemist who conducted the tests was that "slate flour shows up very well; if the price is low enough it can be used advantageously."

A manufacturer of mechanical rubber goods, tubing, friction and rubber tape found that slate flour could be substituted for cheap whiting in gray and black products. The whiting which it might replace is quoted in 1921 at $13 to $16 a ton.

A sample of slate pulverized to a fineness such that 95 per cent would pass through a 200-mesh screen and 90 per cent through a 300-mesh screen was supplied to one rubber company. As a result of tests made on rubber compounded with this filler, the opinion was expressed that slate flour was not quite as good as high grade clay, but gave better results than whiting or ground barytes.

The difference of opinion evident from the reports as given above, may, therefore, be largely due to insufficient grinding of the slate flour submitted for testing purposes. At the time most of the tests were made the bureau could not obtain slate flour which would analyze finer than 80 per cent through 200 mesh. The results of the tests, together with opinions expressed by several rubber chemists, indicate that if slate flour of much finer grain had been used the results would have been more uniformly favorable. This is corroborated by the result obtained from one sample of fine material, as noted in the preceding paragraph.

The weight of evidence points to the probability that finely pulverized slate is a satisfactory filler for mechanical rubber goods, and it is important to note that it could be placed on the market at a price considerably lower than that of ordinary fillers now in use.

A few manufacturers who made tests of slate flour as a filler in rubber, such as is used in automobile tires, report unanimously that slate flour is not as satisfactory as fillers now in use. It is felt, however, that the evidence is not to be regarded as conclusive until extremely fine-grained material has been tested.

LINOLEUM, OILCLOTH, AND WINDOW-SHADE FILLER.

Oilcloth, linoleum, other floor coverings, and window shades all contain a varying percentage of mineral fillers. In oilcloth the content of filler varies from 40 to 70 per cent, depending on the grade, and in linoleum it constitutes about 20 per cent of the total mass, with a larger proportion in the backing. English and domestic china clays are used in white oilcloth and white window shades, and colored fillers may be used in other products. Red slate flour and pulverized red shale are used as a backing in red linoleum and as a constituent of felt-base floor covering.

The ordinary mineral fillers used are clay, whiting, barytes, asbestine (a form of talc), ochre, limestone, and slate flour. Products having color other than white require as fillers any low-priced inert mineral product in pulverized form, 95 per cent to 100 per cent of which should pass a 100-mesh screen. At present a considerable tonnage of red slate flour and pulverized red shale are used in the linoleum and other floor-covering industries, but little shale flour of any other color has yet been employed.

One company found that slate flour was too gritty to be used successfully. No information has been obtained as to the fineness of the material tested, and fine grinding might overcome the gritty property. A manufacturer of shade cloth found that a sample of slate flour submitted by the Bureau of Mines was satisfactory as a filler. Its use would depend largely on the price as compared with that of pulverized limestone.

Another manufacturer of shade cloth found that slate flour was satisfactory, except that difficulty was encountered in mixing it with water, as it had a tendency to "ball up." Experiments are now being conducted with a view to overcoming this difficulty by mixing with oil, or by grinding in oil and water.

Tests made on samples of oilcloth by one manufacturer indicated that slate satisfactorily replaces the china clay, ordinarily used as a filler, but the same difficulty was experienced in mixing with water as noted in the preceding paragraph. The great advantage in price of slate flour over china clay would encourage further experimentation on overcoming the difficulties of mixing the filler.

It seems probable, therefore, that slate flour may be a successful filler for oilcloth, floor covering, and window-shade materials, with the exception of those that are white in color. Slate flour compares favorably in price with the cheaper grades of filler, such as ground barytes, off-color talc, impure clay, and pulverized limestone or marble. When substituted for china clay the advantage in price is much greater. A large saving could therefore be effected by substituting slate flour for fillers now in use in these products.

FILLER IN PLASTIC ROOFING AND FLOORING.

About 75 per cent of the volume of certain types of plastic flooring is made up of pulverized slate. The insolubility of slate renders it of special value for acid-proof plastic flooring, and lining for acid tanks.

Roofing mastic is commonly made from a mixture of coal tar and slate flour. It is used to form the bed on which roofing tiles are placed and to fill the joints between them. It is used in the same way with rectangles of slate on flat slate roofs. Both pulverized limestone and slate are used as fillers, and the choice of material depends chiefly on the price. Fillers used by some companies may be manufactured at low cost, as extreme fineness of grain is not required, material averaging 75 per cent through 100-mesh, or even coarser, being acceptable. Other manufacturers require material of such fineness that 75 to 85 per cent will pass a 200-mesh screen. The cost of manufacture will, of course, depend largely on the fineness desired.

Slate flour as a filler in plastic products has passed the experimental stage, for it proves to be well adapted for such purposes, and is now used in large quantities. One company now uses about 50 carloads of slate a year in the manufacture of plastic products. An extension of its use depends almost entirely on the ability of grinding companies to place it on the market at prices that will compete with those asked for pulverized limestone and other low-priced fillers.

SUMMARY.

All of the information available indicates that waste slate may be used to advantage as a filler in mechanical rubber goods and in some classes of oilcloths, floor coverings, and window shades. Apparently it is not adapted for use in rubbers of a grade used in automobile tires. For plastic roofing and flooring products containing coal tar it has long been in use and is a very satisfactory filler. Several hundred carloads a year of waste slate are probably used for this purpose at the present time.

For some products, particularly for rubber, a much finer grained slate flour than any now on the market is demanded. One of the most promising ways in which manufacturers of pulverized slate can promote a wider use of slate flour is by producing a uniform, reliable product, at least 95 per cent of which will pass a 300-mesh screen, and by introducing such product among manufacturers of mechanical rubber goods, linoleum, oilcloth, phonograph records, and other products requiring extremely fine-grained filler.

FILLER IN ASPHALT ROAD-SURFACE MIXTURES.

ROAD-ASPHALT MIXTURES.

The manufacture of filler for road-asphalt mixtures is a promising field for slate-waste utilization. In the preparation of asphaltic mixtures for surfacing roads, in addition to the sand, or stone and sand aggregates, finely pulverized limestone or Portland cement is used as filler. In asphaltic mixtures in which by-product asphalt is used, the weight of filler and asphalt is substantially the same, but when Trinidad and certain other native asphalts are used a somewhat smaller proportion of filler is required. The tonnage of filler used in such asphalt mixtures is very great, one authority estimating that the city of New York alone requires 50,000 tons a year. As road building is such an important industry, and as intimations had been received from several sources that slate flour constituted a superior filler for road asphalt mixtures, an attempt was made to obtain more definite data as to the adaptability of slate flour for such a use.

In order to obtain practical tests the cooperation of manufacturers was requested, and as a result several companies kindly offered to test the material in their experimental laboratories. Samples of finely pulverized slate were submitted for this purpose. Results of the most complete tests are given in the following paragraphs:

IMPACT AND COMPRESSION TESTS.

The slate flour submitted was so fine that 99.3 per cent would pass a 100-mesh and about 80 per cent pass a 200-mesh screen. Tests were made to determine its suitability as a filler in asphalt pavements, both on asphalt-bonded briquets and on standard mixtures of sheet-asphalt pavement. The briquets were prepared by adding

10 per cent of "D" grade Calol asphaltum of 67 penetration to the slate dust and increasing the amount by 2 per cent until the pat test showed only a slight excess. The completed briquets contained 20 per cent of asphaltum. They were made at a temperature of 300° to 350° F. The standard sheet asphalt consisted of a mixture of "D" grade, 67 penetration asphaltum with slate dust and sand. Its composition by weight is:

	Mesh of screen.	Per cent.
Asphalt		10
Slate dust filler		13
Sand retained	200	13
Do	100	13
Do	80	24
Do	50	11
Do	40	8
Do	30	5
Do	20	3
Total sand		77
Total		100

The standard sheet surface mixture was tested for impact with a large Page impact-machine having a 2-kilogram hammer dropping from a height which was increased 1 centimeter with each successive blow. For the asphalt-bonded briquets a small Page impact-machine was used. The cementing value under compression was determined by subjecting the briquets to pressure, increasing uniformly at the rate of 600 pounds a square inch a minute.

Similar mixtures with limestone dust and Portland cement, materials common as fillers in asphalt pavement, were prepared, using the same proportions by weight as in the slate-flour mixtures given above. The results of the tests are shown in Table 3.

TABLE 3.—*Results of impact and compression tests.*

Material as filler.	Impact.	Compression a square inch.	Remarks.
Asphalt-bonded briquets:		*Pounds.*	
Slate flour	59	897	Briquets flattened; good cementing value.
Portland cement	59	764	Do.
Limestone dust	58	600	Do.
Standard sheet surface-mixture:			
Slate flour, 13 per cent	25	572	
Portland cement, 13 per cent	20	493	
Limestone dust, 13 per cent	24	600	

From these results in asphalt-bonded briquets slate flour is evidently superior to both Portland cement and limestone dust in resistance to compression, which is a measure of its cementing value. In the standard sheet surface mixture it is intermediate between limestone dust and Portland cement. As regards impact, little choice seems to exist between the three substances tested as filler in asphalt-bonded briquets, but in standard sheet surface mixture slate flour appears to be somewhat superior.

It is to be noted that the proportion of fillers used was determined on the basis of weight and not of volume, and as the materials used vary in specific gravity a different volume was used in each test. If the fillers had been added on the basis of volume, somewhat different results might have been obtained, particularly for Portland cement, which is considerably heavier than either limestone or slate. The results obtained therefore are indicative only, and are not conclusive.

SETTLEMENT AND DECANTATION TESTS.

In any dust used in asphalt mixtures, only that part which is finer than 200 mesh is available as filler, all material coarser than 200 mesh being regarded as aggregate rather than filler. Richardson[29] states that "only particles smaller than 0.05 mm. in average diameter are to be regarded as true dust, and it is even better to have a considerable proportion of the dust finer than 0.05 mm. in diameter." The best way to determine the percentage of very fine material is by settlement and decantation tests. Such tests of slate-dust samples were made in the laboratory of the Bureau of Mines in accordance with the method outlined by Richardson and termed by him the elutriation method. Five grams of slate dust were placed in a 600 c. c. beaker about 120 mm. high. The beaker was then nearly filled with distilled water at a temperature of exactly 20° C., and the contents were agitated with an air blast until the dust and water were thoroughly mixed, care being taken to produce no cyclonic currents. The liquid was then allowed to stand for a fixed period of time, after which the water and suspended dust were decanted, leaving the sediment in the bottom of the glass. This was repeated three times. It is regarded that particles thus held in suspension for a 15-second period have a diameter of approximately 0.08 mm., and those that remain in suspension for a period of one minute have a diameter of 0.05 mm., although these figures may vary somewhat depending on the specific gravity of the materials. Tests were made at both 15-second and 1-minute periods; the results are shown in Table 4:

[29] Richardson, Clifford, The modern asphalt pavement, 2d ed., 1918, p. 92.

TABLE 4.—*Results of settlement and decantation tests.*

Material.	Screen test. Per cent through— 200-mesh.	Screen test. Per cent through— 300-mesh.	Time of subsidation.	Material decanted.	Percentage recalculated on a 200-mesh basis.	Percentage recalculated on a 300-mesh basis.
			Seconds.	*Per cent.*		
Red slate, Lenhartsville, Pa.	98	96.4	15	97.8	99.8	....
Do.	98	96.4	60	89	....	92.3
Light gray slate, Albany, Pa.	88.8	86.1	15	76.4	85.9	....
Do.	88.8	86.1	60	61.8	....	71.8
Gray slate, Northampton County, Pa.	95	90.2	15	89.2	93.9	....
Do.	95	90.2	60	74	....	82
Do.	86	79	15	85.6	99.5	....
Do.	86	79	60	67.8	....	85.8
Do.	90.3	84.6	15	87.7	97.1	....
Do.	90.3	84.6	60	71.9	....	85

The tests were made with materials various percentages of which failed to pass a 200-mesh screen. As 200-mesh material only is to be considered as effective filler, it seemed important to eliminate from the determination the percentage of material coarser than 200 mesh, and to recalculate the fine dust on the basis of that which passed 200 mesh. Thus in the fifth column of the table is given the percentage of 200-mesh slate flour which remains in suspension at the end of a 15-second period. For comparison a recalculation was made indicating the percentage of 300-mesh slate flour which remains in suspension at the end of 1 minute, and this is shown in the sixth column. It may be observed that the material held in suspension at the end of a 15-second period is a little finer, though almost equivalent to that which passes a 200-mesh screen. Material held in suspension at the end of 1 minute is considerably finer than that which passes a 300-mesh screen.

In order to compare slate flour intelligently with other fillers, Table 5 has been prepared from Richardson's[30] results. The percentages have been recalculated on a 200-mesh basis.

TABLE 5.—*Elutriation tests as given by Richardson.*

Material.	Through 200-mesh screen.	Percentage decanted.	Percentage recalculated on a 200-mesh basis.
	Per cent.		
Limestone	84.0	71.3	84.9
Trap rock	81.0	70.3	86.8
Portland cement	74.0	56.7	76.6

[30] Richardson, Clifford. Work cited, p. 94.

From this table it may be seen that for limestone, trap rock, or Portland cement only 75 to 85 per cent of the 200-mesh material is to be regarded as fine dust suitable as a filler, whereas, according to Table 4, the fine dust in slate flour approximates 100 per cent of all that passes the 200-mesh screen. Slâte dust is, according to these tests, a much more economical filler than either limestone or Portland cement, in that it provides a larger amount of effective filler for each ton of pulverized material purchased. However, in modern practice Portland cement is somewhat finer than that used in the above tests, and consequently may give better results.

VOLUME WEIGHT OF FILLERS.

Filler materials are purchased by weight, and, other considerations being equal, that filler is the most economical which occupies the greatest space for weight purchased. A very heavy filler fills a relatively small space as compared with a light one. As specific gravity is the weight of a unit volume of a material compared with that of an equal volume of water, specific gravity may be regarded as a measure of relative volume weight. A comparison of the fillers under consideration indicates that Portland cement has a specific gravity of about 3.1, average limestone about 2.77, and the average slate of Northampton County, Pa., about 2.78. Slate is, therefore, about equal to limestone in this respect, and has an advantage over Portland cement by about 10 per cent in volume for a given weight.

COST.

Any definite statement as to relative costs of fillers is difficult to make, for the production of pulverized slate is an industry not yet established on a large enough scale to permit uniform price quotations of bulk shipments. For the limited shipments now made in barrels and bags in carload lots, prices vary greatly in different localities. A safe estimate, however, is that slate flour can be placed on the market a little more than half the present price of Portland cement. Current prices of pulverized limestone indicate a decline almost to prewar levels, and whether producers of slate flour can compete successfully in price with producers of pulverized limestone is yet an open question.

SUMMARY.

Actual tests in laboratories of companies preparing road-asphalt mixtures indicate that for resistance to impact slate flour is about equal to other fillers in bonded briquets, and somewhat superior in sheet surface mixtures. In cementing it is superior to both limestone and Portland cement in asphalt-bonded briquets, and intermediate between them is standard sheet surface mixture. Elutriation tests indicate that slate flour contains approximately 15 to 25 per cent more of the fine dust that constitutes effective filler, than limestone, trap rock, or Portland cement. In volume weight slate is about equivalent to limestone, and approximately 10 per cent superior to Portland cement. The cost of slate flour is little more than half that of Portland cement, but its ability to compete in price with limestone is not yet established.

CONCLUSIONS.

The tests already made are not sufficiently comprehensive to give conclusive results, but they are definite enough to suggest possibilities of such importance as to induce further and more extended research both by slate producers and by manufacturers of asphalt road mixtures. The preliminary tests recorded indicate that the use of slate flour as a filler in asphalt road surface mixtures would result in improved highways, and that a wide use of such filler would afford a profitable outlet for waste slate with consequent advantage to the slate-producing industries. It is highly desirable that the conclusions reached in laboratory tests be verified by practical tests on experimental roads.

USE IN CERAMIC PRODUCTS.

BRICK AND TILE MANUFACTURE.

Various sporadic attempts have been made to utilize the waste from slate quarries in the manufacture of ceramic products. The activities of the North Wales Development Co. are of particular interest, as this company contemplates the manufacture of ceramic products from waste slate on an extensive scale. Samples of roofing tile made from slate waste have been submitted by the company to a firm in the roofing-tile trade and the claim has been made that the firm expressed willingness to place an order for 10,000,000 tiles provided regular deliveries could be guaranteed. The company has also experimented in the manufacture of brick from slate waste. One type of brick is made in the same manner as sand-lime brick. Slate dust is mixed with about 8 per cent lime, and hardened under steam pressure. Another type of brick consists of 90 per cent ground slate and 10 per cent clay. The materials are mixed in a pug mill, passed through a brick machine, and burned like ordinary clay brick. Tests indicated that slate brick are as strong and of as low absorption as clay brick.

The manufacture of ceramic products from slate waste has been tried a few times in America, but none of the efforts are of recent date. and no definite information is available concerning them. All the information which the bureau has been able to secure is contained in the following paragraphs.

In the slate region near Arvonia, Va., the upper 35 to 50 feet of the beds consist of decayed slate. Some years ago tests were made and this waste rock was found to be suitable for brick manufacture. No tests of the hard slate have been made.

Some years ago a brick plant was in operation at Whiteford near the Peach Bottom slate district of Pennsylvania and Maryland. About 1910, an experiment was conducted to determine the possibility of using waste slate as a brick constituent. The tests were very crude, no attempt being made to maintain definite proportions, to mix thoroughly, or to grind to a fine consistency. Fragments of slate were thrown into a dry pan with clay, and were thus worked up imperfectly. The mixture was then made into brick and burned in the ordinary way. Vitrefied brick used in the railroad station platform at Delta, Pa., are said to have been made in this way. They are apparently strong and durable. It is reported that the red facing brick used in a large schoolhouse at Cardiff, Md., were made from a mixture of clay and slate as described above. The structure is attractive and the brick appears to be durable.

A red facing brick was made some years ago from a mixture of clay and slate at a plant near Phillipsburg, N. J. Several buildings were constructed of this brick, which is said to have given entire satisfaction. The brick plant burned about 1910, and no definite information has been obtained as to the proportion of clay and slate used, the method of manufacture, or temperature of burning.

A Chicago firm claims that slate brick may be made successfully in the same way as slag brick. The process as described by the firm is as follows: The slate is ground so that the resulting grains are one-eighth inch or smaller. About 5 per cent of a binder (calcium carbonate) is added and the brick are pressed out with special patented presses at a pressure of about 180 tons to the surface area of each brick. The brick are then burned at a temperature of about 1,800° F. for 6 days, or steam cured at a temperature of 300° F. for 8 hours. Brick made by this method are found to be strong and durable. The result of one test indicates that the crushing strength is 3,560 pounds to the square inch. The absorption after 48 hours immersion in water was about 6 per cent.

POSSIBLE USES IN HEAVY CLAY PRODUCTS.

The use of waste slate in the manufacture of common brick or tile is not promising. Such products command a low price and the raw materials for their manufacture are plentiful. Probably, however, much slate could be used to advantage as a constituent of some of the higher grades of ceramic wares such as roofing tile, paving brick, and sewer pipe. One Ohio firm is reported as having expressed a desire to obtain several carloads of waste slate a month to be used as an ingredient of roofing tile. The claim was made that the slate flour gave exactly the desired color to the tile, and was much cheaper than the coloring agent commonly used. This is merely offered as a suggestion, for the bureau has been unable to learn the name of the firm to whom this statement is attributed or any details concerning the proposed use of the slate.

Various reports have been received to the effect that the addition of slate to certain clay mixtures improves the quality of such products as paving brick, sewer pipe, and facing brick.

WASTE SLATE AS A GLAZING MATERIAL.

Tests made by one of the more important manufacturers of refractories in the United States indicated that slate had too low a fusion point to render it of value as a refractory constituent. The low temperature of melting suggested its use as glazing material, and tests were conducted to determine its adaptability for such a purpose. The slate was passed through a fine screen, made up into a slip by mixing with water, and applied to clay bodies of various types. Some samples were fired to cone 9 and others to cone 12, and a very satisfactory, brilliant brown glaze resulted. The slip would evidently mature at a much lower temperature than those recorded above, but the minimum temperature was not determined. From these experiments the conclusion was reached that waste slate could be used satisfactorily in glazes of the type for which Albany slip is now used. That other ceramic manufacturers conduct tests to verify this conclusion is highly desirable. The substitution of slate for Albany slip in brown glazes would result in a considerable saving to ceramic companies, for pulverized waste slate could be purchased at a much lower price than that demanded for Albany slip.

USE IN MANUFACTURE OF SYNTHETIC SLATE.

Several independent investigators have compounded various forms of synthetic slate, using slate dust and a binder. According to a process patented by O. J. Owen,[31] three-fourths of the slate used consists of a coarse powder and one-fourth of a fine powder, but no definite information is supplied as to the grain size of the materials. A binder such as Portland cement is added and the mixture is molded into $\frac{5}{16}$-inch sheets and subjected to a pressure of about 2 tons to the square inch. When seasoned the slates are treated with sodium silicate and calcium chloride to render them nonporous. The artificial slates are used for roofing in the same manner as natural slates. The

[31] Owen, O. J., U. S. Patent 1,193,416, August 1, 1916.

inventor claims that artificial slates are now being manufactured by this process in Europe, but no industry of this character has yet been established in America.

A chemist in Pen Argyl, Pa., has compounded samples of synthetic slate which compare favorably with natural slate in dielectric strength, but have a somewhat lower transverse strength than the natural product. Such materials are proposed for use for electrical and structural purposes and for roofing. As synthetic slate may be molded into forms suitable for ridges, gutters, and cornices, it has certain advantages over natural slate.

A Chicago firm plans to manufacture synthetic slate on a large scale, utilizing the waste from a proposed mill to be erected in the Fair Haven district of Vermont. The purpose is to manufacture small standard knife-switch bases. In natural slate the impurities which may act as conductors are commonly in the form of veins or stringers and form channels through which the electricity passes. When such slate is pulverized and recemented in the form of synthetic slate the impurities are scattered uniformly throughout the entire mass, and so do not act as continuous channels for electric conductivity. Therefore, synthetic slate made from waste fragments is claimed to give better dielectric tests than the same slate in its natural state. That synthetic slate will bear as high a temperature as natural slate is improbable, and it would not therefore be serviceable as switchboard material where high temperatures are encountered.

The feasibility of utilizing waste slate for the manufacture of synthetic slate hinges on the cost of a binder and the cost of pulverizing and recementing the slate. A cheap binder must necessarily be used and none of the synthetic slates thus far manufactured with low-priced binders are as strong as natural slate. Up to the year 1921 synthetic slate had not been manufactured on a commercial scale, and although a limited amount of waste slate may be utilized for such a purpose, it is one of the least promising uses for waste on a broad scale.

OTHER USES FOR PULVERIZED WASTE SLATE.

Slate is used as a filler in certain paints and distempers. The claim has been made that in Wales it has been used successfully in the manufacture of low-grade green bottle glass. It may be used also as a filler in various other products such as metal polish, abrasive soap, insulators, heavy wrapping paper, and cardboard. Slate dust mixed with some binder, the composition of which has not been learned, is being used in England for molded walls of houses. The dust when properly treated is said to set firm, to be almost impervious to moisture, and to be very durable. Specimen houses have been constructed in Birmingham, England. The main structure of an ordinary dwelling house may be completed in a period of 10 to 14 days at a cost of about half that of brick.

Probably slate dust may be used along with certain types of limestone for the manufacture of Portland cement. As slate would constitute not more than one-fourth of the raw material, the location of a cement plant would be governed almost exclusively by the availability of suitable limestone and fuel supply, and by marketing conditions. Clay or shale is generally used to mix with limestone in cement manufacture, and supplies of suitable materials are usually abundant and readily available. There are no cement plants sufficiently near slate regions to justify the transportation of waste slate to them, and the slate itself is too unimportant to be a controlling factor in the location of new plants. Although much publicity has been given to the use of waste slate in cement manufacture, its practical utilization in this industry is too remote to demand serious consideration.

In this connection it is noteworthy that a Vermont cement manufacturing project has been considered involving the utilization of waste marble from the West Rutland district and waste slate from the Poultney and Fair Haven slate districts. The cost of collection and transportation of waste materials probably could not be made low enough to compete with plants which have their raw materials right at hand.

The dusting of coal mines with an inert powder to prevent coal-dust explosions is now compulsory in Great Britain, and this supplies an outlet for much slate. In the United States little dusting of coal mines has yet been done. If a demand for inert powder for this purpose is developed in the future the impure slates so commonly associated with coal could probably be utilized to better advantage than materials shipped in from roofing-slate regions.

Pulverized slate has been used with success as a parting sand in foundries, but for such a use a very small tonnage would be required. Slate dust may also be used as a fertilizer filler.

USE FOR GRANULE MANUFACTURE.

During and immediately following the World War there was a wide demand for low-priced roofing, and on this account a tremendous increase has been noted in the production of granules for slate-surfaced prepared roofing. The production of granules of all types probably exceeded 300,000 tons in 1920, though in 1921 the production decreased greatly. Slate granules alone amounted to about 268,000 tons in 1920. Other materials used for granules are serpentine, trap rock, shale, and epidote.

The granule industry might be expected to afford a ready means of disposing of much of the waste from quarries. However, according to information obtained by this bureau, not a single granule plant was in 1921 utilizing waste heaps or waste materials as they came from the quarries. Manufacturers of granules consider quarrying the rock from the solid ledge more economical than sorting over the waste heaps. Furthermore, the great bulk of the waste is found at the dark gray or black slate quarries, and, prior to 1921, the chief demand in granules was for the red and green colors. In some localities rock best adapted for granule manufacture is of a different character from that best adapted for roofing or structural purposes. Thus in the Granville district at the New York-Vermont boundary the roofing-slate quarries are practically all in the green and purple slates of Vermont, whereas the granule plants are in New York in the belt of harder and less easily splitting red slates.

Recently there is a noticeable growing demand for granules made from the darker slates. Therefore, granules apparently could be manufactured profitably in connection with crushing and grinding plants established for the manufacture of pulverized slate.

USE FOR MANUFACTURE OF INLAID SLATE.

Inlaid slate is a name given to a roofing material made of small rectangles of slate set in a mastic on a backing of prepared roofing. Waste fragments from the splitting shanties are cut with a special machine to rectangles of 3 by 6 inches. Five of these small slates are cemented under heat and pressure to a strip of roofing felt 6 by 15 inches. Such groups of slates are termed units. The projection of the backing laps beneath the adjoining units. The units may be cemented over any standard prepared roofing.

Inlaid slate has been used on flat roofs of a number of important structures. It is well adapted for use where a promenade is desired. It has also been used successfully as a substitute for copper in making large gutters. They are easily applied, provide solid and waterproof roofs, and owing to the small size of the slates and flexibility of the units, they may be fitted over uneven surfaces without cutting the slate.

The Inlaid Slate Co., of Pen Argyl, Pa., ran successfully from 1905 until 1917, when work was suspended owing to war conditions. There is some prospect of establishing a plant for manufacturing inlaid slate in connection with the manufacture of structural and roofing slate. The latter products will be made from the larger masses, the smaller fragments used for inlaid slate. Evidently the field is promising for the development of an industry which will thus utilize large quantities of cuttings that now go to waste.

USE FOR MANUFACTURE OF PERFORATED SLATE LATH AND SLATE VENEER.

The manufacture of perforated slate lath and slate veneer has not yet passed the experimental stage. For the manufacture of both products the Lake slate-splitting machine, as described on page 63, is essential.

For the manufacture of perforated slate, ribbon stock may be used, and as seasoned slate is claimed to split readily with the Lake machine, waste blocks from the dump piles could be utilized. The slate is split to about three-eights inch, and then by means of a special die machine semicircular holes are punched about 1 inch apart. The dies are so arranged that the holes are punched in rows inclined at a small angle to the grain of the slate, for if the rows of holes were in line with the grain the slate would be greatly weakened. Slabs of slate thus perforated may be used instead of wooden or metal laths, either for interior plastering or for exterior work, such as stucco. The material is rigid, gives a true surface, and is non-rusting. One of the greatest advantages claimed is the saving in mortar, for the surface is so true and smooth that the volume of mortar may be reduced to 60 or even 40 per cent of that required for wooden laths. A market for perforated slate would probably not be difficult to find. The chief drawbacks in establishing such an industry are, first, the difficulty in making suitable arrangement with slate producers for the use of their dump piles and, second, the difficulty of disposing of unsuitable waste. The successful operation of slate-splitting machines on a commercial basis has yet to be demonstrated.

For the manufacture of slate veneer the slabs are split to one-sixteenth inch and cementd to gypsum board with a tar compound. A coarse fabric such as jute is saturated with the tar, and placed between the slate and the gypsum board. Slate veneer is claimed to be suitable as wall board for interior or exterior use. The slate surface is well adapted for painting, and thus walls may be decorated in any desired manner. The success of a slate-veneer industry using waste material also depends largely on the success of the splitting machine on a factory scale, for it would involve the splitting of many seasoned blocks, which can not be split into thin slabs by methods now in use.

The most recent development in the use of slate veneer is in the manufacture of slate-surfaced roofing-shingles. At the time of writing such shingles are surfaced with granules, but the proposed methods, which is yet in the experimental stage, is to substitute a thin slab of slate for the granules. Any ordinary composition tar roofing may be used as a backing, to which a slab of slate one-sixteenth inch thick is cemented. The shingles are laid in the same way

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as wooden shingles; they have the advantage of being much lighter in weight than slates, and may be nailed like wooden shingles without previous punching. Also broken slates are held in place by the backing. Samples of the new slates examined by the Bureau of Mines are very attractive, and appear to be of a quality that would justify wide use. Plans are now being made to manufacture such slates on a large scale, and production is expected to begin some time during 1922.

MISCELLANEOUS USES FOR WASTE SLATE.

Waste fragments may be utilized to some extent for sidewalk stone, building stone, and fence posts. As slate presents an exceptionally satisfactory surface for painting, the use of waste slabs for sign boards merits consideration. Slate waste has been tried as railroad ballast, but the tendency for the flat fragments to slide on each other results in instability and gradual flattening of the grade. Consequently there is no prospect of finding any extended field of utilization in railroad work except possibly in the use of the larger massive fragments. Slate pulverizes to dust too readily for a road surface, but it may have some value in road construction when applied to the lower courses.

NEED FOR AGGRESSIVE WORK.

In this age of by-product utilization many industries owe their continued activity to the profitable utilization of materials that were at one time wasted. The slate industry has lacked enterprise in such undertakings, and as competition becomes keener and keener there is a correspondingly greater need for the finding of new or wider uses for materials that are now worse than useless in that they are costly to handle, impede development, and cover land or rock that might otherwise be utilized to better purpose. Ample evidence seems to support the prediction that the most successful operators in the future will be those who devote most thought and energy to solving the problems of waste.

ASSISTANCE FOR BY-PRODUCT ENTERPRISES.

Quarry operators should strive to encourage in every way any enterprise that promises to utilize waste. In the past they have been notably lacking in cooperation with prospective users. The operators realize that the waste is worse than useless as it stands, yet on several occasions the mere prospect that some enterprising manufacturer was about to reap a profit from waste products resulted in an immediate advance in the price of waste to a point prohibitive to the new industry. Such an inexcusable lack of foresight has defeated several waste-utilization enterprises that had a fair expectation of successful development. Operators are urged to encourage to the utmost such infant industries, for with proper care they may develop and become established.

CRUSHING AND PULVERIZING.

GRANULE AND SLATE-FLOUR INDUSTRIES.

Slate crushed to a granular form is known commercially as "granules," comparable in size with the grains of a fine gravel; the manufacture of these has lately developed into an important industry. Granules range in size from 10 to 30 mesh, and are used to coat various forms of tar roofing. Although they are in general termed slate granules, other materials, such as trap rock, shale, and serpentine, are also included. The industry is quite distinct from the manufacture of roofing slate; it is, in fact, a competitor, for large quantities of slate-surfaced roofing are now being sold for use not only on sheds, garages, and other low-priced structures, but also on moderate-priced dwelling houses of a class commonly roofed with slate. As noted previously (p. 104) no granules are now made from slate-quarry waste.

A small amount of waste slate is pulverized and sold chiefly as a filler, but such work is now done exclusively by grinding companies who purchase the waste slate from quarries.

It is noteworthy, therefore, that slate crushing and pulverizing plants are not at present operated by any of the manufacturers of roofing, structural, or electrical slate. The only justification for including a discussion of these processes in the present report is the desirability of establishing both granule and pulverizing plants in connection with quarries to utilize waste materials and to produce by-products that bring some return to the quarry operators and thus lower the cost of production.

VARIATION IN PLANT EQUIPMENT.

The types of crushing and grinding equipment used vary widely. Where a plant is erected primarily for making granules, the purpose is to crush with a minimum production of fines, for at most granule plants the fines are largely discarded as waste. Where there is a good market for pulverized material a large proportion of fines may not be regarded as a disadvantage. Even where the same type of product is desired, no two grinding plants are alike. This is due to such causes as differences in the raw materials, amount of capital available, and different views of the efficiency of different types of machines.

TYPES OF PRESENT PLANTS.

A plant in New York designed for the manufacture of granules only uses for primary crushing a jaw crusher, reducing the rock to 1½ inches. It discharges to two hammer mills, which break the rock to about ⅜ to ½ inch. Each hammer mill is followed by three roll crushers, which crush to the desired size of the finished product. The material from the rolls is passed to double rotary screens, the finished product going to storage, the fines to the dump, and the oversize is returned to the hammer mills. This is shown in Figure 33.

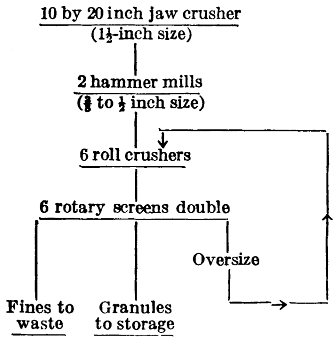

FIGURE 33.—Flow sheet No. 1 for granule plant.

Another plant in New York producing granules only uses a jaw crusher, disk crusher, and Newaygo screens. The flow sheet is shown in Figure 34.

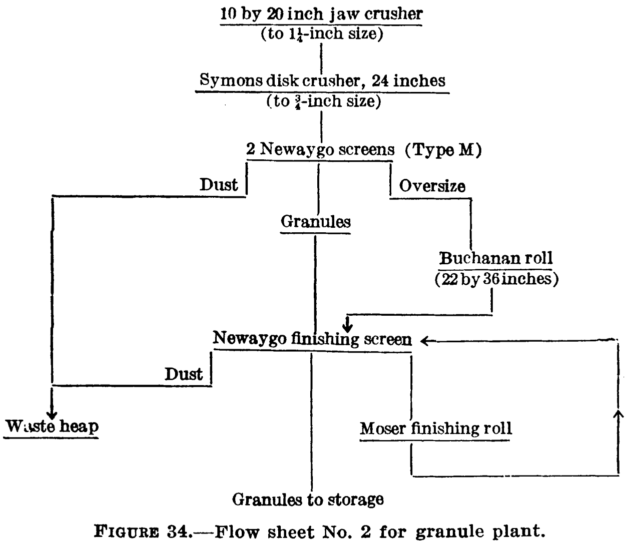

FIGURE 34.—Flow sheet No. 2 for granule plant.

Another New York ccmpany manufacturing both granules and pulverized slate uses a large jaw crusher for primary crushing, the product of which is screened to 1-inch size, and the oversize passed through a small jaw crusher. Further crushing is done by a series of 4 roll crushers in tandem with intermediate screens, and a final finishing screen. The flow sheet is shown in Figure 35.

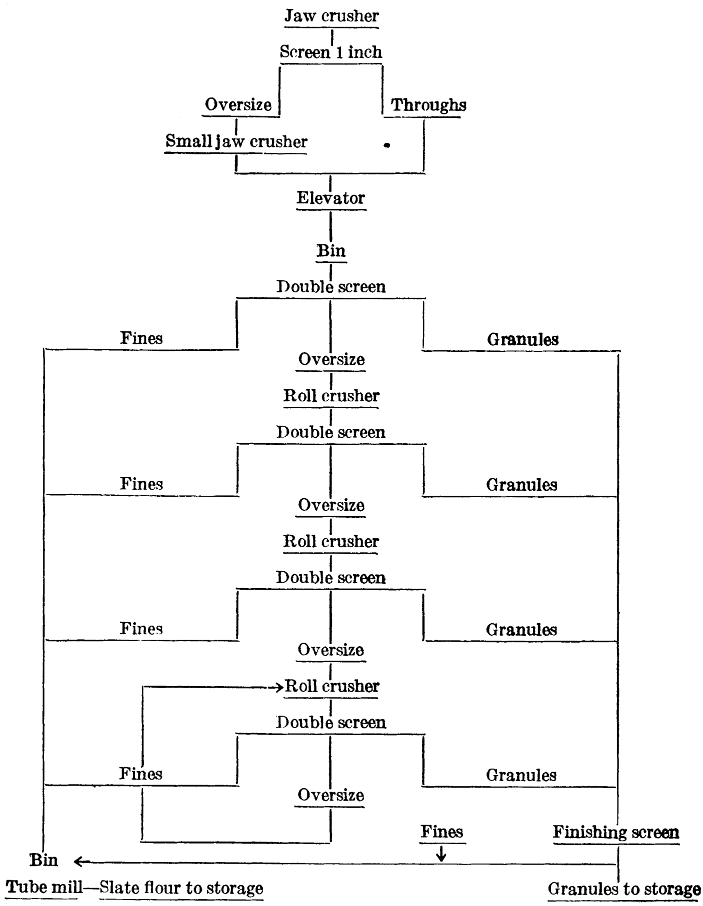

FIGURE 35.—Flow sheet for granule and pulverizing plant.

A new granule plant using green slate was built in Vermont in 1920, with a capacity of about 25 tons of granules per hour. The equipment is indicated by Figure 36.

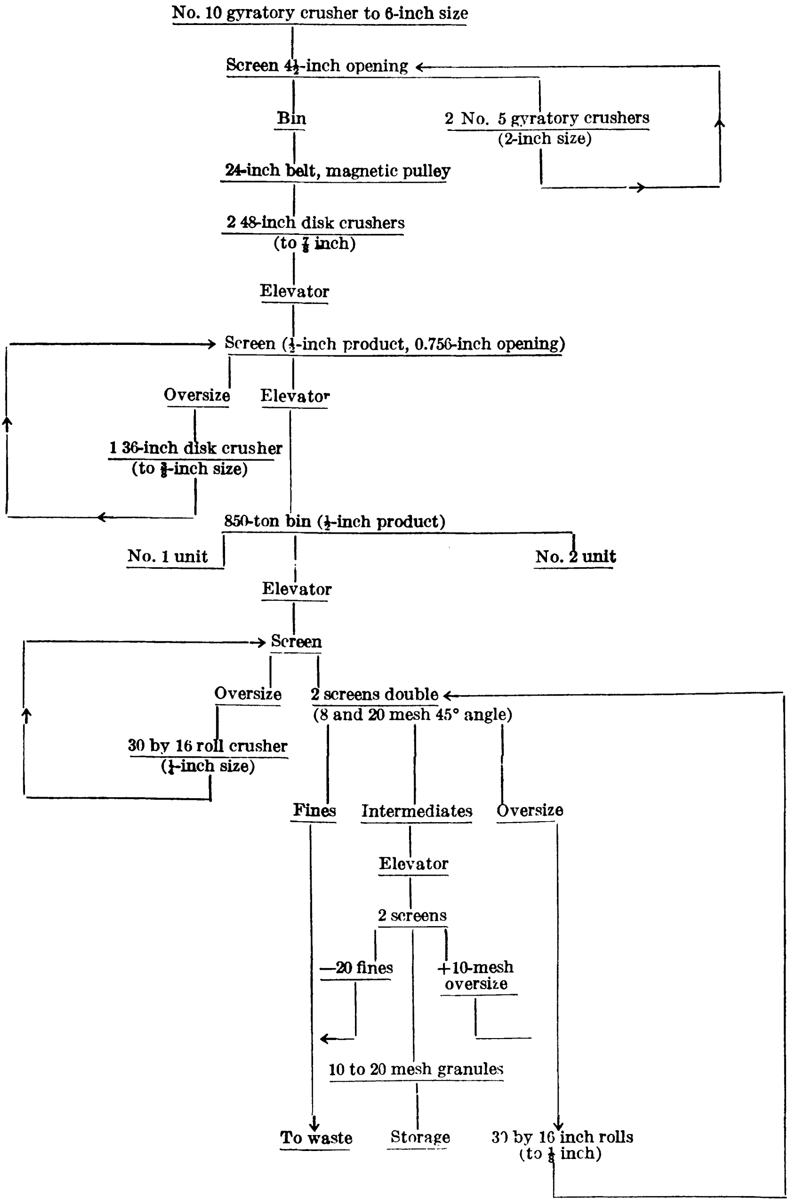

FIGURE 36.—Flow sheet of green slate granule plant.

A manufacturer of red slate granules in New York employs a combination of jaw crushers, hammer mills, and rolls, as indicated by Figure 37.

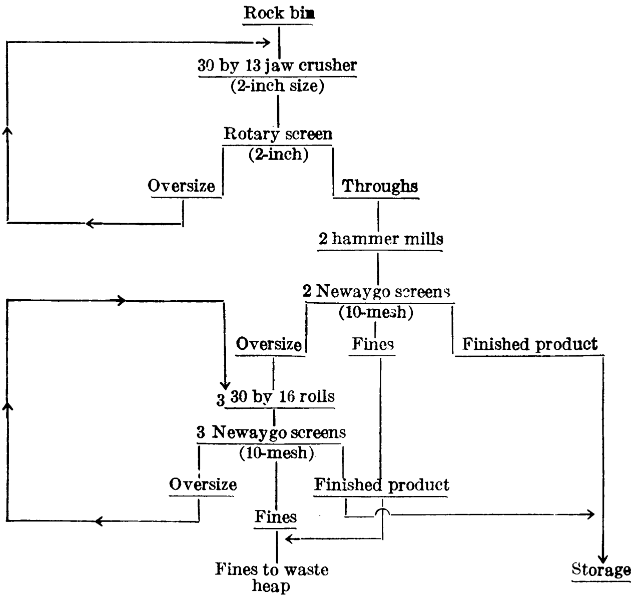

FIGURE 37.—Flow sheet of red slate granule plant.

A red shale deposit in Pennsylvania is quarried for the manufacture of roofing granules, and the fines pulverized chiefly for linoleum manufacture. A very simple and apparently efficient equipment for soft rock is outlined in Figure 38.

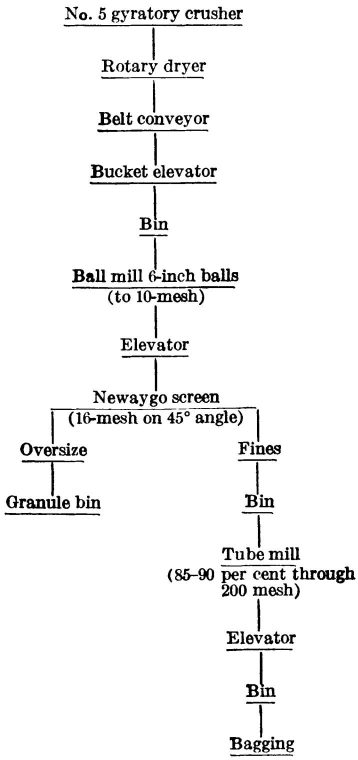

FIGURE 38.—Flow sheet of red shale, granule and pulverizing plant.

A company in Pennsylvania crushing trap rock for granule manufacture has equipment as indicated in Figure 39.

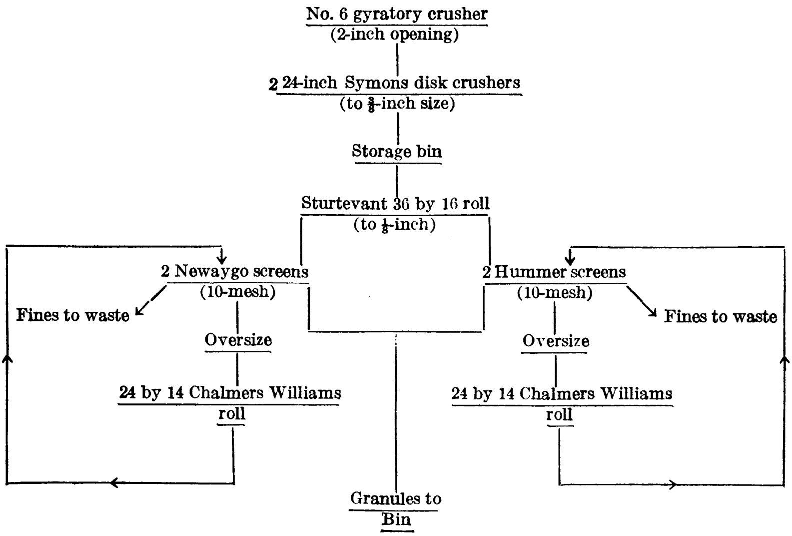

FIGURE 39.—Flow sheet of trap-rock granule plant.

One of the important slate-producing companies at Pen Argyl, Pa., built a grinding and pulverizing plant during 1921. The plant is designed to crush waste slate for the manufacture of granules and to pulverize the fines for filler uses. The mill has been carefully designed and has first-class equipment throughout. A noteworthy feature is the use of individual motors for each machine. As pioneers in this important by-product field, the company is to be congratulated for its enterprise. The mill design is given in Figure 40.

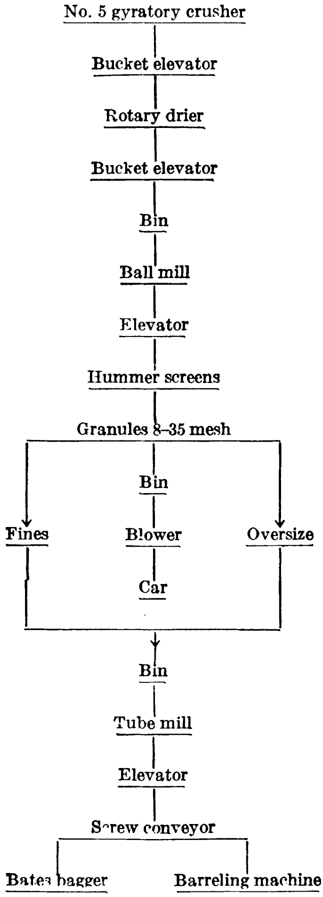

FIGURE 40.—Flow sheet of granule and pulverizing plant at Pen Argyl, Pa.

Conditions vary so greatly that no one plan can be recommended as the best, but the foregoing flow sheets may offer suggestions for operators of prospective grinding mills. The equipment should be as simple as is consistent with efficiency, and rehandling of material should be reduced to a minimum.

CHOICE OF EQUIPMENT.

The factors upon which the selection of proper milling machinery depends are the physical character of the rock, power cost, size of output and grades of product desired, and relation between first cost and operating expense.

PHYSICAL CHARACTER OF ROCK.

Slates vary greatly in hardness, and a different type of equipment may be used in soft slate than in hard. For example, one plant grinding soft shale reduces 2-inch fragments to 200 mesh in a single operation in a tube mill. With harder materials some intermediate grinding would probably be required. Equipment suitable for crushing waste in the "soft-vein slate-belt" might not prove successful in the "hard-vein slate-belt." In general where hard stone is ground the reduction should take place in more gradual stages than where the stone is soft.

POWER COST.

The price at which pulverized slate or granules may be placed on the market depends greatly on the power cost. Where hydroelectric or water power is available the cost is usually lower than where coal is used. The availability of cheap power should encourage the construction of a waste utilization plant.

If power is cheap the use of machines that are not economical of power may be justifiable. For example, a ball mill and tube mill equipment has been found to give a very uniform product and to be satisfactory in every way except for high power consumption per ton of product. If power is cheap this equipment is not to be condemned, but if power costs are high some other type of equipment is desirable.

SIZE OF OUTPUT AND GRADES OF PRODUCT.

The size of output desired and the grades of product to be made are interdependent. Some types of grinding machinery are made in several sizes so that almost any desired output may be obtained from one or more machines. Other machines, such as the Raymond roller mill, can not successfully be made to grind small sizes, and if a small production is desired other types of machines should be used. If products of several different sizes are desired proper machinery must be chosen to produce the different grades in the required proportion. Some grinding machines will make a large proportion of —300 mesh, but others may give a large percentage —150 mesh and very little of —300-mesh grade. Many fine grinding machines may be adjusted to give a large percentage of very fine material, but with greatly reduced capacity.

RELATION BETWEEN FIRST COST AND OPERATING EXPENSE.

The first cost of a plant is the cost of machinery plus the cost of installation. The operating cost includes interest on investment, depreciation, repairs, power, and labor. The attempt is commonly made to save expense by putting in a cheap equipment, but the excessive operating costs render this an expensive plant in the end. On the other hand, a costly plant may not be desirable, even though the operating expense is low, for too heavy an outlay of capital may be required. Both first cost and operating expense should be carefully considered, and if proper judgment is exercised a moderate-priced plant with moderate operating cost will possibly result.

IMPORTANCE OF PLANT EFFICIENCY.

As present uses for waste slate are gradually enlarged and new outlets are found, crushing and grinding will probably play a more and more important part in slate quarrying. With threatened over-production of granules, and keen competition with other pulverized materials, the success of grinding enterprises will depend largely on the efficiency of the plant established.

QUARRYING RAW MATERIALS FOR GRANULE MANUFACTURE.

One granule plant in Vermont uses churn drills for making blast holes, loads with a steam shovel, and transports the rock to the crusher in cars with locomotive haulage. This is the only plant yet observed that has modern quarrying and transportation equipment. Most granule plants are in slate regions and use slate-quarry methods. The rock is drilled with hammer drills or tripods, loaded into pans by hand, hoisted and conveyed by overhead cableways. Although the latter method of haulage may be justified in handling slate from deep and wide quarries, it is not at all suitable for any type of rough-stone quarrying from small excavations. For small quarries an inclined track, with cable-car haulage, is to be preferred to the aerial tramway. For larger quarries the use of steam-shovel equipment as described in the first part of this paragraph will tend to reduce quarry costs to a minimum.

ACCIDENT PREVENTION.

No aspect of slate quarrying is more important from both the operator's and the employees' point of view than that of safety. Accidents involve the company in heavy expense, deprive it of the services of skilled men, and lower the morale of the entire working force. The disability of the workman may leave a dependent family without visible source of income, the workman may in fact, become a burden rather than a support. No operator and no employee can afford to neglect any reasonable means of reducing accidents to a minimum.

ACCIDENT STATISTICS.

Every year the Bureau of Mines issues a publication giving quarry-accident statistics. As the accidents are classified by cause for each type of rock it is important that operators study these figures in order to determine the chief sources of danger, and be guided by this information in seeking to improve safety conditions.

The total number of men employed in the slate industry in 1920 on a 300-day working basis was 3,364. Five men were killed and 364 injured during the year. The number of injured was 108 per 1,000, of 300-day workers, or about one man in each 10 employed. No injury is considered in compiling these figures unless the worker loses one or more days work as a result of the accident. The figures indicate that there is room for great improvement in safety conditions in slate quarries.

The first step in making conditions safer is to study the causes of accidents to determine the most prolific sources. Table 6 gives the classification of accidents in 1920 by cause, and Table 7, gives supplementary information such as number of men employed and days worked.[32]

TABLE 6.—*Fatalities and injuries by causes in slate quarries during the year ended Dec. 31, 1920.*

	In and about quarry.																In outside works.												
	Falls or slides of rock or overburden.	Handling rock at face.	Timber or hand tools.	Explosives.	Haulage.	Falls of persons.	Falling objects (other than 1 and 2).	Flying objects.	Electricity.	Drilling and channeling (by machine or hand).	Machinery.	Nails, splinters, etc.	Boiler and air-tank explosions.	Burns.	Other causes.	Total.	Haulage.	Machinery.	Hand tools.	Nails, splinters, etc.	Electricity.	Falls of persons.	Falling objects (rocks, timbers, etc.).	Flying objects.	Handling rock by hand.	Burns.	Other causes.	Total	Grand total.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		16	17	18	19	20	21	22	23	24	25	26		
Killed	3			1			1									5													5
Injured	33	52	6	3	19	6	15	16		5	17	4			48	224	20	29	11	6	1	4	4	9	40	2	14	140	364

[32] For other tables giving information in greater detail, see Adams, W. W., Quarry accidents in the United States in 1920, Tech. Paper 295, Bureau of Mines, 1922, 68 pp.

TABLE 7.—*Men employed in slate quarries, number killed and injured, and days worked, by States during the year ended Dec. 31, 1920.*

State.	In and about quarry.					In outside works.					Total.						Widows.	Orphans.
	Men employed.	Days of labor performed.	Average days active.	Killed.	Injured.	Men employed.	Days of labor performed.	Average days active.	Killed.	Injured.	Active operators.	Men employed.	Days of labor performed.	Average days active.	Killed.	Injured.		
New York	27	6,445	239	....	....	10	2,600	260	....	....	4	37	9,045	244	....	....	....	....
Pennsylvania	1,646	504,287	306	5	171	579	142,510	246	....	101	41	2,225	646,797	291	5	272	3	9
Vermont	616	177,281	288	....	49	131	39,777	304	....	28	22	747	217,058	291	....	77	....	....
Virginia	187	41,734	223	....	....	....	....	....	....	....	4	187	41,734	223	....	....	....	....
Not segregated [a]	121	35,582	294	....	4	179	59,028	330	....	11	4	300	94,610	315	....	15	....	....
Total 1920	2,597	765,329	295	5	224	899	243,915	271	....	140	75	3,496	1,009,244	289	5	364	3	9
Total 1919	2,316	579,167	250	3	214	1,057	264,404	250	2	63	78	3,373	843,571	250	5	277	4	10

[a] Includes Maine and Maryland. No accidents reported from Maryland.

Accidents within quarries are chiefly due to falls or slides of rock, or overburden, and handling rock at the face. Haulage, falling, and flying objects, and machinery constitute the next most important group. These six causes account for about 70 per cent of the total accidents.

As pointed out in a previous publication [33] of the bureau, preventable accidents in quarries may be grouped into three classes—those due to faulty equipment, to improper methods of operation, or to carelessness. Consideration will, therefore, be given to these three sources of danger as they apply particularly to slate quarries.

DANGERS FROM FAULTY EQUIPMENT.

In most slate regions employees enter and leave the quarries by means of the hoisting equipment used for elevating rock. On this account particularly all hoisting equipment should be kept in the best of repair. The main cables on which the carriage operates should be well secured at the ends. Cables have been noted that were attached to a log or timber buried beneath masses of rock. This may be perfectly safe as long as the log is sound, but in time such a support is weakened by decay. Draw cables should be carefully examined at frequent intervals for broken strands or other signs of weakness. Draw cables are often prematurely weakened by using sheaves that are much too small in proportion to the diameter of the cable. This results in bending the cable at too short an angle, and such repeated bending greatly shortens its life.

Where men enter and leave the quarry on the hoist pan the hooks by means of which the chains are secured to the pan should be provided with automatic locking devices. The walls of some quarries are inclined at steep angles, and as the pan descends vertically it may come in contact with the quarry wall before it reaches the bottom (p. 121). In such quarries locking devices on chain hooks are desirable, for the pan may be held up momentarily by some projection on the wall and thus permit the chain to unhook. Hoist engines should also be kept in the best of repair where the lives of men are dependent on proper operation. This applies to both hoisting machinery and to the brake that governs and controls the rate of descent.

Transportation equipment outside the quarry is commonly a source of danger. At most quarries either waste materials, finished products, or both are conveyed by cable cars on heavy grades. The waste may be hauled up steep inclines to the dumps, and the finished products may be conveyed down heavy grades to the railroad sidings.

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[33] Bowles, Oliver, Safety in stone quarrying, Tech. Paper 111, Bureau of Mines, 1915.

Obviously many dangers are encountered on heavy grades that do not exist in approximately level haulage. All cars, cables, sheaves, and hoist engines should be examined frequently and any weaknesses repaired immediately. A runaway car is a source of extreme danger and no effort should be spared in guarding against loss of car control.

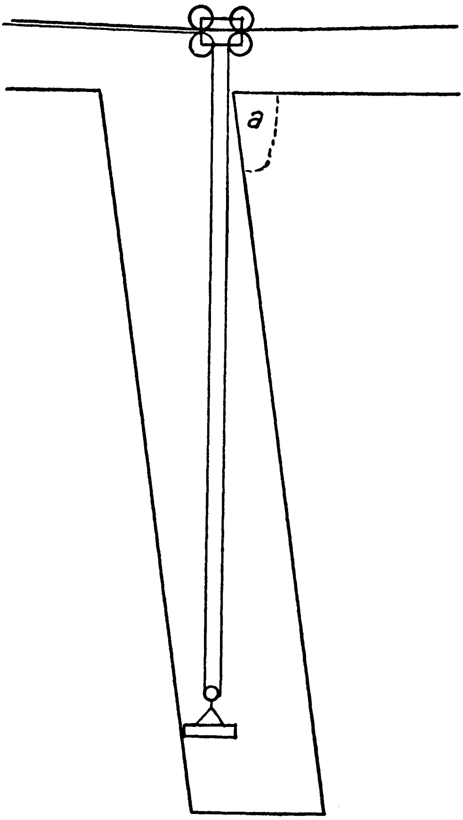

FIGURE 41.—Inclined quarry walls that prevent free descent of hoist pan : *a*, Mass of rock that may be removed to permit free movement of pan.

Splitting shanties and mills are commonly located on broad, flat-topped waste heaps. In order to reach this level workmen are in many places required to ascend precipitous paths over waste blocks and rubbish. Slate blocks have smooth surfaces, and the smaller slabs, such as waste from the trimming sheds, are inclined to slip very readily under the pressure of a footstep. Such steep paths, therefore, constitute a continual source of danger. Some operators have adjusted the waste blocks so as to form a series of steps, and the danger from falls is thereby reduced to a minimum. Making a dangerous pathway safe involves so little time or expense that it is surprising how few have given it any attention.

Paths about a quarry are commonly overgrown with weeds, and holes made by watercourses or by the caving of banks, may be hidden from view and be a danger to pedestrians. All obstructions to a clear view of possible dangers should be removed.

DANGERS FROM IMPROPER METHODS.

Even with perfect quarry equipment many accidents may result from improper use of equipment or improper plan of quarrying or method of rock removal.

Reference was made on page 119 to a condition that exists in at least two quarries observed, where the slope of the wall prevents free descent of the quarry pan from the cableway. Thus, as indicated in Figure 41, when the hoist cable is quite close to one wall of the quarry at the top, the pan may come in contact with the other wall before it reaches the bottom of the pit. Usually a man standing in the pan places his foot against the quarry wall and thus repeatedly pushes the pan out to permit its uninterrupted descent. This is very dangerous, for even a momentary suspension of the pan on a rock projection might permit the chains to unhook and allow the pan to fall. Similarly, as the pan ascends, particularly if heavily loaded, its contact with the wall may occasion unequal strains that may snap a cable or otherwise disarrange the hoisting equipment. Some safer means of hoisting should be devised, particularly where workmen must travel up and down on the pan. The simplest solution evidently would be to remove a mass of rock at the quarry edge as shown at *a* in the figure, thus permitting the cable to move laterally enough to free the pan from the opposite wall.

As indicated by the figures for accidents by causes shown in Table 6, page 117, falls or slides of rock or overburden is one of the most important. Although accidents from this cause may be due in part to carelessness, improper methods of operation account for many of them. The overburden face is commonly so close to the quarry face that slides of soil and bowlders may fall over the edge upon the workmen below. This condition is shown in Plate I, *B*, page 26; the overburden face approaches to the very edge of the quarry excavation. This dangerous condition may be overcome by stripping back the overburden so as to leave a flat surface where falling débris may collect. As shown in Plate IV, page 50, a timber barrier is sometimes employed to prevent slides of overburden.

Rock slides are sometimes caused by the presence of steeply-inclined open joints. If masses of rock above such joints are left without support there is imminent danger of disastrous slides. To permit such masses to remain in a precarious position above workmen is faulty quarry practice, and such masses should be removed before they fall.

Accidents commonly result from falling fragments from the quarry face. Careful cleaning down of walls is a process that no quarryman can afford to neglect. Workmen provided with picks and bars should be suspended from the surface at successive levels. They should carefully examine the face and remove all loose rock. A single cleaning of the walls is not sufficient as frost action and erosion will gradually set other fragments free, and successive cleanings at regular intervals are necessary. Probably the most dangerous period is in the spring after the frost has disappeared from the rock, and consequently this is the best time for cleaning down the walls.

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Accidents at the face may also result from insufficient wall or roof support where undercutting or underground operations are conducted. At one mine near West Pawlet, Vt., the shafts descend at angles of about 70° to the horizontal, and masses of slate nearly as wide as the shafts are left for support between each pair of shafts. This renders the mine safe from caving. Likewise, in running horizontal drifts the ceilings should be kept free of all loose material, and the drifts should be kept narrow so as to prevent roof collapse.

Another source of danger is the overloading of hoisting equipment. The overhead cableways as used at most slate quarries will carry in safety not more than 3 to 5 tons. Rock is a very heavy material, and many quarrymen fail to realize how small a fragment will weigh a ton. An average slate weighs about 165 pounds a cubic foot, or about 12 cubic feet to the short ton. Therefore, a mass of slate 6 feet long, 2 feet wide, and 1 foot thick weighs approximately a ton. By underestimating the weight of a block the hoisting equipment may be overloaded and a serious accident may result.

Danger also occurs in hoisting the smaller fragments of waste. The small pieces of slate, drill cuttings, and all other forms of quarry waste are loaded into pans and hoisted to the surface. The danger of overloading the pans in so far as weight is concerned is small, but the pans may be filled too full. If fragments are insecure they may fall from the pan and injure workers below. The greatest danger is at the moment the pan reaches the carriage and starts its lateral course, for it may swing and tilt in such a manner that any insecure fragments may be displaced and fall.

Blasting is a constant source of danger. Rules for the safe handling of explosives and for proper methods of blasting have been given in detail in previous publications of the bureau[34], copies of which may be obtained on request.

DANGERS FROM CARELESSNESS.

Carelessness is, perhaps, the chief cause of accidents in slate quarries. Responsibility for lack of due care is to be shared both by operators and employees. The operator's duty is to formulate all necessary safety rules and regulations and to insist on obedience to them. Moreover, he should employ superintendents and foremen who are themselves careful, and who require the cultivation of careful habits in the employees. The operator should also bear the responsibility of requiring careful and systematic examination of equipment and machinery, and all conditions about the quarry

[34] Munroe, C. E., and Hall, Clarence, A primer on explosives for metal mines and quarrymen: Bull. 80, Bureau of Mines, 1915, 125 pp.

Bowles, Oliver, Safety in stone quarrying: Tech. Paper 111, Bureau of Mines, 1915, pp. 18–25.

and mill that affect in any way the health or safety of the employees. If the results of such examinations reveal defects or undesirable conditions, steps should be taken immediately to correct them. Equal responsibility rests upon employees. Careless habits may at any time result in fatal or serious accidents not only to the careless employees but also to others associated with them. The advantages of safe equipment and approved methods of operation are largely nullified when workmen are habitually careless.

As indicated by the figures in Table 6, handling rock by hand is the greatest source of danger both within quarries and in outside works. Most of such accidents are due to lack of care. The workmen should be alert to all the dangers of rock slides, falling or flying materials, and to the risks that may be involved in the use of tools, machines, or hoisting equipment.

A special responsibility rests with the signal man and the hoist engineer, especially when workmen are being carried into the pit or out of it. A wrong signal or a mistake in handling the machinery may have most serious results.

Falls of persons result in many injuries. Great care should be exercised in walking over slippery or rough paths or climbing over rocks. If work must be done in exposed places, such as cleaning down quarry walls, the workman should be safely secured by a rope attached to his body.

A practice which is common around slate quarries and one which the bureau has condemned on many occasions is riding on loaded or empty cars either up or down steep inclines. At many quarries a workman rides on a carload of waste rock to the top of the dump heap, unloads the car, and rides back on the empty. Such cars commonly travel at dangerous speed, and risk of derailment, particularly on curves, is great. In the interest of safety, operators are urged to discourage workmen from riding on quarry cars, particularly when the cars are loaded.

SAFETY RULES AND REGULATIONS.

Both employers and employees should devote careful study to accident prevention as applied to mines and quarries. The Bureau of Mines has devoted much attention to such problems, and has published the results of its studies so that they may be available to all. General safety problems in quarrying are contained in a publication entitled Safety in Stone Quarrying, Technical Paper 111. In this paper reference is made to several other publications of the bureau dealing with special phases of the subject in greater detail. Quarrymen are urged to send for these publications, to read them, and to apply the information thus gained in such a practical way that the record of accidents in slate quarries will indicate a marked improvement in conditions.

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The following bibliography includes references which have a direct bearing on the subject matter of the bulletin. The bibliography is thus confined almost exclusively to economic phases of the slate industry. Many brief articles on slate, some without title, that have appeared in the technical press, are not included in this bibliography. Anyone interested in them may consult the files of such periodicals as The Slate Trade Gazette, The Quarry and Surveyors' and Contractors' Journal, Stone, Rock Products, or Cement Mill and Quarry.

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