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SLATE IN THE UNITED STATES

BY

T. NELSON DALE AND OTHERS

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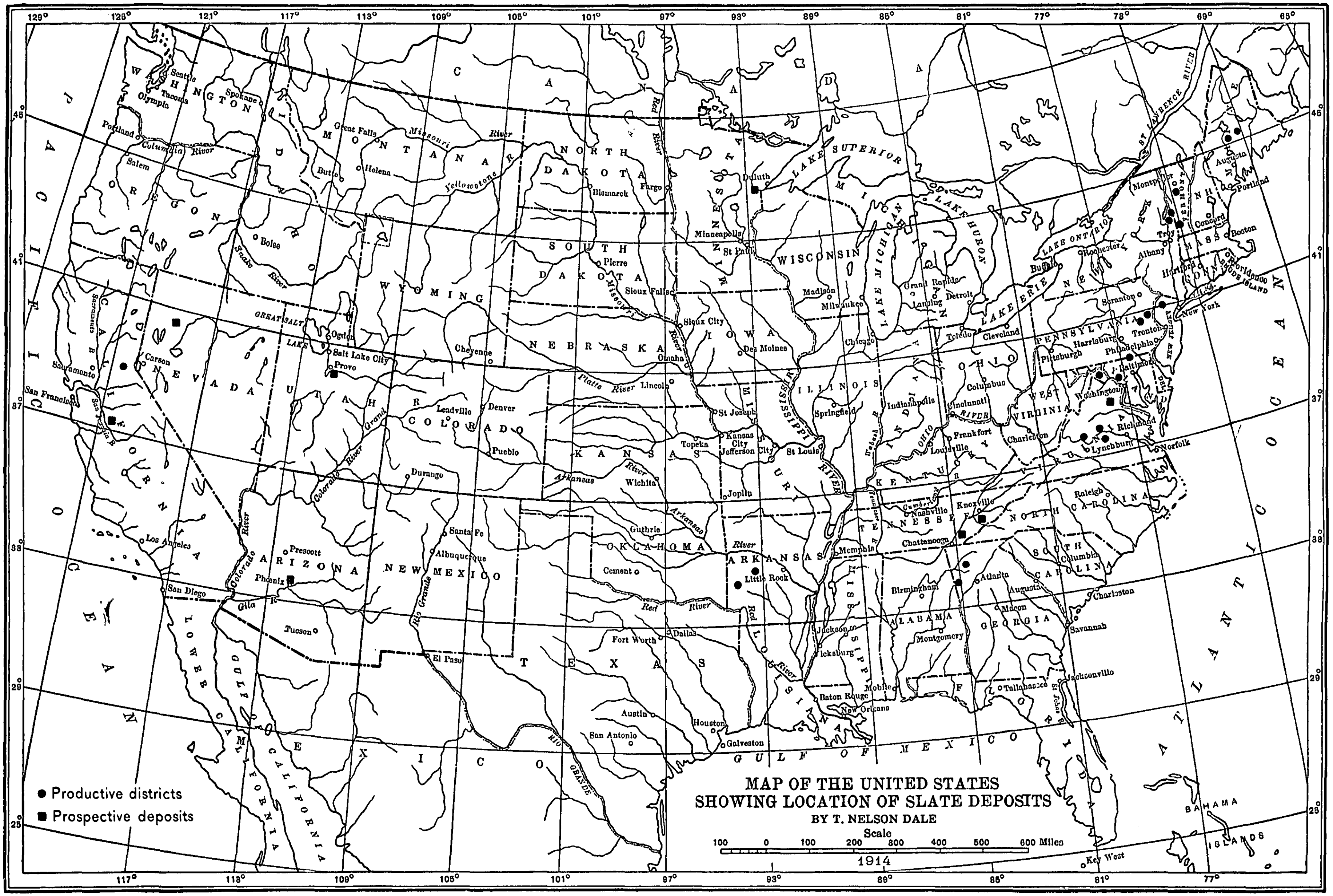
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SLATE IN THE UNITED STATES.

By T. Nelson Dale and others.

INTRODUCTION.

By T. Nelson Dale.

Bulletin 275 of the United States Geological Survey, "Slate deposits and slate industry of the United States," issued in 1906, included, besides the results of the writer's field and microscopic work on the slates of New England, New York, Pennsylvania, Maryland, and Virginia, a series of elaborate analyses of slate and a note by W. F. Hillebrand, the results of E. C. Eckel's visits to the slate districts of California, Utah, and Arkansas, and a series of physical tests of slates made for the Survey by Mansfield Merriman.

Since the publication of that bulletin, the edition of which was exhausted several years ago, slates of more or less economic value have been found in Merced County, Cal., in Colorado, in Bartow County, Ga., in Nevada, in Lancaster and Dauphin counties, Pa., and in Monroe County, Tenn., and all of them have been examined microscopically by the writer. He has also recently visited some of the prospects and quarries in Georgia and Tennessee, and the quarries of Penlan and Esmont, Va., of Sussex County, N. J., and of Aquashicola and Windgap, Pa., and has revisited some of the Maine and Vermont slate districts. Since the publication of Bulletin 275, A. H. Purdue's studies of the slate region of Arkansas have also appeared and two papers by T. L. Watson on the slates of Virginia.

The present bulletin is not only a corrected and revised edition of Bulletin 275, but contains also the results of all these recent discoveries and studies. Its plan is to set forth in Part I, in succinct form, the present state of scientific knowledge as to the origin, structure, texture, and chemical and mineral composition of slate; in Part II to describe in more or less detail the slates and quarries of each district; and in Part III to consider the economic geology of slate, including the scientific prospecting for slate, the methods of testing it, slate machinery, the uses of slate and slate waste, together with a tabular summary of all the slates described.

Geologists will find in Part II geologic notes on many of the slate districts, data as to the weathering of the slates of Pennsylvania, Maryland, and Georgia, and petrographic descriptions of all the slates. Those of Maine, Maryland, New York, Pennsylvania, Vermont, and Virginia are treated most fully. The accounts of the various lenses in slate, given on pages 70, 86, 91, 93, 112, 122, and 157, will probably interest petrographers.

A bibliography of slate, both economic and scientific, and a glossary of geologic and slate-quarry terms are appended.

Mr. C. A. Bonine, now of this Survey, has kindly made contributions from his Lehigh University thesis, "The slate deposits of Northampton County, Pa.," written prior to his connection with this Survey. These include the map (Pl. XV) showing the locations of the slate quarries of that county, and also several paragraphs on its stratigraphy, which are credited to him in their place.

In the geologic mapping of the slate belt of western Vermont and eastern New York the writer was assisted in 1895–96 by Messrs. L. M. Prindle and F. H. Moffit. The quarry sites on the map of Slatington, Pa. (Pl. XVI), were located by Mr. Moffit.

As in Bulletin 275, Miss A. T. Coons contributes a chapter on the statistics of slate production.

The portions of this bulletin not specifically credited to others have been prepared by the writer.

PART I.—ORIGIN, COMPOSITION, TEXTURE, AND STRUCTURE OF SLATE.

DEFINITION AND CLASSIFICATION OF SLATE.

The term *slate*, in ordinary usage, denotes a rock which has more or less perfect cleavage, being thus adapted to various commercial uses, and in which the constituent particles, with very few exceptions, can not be distinguished except in thin section under a microscope. In contradistinction a *schist* is a rock that may be of identical chemical and mineral composition but is either made up of coarser particles or possesses a wavy structure, or else is marked by both of these features. Both slates and schists may have originated in deposits of identical character, but they have undergone different processes.

Slates as above defined vary greatly in color—from black through various shades of gray to greens, reds, and purples of different hues. They vary also in luster—from having none to being almost as bright as mica itself. They vary greatly not only in grade of fissility but in surface texture, as seen by the unaided eye or determined by touch, and still more in microscopic texture, as seen in thin section. They differ also in their mineral and chemical composition and in their physical properties.

On account of their peculiar properties slates are adapted to a great variety of uses—roofing, flooring, electric switchboards, blackboards, hand slates, billiard and laboratory table tops, vats, tubs, mantels, grave linings, wainscoting, hearths, chimney and well caps, memorial tablets, bread boards, refrigerator shelves, etc. This stone has thus become linked with some of the principal necessities of life and death.

The appearance of large masses of fresh slate of good quality in cross fracture is shown in Plates XIII, XIV, and XIX.

Slates divide themselves naturally into (1) those derived from aqueous sediments and (2) those of igneous origin. The latter, however, are very exceptional. For commercial purposes the basis of classification of the aqueous sedimentary slates must be, first, textural, for the cost of their production and the degree of their strength depend primarily upon their texture; second, it must be mineralogic, for their durability depends upon their content of certain mineral constituents.

Slates in which the particles have been merely compressed by weight or pressure and cemented by carbonates of lime and magnesia, by kaolin, or by different combinations of iron, and whose fissility, strength, and elasticity are therefore low, must be distinguished from those in which, under metamorphic processes, the kaolin and feldspar have passed into mica, forming a more or less dense and regular crystalline fabric of overlapping scales and fibers inclosing any remaining sedimentary particles. Such slates necessarily possess a high grade of fissility and considerable strength and elasticity. The first group includes clay slates; the second mica slates or phyllite slates. Those in which the micaceous matrix is but partly formed and which represent a transition from clay slate to mica slate are more conveniently put into the clay slate group. Thus the dark-purple ("red") roofing slate of Penrhyn, in Wales, is a clay slate, and so also is the black slate of Martinsburg, W. Va.; but the French Ardennes slate, the Welsh Festiniog, and the Peach Bottom slate of Pennsylvania and Maryland are all mica slate.

But mica slate includes slates of very different composition and structure, and therefore of very different properties and value. The first distinction to be made is based upon the amount of ferrous carbonate—whether or not it is sufficient to produce discoloration on continued exposure to the weather—for this is an important factor in the value of slates used for roofing. This distinction gives a group of fading and one of unfading slates, each of which can be further subdivided as to color. But each of the color groups of fading and unfading mica slate embraces slates having a wide range of texture. Some, like the Arkansas black and light-greenish slates, have a matrix of extremely fine sericite fibers; while the black slates of Arvonia, Va., and the Peach Bottom slate have a texture approaching that of a schist. In some slates the sericite fibers are remarkably even and parallel; in others they make up minute elongated lenses, so that the slate in cross section is seen to consist of tiers of lenses. Such differences in texture can not but result in differences in physical properties. The grades of texture are sufficiently designated by the words very fine, fine, medium, and coarse. There are also distinctions in the grade of fissility which do not always correspond to the grade of texture. These are conveniently numbered from 1 to 4, beginning with those of the best fissility. Finally there are differences in luster and amount of magnetite—differences which are purely specific. The general distinctions are formulated in the following table:

Classification of slate.

I. Aqueous sedimentary:
  - A. Clay slates: Matrix without any or with but very faint aggregate polarization.
  - B. Mica slates: Matrix with marked aggregate polarization.
    1. Fading: With sufficient $FeCO_3$ to discolor considerably on prolonged exposure.
       - (*a*) Carbonaceous or graphitic.
       - (*b*) Chloritic (greenish).
       - (*c*) Hematitic and chloritic (purplish).

I. Aqueous sedimentary—Continued.
  B. Mica slates: Matrix with marked aggregate polarization—Continued.
    2. Unfading: Without sufficient $FeCO_3$ to produce any but very slight discoloration on prolonged exposure.
      (*a*) Graphitic.
      (*b*) Hematitic (reddish).
      (*c*) Chloritic (greenish).
      (*d*) Hematitic and chloritic (purplish).
      (*e*) Hematitic, specular, and graphitic (bluish blackish).

II. Igneous.
  A. Ash slates.
  B. Dike slates.

The scientific basis for these subdivisions will be seen by consulting the table facing page 188 and the microscopic and chemical analyses of the slates there named. The application of this scheme to 20 kinds of American slates will be found on page 189.

ORIGIN OF SLATE.

With the exception of the rare slates of igneous origin, referred to in the previous section, slates originate in marine deposits of clay and sand. The common occurrence of angular grains of feldspar and of quartz in slate implies the nearness of shores or land masses of granitic rocks to such deposits. The alternation of beds of slate with beds of quartzite or grit ("ribbons," "hards," altered sandstone) corresponds to the alternation of extremely fine clayey sediments, derived from the waste of such granitic land masses with sandy sediments consisting of coarser material from the same source. The repeated alternation of such fine and coarse sediments is attributed to the alternation of calm water, favorable to the deposition of fine material, with strong currents that brought coarse sediments more rapidly from the shore. These materials consisted largely of quartz, feldspar, and mica but included also zircon and other silicates, various compounds of iron, lime, and magnesia, and kaolin arising from the decomposition of the feldspar. In such a slate region as that of western Vermont and eastern New York, where the slate is interbedded with fossiliferous limestone, it is evident that periods of such changing conditions in the water also alternated with periods when marine life abounded and the sediments were entirely calcareous. Black slates owe their blackness to carbonaceous matter, probably derived from the decomposition of marine organisms on the sea floor. Red slates owe their color to the access of ferruginous matter from the land, and purplish slates to an admixture of such matter and a green magnesian mineral (chlorite) of secondary origin. In both the reddish and the purplish slates the iron is supposed to have been originally precipitated in the form of the rust-colored limonite ($2Fe_2O_3.3H_2O$) from iron-bearing solutions and to have been afterward altered by loss of water (H_2O) to the reddish hematite (Fe_2O_3).[1]

An accumulation of several hundred feet of such clayey and sandy sediments when buried under several thousand feet more of other sediments of like origin on a gradually subsiding sea bottom must have been subjected to sufficient vertical pressure, in connection with a small amount of moisture, to be cemented together and hardened—the clay into shale and the sand into sandstone. During this process the particles in these sediments retained the general horizontal and parallel arrangement which they had received from their distribution by sea water but became firmly compacted and thus acquired a bedding foliation.

The next stage in the formation of slate is attributed ultimately to the radiation of heat from the earth's interior into space, resulting in a contraction of the interior and consequently in a corrugation of the outer portion. This corrugation, for reasons not yet perfectly evident, took place, so far as observation extends, chiefly within certain belts in which the mountain systems were formed from the lateral compression of a great mass of parallel strata. The first effect of this compression was to bend at least the lower portion of the strata into wavelike folds, and thus to shorten its horizontal area in one direction and increase its vertical thickness. The character of this folding is well shown in the slate regions of Pennsylvania and western Vermont. (See Pls. III; XIII; XIV; XVII; XVIII; XIX, *A;* XXII; XXV.) But another effect of this compression was to metamorphose the shale into slate. This metamorphism probably did not take place until the folding was well initiated. The transformation included two processes, and it is uncertain which preceded. Each individual sedimentary particle was rotated from its original horizontal position in the bedding foliation into one forming a considerable angle to the direction of pressure. There was also, under the combined presence of moisture and the effect of pressure and heat, both the heat which must have been generated by the pressure and that which pervaded the strata at the depth at which they were buried, such a chemical recombination of the silica, alumina, potash, iron, and water of the feldspar, kaolin, and iron of the shale as to generate new potash mica in amount sufficient to constitute, in the mica slates, over 33 per cent of the resulting slate. This muscovite was formed in scales of infinitesimal thinness and other dimensions and generally of longish, tapering, or ribbonlike outline. Most of these scales arranged themselves with their flat sides parallel to or overlapping one another but facing the direction from which the pressure came and also with an angle

[1] See on these changes Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, pp. 225, 232, 1904.

of inclination governed by that pressure. A small but variable proportion, however, of these scales took such a position that their flat sides became parallel to the direction of the pressure. As mica crystallizes in columnar crystals, and as the plates or scales due to its molecular structure are transverse to the crystal column, and as a slab of slate consists largely of parallel scales of mica it may be said to correspond when held horizontally to such a crystal held vertically. When a mica slate is cut in thin section across the cleavage its optical behavior under polarized light is like that of a mica crystal cut across its crystal cleavage. Yet as not only a considerable number of the mica scales in slate lie across the cleavage, but as some scales of chlorite and crystals of other minerals do also, the texture of a mica slate combines some of the features of a crystal with some of those of a tissue. Extremely thin sections of slate transverse to the cleavage may show this interlacing of the two sets of scales on their attenuated edges. It is to this microscopic texture that the slate largely owes its peculiar properties.

This crystalline fabric may inclose in its meshes any sedimentary particles of quartz, zircon, feldspar, kaolin, or other minerals which were not or could not be made over into mica or secondary quartz but whose alignment became more or less parallel to that of the major part of the new mica. During this metamorphism other chemical combinations were formed by the constituents of the shale, which crystallized in isolated scales or crystals of chlorite, biotite (magnesia mica), various carbonates, pyrite, magnetite, graphite, tourmaline, andalusite, etc. These arranged themselves variously—some in the cleavage direction, some in the grain direction. Lenses consisting of some one mineral surrounded by one or two others were also formed and concentrically or radiately arranged. The limonite became hematite. During these changes in the fine sediments the intercalated beds of sandstone passed into quartzite and metamorphic grit by the formation of siliceous and micaceous cement between their particles.

The essential part of the process of the transformation of a granitic rock into clay and of that into mica may be made generally intelligible by recalling two well-known experiments of Daubrée, the French geologist. In the first, angular fragments of granite and quartz were rapidly rotated in a horizontal iron cylinder filled with water and moving on an axis. The trituration resulted in producing a very fine clay. The second experiment consisted in inclosing clay and water in a closed wrought-iron tube, which was then placed in a gas furnace and exposed for several weeks to a very high temperature. The result was the production of scales of mica. In the first experiment the factors of stream and wave erosion were duplicated, and in the second the elements of moisture, pressure, and heat involved in the crystallization of new minerals from clay were reproduced.

Two other experiments illustrating the arrangement of the mica thus formed, as well as the sedimentary mica and other minerals, may well be cited here. The familiar one of Tyndall consisted in subjecting wax to pressure between glass plates and, after cooling it in ice and salt, breaking it edgewise with a hammer. The fractures showed that it had acquired slaty cleavage. The other experiment was made by Jannetaz and consisted in subjecting a mass of clay in a wrought-iron box, open at one side, to hydraulic pressure, which resulted in the formation not only of slaty cleavage but also of the grain texture.

The general microscopic texture of slate is such as to warrant the assumption that the compression which produced it operated not only with great uniformity but also very gradually.

The microscopic features of slate are more fully considered in the following section on the petrographic characters of slate. The above notes will suffice, however, to convey, with as few technical terms as possible, a general idea of the principal steps in the formation of a mica slate of aqueous sedimentary origin. The history of clay slate is similar, but the metamorphism to which it has been subjected has been insufficient to produce the micaceous texture.

After the slate was formed the mass was subjected to various stresses (tensions, shears, contractions), which resulted in several systems of joints, in faults, slip cleavage ("false cleavage"), shear zones ("hogbacks"), and irregular openings in which veins of quartz and calcite were formed by infiltration. Some masses were also traversed by fissures penetrating to the molten zone and thus permitting the exudation of lava-like material which formed dikes.

The folds into which the slate beds were bent are rarely complete, for the reason that their upper portions have generally been removed through various erosive processes—the decomposition due to atmospheric agencies, the action of streams, and, in places, the erosion of the continental glacier. Plates III, XIII, XIV, XVII, XVIII, and XXV all illustrate this feature. In the Appalachian region generally the thickness of this eroded material was very considerable.

From the foregoing statements it may be seen that a piece of slate is in itself a record of a long series of complex geographic, geologic, chemical, mineralogic, and physical processes of great scientific interest.

MINERALS OF SLATE AND THEIR ARRANGEMENT.

HISTORY OF RESEARCH.

However uncertain the structural, textural, mineral, and chemical features of roofing slates may once have seemed, these are all now well understood. Sedgwick, Sorby, Phillips, Tyndall, Daubrée, Gosselet, Jannetaz, and Becker have studied the structure of slates in the field or the laboratory or in both, and Sorby, Zirkel, Renard, and others have investigated their mineral composition. Summaries on the cleavage of slate were published by Loretz in 1880 and Harker in 1886, and on its petrography by Kalkowsky in 1886, Zirkel in 1894, and Rosenbusch in 1898. Chemical analyses are given in Roth's "Chemical geology" (1890), and in Zirkel's "Petrography" (1894). Hillebrand, Reade, and Holland made a number of complete analyses between 1899 and 1901. Van Hise, in his "Treatise on metamorphism"[1] (1904), discusses the theory of metamorphism in schists and slates, and Leith, in his paper on rock cleavage[2] (1905), treats of the theory of bedding and cleavage, basing his conclusions more largely on the microscopic study of schists than of roofing slates. The bibliography on pages 205–210 shows how much has been written on the different aspects of the subject. It is not proposed to give here a summary of all this literature, but an attempt will be made to set forth, in a series of statements, quotations, and questions, the state of scientific opinion on the more important and interesting features of slate.

Slaty cleavage may be defined simply as a rearrangement of the particles of a deposit by lateral pressure, together with the arrangement of any new crystalline particles formed during and in consequence of that pressure. This arrangement of old and new particles is related to the directions of pressure and resistance. The older authorities on slaty cleavage usually define the direction of pressure as being at 90° to the cleavage. This definition of the direction has, however, been under discussion in recent years. The latest phase of opinion appears in the writings of Van Hise, Becker, and Leith. Van Hise[1] expresses his views in these words:

> During the process of recrystallization at any given moment there is maximum shortening in the direction of greatest stress, maximum elongation in the direction of least stress, and shortening or elongation in the direction of mean stress. Consequently the shape of the modified particle may be that which would be produced if a plastic grain were rolled out, the sides being confined in one direction, but with liberty to elongate in another direction in the same plane; or it may be that which would be produced if a roundish cake of dough were flattened between two boards, and consequently elongated in all directions at right angles to the direction of greatest pressure. * * * The particles are arranged with their greater, mean, and minor diameters, corresponding to least, mean, and greatest pressures. In proportion as the movement involves shearing motion or scission the mineral particles are rotated from a position in which the direction of greatest elongation is at right angles to the direction of greatest pressure, although at any given time the mineral particles tend to develop with their longer axes at right angles to the maximum pressure.

Becker's experimental studies were directed to determining the mathematical character of the deformation undergone by a plastic but crystalline mass under pressure. For this purpose he pierced a

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[1] U. S. Geol. Survey Mon. 47, pp. 752, 753, 1904. [2] U. S. Geol. Survey Bull. 239, 1905.

block of ceresin with needle holes at regular intervals in both a vertical and a horizontal direction, drawing a thread smeared with coloring matter after the needle, and subjected the block to powerful vertical pressure. The curves then assumed by the colored lines enabled him to determine the position of the axes of the strain ellipsoid with relation to the direction of pressure. The result of this and of other experiments described in the same paper is that—

cleavage does not coincide even approximately with the direction of the major axes of the strain ellipsoid. Neither does the cleavage correspond to the position of the major axes of the strain ellipsoids at any previous stage of the strain.[1]

In other words, slaty cleavage is not perpendicular to the smallest axis of the strain ellipsoid but makes with "that axis an acute angle equal or greater than 45° and increasing as the strain grows greater." Both the experiments and the reasoning seem simple and clear.

Leith, following Van Hise, states that—

Cleavage is always tending to develop normal to the greatest principal stress, but its final position may or may not be inclined to the greater stress, depending upon the nature of the strain.[2]

This question of the relation of the dip of slaty cleavage to the direction of pressure is not purely speculative but bears directly upon problems in field geology. Thus where cleavage is nearly horizontal it is probable that a secondary crustal movement must have diminished the original inclination of the cleavage and consequently the whole attitude of the folds. Were the limiting angle at which slaty cleavage forms established, then, in the case stated, a maximum figure for the angular displacement of the cleavage could be obtained.

There is some vagueness in scientific literature, as well as in popular conception, as to what constitutes a slate. Sorby drew this distinction:

When a section [of a fine-grained slate] cut at right angles to the cleavage is rotated in polarized light it becomes, over nearly the whole surface, very bright, and much darker at different azimuths, like a doubly refracting crystal, whereas there is little or no such change in the case of true clay slates of the normal granular type containing much kaolin and very little mica.[3]

Micaceous luster is not a satisfactory criterion, for some slates, like those from Monson, in Maine, are almost lusterless and yet possess a brilliant aggregate polarization and are very sonorous. They are mica slates (phyllite slates), as are the slates at Brownville, in the same State, which have a micaceous luster.

An interesting transition from a shale to a mica slate, described on page 104, occurs at Lehigh Gap, Pa. The new muscovite (sericite)

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[1] Experiments on schistosity and slaty cleavage: U. S. Geol. Survey Bull. 241, p. 21, 1904.

[2] Rock cleavage: U. S. Geol Survey Bull. 239, p. 138, 1905.

[3] Sorby, H. C., On the structure and origin of noncalcareous stratified rocks: Geol. Soc. London Quart. Jour., vol. 36, p. 76, 1880.

has begun to form across the bedding of the shale without as yet any change of orientation in the clastic particles. In a specimen of shale from Rensselaer County, N. Y.,[1] the incipient alignment of clastic muscovite across the bedding is well shown in thin section, and slip cleavage seems about to be set up. Some specimens of clay slate from Martinsburg, W. Va., possess fissility without any matrix of muscovite whatever, but others show the beginning of slaty cleavage by a faint aggregate polarization. These cases suffice to show that all transitions from a shale to a clay slate and to a mica slate occur.

While it is supposed that mica slate is the product of a less intense metamorphism than schist[2]—and it is also assumed that the process by which slaty cleavage was produced was marked by great uniformity and also took place slowly—there are as yet neither observations nor experiments for a perfectly satisfactory reply to the following questions: Why should one part of a sedimentary formation have been altered into roofing slate and an adjacent part of the same into schist? Would continued metamorphism transform a roofing slate into a schist? Was schist of sedimentary origin at one stage roofing slate? Why should metamorphism begin in some shales by the formation of slip cleavage leading to schist and in others by slaty cleavage?

As to the mineral constituents of slate, Sorby gives the average size of the scales of sericite[3] in the best Welsh slates as one two-thousandth of an inch in breadth by one six-thousandth in thickness.[4] Scattered about among the meshes of the muscovite are minerals which extinguish irregularly. Chief among these is quartz, mostly in clastic grains, sometimes formed in place or in lenses of chalcedony. This secondary quartz may attach itself to the quartz fragments or to the various other minerals to be named. Next in importance is a chloritic mineral, dichroic (light yellow, dark green), polarizing from a Prussian or plum blue to a violet or olive when the section is transverse to the scale, but remaining dark between crossed nichols during a complete revolution when the section is parallel to it. These scales are usually intergrown with lamellæ of muscovite or in places of biotite. Some lie transverse to the cleavage and parallel to the grain, and others lie parallel to the cleavage.[5] Chlorite and quartz may make up minute lenses with their long

[1] See U. S. Geol. Survey Bull. 242, Pl. II, *B*, 1904.

[2] Van Hise, op. cit., p. 894: "When the depth is not great and the mass-mechanical action is not very severe, slates are likely to form. When the depth is greater and the mass-mechanical action is severe, schists or gneisses are likely to develop."

[3] See Laspeyres, H., Sericit: Zeitschr. Kryst. Min., vol. 4, p. 224, 1880.

[4] Sorby, H. C., op. cit.

[5] See Renard, A. F., Recherches sur la composition et la structure des phyllades ardennais: Mus. roy. hist. nat. Belgique Bull., vol. 3, p. 235, Pl. XII, 1882; Zirkel, F., Lehrbuch der Petrographie, p. 298, 1894; and Rose, G., Über die regelmässige Verwachsung der verschiedenen Glimmerarten mit einander sowie mit Pennin und Eisenglanz: K. Akad. Berlin Monatsber., 1869.

axes parallel to the cleavage, or chlorite surrounded by sericite makes lenses with their long axes in the grain direction. Some of these scales of chlorite contain needle-like crystals, probably rutile, crossing one another at angles of 60° and 120°. (See p. 102.) This chloritic mineral is regarded as of secondary origin. Rutile needles are generally but not invariably present, and in great abundance.[1] This mineral occurs also in irregular masses 0.05 millimeter or less in diameter, consisting of a network of prisms forming angles of 60° and 120° (sagenite twins), as at Peters Creek, Lancaster County, Pa., at Bremo, Va., and in Humboldt County, Nev. (See p. 155.) Hematite occurs in very minute scales and dots and very plentifully in the reddish and purplish slates. At Esmont, Va., the hematite is specular, giving an almost metallic luster to the slate when wet.[2]

Slate may contain also cubes, lenses, or spherules of pyrite. The spherules abound in black slates. The slate of Northfield, Vt., contains lenses of magnetic iron pyrites (Fe_7S_8). Carbonaceous matter and graphite abound in the black and dark-gray slates. Clastic grains of feldspar and of zircon are characteristic. Hemimorphic prisms of tourmaline are not unusual.

Calcite and other carbonates, particularly one of lime, iron, and magnesia, are likely to be evenly disseminated in rhombs and plates. Rarely calcite fossils appear, as at Arvonia, Va. Rhodochrosite ($MnCO_3$) probably also occurs. (See p. 91.) The following have also been identified: Ottrelite, staurolite, garnet, andalusite, sphene, anatase, biotite, hornblende, epidote, apatite, gypsum, magnetite, limonite, pyrophyllite, and talc.

Many slates are speckled with minute protuberances which under the microscope resolve themselves into the lenses just referred to—so-called "eyes" or "knots." Instead of consisting of chlorite and quartz, or of these and carbonate, they may consist of an octahedron of magnetite partly surrounded by quartz and that entirely by chlorite.[3] This quartz is then regarded as a later infiltration into a cavity formed between the magnetite and the chlorite by pressure. Others consist of chlorite surrounded by calcite and that by quartz.[4]

1 On these see Zirkel, F., Ueber die mikroskopische Zusammensetzung von Thonschiefern und Dachschiefern: Poggendorff's Annalen, vol. 144, p. 319, 1891; Van Werveke, Neues Jahrb., 1881, vol. 1, p. 178; Sauer, A., idem, pp. 227-238; Cathrein, A., Ueber das Vorkommen mikroskopischer Zirkone und Titan-Mineralien in den Gesteinen, Würzburg, 1884; Kalkowsky, E., Elemente der Lithologie, p. 257, 1886, Sorby (op. cit., p. 68) gives the diameter of the slate needles as less than $\frac{1}{10000}$ inch.

2 Renard gives the size of the granules of Fe_2O_3 as 0.020-0.005 millimeter (op. cit., vol. 3, p. 234). See also his Pl. XII, fig. 2, of purple and green slate, in same volume. J. Gosselet (Études sur l'origine de l'ottrelite: Soc. géol. du Nord Ann., vol. 15, pp. 188-189, Lillie, 1888) describes hematite as occurring in three forms in the reddish slates: (1) In irregular grains 0.01 to 0.02 millimeter or less; (2) in scales with a bluish steel-like luster under a mixture of reflected and transmitted light; (3) in minute granules which are always red—brick-red under reflected light.

3 See Geinitz, E., Der Phyllit von Rimogne in der Ardennen: Min. pet. Mitt., new ser., vol. 3, also Renard, A. F., op. cit., vol. 2, pp. 133 et seq. and Pl. VI, 1883.

4 Renard, A. F., op. cit., p. 248.

The slates of Esmont, Va., have lenses of carbonate, chlorite, quartz, and muscovite radially arranged along the cleavage foliation.

Others have a central crystal of pyrite instead of magnetite,[1] or the pyrite may have been changed to limonite.[2] Still others consist of chalcedony surrounded by chlorite scales,[3] or of quartz surrounded by radial plates of muscovite,[4] or of biotite surrounded by quartz. (See p. 80.) These lenses may, as in the Peach Bottom slate (p. 111), be so minute as not to result in any visible speckling of the surface, and they may consist of crystals of andalusite surrounded by chlorite, quartz, or muscovite, the orientation of the lens being different from that of the crystal. These crystals of andalusite may have quartz on one side and muscovite on the other.

Finally, the discoloration once attributed by Bischof to the hydration and oxidation of a ferrous oxide has been shown to be due, in some slates at least, to the alteration of a ferrous carbonate to limonite, and it is thought to be probably due to this in most slates. (See pp. 55, 140.)

The presence of kaolin is, of course, to be assumed in all clay slates and also in all mica slates in which the micasization of the matrix is incomplete. Its presence in minute quantities in those mica slates which have little or no luster, like the slates of Monson, Maine, and probably the slates of Lehigh and Northampton, Pa., may be suspected but not demonstrated.

Leaving out the rarer and less significant constituents and basing his estimates on the chemical and microscopic analyses of the principal varieties of slate from the French Ardennes, Renard computes the mineral percentages as follows:

Percentages of minerals in slates of Ardennes, France.

Mineral.	Purple.	Green.	Bluish black.	Grayish green.
Muscovite (sericite)	40.69	39.54	37.75	37.97
Chlorite	7.75	5.81	12.55	17.99
Quartz	40.41	45.78	40.58	30.97
Hematite	6.23	2.90	4.81	....
Rutile	1.55	1.04	....	1.44
Limonite	....	....	....	3.09

In round numbers this amounts to—

Muscovite	38–40
Chlorite	6–18
Quartz	31–45
Hematite	3– 6
Rutile	1– 1½

[1] See Harker, Alfred, on "eyes" of pyrite and other minerals in slate: Geol. Mag., dec. 3, vol. 6, No. 103, p. 396, London, Sept., 1889.

[2] Loretz, H., Ueber Transversalschieferung, etc., pp. 283–289, 1882. (For full titles of papers and works cited see Bibliography, pp. 205–210.)

[3] Mallard, E., Sur l'examen microscopique de quelques schistes ardoisiers: Soc. min. France Bull., vol. 3, No. 4, p. 101, 1880.

[4] Zirkel, F., Lehrbuch der Petrographie, Thonschiefer, p. 744, 1894.

Renard [1] calls attention to the fact that the green slates of Fumay, in the Ardennes, contain 4 per cent more SiO_2 than the purple ones and about $3\frac{1}{2}$ per cent less Fe_2O_3.

Rosenbusch,[2] in comparing 18 analyses of clay slates from different parts of Europe, calls attention to the strikingly characteristic preponderance of the MgO as compared with the CaO, along with a uniformly high percentage of iron oxides and of Al_2O_3, and also to the like preponderance of the K_2O over the Na_2O, which he explains thus:

> Clays and clay slates constitute the finest mechanical detritus from quartz-feldspar rocks; whatever silicates of lime they contain was removed as a soluble bicarbonate and for this reason very little lime-soda feldspar can occur in such a detritus.

While there has been substantial agreement as to the general microscopic and chemical character of roofing slates, there have been questions as to the origin of some of their constituents. Is the muscovite (sericite) which makes up from a third to a half of the mica slates the product of the metamorphism of argillaceous material, or are these shredlike scales the result of the disintegration of some micaceous rock, the effect of pressure having been simply to bring the shreds into parallelism and to mat them together? A shale under the microscope shows a considerable amount of apparently clastic muscovite in scales of various sizes with more or less arrangement in the direction of the bedding. Sorby regarded the micaceous mineral of slates as formed in place by an alteration of partly decomposed feldspar, yet he admitted that the structure was just such as would result from the deposition of material sorted by gentle currents and subsequently compressed. The chlorite he considered as undoubtedly secondary.[3]

Rosenbusch wrote:

> Of course the material of clay slates was mechanically brought together, but the mineral constituent of that part which is mainly micaceous and without feldspar was certainly the result of metamorphic processes which were intimately connected with dynamic geologic processes.[4]

Hutchins expressed his conclusions thus:

> This fine mixture of biotite, muscovite, kaolin, the minutest waste of feldspar, and in less degree of quartz, and probably other substances, under the joint action of pressure, warmth, and mineral solutions, gives rise to various decompositions and recombinations which result, among other things, in the formation of new mica, with the separation of titanic acid in the form of rutile. Into these reactions, whatever may be their exact course, even the muscovite in very fine state of division appears to enter; and there is good reason to conclude that in fine-grained sediments of suitable composition, exposed long enough to the necessary conditions as to pressure, tempera-

[1] Op. cit., vol. 2, p. 147, 1883.

[2] Elemente der Gesteinslehre, p. 424.

[3] Sorby, H. C., On the structure and origin of noncalcareous stratified rocks: Geol. Soc. London Quart. Jour., vol. 36, pp. 67–77, 1880.

[4] Neues Jahrb., 1881, vol. 1, p. 399.

ture, and percolation of solutions, an almost complete regeneration of the "paste" to mica can and does take place, and that this regenerated material, under intenser dynamometamorphic action, is converted into some of the forms of micaceous slates known to us. The mica so formed is probably what in its more advanced stages of development is often known as sericite.[1]

As slates are evidently derived from the waste of granitic rocks, this material must have contained clastic mica, as do the shales, and wherever the feldspar of the granite or gneiss had previously been sericitized such sericite must have found its way into the sediments and into the slate without very great loss by decomposition. As a matter of observation, fine-grained mica slates do contain scattered scales of muscovite apart from the matrix, which may be of clastic origin, but the micaceous matrix of mica slate is regarded as mainly of metamorphic origin.

A question has also been raised as to the origin of the rutile needles. Roth[2] is decidedly of the opinion that they belong to the original sediment. Thürach,[3] Pfaff,[4] and Credner[5] find an abundance of them in clay. Rosenbusch[6] states that while zircon and apatite bear traces of their clastic origin, such traces are entirely absent in both the rutile and the tourmaline. It will be noticed in looking over the 62 microscopic analyses of roofing slates made for this volume by the writer that the abundance of these needles varies greatly. In some very crystalline slates (Peach Bottom slate of Pennsylvania and the slates of Penlan, Va., and of Maine) they are hard to find, and in some less crystalline slates (those of Arkansas and Vermont) they are very abundant.

The sizes of the mineral particles and the numerical abundance of some of them, as determined during the microscopic study of all the roofing slates described in this bulletin, are here summarized. The dimensions are given in millimeters.

Quartz, grains—0.013 to 0.1 by 0.004 to 0.03 (exceptionally 0.347 long).

Feldspar (plagioclase), grains—up to 0.047 by 0.052.

Muscovite (sericite) of matrix—thickness down to 0.00017, length from 0.006 to 0.06 and over.

Biotite, scales—up to 0.085 by 0.047 (exceptionally 0.2 by 0.09) and numbering up to 63 per square millimeter.[7]

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[1] Hutchins, W. M., Clays, shales, and slates: Geol. Mag., vol. 7, p. 317, 1896.

[2] "Doubtless some of the constituents are of secondary origin (as quartz, pyrite and the products of its oxidation, calcite, hematite, and limonite, gypsum), but the evidence of the secondary origin of the rutile needles does not seem to me convincing. Unstratified sands also contain a series of minerals."—Allgem. chem. Geologie, vol. 2, p. 586, 1887.

[3] Thürach, H., Ueber das Vorkommen mikroskopischer Zirkone und Titan Mineralien in den Gesteinen: Phys.-math. Gesellsch. Wurzburg Verh., N. F., vol. 18, No. 10, 1884.

[4] Pfaff, E., Petrographische Untersuchungen über die eocenen Thonschiefer der Glarner Alpen: K. k. Akad. Wiss. Munich Math.-phys. Classe Sitzungsber., vol. 10, p. 479, 1880.

[5] Credner, G. R., Die Krystallinischen Gemengtheile gewisser Schieferthone und Thone: Zeitschr. ges. Naturwiss., Halle, 1874.

[6] Elemente der Gesteinslehre, p. 424, 1910.

[7] The square millimeter given comprises only the thickness of the thin section.

Chlorite, scales—0.047 to 0.17 by 0.006 to 0.1 (exceptionally 0.38 by 0.25) and numbering up to 380 per square millimeter.

Carbonate, rhombs—0.002 to 0.065.

Rutile "needles"—0.0017 to 0.095 by 0.0006 to 0.006 and averaging in certain Vermont slates about 65,000 per square millimeter, or about 40,000,000 per square inch. In a slate from Lancaster County, Pa., groups of intergrown rutile crystals measure up to 0.04 in diameter and average about 15 per square millimeter.

Pyrite, lenses and distorted cubes—0.002 to 0.094 by 0.47 (rarely 0.6 by 0.1) and numbering up to 1,160 per square millimeter.

Pyrite, spherules—0.0017 to 0.027 and numbering up to 18,000 per square millimeter.

Magnetite, distorted octahedra—0.009 to 0.14 by 0.02 (rarely 0.17 by 0.04) and numbering up to 49 per square millimeter.

Hermatite, dots—0.0004 to 0.01.

Tourmaline, prisms—0.005 to 0.076 by 0.001 to 0.009.

Andalusite, prisms—0.008 by 0.001 to 0.11 by 0.03 (exceptionally 0.2 by 0.02) and numbering up to 310 per square millimeter.

Lenses of chalcedonic quartz and rhodochrosite: 0.32 by 0.15 (exceptionally 1 millimeter long).

Lenses of biotite and quartz—up to 0.565 by 0.14 (rarely 1 by 0.075).

Lenses of pyrite and quartz—up to 0.75 by 0.12.

Lenses of carbonate, chlorite, quartz, and muscovite measure from 0.2 to 2 in length and up to 0.7 in width and number up to 4 per square millimeter.

Lenses of chlorite or quartz or muscovite or combinations of them, containing each an andalusite prism and measuring 0.04 to 0.25 by 0.04 to 0.1.

As the mineral constituents of aqueous sedimentary slates were either (1) derived from older rocks and deposited either as mechanical sediments or chemical precipitates, or (2) formed during metamorphism, or (3) derived from marine organisms, they are to be classified as follows:

Classification of mineral constituents of slates.

Clastic.	Clastic or authigenous.	Authigenous.	Organic.
Quartz grains. Feldspar grains. Zircon grains. Muscovite scales. Kaolin. Apatite. Magnetite? Carbonates, granular.	Rutile needles. Tourmaline.	Quartz, chalcedonic. Quartz, vein. Muscovite (sericite). Biotite. Chlorite, interleaved with muscovite or biotite. Pyrite, pyrrhotite. Magnetite. Hematite. Carbonates of lime, iron, magnesia. Carbonate of manganese. Andalusite. Barite. Gypsum. Talc.	Carbonaceous matter. Graphite. Calcite (fossils).

Of course these secondary or authigenous minerals were merely new combinations, sometimes in crystalline form of clastic minerals. Thus the hematite originated in sedimentary limonite. The andalusite ($Al_2O_3.SiO_2$) probably originated in kaolin.

The principal elements in roofing slates, as determined by the chemical analyses given in the section on the chemistry of slate (p. 50), are to be attributed to the mineral constituents in the following way:

SiO_2 to quartz, muscovite, biotite, feldspar, chlorite, tourmaline, andalusite, zircon, and kaolin.

TiO_2 to rutile.

Al_2O_3 to muscovite, biotite, feldspar, chlorite, tourmaline, andalusite, and kaolin.

Fe_2O_3 to hematite, magnetite, muscovite, and biotite.

FeO to chlorite, magnetite, carbonate, and biotite.

MnO to rhodochrosite.

CaO to plagioclase, calcite, carbonate of lime, iron, magnesia, and apatite.

BaO to barite and some silicate.

MgO to chlorite, biotite, and carbonate.

K_2O to muscovite and orthoclase.

Na_2O to muscovite and plagioclase.

Li_2O to tourmaline.

H_2O to muscovite, chlorite, limonite, and kaolin.

P_2O_5 to apatite.

CO_2 to calcite, rhodochrosite, and carbonate of lime, iron, and magnesia.

FeS_2 to pyrite.

SO_3 to barite and gypsum.

C to graphite and coaly matter.

Zr_2O to zircon.

The mineral sources of the nickel, cobalt, chromium, vanadium, and ammonia detected by Dr. Hillebrand in the slates of Vermont and New York have not been determined.

SPOTTED SLATES.

GENERAL CHARACTER OF SPOTS.

The spots in roofing slates have long attracted attention.[1] In the slate region of eastern New York and western Vermont many of the purple slates have green spots of circular, oval, or irregular outline. These spots locally occur only along lines of bedding and correspond to or pass into green "ribbons." In places, however, an entire bed of purple slate several feet thick is irregularly spotted throughout. Some of the red slates are also spotted. The spots are commonly circular or oval, measure from a fraction of an inch to several inches in diameter, and are of pale-green color, with or without a purple border. Some of the spots, however, have no symmetry whatever. In order, if possible, to throw some new light on this subject a few thin sections were prepared across small spots in directions parallel

[1] Tyndall, John, Comparative view of the cleavage of crystals and slate rocks: Philos. Mag., vol. 12, July, 1856. Maw, George, On the disposition of iron in variegated strata: Geol. Soc. London Quart. Jour., vol. 24, p. 379, Pl. XIV, figs. 29, 31, 32, 1868. Gosselet, J., Les schistes de Fumay, Soc. géol. Nord Ann., vol. 10. pp. 63-86, Lille, 1884; L'Ardenne, p. 35, 1888. Geikie, Archibald, Text-book of geology, 4th ed., vol. 1, p. 451 (2), 1893. Zirkel, Ferdinand, Lehrbuch der Petrographie: 2d ed., vol. 3, pp. 296-297, 1894.

to and across the cleavage, and chemical analyses were made by Dr. Hillebrand of the green center of a spot from the spotted red slates, of its purple rim, and of the outer red slate.

MICROSCOPIC ANALYSES OF SPOTS.

An elliptical green spot, 1 by $\frac{3}{4}$ inch, in purple Cambrian slate from the Lake Bomoseen Slate Co.'s quarry at Cedar Point, Castleton, Vt., in a section cut parallel to the cleavage, shows, in the green part, muscovite scales lying in all directions, large chlorite scales, quartz fragments, carbonate rhombs, and a few irregular spherules of pyrite. In the center is some opaque noncalcareous matter, partly surrounded by an aggregation of spherules of pyrite in a cloud of rutile needles. There are also cracks filled with secondary sericite. In the surrounding purple rim the same elements recur, but the pyrite is much more abundant, measuring up to 0.021 millimeter. There are also many dots of Fe_2O_3 from less than 0.003 to 0.009 millimeter, and rutile needles up to 0.012 millimeter in length.

An elliptical green spot, 3 inches long, with a purple rim, in Ordovician red slate from the National Red Slate Co.'s quarry north-northwest of Raceville, N. Y. (specimen D. XIV, '95, 397a), when cut transversely to the cleavage, measures half an inch in thickness and shows a black streak 1 inch long in the center. The central streak consists of strings of minute irregular lenses of cryptocrystalline quartz and possibly carbonate of manganese (rhodochrosite) containing spherules of pyrite. The green part consists of a mass of fibers of muscovite, which polarize as one mineral, with much carbonate and many lenses like those in the center, and also quartz grains. In the purple rim there is a decrease of carbonate and the hematite fragments begin to appear, and in the surrounding red slate hematite becomes still more abundant.

A green spot in Ordovician red slate (D. XIV, '95, 201c), from the Empire Red Slate Co.'s quarry, 1 mile north of Granville, N. Y., cut parallel to the cleavage, shows slate needles (TiO_2) up to 0.043 millimeter long, carbonate rhombs up to 0.030 millimeter, chlorite scales up to 0.030 millimeter, angular quartz grains up to 0.039 millimeter, and prisms of tourmaline up to 0.021 by 0.002 millimeter. The surrounding red slate, that of analysis K (p. 92), is described on page 91.

Another spot, almost circular, 0.44 inch in diameter, from a piece of red slate (D. XIV, '95, 201 l) from the same quarry, cut parallel to the cleavage, shows a central dot 0.03 inch in diameter, consisting mainly of carbonate and of a dense brown material. About this is a zone about 0.1 inch wide, of elliptical shape, consisting of carbonate, with some fibrous quartz along the margin. Then comes a zone, 0.08 inch wide, of green slaty material, containing angular quartz grains, muscovite scales, rutile needles, nodules of pyrite, and thinly disseminated areas and rhombs of carbonate; then a very narrow zone made up entirely of carbonate and pyrite. Outside of this, another zone of green slate, 0.08 inch wide, like the first, but with very little carbonate. The angular quartz grains measure up to 0.030 millimeter. There are also slender tourmaline prisms. Outside of all comes the red slate, full of Fe_2O_3 pigment. Chlorite was not detected in the green zones, but it may be present in minute scales.

CHEMICAL ANALYSES OF SPOTS IN RED SLATE.

The specimen (Q, R) analyzed by Dr. Hillebrand came from the same quarry (near Raceville) as the large spot described above. It was a green spot with purple rim, in red slate. The analysis of the red slate M, on page 92, is repeated for comparison.

Chemical analyses of spotted red slate.

	M	Q	R		M	Q	R
Silica (SiO_2)	63.88	64.59	65.44	Magnesia (MgO)	5.37	5.12	4.92
Titanium dioxide, rutile (TiO_2)	.47	.51	.52	Potassa (K_2O)	3.45	3.70	3.57
Alumina (Al_2O_3)	9.77	10.23	9.38	Soda (Na_2O)	.20	.23	.22
Ferric oxide (Fe_2O_3)	3.86	1.79	1.09	Lithia (Li_2O)	Str. tr.	Str. tr.	Str. tr.
Ferrous oxide (FeO)	1.44	1.19	1.06	Water below 110° C. (H_2O)	.27	.28	.25
Manganous oxide (MnO)	.21	.26	.32	Water above 110° C. (H_2O)	2.48	2.29	2.10
Nickelous oxide (NiO)	Trace.	Trace.	Trace.	Phosphoric oxide (P_2O_5)	.08	.08	.08
Cobaltous oxide (CoO)	Trace.	Trace.	Trace.	Carbon dioxide (CO_2)	5.08	5.84	6.55
Lime (CaO)	3.53	4.07	4.53	Pyrite (FeS_2)	Trace.	Trace.	.04
Baryta (BaO)	.05	.05	.06		100.14	100.23	100.13

M (=D. XIV, '95, 397 *a*), Red slate, 1 mile north-northwest of Raceville, in Granville, Washington County, N. Y., about a spot; Q, purple rim of the spot; R, green portion of the spot.

Dr. Hillebrand adds this observation:

Calculation shows that with no CO_2 there would be only enough CaO for the P_2O_5, and, further, that the result would be no MnO. How much FeO, if any, exists as carbonate is not indicated. If, after allowing for apatite, for $MnCO_3$, and $CaCO_3$, the remainder of the CO_2 is charged to MgO, we find the proportions shown in the columns below. [See p. 58.]

	M	Q	R
CaO_3	6.14	7.11	7.93
$MgCO_3$ (in part $FeCO_3$)	4.22	4.77	5.36
$MnCO_3$	.38	.47	.57

DISCUSSION OF THE SPOTS.

From Dr. Hillebrand's analyses it would appear that there is a decrease of the carbonates of lime and manganese and magnesia and of silica and rutile from the center of the spot outward and an increase of Fe_2O_3 in the same direction.

The main results of the microscopic and chemical analyses agree even as to the relative amount of pyrite. The difference in color from the green to purple and red is manifestly due to the differences in the amount of hematite. Pyrite, rutile, carbonate, and tourmaline are more abundant within the spots than without them.

Certain green fossil impressions in purple slate at Middle Granville, N. Y., may throw some light on the origin of these spots. In this locality the effect of organic matter, whether the carbonaceous matter of the lining of an annelid boring or matter from a marine alga, has been to diminish the quantity of Fe_2O_3 in the slate and possibly to increase the amount of chlorite.[1] Gosselet regards the spots as the result of the reduction of the hematite (Fe_2O_3) by decaying organisms to the ferrous oxide (FeO) and its removal as an organic salt or as a carbonate. He observes that the green spots in purple tiles wear less readily than the rest of the tile, because they contain more quartz, and this SiO_2 he attributes to infiltration.[2]

In the spots from the slates of New York and Vermont examined by Dr. Hillebrand and the writer the marked decrease of Fe_2O_3 is accompanied by a marked increase of carbonate of lime, iron, and manganese and of SiO_2, also by a slight increase, in some of the thin sections at least, of FeS_2. Carbonates are also characteristic of the spots in some European slates.[3] The increase of the carbonates may be directly connected with the production of CO_2 by decaying organisms and the consequent decrease of the Fe_2O_3. Not impossibly the organism may have had a calcareous exoskeleton which was dissolved and then redeposited as crystalline $CaCO_3$. The infiltration of SiO_2 and the formation of chalcedony may be purely secondary, and likewise the deposit of FeS_2, or there may have been some precipitation of FeS_2 about the decaying organism, as seems to have occurred in some fossiliferous sediments. At any rate, the rim of intermediate composition would be the zone in which chemical reaction was less effective. In view of all these facts and indications the spots may be safely regarded as probably produced by chemical changes in the sediments consequent upon the decay of organisms. If this is the correct view, the green ribbons, which traverse both purple and red slate, would correspond to small deposits of decomposing organic material that effected similar changes in the Fe_2O_3 of the argillaceous sediments. Where a bed of quartzite forms the center of such a ribbon quartzose sedimentation must have taken place also, and possibly this may have been the very condition which proved favorable to marine life.

Not to be confounded with the spots described above are certain white or whitish spots on the cleavage surfaces of some slates (Northfield, Vt., and Penlan, Va.) measuring up to 2 inches in diameter and

[1] See Tyndall, Maw, Gosselet, Geikie, and Zirkel, as indicated by titles given in footnote on p. 23.

[2] Maw (loc. cit.) had analyses made of dark-greenish ribbons in the Welsh blue slates, and found that the ribbons contained 6 per cent more SiO_2, 7 per cent more Al_2O_3, 4.5 per cent more MgO (= 7 times as much), but 4 per cent less Fe_2O_3, 1 per cent less FeO, and 3.5 per cent less K_2O than the adjacent blue beds. Under the microscope the green ribbons showed more feldspar and chlorite. Maw attributes these differences to change in sedimentation.

[3] Zirkel, Ferdinand, loc. cit.

consisting of a fine film of calcite, with or without other carbonates, deposited by water percolating along the cleavage, the water, originally acid, having dissolved the carbonate from the slate itself. The cause of these spots is analogous to that of some of the minerals found coating the joint planes in slate. (See p. 42.)

IGNEOUS SLATES.

Some very remarkable slates of igneous origin are the green slates from the English lake district (Buttermere, Tilberthwaite, etc.), which consist of volcanic ash and which have long been known in England as excellent roofing material. These have been chemically and microscopically analyzed and described [1] and were found to consist chiefly of chlorite, calcite, quartz (mostly secondary), and muscovite, but to contain also andesitic lapilli, feldspar, garnets, sphene, and anatase. Slate needles and tourmaline are conspicuously absent. The chemical analyses show the following important constituents:

SiO_2	50.16–54.02	FeO	5.97–7.06
Al_2O_3	11.94–17.85	CO_2	2.45–5.41
CaO	3.67– 6.46		

The CO_2 if calculated to $CaCO_3$ would give from 5.56 to 12.29 per cent of $CaCO_3$. The specific gravity ranges from 2.775 to 2.788. The percentage of SiO_2 is low, and that of FeO is near that of the "unfading green" slate of Vermont (p. 142).

Still more remarkable are the slates first described by E. C. Eckel in 1903,[2] which seem to have been formed directly from igneous rock by shearing. They show from 3 to 9 per cent less SiO_2 than the English ash slates and more than double the per cent of MgO of the European and American roofing slates of aqueous sedimentary origin, analyses of which are given under the heading "Chemistry of slate" (p. 50). These slates are fully described by Mr. Eckel on page 68.

In this connection E. B. Mathews now regards some of the slates of Maryland as at least partly of volcanic origin (p. 85), and J. E. Pogue, jr., describes a schistose slate from North Carolina as of mixed sedimentary and volcanic origin (p. 208).

STRUCTURE OF SLATE.

BEDDING.

Ordinary planes of bedding may be defined as those which are approximately parallel to the surface of the water in which the sediment was formed. If the sediment changes in character, then a hori-

[1] Hutchins, Maynard, The ash slates of the lake district: Geol. Mag., 1892. Reade, T. M., and Holland, Philip, The green slates of the lake district, with a theory of slate structure and slaty cleavage: Liverpool Geol. Soc. Proc. (1900–1901), 1901.

[2] U. S. Geol. Survey Bull. 225, p. 419, 1904; On a California roofing slate of igneous origin: Jour. Geology, vol. 12, p. 15, Jan.-Feb., 1904.

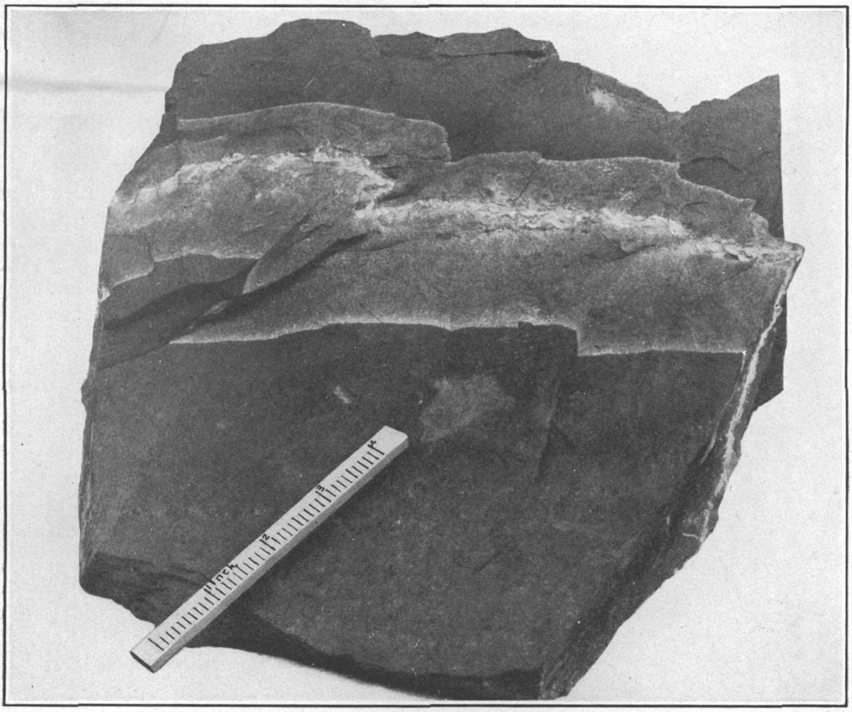
zontal bed of different material results. If, deposition being interrupted, annelids creep over the bottom or algæ decompose there, and the same kind of sedimentation is afterward resumed, then two horizontal beds of the same material will result, separated by a plane covered with trails and impressions. Some bedding planes are due to the changing size or arrangement of the particles, some may be the result of contraction in drying, and some are the effect of vertical compression. Whatever explanation may be offered for bedding, the bed is the starting point in a slate quarry, for the direction of the bed indicates (cleavage, etc., being equal) where the same quality of slate is likely to recur.

In those places where folding has brought the bedding plane to the angle of inclination required by the cleavage, the unaltered sedimentary particles of the slate still retain their parallelism to the bedding—that is, cleavage and bedding are parallel—but in all other places cleavage is necessarily more or less transverse to bedding. This statement, of course, assumes that the slate beds still retain the position they had when slaty cleavage was set up in them.

Plate II, *B*, shows a ledge of green roofing slate with a cleavage striking N. 15° W. and dipping 20° E. and joints striking N. 30° E. and dipping 45° E. The upper part is a quartz sandstone or grit, with calcareous concretions containing Lower Cambrian trilobites. The direction of the axial planes of the calcareous bodies and the direction of the line of contact between the slate and sandstone show that the direction of the bedding is horizontal.

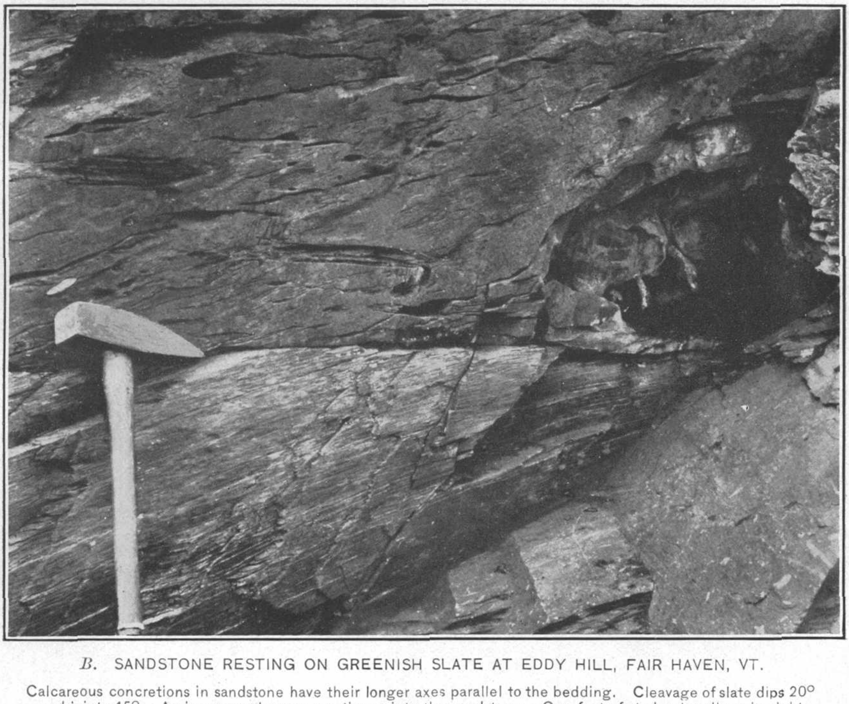
The "ribbons" of the Pennsylvania quarries (shown in figs. 9–12 and Pls. V, *B;* XIII; XIV; and XVIII) consist of small beds of quartz sandstone or grit in which the particles are held together by a calcareous and locally a sericitic cement, the original clay having gone into muscovite. These beds are also very carbonaceous (Pl. VI, *A*). Here and there the slate beds are separated, as in the Vermont and New York quarries (Pls. XXIII, XXIV), by beds of calcareous quartzite reaching several inches in thickness and consisting of grains of quartz sand cemented together by secondary quartz and calcite and other carbonates. Such beds may be but a fraction of an inch in thickness and consist mainly of carbonate, as in the syncline at West Pawlet, Vt., shown in Plate XXV. In some places bedding is indicated simply by a variation in the amount of lime in successive beds, as in the syncline at West Castleton, Vt., shown in Plate III. Here the solution of the lime by the acids of the atmosphere has etched the joint face, as it were, and the more calcareous beds thus stand back from the less calcareous beds.

Planes of bedding may be indicated by the position of fossils, as the brachiopods, crinoids, and trilobites at the Arvonia quarries in Virginia, or by bifurcating impressions, possibly made by seaweeds,



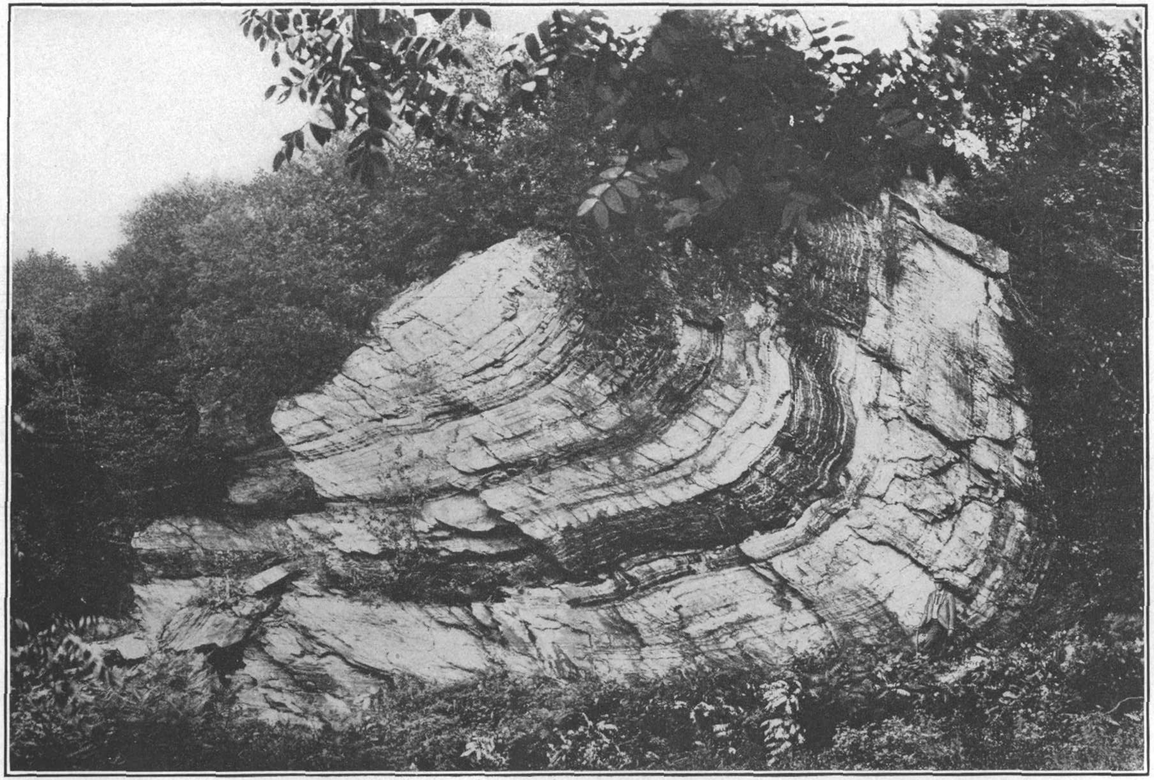
A. RED SLATE FROM QUARRIES 1½ MILES SOUTH OF HATCH HILL, WHITEHALL, N. Y.

Whitish streak is bed of greenish dolomite, rimmed by very thin green slate, and this by purple slate, the whole an inch wide. It crosses the cleavage diagonally.



B. SANDSTONE RESTING ON GREENISH SLATE AT EDDY HILL, FAIR HAVEN, VT.

Calcareous concretions in sandstone have their longer axes parallel to the bedding. Cleavage of slate dips 20° and joints 45°. An irregular cleavage continues into the sandstone. One foot of sledge handle is in sight.



SYNCLINE IN BLACK AND GRAY BANDED SLATE AT WEST CASTLETON, VT.

Showing effects of erosion on the more calcareous beds. Cleavage dips 30° E. (to the right). Age, Ordovician.

and serpentine tracks made by annelids, or by the small black beds in green slate due to the decomposition of various marine organisms, all of which may be seen in the slate quarries of western Vermont and eastern New York.

Plate II, *A*, from a photograph of a piece of red slate from the old quarries of the Fair Haven Red Slate Co., in the southeast corner of Whitehall, N. Y., shows a bed an inch thick crossing the cleavage diagonally and therefore spreading out to double that width on the cleavage surface. In the center of the "ribbon" is a bed one-fourth inch thick of greenish dolomite, and on either side of the ribbon is a very thin rim of green slate; the rest of it is purple. Under the microscope the composition of these little beds is found to be this: The central green bed consists of dolomite and of rhombs of sideritic dolomite; the siderite is altered to limonite. There are large quartz grains, muscovite scales without parallel orientation, and scattered plagioclase grains. The purple material consists chiefly of scales of muscovite and chlorite, lying in two directions, at right angles to each other, irregular dots of hematite, some carbonate rhombs, quartz grains, and rarely a grain of plagioclase. The thin green strips on the sides contain less hematite than the purple material, and a large number of the muscovite and chlorite scales lie parallel to the bedding and transverse to the cleavage. The red slate itself is like the purple but contains far more hematite and probably less chlorite. The iron obscures the other minerals. In this specimen the central bed of quartzose dolomite is due to change of sediment. The varying amount of ferric oxide in the purple and green parts of the ribbon as compared with the red of the slate beds may be due to a chemical change brought about by the decomposition of organisms on the sea floor, as has been shown on pages 25, 26 to be probably true of the green and purple spots in the same slate. Locally the quartzose ribbons of the red slate are parallel to the cleavage. This parallelism between bedding and cleavage characterizes some of the Maine and Vermont quarries. (See Pl. XII.)

The purple slate of Vermont has in many places small beds of green slate, with or without a central band, crossing the cleavage; and some of the village sidewalks in that region are flagged with such purplish green-banded slate. The roofing slates of this kind, whose grain, owing to folding and pitch, is not at right angles to the bedding, have diagonal green ribbons. These green ribbons, both in the red slate of New York and in the purple slate of Vermont, run into planes or rows of spots of various sizes, usually more or less oval in outline. Where a series of such spots are in line they indicate the course of the bedding.

The small beds or ribbons may be plicated, as shown in Plate XXIV, *Q*, *R*. Plate IV, *E*, is a microscopic drawing of a thin section

PLATE IV.

PLICATED AND FAULTED BEDS IN SLATE.

A. Extremely plicated bed of quartzose limestone or calcareous quartzite in Cambrian slate at Fair Haven, Vt. Natural size. The slate on both sides of the bed for half an inch is green; beyond that, purplish.

B. Extremely plicated bed of quartzose dolomite or calcareous quartzite in Cambrian slate at Fair Haven, Vt. Reduced one-half.

C. Faulted quartzite bed in slate at Meadow Slate Co.'s quarry, Fair Haven, Vt. Normal fault.

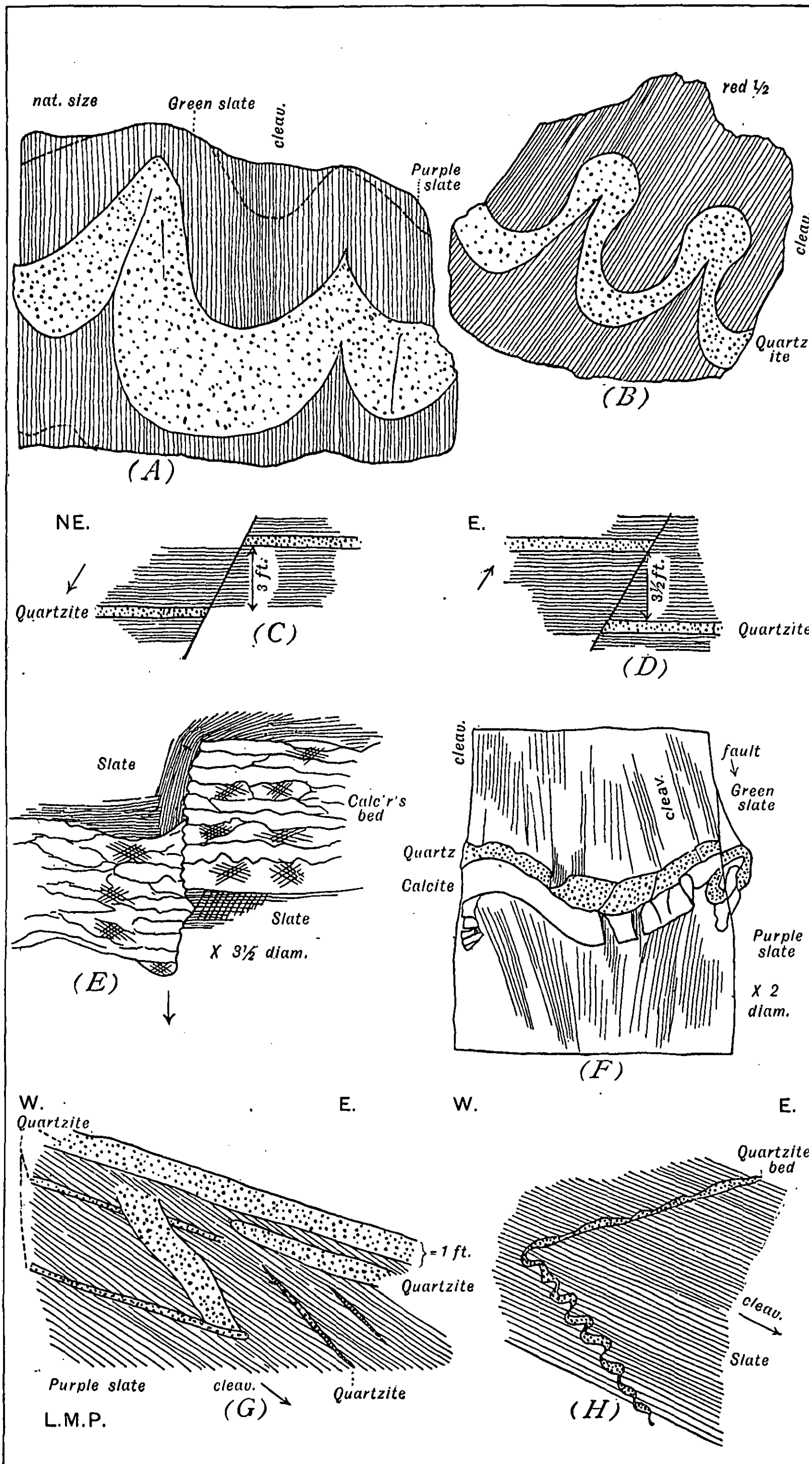
D. Faulted quartzite bed in slate at Eureka quarry, Poultney, Vt. Reversed fault.

E. Thin section of faulted calcareous bed at Pawlet, Vt., given in Plate XXIII, *D* (p. 126), showing adjustment of cleavage to faulting and production of secondary cleavage. Enlarged 3½ diameters.

F. Thin section of plicated and faulted beds of calcite and quartz separating beds of purple and green Cambrian slate at Blissville, Castleton, Vt. Enlarged 2 diameters. Both calcite and quartz beds are bordered on both sides with chlorite scales.

G. Dislocated beds of quartzite in purple Cambrian slate at old quarry about 1 mile south of West Castleton, Vt. A fragment of a bed of quartzite has been turned about into the cleavage foliation and across smaller beds of quartzite. By L. M. Prindle.

H. Plicated and folded quartzite in Cambrian slate at Fair Haven, Vt. Height, 40 feet. Minor plications somewhat enlarged.



PLICATED AND FAULTED BEDS IN SLATE.

of the plicated bed of Plate XXIII, *D*. The bed here consists of calcite and vein quartz, the original calcareous sediment having been crystallized and vein quartz deposited. The diagram shows the faulting of the bed, the bending of the cleavage foliation, and the slip cleavage caused by the dislocation. The plication of some of these small beds of quartzose limestone and calcareous quartzite is extreme, as shown in Plate IV, *A*, *B*, *H*. The folding in such places seems to have been preserved only in the hard beds, while in the more plastic material of the slate on either side slaty cleavage has obscured or effaced the bedding.[1]

Plate IV, *F*, represents a plicated bed of quartz and one of calcite separating beds of purple and green slate. Under the microscope both quartz and calcite beds are bordered with chlorite scales on the outside and separated by such scales; there is also some pyrite along the edges. The cleavage of the slate is at right angles to the course of the bedding but is slightly deflected near the plicated beds. In several places the slaty material has been drawn partly into the bed.

A thin section of a small plicated bed of quartzite in the purple slate of the Cedar Point slate quarry, in Castleton, Vt., shows that the bed consists mainly of quartzite, but this contains grains of plagioclase, rhombs of dolomite, and scales of muscovite. Toward the slate there are coarse fibers of muscovite. The slate merges into the quartzite, sending out long streamers of sericite, which penetrate between the grains of quartz and calcite. The slate contains large scales of chlorite within the meshes of sericite, and these scales lie at right angles to the cleavage—that is, parallel to the course of the bed. It also contains grains of quartz. The fibrous character of the slate is apparent at the border of the quartzite bed. The significance of such a bed is that sandy material was deposited for a brief interval during the deposition of the finer material which produced the slate; there were grains of quartz and of feldspar and probably scales of mica, together with calcareous mud. Under the compression and the chemical changes which accompanied it the quartz grains were cemented into quartzite, the calcareous mud was crystallized, and the bed was plicated and became entangled with the slaty material. The slaty material itself was also somewhat plicated, and a secondary cleavage (slip cleavage) was produced in it. The plication and overturning of quartzite beds are shown on a large scale in Plate XXIV, *T*.

[1] See Hitchcock, C. H., Second annual report on the natural history and geology of Maine, p. 285, fig. 45, 1862, where he describes a bed of strongly plicated limestone lying between unplicated beds of slate. See also the classic figure of H. C. Sorby given in his paper on the origin of slaty cleavage; Edinburgh New Philos. Jour., vol. 55, pp. 139, 140, July, 1853, which was reproduced by Tyndall in his Royal Institute lecture, and also by Phillips in his British Association report on cleavage.

Exceptionally the quartzite beds seem to have been pushed out of their normal parallelism, even without folding or faulting. Brecciation on a somewhat large scale is shown in Plate IV, *G*, from a photograph taken near the place shown in Plate XXIV, *T*.

The slate of Rockmart, Ga. (p. 73), shows very unusual ribbons, single compressed folds covering an area of the cleavage surface 10 inches square. (See fig. 1.)

In many places, however, the bed surface is simply a parting whose meanderings must be carefully followed in order to distinguish it from fractures of various kinds, as in parts of the West Pawlet syncline (Pl. XXV); or the bedding may be indicated by the weathering out of calcareous matter from the slate itself, some beds containing more of it than others, as at the syncline at West Castleton (Pl. III). The rock at West Castleton is a shaly slate, consisting of alternating light and dark gray bands—that is, beds of muscovite and chlorite scales—grains of quartz, spherules of pyrite, and some carbonate, but there is more carbonate in the gray bands than in the black ones, which contain more carbonaceous matter. Here and there is a minute bed consisting largely of calcite. This explains why the beds are so clearly and yet so delicately brought out on the joint face. The original sediments contained varying amounts of calcareous material. The carbon dioxide brought down from the atmosphere by the rain has, as it were, carried away the more calcareous parts, leaving the less calcareous parts in relief.

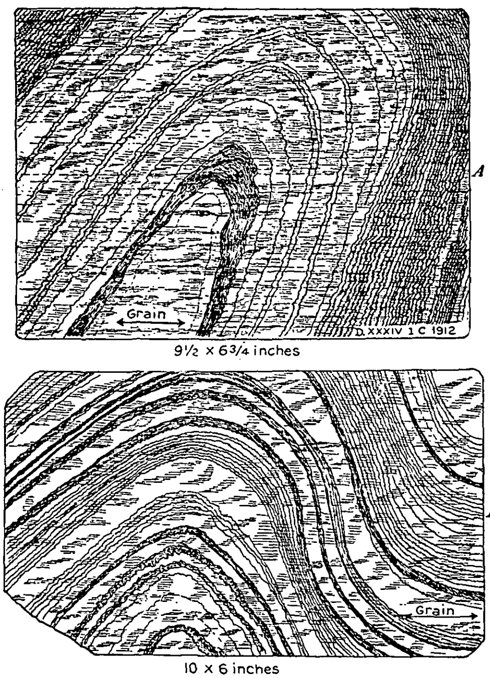
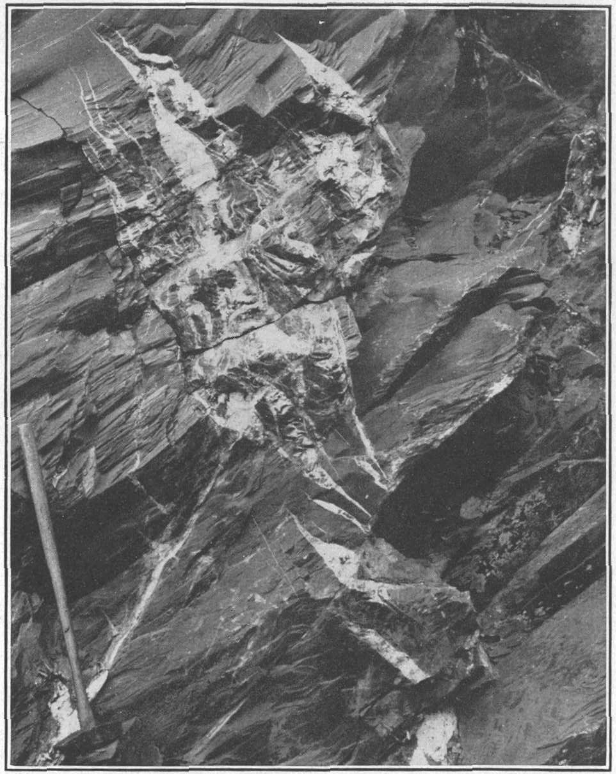


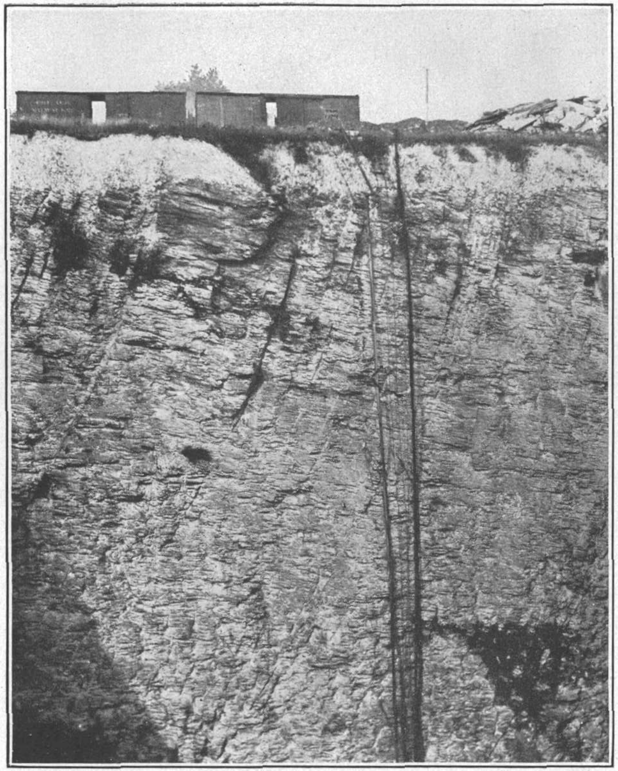
FIGURE 1.—Sketches of the cleavage surfaces of two roofing slates from the Pritchard & Davis quarry, Rockmart, Ga., showing greatly plicated bedding crossing the cleavage at a very acute angle, with the grain nearly at right angles to both. The little beds contain more quartz and carbonate than the intervening slate.

In many of the eastern New York and western Vermont quarries change of color alone is an indication of the passage from one bed to another. This change may be gradual or abrupt. But color is not an infallible guide, as the red slate may pass into the green along the



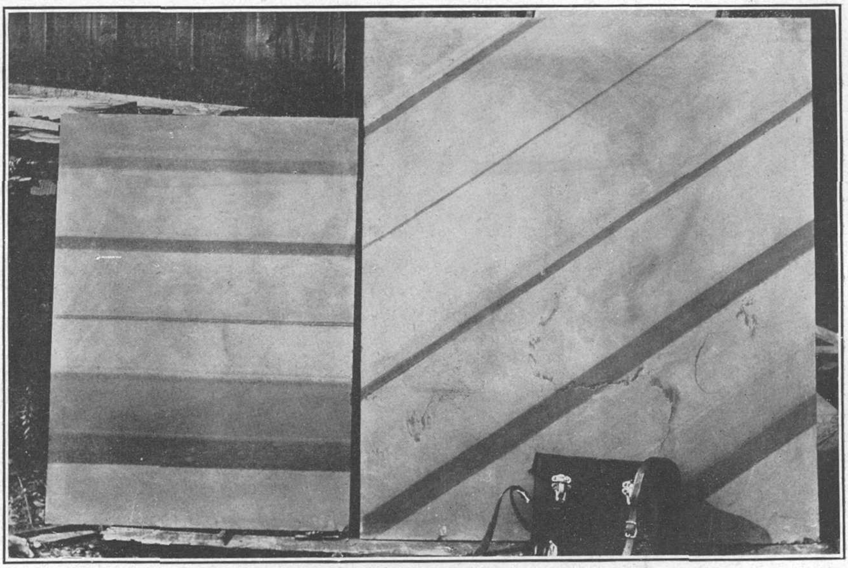
A. QUARTZ VEINS IN SLATE AT JAMESVILLE, N. Y.

Shows quartz vein of segregation crossing the cleavage of greenish slate. Sledge handle is 30 inches long.



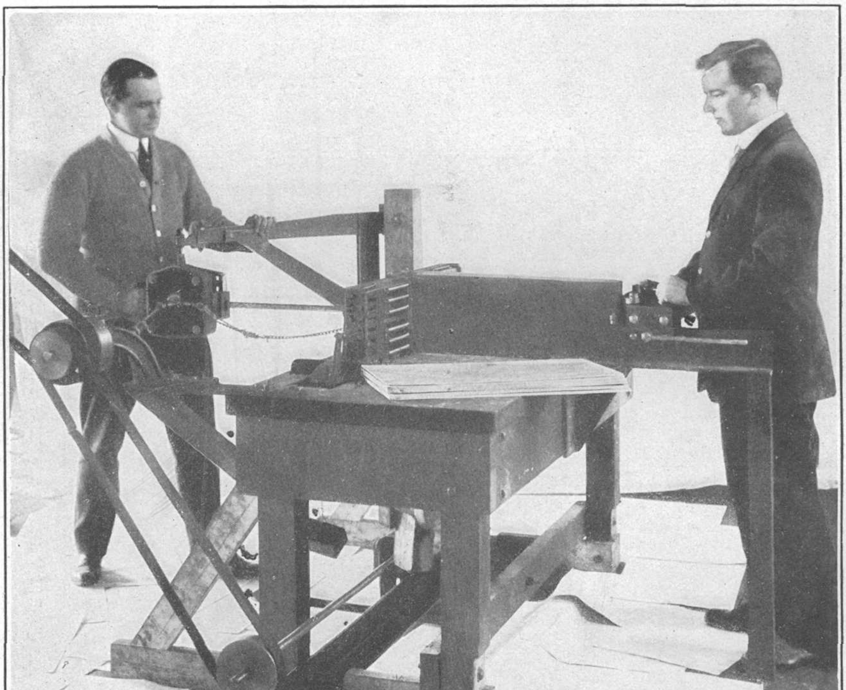
B. BEDDING AND CLEAVAGE IN PHOENIX QUARRY, WINDGAP, PA.

The more calcareous, "ribbon" beds, a little weathered at the top, curve steeply northward.



A. BLACK-BANDED GRAY SLATE FROM PHOENIX QUARRY, WINDGAP, PA.

Smoothly ground slabs showing variation in width of ribbons. Camera case 12 inches square.



B. SLATE-SPLITTING MACHINE IN OPERATION.

The wide blade of the chisel is entering the slate block.

same bed, and there is no reason why the Cambrian purple should not likewise pass into the green of the same formation.

In some places where there are no fossil impressions or intervening beds of very different material or partings or slight changes in the composition of the slate itself producing changes of color or different degrees of erodibility the course of the bedding may be made out in a thin section cut transverse to the cleavage when examined under the microscope. There may be an occasional arrangement of the particles parallel to the original bedding or an extremely minute bed of other material, or lines of different particles may cross the cleavage foliation. Plate VII, *C*, illustrates slates of this kind.

Gosselet [1] gives some remarkable instances of intense and complex folding of beds of slate on a large scale. These great folds are very acute and overturned. In some places shafts have been dug through other rocks in order to reach underground portions of synclines and anticlines and quarry the slate. Slate quarrying in the Ardennes thus resembles coal mining in a region of intense folding. The great flat slate syncline of Bangor, Pa., is shown in Plates XIII and XIV.

SLATY CLEAVAGE.

The causes and the structure of slaty cleavage have already been discussed under the headings "Origin of slate" and "Petrographic characters."

Relation to bedding.—In most slate regions cleavage is not coincident with bedding. Its relations to bedding are illustrated in figs. 9–12 and Plates III; V, *B;* XII–XIV; XVII; XVIII; XIX, *A;* XXIII–XXV. The lowest inclination of slaty cleavage in slate districts visited by the writer is 5°–10° and occurs in Pennsylvania. (See Pls. XIII, XIV.) [2] The lowest in the eastern New York and western Vermont belt is 20°. Where the cleavage approaches horizontality within 5° to 10° its position is probably due in part to a secondary crustal movement, and the local curvature of both joints and cleavage in the Pennsylvania region also points to such a movement.

Amount of compression in the formation of slaty cleavage.—Sorby calculates that on a small bed of intensely plicated sandy slate, inclosed in ordinary slate, the amount of shortening by plication was about 75 per cent, and reasons that the clayey material of the slate itself must therefore have been compressed to the same extent. This is the only way in which the amount of compression actually suffered by a mass of slate could be computed. But this calculation does not take into consideration the elongation of the slate in the shearing.

[1] Gosselet, J., L'Ardenne, p. 41, fig. 7 (Les rapports de Ste. Marie avec les Trésfossés), 1888; Les schistes de Fumay, Pl. III, fig. 1 (Bond dans les schistes de Fumay), 1884.

[2] See also U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, Pl. XC, 1893, showing a slate quarry near Lebanon, N. Y., with cleavage dipping 10°.

Relation of cleavage dip to dip of inclosing hard beds.—Gosselet brings out the fact that where a bed of slate lies between beds of a hard rock like quartzite there is a constant geometric relation between the cleavage dip of the slate and the dip of the beds of quartzite. The same thing is true, as he shows, in the horizontal relations between the strike of the cleavage, that of the quartzite bed, and the direction of movement:

Unless the ancient shore yielded to the pressure from the south the lower beds must have had a tendency to rise against that obstacle, to slide as a wedge between the obstacles and the overlying beds. The slaty material inclosed between the two beds of quartzite is thus pushed upward in a direction which is the component between a vertical line (that is, vertical to the horizon) and the oblique movement of the wall (that is, along the surface of the slate bed). Cleavage will be developed along that component, and we actually find that it dips 40° while the bed dips 27°.

Gosselet's figure is here repeated (see fig. 2) with the construction added.[1] The gist of his statement is that if we knew the dip of the

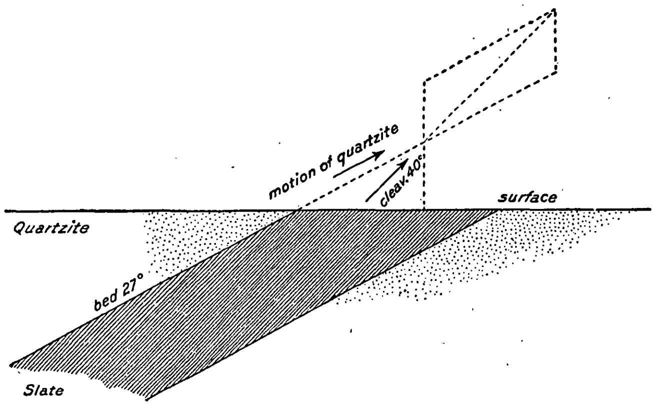


FIGURE 2.—Diagram showing relations of cleavage of slate to dip of inclosing hard beds. After J. Gosselet.

hard beds on either side of a bed of slate we could foretell the cleavage dip of the slate. This, however, would be applicable only where no secondary disturbance of sufficient force to affect the relations had occurred.

Relations of cleavage to axes of folds.—Some pre-Cambrian and Paleozoic schist masses have two transverse systems of folding, which within small areas interfere with one another and both of which are intersected by a cleavage with a constant strike different from that of each.[2] Where only one system of folding occurs, the strike of the cleavage is not necessarily parallel to that of the bedding. In such a case the cleavage is attributed to a change in the direction of the pressure.[3]

[1] Gosselet, J., Les schistes de Fumay, pp. 68, 69, fig. 5, 1884.
[2] Loretz, H., Ueber Schieferung, pp. 69–70, 1880.
[3] Idem, pp. 83, 84.

The cleavage planes of the slate rocks of North Wales are always parallel to the main direction of the great anticlinal axes but are not affected by the small undulations or contortions of these lines.[1]

The strike of the cleavage in a district is far more constant and regular than the strike of the beds.[2]

To these facts should be added this—that in a pitching fold the cleavage, although parallel to the axis of the fold, must necessarily intersect the strikes of the sides of the fold. Phillips [3] gives a section from Sedgwick, which he calls a local exception, in which the cleavage planes, while coinciding in strike with that of the anticline that they traverse, incline on either side of it toward its axis. Rogers [4] describes a case of this fanlike cleavage in an anticline. Such a structure could be produced by secondary movement creating an anticline in horizontal beds already possessing a vertical cleavage, and in the synclinal part of the fold the fan structure would radiate downward.

Sorby [5] figures, from Ilfracombe, North Devon, a small, highly plicated bed of coarse-grained light-colored sandy slate traversing a mass of vertically cleft shaly slate. The gritty beds show a coarse and imperfect fanlike cleavage which curves slightly around the anticlines into the synclines. Here the fan structure seems to be due, in part, at least, to the deflection of the cleavage by the coarser material, and there is no need of supposing a secondary movement. The fine and more plastic material has developed a vertical cleavage which in the coarser material has become rudely fanlike.

Effect of frost on cleavage.—As all slate quarrymen know, repeated freezing and thawing is disastrous to the cleavability of roofing slates. The material must be split fresh from the quarry. In order to ascertain, if possible, the difference in microscopic structure produced by freezing and thawing this experiment was tried: A fresh and unfrozen specimen was obtained from the quarry early in the winter and was kept moist in a moderate temperature until severe weather set in. It was then broken into two equal parts, one of which was kept moist indoors, the other exposed on the sill of a north window for a week, during which the temperature went down to 10° below zero F. This part was then thawed out over a furnace register. Both frozen and unfrozen pieces were after some accidental delay sliced and examined microscopically. The whole texture of the frozen slate was found to be perceptibly closer than that of the unfrozen. The test would have been more satisfactory had the thin sections been made at once. The loss from freezing and thawing is so considerable that

[1] Phillips, Prof., quoted in Sharpe, Daniel, Contributions to the geology of North Wales: Geol. Soc. London Quart. Jour., vol. 2, p. 309, 1846.

[2] Sharpe, Daniel, idem.

[3] Phillips, John, Report on cleavage, p. 374, 1857.

[4] Geology of Pennsylvania, vol. 2, pt. 2, p. 903, fig. 715, 1858.

[5] Sorby, H. C., On the origin of slaty cleavage, p. 138, 1853.

means to recover it have been sought, and a process has recently been patented by W. A. McLaughlin, of Delta, Pa., for restoring the fissility of slate by the use of liquid air.

Curvature of the cleavage.—As far back as 1839 De la Beche [1] called attention to the curvature of cleavage planes when approaching a bedding plane. Baur [2] in 1846 observed S-like cleavage foliation in Germany, and describes certain slates which were so much curved as to be fit for use only on the roofs of towers, but he does not explain whether this curvature was parallel or transverse to the bedding. John Phillips,[3] in his British Association report, ascribed the curvature to the differing density of the beds. Harker [4] attributes it to a gradual change in the texture of the beds. Hughes [5] explains it as due to a secondary motion. Curvature of the cleavage is not uncommon in the Lehigh and Northampton County quarries in Pennsylvania, where it is plainly not dependent on change of texture. (See p. 105.) Slates from the beds so affected are also used for roofing towers.

In some of the Pennsylvania and New Jersey quarries (p. 88) the cleavage, instead of being curved, is deflected in dip at the ribbon; and thus where ribbons abound a roofing slate of ordinary size may have several large-angled zigzags in it.

Phillips [6] gives a figure, the original authorship of which he does not mention, representing the cleavage surface of a piece of slate in which gently plicated ribbons are shown. A normal fault crosses the piece diagonally, displacing the beds. The cleavage surface also shows the "flexuous" lines of a third foliation oblique to the cleavage. Finally two small calcite veins cross the primary cleavage, the plicated bedding, the plicated secondary cleavage, and also the fault plane. The specimen thus bears traces of at least five if not six motions.

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[1] De la Beche, H. T., Report on the geology of Cornwall, Devon, and West Somerset, p. 620, fig. 31, London, 1839.

[2] Ueber die Lagerung der Dachschiefer, etc., pp. 392, 393, fig. 9, 1846. (For full titles of works cited see Bibliography, pp. 205-210.)

[3] Op. cit., p. 384, fig. 23. See also Jukes, Geol. Soc. London Quart. Jour., vol. 22, p. 359, 1866. That the angle and amount of cleavage change with the density of the rock was shown by Phillips in 1828. See also Harkness, Robert, Edinburgh New Philos. Jour., new ser., vol. 2, No. 4, 1855.

[4] On slaty cleavage, etc., 1886.

[5] Hughes, T. M., quoted in Lyell's Students' elements, 7th ed., pp. 53, 573, fig. 625, 1871.

[6] Report on the geology of Cornwall, etc., p. 372, fig. 2.

SLIP CLEAVAGE ("FALSE CLEAVAGE").

Several writers—Sedgwick,[1] Phillips,[2] De la Beche,[3] Zirkel,[4] Loretz[5]—describe a striation or an extremely fine plication that appears on the cleavage surfaces of some slates. This is the "bate" or "false cleavage" of quarrymen. Two systems of such lines or plications may occur in the same slate. These are due to a secondary and tertiary cleavage, a slip cleavage developed upon the primary slaty cleavage. They consist simply of very minute plications which usually result in microscopic slippages or faults along which the slate easily breaks. This structure may show itself where slaty cleavage alone is visible or in the bedding also. (See Pls. VII and XI, *A*.) There is a readjustment of the slaty cleavage and the bedding foliation with reference to the new pressure instead of a rearrangement of all the particles as in slaty cleavage. The presence of "false cleavage" can be detected microscopically in a piece half an inch square as certainly as from tests applied to pieces of commercial size. The specimen shown in Plate VII came from a quarry which proved a failure on account of this structure, but it was not detected until after the expenditure of much money. The slate from Arizona, described on page 60, shows two slip cleavages crossing each other, as well as both bedding and slaty cleavage.

False cleavage has received in recent years a variety of technical names, such as close-joint cleavage, strain-slip cleavage, Ausweichungs-clivage, fissility, fracture cleavage. Science is not advanced by the mere multiplication of technical terms. The term "fissility," being a synonym of Latin derivation for cleavability, which is of Anglo-Saxon origin, is likely to be misleading. "Close-joint cleavage" and "fracture cleavage" are objectionable because they may be applied to jointing. The term "slip cleavage" has brevity and definiteness in its favor, as well as priority over the two just mentioned. Slip cleavage is a common feature in schist and is particularly characteristic of the Taconic region in western Massachusetts, Vermont, and eastern New York, where it seems to be due to a con-

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[1] "While my first observations on cleavage planes were made during long bygone years in Cumberland, I had hardly noticed the phenomenon of a second cleavage plane; but on many occasions I have subsequently collected, from various parts of England, a considerable and unpublished mass of materials in illustration of this second plane. The second cleavage plane is generally inclined at a great angle to the first plane. Most beautiful examples of this double structure were seen in 1839 by Sir R. Murchison and myself in the quarries of the Ardennes, where the fine, glossy surfaces of the slates are frequently marked by the parallel striæ of second cleavage, and the economical value of the slates is sometimes much deteriorated by the second plane. By a powerful reflected sunlight I have frequently been able to trace these striæ of a second cleavage on the surface of the Bangor slates which have been brought to Cambridge." A synopsis of classification of the British Paleozoic rocks, p. xxxv, London, 1855. Also Geol. Soc. Trans., 1840, p. 655.

[2] On a group of slate rocks, p. 1, 1829.

[3] Geological observer, 2d ed., p. 588, fig. 239, 1853.

[4] Lehrbuch der Petrographie, pp. 307, 308, 1894.

[5] Ueber Transversalschieferung, pp. 263, 264, 1882. J. E. Spurr, Am. Jour. Sci., 3d ser., vol. 48, p. 159, 1894, describes slates in Minnesota with two and three cleavages and bedding.

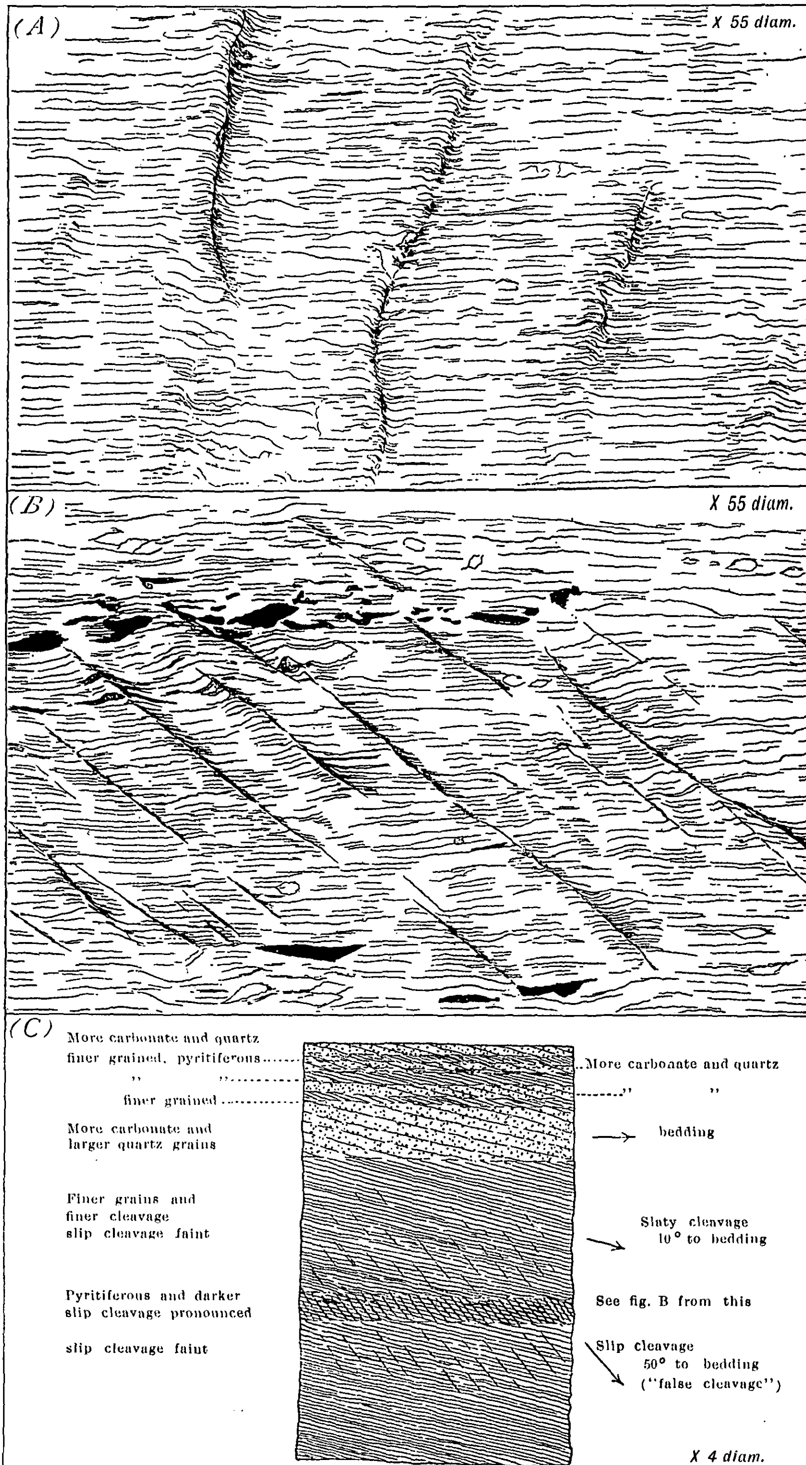
PLATE VII.

Thin Sections of Roofing Slate with Slip Cleavage ("False Cleavage").

A. Microscopic view of a thin section of purple Cambrian roofing slate from an old quarry three-fourths of a mile south of Fair Haven, Vt., showing slip or "false" cleavage originating in minute wrinkles. Section transverse to both cleavages. Enlarged 55 diameters.

B. Microscopic view of a thin section of green Cambrian roofing slate from the Huckleberry Hill quarry, 2 miles southeast of West Pawlet, Vt., showing slip or "false" cleavage. Section transverse to both cleavages. Enlarged 55 diameters. The black spots are pyrite. This figure represents a small part of the dark band shown in *C*.

C. Microscopic view of the same thin section, entire, showing alternation of fine and coarse beds, some of which are pyritiferous, and in only one of which is the slip cleavage pronounced. Enlarged 4 diameters.



SLIP CLEAVAGE AFTER SLATY CLEAVAGE.

tinued if not, in some instances at least, a secondary crustal movement consequent upon the first metamorphism. H. B. Muff [1] finds in a folded Scotch slate two sets of slip cleavage, each at about 45° to the slaty cleavage. He regards all three cleavages as concomitant but not simultaneous, although a difference in the strike of the slip cleavage from that of the other structures requires a slight veering of the direction of maximum pressure toward the close of the earth stress.

Good illustrations of slip cleavage will be found in the following publications of the United States Geological Survey: Monograph XXIII (1894), figures 44, 45, 46, 53, 56; Thirteenth Annual Report, part 2 (1893), page 319, figure 25; Fourteenth Annual Report, part 2 (1894), page 537, figure 57; Sixteenth Annual Report, part 1 (1896), figures 89, 96, 97; and Bulletin 521 (1912), Plates V, *A;* VIII, *B*(b). A careful study of these microscopic drawings and photographs will show that the minute faults along which more or less slippage has occurred are the necessary result of the lateral shortening of the rock mass by plication. This plication was as much due to a lateral compression as was the major folding of the Appalachian system. Slip cleavage should therefore not be confounded with two intersecting systems of fractures (jointing on a small scale), the strike of neither of which would be at right angles to the direction of strain but diagonal to it; or to a single system of such fractures, which might be the result of stretching.[2] The same pressure which produced slip cleavage in buried masses of micaceous matter (slate and schist) may have produced fractures at the surface; but where both schist and a rigid vitreous rock like quartzite have (in contact) been subjected to the same pressure, in the Taconic region, both have usually been folded, the schist in smaller folds, the quartzite in larger ones, but slip cleavage has been confined to the schist.[3]

The faults or fractures in slip cleavage belong rather to a process of "rock flowage" than to one of "rock fracture." As Heim [4] put it: "By real cleavage is always to be understood a cleavability of the material pervading the entire mass and visible in each little fragment." A light-green slate from Bartow County, Ga., shows planes 0.05 to 0.5 inch apart, carrying secondary chlorite along which the ribbon has been displaced 0.1 to 0.9 inch by faulting. The slaty cleavage, which is at right angles to the bed, does not seem to have been affected by these faults, nor has the slate been weakened. Such faulting would not come under Heim's definition of slip cleavage.

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[1] Peach, B. N., Kynaston, H., and Muff, H. B., Geol. Survey Scotland Mem., Expl. Sheet 36, p. 16, fig. 3, 1909.

[2] Pl. XIX, *A*, in U. S. Geol. Survey Bull. 239, clearly shows close jointing, not slip cleavage.

[3] U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, fig. 25, 1893.

[4] Heim, A., Mechanismus der Gebirgsbildung, vol. 2, p. 59.

GRAIN.

Sharpe's explanation for slates splitting more readily along the "grain" than across it is that the mineral particles lie with their flat surfaces parallel to the cleavage and their longer axes in the direction of the cleavage dip. A fracture across the cleavage and parallel to the dip is parallel to the longer sides of the particles, whereas one parallel to the strike of the cleavage is across both longer axes and sides.[1]

Renard [2] states that the scales of chlorite lie perpendicular to the cleavage—that is, about in the direction of the grain. Jannetaz's experiments[3] in reproducing grain have already been referred to (p. 14), and his experiments showing that the direction of the grain is that of the greatest elasticity are given on page 172.

Daubrée,[4] in one of his experiments, produced a lamination in the direction of pressure and motion, which is the relation of grain to pressure. It seems, therefore, that besides the cause assigned to grain by Sharpe there is the formation of exceedingly obscure vertical divisional planes in the direction of the pressure and the crystallization of secondary minerals along these planes.[5] The variation of the strike of the grain from the direction of the cleavage dip at Rimogne (Ardennes) is from 1 to 20°. At Fumay, in the same region, that variation is 6°.[6] At Rimogne the strike of the grain bisects the acute angle formed by two sets of joints. In some of the Ardennes slates plates of hematite lie in the "grain" and indicate its direction.[7] Watrin states that as the longer axes of distorted octahedra of magnetite all lie in the direction of the grain in some of the Ardennes slates, their combined magnetism gives a polarity to the slate in the direction of the grain and enables the quarrymen to ascertain its direction by the magnetic needle. A like arrangement of lenses and distorted cubes of pyrite characterizes the slate at Northfield, Vt. (see p. 122), and of folia of biotite in the slate of Arvonia, Va. (See p. 151.)

The same feature is occasionally seen in schists. Thus scales of biotite in a schist in Beekman and Pawling, Dutchess County, N. Y., and actinolite crystals in schist in Hubbardton, Vt., have their axes in any direction, but their flat sides are transverse to bedding and cleavage.

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1 Sharpe, Daniel, Geol. Soc. London Quart. Jour., vol. 5, p. 114, 1849.
2 Renard, A. F., Mus. roy. hist. nat. Belgique Bull., vol. 3, p. 235, 1884.
3 Jannetaz, E., Mémoire sur les clivages des roches (schistosité, longrain), et sur leur reproduction: Soc. géol. France Bull., 3d ser., vol. 12, p. 211, 1884.
4 Daubrée, A., Études synthétiques, p. 422, 1879.
5 Rosenbusch (Elemente der Gesteinslehre, fig. 73, p. 437, 1910) figures biotite scales transverse to cleavage.
6 Renard, A. F., op. cit., vol. 3, p. 3.
7 Daubrée, A., op. cit., p. 336.

The "grain" shows itself in a more or less obscure striation of the cleavage surface in a direction nearly parallel to the cleavage dip and locally to the dip joints. In some slates the grain is very conspicuous, as in that from Georgia sketched in figure 1.

In several of the Maine quarries the grain is abnormally nearly horizontal, but the bedding is steeply inclined. As the strike of the grain is about the same as the direction of the pressure which produced the cleavage, the logical inference seems to be that the folds at these quarries, if reconstructed, would be found to have a nearly vertical pitch, and this would have to be attributed to a secondary movement. The workmen at these quarries speak of the slate as being "on end." The slate blocks are broken along the grain to reduce them to workable proportions, and as the grain is the direction of weakness, roofing slates are always cut with their long sides parallel to the grain, but in some localities there is hardly any grain.

In making thin sections for the microscopic studies for this bulletin the writer obtained fresh specimens from the quarries with the grain direction marked on them by the foremen. Thin sections were then prepared transverse to the cleavage and parallel to the grain and also at right angles to it. Where any difference is noticeable between the two sets it consists in the presence of large flakes of chlorite with their flat sides lying in the grain direction or in the longer axes of lenses and crystals lying also in that direction, and, where the sections are very thin indeed, in many small scales of muscovite being similarly oriented. Where the matrix is very micaceous and not obscured by carbonate or other minerals, sections parallel to the grain polarize more brilliantly than those across it.

JOINTS.

Nature of joints.—Joints are simply ruptures of continuity due to various strains. Exceptionally later movements may cause slippage along joint planes and result in polishing the joint faces (slickensides). The usual character of joint planes, however, points to a sudden rupture of large masses of rock affected in all its parts by one and the same mechanical expression of energy.[1] The same stress may produce several sets of joints.

Sedgwick[2] termed the three commoner kinds of joints occurring in slate regions strike joints (joints parallel to the strike), dip joints (joints parallel to the direction of the dip), and diagonal joints (joints diagonal to strike and dip)—terms which ought to be ever kept in use. To these should be added horizontal joints (bottom or flat joints), which in some slate regions are of much economic importance.

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[1] Loretz, H., Über Schieferung, pp. 98-100, 1880.

[2] Sedgwick, Adam, A synopsis of classification of the British Paleozoic rocks, p. 35, London, 1885.

Rogers[1] called attention to the parallelism of joints to dikes in Pennsylvania, a parallelism previously observed in England. This is so true in western Vermont that the proximity and course of a dike can be foretold by the prevalence of certain diagonal joints. Some joints are open and filled with vein matter; more commonly, when scarcely parted, they have their sides coated with crystals of chlorite, calcite, gypsum, pyrite, barite, anatase, etc.

Curved joints.—Exceptionally joint planes undulate like bedding planes across both bedding and cleavage. (See Pl. XVIII; also p. 157.) This may be attributed to a compression similar to that which produced the undulating sheet structure in granite. The joints shown in Plate XVIII could hardly have been produced by the flexure of a flat joint by secondary movement without faulting the syncline itself. The flat joint near the surface of the Peach Bottom slate belt, with its mass of crushed slate, is probably also of secondary origin.[2]

At Foulk Jones & Sons' quarry at Slate Hill, 2 miles northeast of Delta, Pa., a curvature in jointing has produced a conical structure 20 to 30 feet high and 15 feet in diameter at the base. In view of the peculiar curvature of fractures across the cleavage of slate resulting from the use of explosives such conical forms may also be the result of shock.

Plicated joints.—In the quarry just referred to a vertical dip joint filled with quartz three-twentieths of an inch thick is in plications from one-fourth to one-half inch wide. These plications may have been due to the zigzag course of the original fracture. Some finely plicated jointing has, however, a different history. Near the extreme north end of the slate belt of western Vermont (more exactly, one-fourth mile north of the northwest end of Hincum Pond, in Sudbury, Rutland County) there is a gray slate with a micaceous matrix in which bedding is clearly indicated by the alternation of small carbonaceous beds with noncarbonaceous beds, and also by minute beds with quartz grains as much as 0.1 millimeter in diameter alternating with beds without any quartz. All these beds are crossed at an angle of 40° by slaty cleavage, and both bedding and cleavage are crossed by joints which in places are plicated, measuring an inch from crest to crest, but they are plicated in two directions. In some parts of the rock these joints are only one-fourth inch apart and are parted from one-tenth to one-fifth inch, the openings being filled with banded veins of quartz and fibrous calcite. The solution of these veins at the surface has left a series of plicated gaping joints crossing both

[1] Rogers, H. D., Geology of Pennsylvania, vol. 2, pt. 2, p. 912, fig. 718 (joints in red shale parallel to dike), fig. 719 (joints in argillaceous sandstone), 1858.

[2] See, on curved joint planes in the Peach Bottom district, Mathews, E. B., Maryland Geol. Survey, vol. 2, p. 223, Pl. XXII, fig. 1, 1898.

bedding foliation and slaty cleavage. Under the microscope these joint veins are seen to consist on either side of a border of vein quartz, followed by a band of calcite fibers, then a band of quartz, and a central band of gently curving calcite fibers with a central parting containing a little quartz at intervals. The slate between these joints also shows a slip cleavage crossing bedding and slaty cleavage in the general direction of the joints but not plicated. The history of this slate thus appears to be: (1) The folding of a mass of marine sediments of alternating composition and the formation of slaty cleavage at an angle of 40° to the folded beds; (2) compression along the strike resulting in slip cleavage; (3) the elongation of the mass along the strike, producing open joints; (4) compression, both in the direction of the dip of the slaty cleavage and in a direction at right angles to that, thus plicating the joints in a twofold way; (5) the infiltration of SiO_2 and $CaCO_3$ in alternation into the open joints, resulting in banded veins; (6) the solution of the $CaCO_3$ by carbonic and organic acids and the crumbling away of the SiO_2 in consequence of exposure by erosion. Such a slate shows what complex structures successive crustal movements may produce in ordinary sediments as well as how fatal such movements may be to the commercial value of slate. These joints were probably first formed by elongation and thus are different from ordinary joints.

FAULTS.

Faults of no great magnitude are common in slate regions. The fault plane is frequently a cleavage or a joint plane. From the shear involved in slaty cleavage reversed faults are more common in slate than normal faults.[1] Minor faults in slates from the western Vermont region are shown in Plate IV, *C, D*. One of these is a normal fault, the part overlying the fault plane having slid down; the other is a reverse fault, the similar part having been forced up. A microscopic section across the reverse fault shows the sharp bending of the beds at the fault plane and the deposition of a thickness of one-sixteenth of an inch of vein matter in bands along that plane. This matter consists of chlorite, calcite, and quartz.

Some of the slate slabs in the sidewalks of the villages of the Vermont-New York slate belt are finely faulted. The slate of Bolivar, Ga., is similarly faulted, but diagonally to the grain, and possibly the faulting occurred prior to the setting up of slaty cleavage. Faulting may occur both along the cleavage and along the grain—that is, in two directions at right angles to each other.[2]

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[1] See Herbert, E. J., Reversed faults in bedded slates: Geol. Mag., new ser., dec. 2, vol. 4, p. 441, 1877.

[2] Such faulting occurs in the Hudson slates of Rensselaer County, N. Y. (U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, Pl. CI, p. 320, fig. 26, 1893). See also, in this connection, Teall, J. J. H., A faulted slate slab: Geol. Mag., dec. 3, vol. 1, Pl. I, London, 1884.

The dropping of a block of some superjacent valueless strata into a mass of commercial slate between two fault planes is a possibility that should not be overlooked in slate quarrying.

SHEAR ZONES.

The terms "shear zones," "zones of shearing," "Knickungsebenen," and "Querknicke" apply to one and the same feature. Rosenbusch,[1] Brögger,[2] Reusch,[3] and Turner[4] describe shear zones in Norway, Saxony, Alsatia, and California. Their occurrence in the slate belt of eastern New York and western Vermont is fully described below. The writers cited explain this feature as an angular plication, or a series of such plications, due to shearing pressure on somewhat rigid material. In places the pressure was great enough to produce a slight faulting on either side of the deflected portion or zone. Very rarely a cleavage foliation is produced within the zones. Turner's term, abbreviated to "shear zone," affords a convenient designation, with the understanding, however, that in this sense it applies only to sedimentary rocks.

The term "hogback" is used by coal miners to describe a sharp rise in the floor of a coal seam. The propriety of its application in slate quarries is not so obvious. It is used there to designate peculiar bends or fractures, which consist of two angular bends in opposite directions and near each other, traversing a mass of slate. These flexures may merge into fractures, and the slate between the two planes of fracture is broken into small fragments. The two bends or fractures may be from one-sixteenth of an inch to 4 feet apart. At one of the old quarries at Middle Granville, N. Y., a slate surface shows within a space of 4 inches four shear zones from one-sixteenth to one-fourth inch in width. Another has six in a space of 6 inches. At one of the quarries at Arvonia, Va., a mass 5 feet thick is traversed by numerous shear zones. As these zones generally traverse the cleavage diagonally, the blocks of slate adjacent to them come out in triangular form and thus occasion much waste. The strike of some of the shear zones in western Vermont is parallel to that of several of the dikes, and both may have been formed under the same stress. Figures *E*, *G*, and *I*, Plate XXIII, and figures *L*, *U*, and *V*, Plate XXIV, show the relations of shear zones at several quarries. Plate VIII, *A*, shows the microscopic structure of the "hogback" of Plate XXIV, *V*. The section was made where the bends had not as yet developed into complete fractures. The entire

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[1] Rosenbusch, H., Die Steiger Schiefer, p. 95, 1877.

[2] Brögger, W. C., Die silurischen Etagen 2 u. 3 im Kristiania Gebiet auf Eker, p. 216, fig. 31, Kristiania, 1882.

[3] Reusch, H., Die fossilienführenden krystallinischen Schiefer von Bergen in Norwegen; German translation by R. Baldauf, pp. 52, 53, fig. 35; and p. 38, fig. 23, Leipzig, 1883.

[4] Turner, H. W., Further contributions to the geology of the Sierra Nevada: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, p. 662, fig. 22, 1896.

width of the shear zone is nine-tenths of an inch. Between the two sides is a system of cracks crossing the cleavage at an angle of 15°; another system crosses the cleavage at 25° and extends beyond one side. This may be the original bedding. Both of these systems of cracks are filled with secondary calcite. Another set, likewise filled with calcite, crosses the cleavage here and there about at right angles, but in zigzag. (See figs. *B*, *C*, *D*, Pl. VIII.) These cracks, farther on in the quarry, become continuous fractures. The secondary fractures within the zone probably result eventually in breaking up the slate, as it occurs usually in fragments within a fully developed shear zone. The observations at this quarry were: Strike of bed N. ±, dip 30° E.; strike of cleavage N. ±, dip 42°–45° E.; strike of shear zone N. 35°–40° E., dip 65° NW. In this quarry the strike of the shear zone corresponds to that of the diagonal joints of the region and of a number of the dikes. Figures *E* to *L*, Plate VIII, illustrate the development of a shear zone still further. In figure *L* the diagonal fractures are filled with quartz, and a slip cleavage also occurs. Other observations of shear zones are given in the quarry tables, pages 137, 138.

CLEAVAGE BANDS.

While characteristic of slate regions, cleavage bands do not occur or have not yet been reported in commercial slate. They would be quite as objectionable as shear zones.

Plate XI, *B*, is made from a photograph taken by the writer at a locality in Rupert, Vt., found by L. M. Prindle. Cleavage banding is of common occurrence in the Vermont and New York slate belt and in the schist mass east of it, although not always as well shown as at this point. It resembles the shear-zone structure just described but presents further stages. The rock shown in Plate XI, *B*, is divided into alternate bands of hard, uncleft quartzose shale and bands of very finely cleft shale. The bedding zigzags across both bands. The material of both bands was originally identical. The present differences are the result of a difference in the amount of motion—that is, of slip cleavage—along alternating strips of rock and of the consequent difference in resistance to erosion. There is also a difference in color, some infiltration of limonite having taken place along the more highly cleft bands.

A similar structure in purple slate is shown in figure 3 (p. 47), but here the bands themselves have slipped.[1] Small beds of green slate indicate the course of the stratification and show the amount of slippage suffered by the bands.

Along Poultney River about a mile east of East Poultney certain hard bright-green and purple slates near the schist mass show the

[1] See also U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, pp. 561-564, figs. 88-91, 1896.

PLATE VIII.

Shear Zones.

A. Diagram of thin section of "sea-green" Cambrian slate from Williams & Edwards's quarry in Wells, Vt. Enlarged 2 diameters. Section across the cleavage and an incipient shear zone, showing the two bends in opposite directions and developed in but two places into fractures. Secondary fractures at 15° to cleavage cross the zone. A calcareous strip, possibly a trace of bedding, crosses the cleavage at 45°. All the fractures filled with calcite.

B, *C*, *D*. Microscopic drawings from thin section shown in *A*, enlarged 40 diameters, showing in reversed position the outlines of several of the vertical and diagonal fractures within and at edge of zone.

E. Diagram from specimen of shear zone, from E. E. Lloyd's sea-green slate quarry, Poultney, Vt.

F. Slate from within a fully developed shear zone, showing outline of fracture. Same location as *E*.

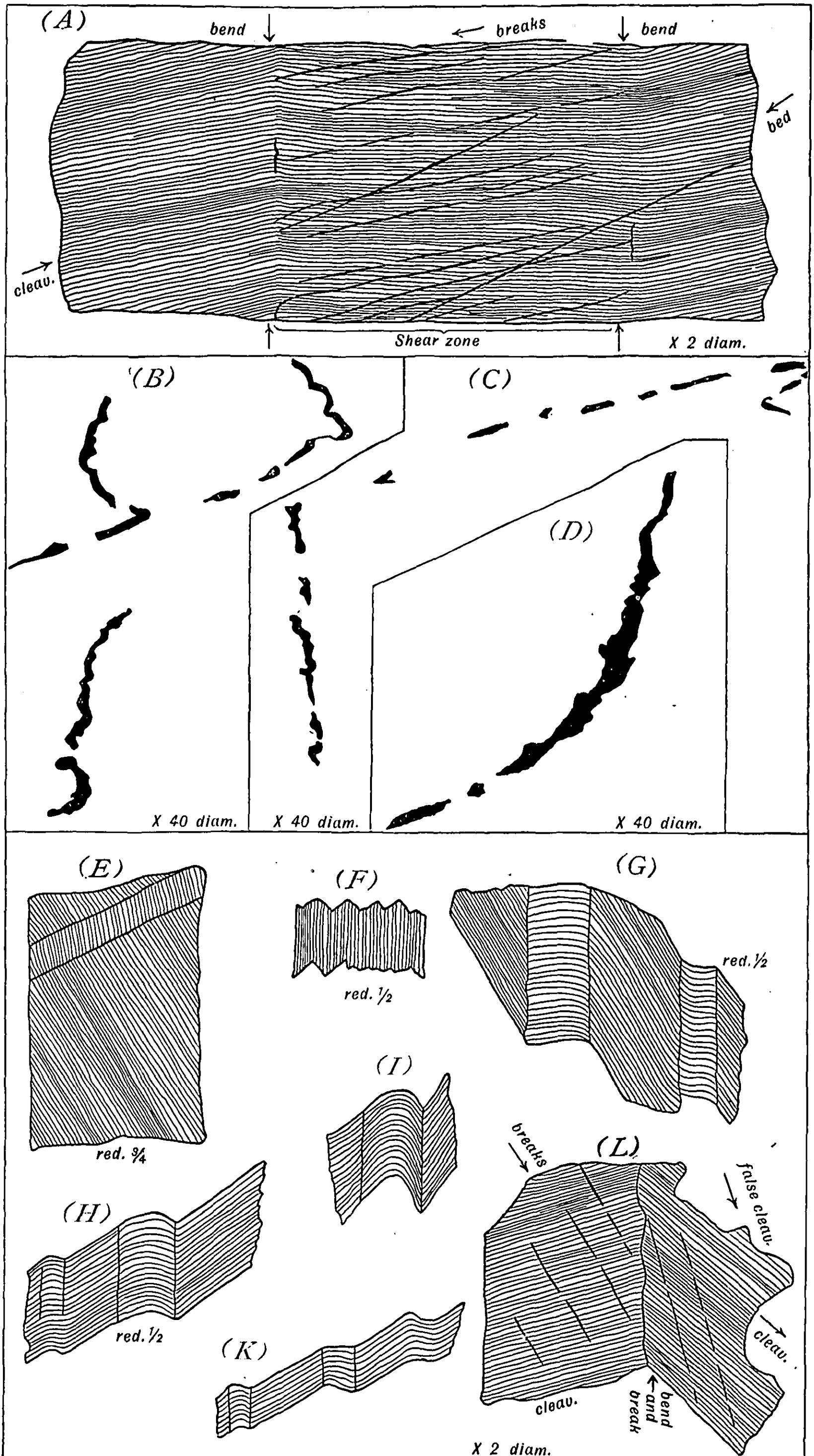
G. Slate showing two shear zones. Same location as *E*.

H. Diagram from specimen of Cambrian slate from Eddy Hill, Fair Haven, Vt., showing development of shear zones. Secondary quartz occurs along the fractures. One-half natural size.

I. Shear zone in Ordovician schist 1½ miles east of Rupert, Vt.

K. Diagram from specimen from top of the Pattern, in Pawlet, Vt.

L. Diagram from thin section of Cambrian slate from Eddy Hill, Fair Haven, Vt., enlarged 2 diameters, showing one of the main fractures of a shear zone with diagonal fractures which are filled with quartz, and beside it slip cleavage.


(A)
bend
breaks
bend
bed
cleav.
Shear zone
X 2 diam.
(B)
X 40 diam.
(C)
X 40 diam.
(D)
X 40 diam.
(E)
red. 3/4
(F)
red. 1/2
(G)
red. 1/2
(I)
(H)
red. 1/2
(K)
breaks
(L)
false cleav.
cleav.
cleav.
bend and break
X 2 diam.

SHEAR ZONES.

cleavage banding well. In breaking up such a rock the denser uncleft parts come out in slablike blocks, the larger surfaces of which lie transverse to the bedding.

Becker[1] explains this structure by the alternate interference and coincidence of waves of vibration produced by shock. Where the waves of vibration coming from opposite directions coincide, cleavage fractures—that is, planes of slip cleavage—will be numerous.

Van Hise[2] regards such structures simply as the result of the concentration or sparseness of slip cleavage.

In the ledge figured in Plate XI, *B*, there are between 360 and 530 such planes to the inch in the cleft bands. The hard bands in the same ledge show as many fractures, but they are discontinuous or merely incipient. Both hard and soft bands consist of stratified

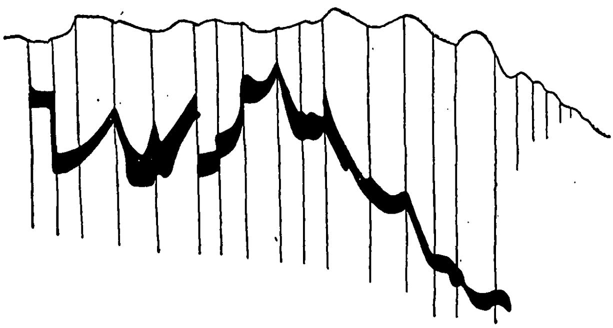


FIGURE 3.—Cleavage banding showing slippage of bands, at brook in Gorham, Poultney, Vt.

shale made up of quartz fragments, muscovite and chlorite scales, etc., but in the soft bands the pressure has in places brought about sufficient alignment of the muscovite to produce aggregate polarization, not in the direction of the slip cleavage but in that of the bedding. There has also been a formation of sericite along the slip-cleavage planes, and thus the rock is becoming a schist.

In a piece of sericite schist from the mass east of Rupert the rock consists of alternating strips with and without slip cleavage, those without being wider. The slip-cleavage planes meander about and run into one another, though having a general parallelism. The pli-

[1] Finite homogeneous strain, flow, and rupture of rocks: Geol. Soc. America Bull., vol. 4, Jan., 1895. On page 16 he says: "Thus there seems sufficient reason to believe that a pressure very rapidly applied, producing primary ruptures attended by schock, will be immediately followed by secondary ruptures in the same direction as the others at intervals dependent upon the wave length of the impulse. In much the same way a high explosive shatters a rock far more than black powder. A phenomenon of which no explanation has been offered in this paper is that of thick slates and of those flags which are to be considered as very thick slates. These, though cleavable in a certain thinness are not capable of further splitting. Such rocks indicate a flow which is not uniformly distributed through the mass but on the contrary passes through maxima at intervals corresponding to the thickness of a slate or flag. It is possible that at the inception of strain such masses were in a state of tremor so intense that the interference of waves determined surfaces along which flow began. These surfaces would be weakened by the flow, and further strain would be distributed among them rather than over the intervening solid sheets. Effects of a similar kind are produced on a pile of sheets of paper, such as 'library slips,' resting on an inclined cloth-covered table which is jarred by rapid blows."

[2] Principles of North American pre-Cambrian geology: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, pp. 662-664, 1896.

cation is much more intense and irregular in the cleft strips and also appears to be more sericitic there.

In all these cases the fractures are the result of the plications.

It seems probable that the shear zones represent but a variation of the process involved in the cleavage bands. The force bent and crushed the slate in the bands instead of producing very numerous planes of slip cleavage within them.

VEINS.

Quartz veins, or "flints," as the quarrymen call them, are a striking feature of slate beds and a cause of perplexity in quarrying. They appear at the most unexpected points, ramify very irregularly, and disappear as abruptly. Plate V, *A*, from a photograph taken at the old quarries at Jamesville, N. Y., shows a good type of such veins of segregation. Some of these veins show a rough parallelism. They may occur partly in the bedding and partly in the cleavage or may cross both bedding and cleavage, their general dip being roughly at right angles to that of the cleavage and their strike probably not very different from that of cleavage and bedding. Such veins may be several hundred feet long and several feet thick or may form lenses several feet in length. At Benson, Vt., and Ijamsville, Md., small joint veins of fibrous calcite form series of gashes "en échelon." The fibers or prisms lie transverse to the course of the vein. Daubrée[1] regards such veins as due to stretching. It is evident that the material of the veins described, of whatever sort, must have come from the adjacent slate itself, and also that it was deposited in solution.

In the cases adduced there is some relation between the foliations of the slate and the course of the veins, but some veins appear to be quite lawless, crossing in every direction, anastomosing, intersecting one another, and in places inclosing fragments of the adjacent slate and constituting the cement of a brecciated mass. That the veins are the result of various secondary stresses, producing openings of more or less irregularity, is manifest. Where the stress ceased to operate the vein tapers out; where the stresses were complex the veins are complex also.

The material which filled the openings thus made is chiefly quartz, commonly "milky" in color and in many places finely crystallized in small cavities. With the quartz are often associated chlorite, biotite, calcite, and possibly dolomite. The chlorite locally occurs in hexagonal scales, in vermicular aggregations, or in tortuous columns. Some of the smaller veins are banded, presenting alternations of quartz and fibrous calcite, or of quartz and rhombs of calcite, like those in plicated joints described on page 42. Here and there the quartz contains cavities measuring from 0.002 to 0.005 millimeter in diameter, filled with fluid, each containing a moving vacuole, as in

[1] Daubrée, A., Géologie expérimentale, p. 144, fig. 166, 1879.

the quartz of granites.[1] Galenite in small particles was found in veins in the quarries at Jamesville, N. Y.

NODULES.

In some of the western Vermont quarries very hard lenticular nodules, a few inches in diameter, occur along the bedding planes. They consist of a quartzite nucleus containing much calcite and large scales of muscovite surrounded by slaty layers carrying calcite, quartz, and muscovite scales. Pyrite is disseminated throughout both nucleus and outer zone. Such nodules are evidently of sedimentary origin.

Müller[2] describes concretions of pyrite and quartz in the slate quarries of Thüringen and observes that the slate in their vicinity is of superior quality, containing less pyrite than it does at a distance from the nodules. The explanation is that all the pyrite has congregated in the large nodules instead of being more widely disseminated in small crystals. The nodules are thus of economic advantage.

DIKES.

Volcanic dikes are not uncommon in slate deposits. Aside from the very exceptional one described by Mr. Eckel on page 68, dikes are almost as detrimental as veins. They are usually more regular than veins of segregation, and, as stated under "Joints," their proximity is likely to be indicated by an abundance of joints parallel to them. For several feet on each side of the dike these joints become very close and are in places crossed by an equally numerous set of horizontal joints, thus breaking up the slate into small blocks. At Arvonia, Va., the quality of the slate a little beyond the dike is better than it is farther away, so that a dike traversing a slate deposit is not necessarily without economic value.

GEOLOGIC RELATIONS OF SLATE.

In view of the origin and structure of the marine sedimentary slates it is evident that such slate deposits are to be looked for along the borders of or in proximity to granitic land masses where the dominant pressure has come mainly from one direction and where it has not been sufficiently intense to result in extreme metamorphism. The slate belt of Maine lies not far south of a granitic area. Two of the slate belts of Vermont are but a few miles west of the Green Mountain granitic axis and two others east of it. In eastern Pennsylvania, West Virginia, and Maryland the slates lie not far northwest of a granitic area, and the slate of Virginia is not many miles southeast of one.

From the facts brought out in considering the structure of slate it is also evident that slate belts generally bear evidence of more

[1] Dale, T. N., The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: U. S. Geol. Survey Bull. 354, pp. 42-47, 1908.

[2] Müller, F. E., Die normalen Schiefer des Hennbergs: Neues Jahrb., 1882, vol. 2, p. 218.

than one crustal movement. Along the entire Appalachian province, where at least two major mountain-making movements occurred—the Ordovician and the Carboniferous—and where the slates are mostly of Cambrian or Ordovician age, they must needs show the effect of at least one disturbance of the slaty cleavage.

Where, as in western Vermont and eastern New York, slates of two geologic periods occur in proximity, and where one is even superposed on another, the question of their mutual relations becomes of economic and scientific importance.[1] There was here at the close of Lower Cambrian time a crustal movement which resulted in the cleavage of the Lower Cambrian sediments and their emergence They were afterward in places submerged and received Ordovician deposits, which, at the close of Ordovician time, were folded and also received a slaty cleavage. Moreover, the folds of both periods are overturned.

CHEMISTRY OF SLATE.

CHEMICAL COMPOSITION.

Comparatively few complete chemical analyses of roofing slates have found their way into scientific literature. Several of the rare elements are usually omitted. FeO and Fe_2O_3 are not distinguished, nor CaO and CO_2, so that several of the percentages are more or less misleading. Fourteen selected analyses, all but one from European sources, are here given for reference.

Selected analyses of roofing slates.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Silica (SiO_2)	58.30	61.57	65.63	61.43	67.56	59.35	55.880	55.06	60.68	60.17	56.71	56.92	57.23	63.06
Titanium dioxide (TiO_2)	.23	1.31	.94	.73	......	1.00	1.270	......	.59	1.15	.70	.90	.89	.73
Alumina (Al_2O_3)	21.89	19.22	20.20	19.10	12.23	13.56	21.849	22.55	21.20	18.89	14.43	16.41	20.43	18.03
Ferric oxide (Fe_2O_3)	7.05	6.63	2.72	4.81	2.87	1.10	......	1.97	5.68	6.17	1.98	.53	1.33	2.24
Ferrous oxide (FeO)	2.57	1.20	.85	3.12	6.99	4.75	9.033	5.96	.46	.95	3.65	3.52	5.64	4.07
Lime (CaO)	.39	.22	.19	.31	.27	5.20	.155	1.30	1.71	1.75	3.83	2.94	1.54	.81
Baryta (BaO)	......	......	......	......	......	......	......	......	......	.04	.04	.03	.02	......
Magnesia (MgO)	1.09	2.00	1.54	2.29	3.03	3.60	1.495	2.92	.88	1.85	3.47	3.14	2.49	2.21
Potassa (K_2O)	2.45	3.63	3.81	3.24	1.76	1.77	3.640	3.82	3.64	2.76	2.61	3.27	2.39	3.07
Soda (Na_2O)	1.18	.93	.71	.83	1.28	1.48	.460	2.17	2.09	1.39	2.59	1.47	3.97	1.51
Carbon dioxide (CO_2)	......	......	......	......	......	4.45	......	......	......	1.04	3.71	2.68	......	None
Carbon (C)	......	......	......	......	3.11	......	1.794	......	.07	......	.77	1.54	Trace	......
Manganous oxide (MnO)	......	......	......	......			0.586	......		0.20	0.06	0.16	0.05	0.30
Phosphoric oxide (P_2O_5)	......	......	......	......	0.10	0.31	......	......	0.16	.11	.05	.09	.54	.06
Sulphuric oxide (SO_3)	......	......	......	......			.022	......		......	.12	.10	.03	.09
Water (H_2O)	4.61	3.25	3.17	3.52	1.00	3.41	3.385	4.35	2.88	a3 70	a2.74	a2.21	3.94	a3.62
Pyrite (FeS_2)	......	......	......	......	......	......	.051	......	......	......	2.64	3.97	......	......
Cobaltous oxide (CoO)	......	......	......	......	......	......	Trace	......	......	......	......	......	......	......
	99.76	99.96	99.76	99.38	100.20	99.98	99.801	100.10	100.04	100.17	100.10	99.88	100.09	99.80
Specific gravity [b]	2.81	......	......	......	......	......	c2.89	2.78	......	......	......	......	......	2.83

a Combined water.

b The specific gravity of the Festiniog black slates of Wales was determined as 2.751 at the physical laboratory of Williams College in 1899. Since the publication of Dr. Hillebrand's note on the slates of New York and Vermont, Reade and Holland find as a mean of 13 Welsh slates Cr_2O_3, 0.003; V_2O_5, 0.032; ZrO_2, 0.022. See Liverpool Geol. Soc. Proc., 1900–1901, p. 101 and table.

c Specific gravity from Merriman.

[1] See U. S. Geol. Survey Bull. 242, 1905.

1. Gray roofing slate, best quality, Delabole, Camelford, Cornwall; two analyses by J. A. Phillips, London, Edinburgh, and Dublin Philos. Mag., 4th ser., No. 27, pp. 95–96, Feb., 1871.
2. Purple roofing slate, Fumay, Ardennes, northwest France; by A. Renard, Recherches sur la composition et la structure des phyllades ardennais; Mus. roy. hist. nat. Belgique Bull., vol. 1, p. 239, 1882.
3. Green roofing slate beds from purple, Fumay, Ardennes, as above.
4. Blue-gray roofing slate, La Richolle quarry, Rimogne, Ardennes, northwest France; by Klement; Renard, A. F., op. cit., p. 233.
5. Roofing slate (probably black, Devonian), Westphalia; by H. von Dechen; Roth, J., Allgemeine und chemische Geologie, vol. 2, pp. 586, 587, 1884. (No. 107.)
6. Roofing slate (color not given, Devonian), Frankenberg, near Goslar, in Prussia; by A. von Groddeck; Preuss. geol. Landesanstalt Jahrb. 1885–86; quoted by Roth, J., op. cit., pp. 586, 587.
7. Black roofing slates (Peach Bottom) from J. Humphreys Co.'s quarry half a mile east of Delta, York County, Pa.; by Andrew S. McCreath, Second Geol. Survey Pennsylvania Rept. Prog., vol. CCC, pp. 269, 270, 1880.
8. Bluish roofing slate of Carboniferous age, Mohradorf, near Wigstadl, Austrian Silesia; by Nikolic, Min. pet. Mitt., 1871, p. 207; quoted by Roth, J., op. cit., pp. 588–589.
9. Blue slate, Glyn quarries, Llanberis, Wales; analysis made at Museum of Practical Geology, London, for George Maw, Geol. Mag., vol. 5, p. 123, London, 1868.
10. Reddish roofing slate (best), Alexandra quarry, Moel Tryfaen, North Wales; by Reade and Holland, Liverpool Geol. Soc. Proc. 1899–1900. (No. 1.)
11. Very dark banded roofing slate, Llansantfraid, Glyn Ceiriog, near Llangollen, North Wales; by Reade and Holland, op. cit. (No. 2.)
12. Very dark roofing slate, Moel Ferna, North Wales; by Reade and Holland, op. cit. (No. 3.)
13. Green roofing slate from quarry between Camlyn and Cemmaes, Anglesey; by Reade and Holland, op. cit. (No. 4.)
14. Green roofing slate, Velenhelli, Wales; by Reade and Holland, op. cit. (No. 6.)

The 15 complete analyses of New York, Vermont, and Pennsylvania roofing slates made by the chemists of the United States Geological Survey and given under the descriptions of those slates are summarized in the following table. Wherever several analyses were made of one kind of slate the average is given. The rarer elements and water below 110° C. have here been thrown together.

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 and water below 110° C	.66	.77	.69	.51	.39	.56	.70	1.11	.67
	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.

If analysis K^2 of red slate on page 92 is included with the four others, the Fe_2O_3 in the red slates would range from 3.48 to 7.10 per cent and would average 5.08. Comparing, then, the amount of Fe_2O_3 in the colored slates, we shall find that it steadily increases from the variegated to the purple and to the red, as the microscopic sections show.

On the other hand, there is a decrease of FeO in passing from the unfading green to the variegated, sea-green, bright green, purple, and red. This decrease corresponds to and is probably consequent on the decrease of chlorite, a hydrous silicate of MgO and FeO.

There is more lime (CaO) and carbon dioxide (CO_2) in the Lehigh slate than in any of the others. There is less CaO and CO_2 in the unfading green and in the variegated analyzed than in any of the other slates.

There is less pyrite (FeS_2) in the red and most in the black.

Dr. Hillebrand's discussion of the analyses of slates from New York and Vermont and of the causes of the discoloration of the sea-green slate is given on pages 55–59. While his investigation was undertaken primarily to determine the cause of discoloration in one kind of slate, microscopic analyses show that discoloration in the black slates of Pennsylvania is also greatest where carbonate is most abundant. It is safe to assume that ferrous carbonate plays an important part in the discoloration, not only in these slates but in all slates. The red slates of New York contain much carbonate but do not discolor, the carbonate probably not being ferrous.

These 29 analyses are sufficient to give within certain limits the essential chemical composition of commercial slate of aqueous sedimentary origin.

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		

For comparison a composite analysis of 51 American Paleozoic shales made by H. N. Stokes, of the United States Geological Survey,[1] is added, the unessential elements being omitted.

Composite analysis of 51 Paleozoic shales.

Silica	60.15	Soda	1.01
Alumina	16.45	Magnesia	2.32
Ferric oxide	4.04	Lime	1.41
Ferrous oxide	2.90	Water above 110° C	3.82
Potash	3.60		

As these figures come between the extremes of the slate analyses, and as the analyses of numerous clays and some schists do also,[2] it is evident that a chemical analysis of a slate is not sufficiently characteristic to prove that it is not that of a shale, a clay, or a schist. Indeed, but for the low maxima for soda (2.17, 2.59, and 3.97 per cent) in three out of the 29 analyses, and the high minima for com-

[1] U. S. Geol. Survey Bull. 168, p. 17 (B), 1900.

[2] For clays see Ries, Heinrich, Technology of the clay industry: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 4, pp. 523–575, 1895; also Prof. Paper 11, 1903. For schist, see Clarke, F. W., and Hillebrand, W. F., Analyses of rocks, etc.: U. S. Geol. Survey Bull. 148, p. 221 (L) and p. 99 (K), 1897.

bined water, many granites, syenites, porphyries, diorites, and basalts could pass chemically as roofing slate. It follows from the foregoing discussion that while considerable scientific interest attaches to the chemistry of slate there is little correlation between its chemical composition and its physical properties. These depend primarily on its texture and secondarily on its mineral composition, and both of these are best determined by microscopic examination.

That there should be chemical similarity between slate, shale, and clay results primarily from the fact that the slate here considered is simply metamorphosed shale and that shale is compressed clay. Whatever mineralogic changes metamorphism brought about, the same elements persisted. In some mica slates the grains of quartz, feldspar, zircon, and other minerals are the identical ones of the original clay sediment. The economic bearing of the chemical analyses of slates will be brought out under "Methods of testing slate," in the section on economic geology (p. 180).

CHEMICAL CHANGES IN WEATHERING.

The changes in substance and color which slates undergo in weathering are striking. The black slate of the Peach Bottom district (Pennsylvania and Maryland) and of Buckingham County, Va., passes into a bright reddish-brown clay; the black slate of Lehigh and Northampton counties, Pa., passes into a yellowish ocherous clay and finally into a white clay; and the black slate of Rockmart, Ga., passes into a bright yellow ocherous clay. These alterations will be referred to in the descriptions of each district. These changes in weathering should not, however, be confounded with the relatively slight discoloration which slates on the roof undergo during a fraction of a century or even several centuries. The former changes required tens of centuries.

G. P. Merrill[1] has investigated the weathering of the Peach Bottom slate and has shown that in the passage from the black slate to the red clay the following losses occur: 57.57 per cent of the SiO_2, 8.78 per cent of the iron oxides, all the lime, 28.16 per cent of the MgO, 77.95 per cent of the K_2O, and 99.64 per cent of the Na_2O. All the Al_2O_3 remains, as well as the water. A piece of Peach Bottom slate in the first stages of weathering, examined microscopically by the writer, shows the magnetite crystals and lenses passing into hematite and the andalusite crystals becoming limonitic from the oxidation of its ferruginous inclusions.

In connection with some chemical analyses of slates from Lehigh County, Pa., Dr. Hillebrand made some partial analyses of a piece of black slate from a ledge near the Berks and Lehigh county line, 1¼ miles north-northwest of Rothrocksville, on the road to Hynemansville, in which the stages of weathering were finely shown.

[1] Rocks, rock weathering, and soils, New York, 1897.

Analysis A represents the black but slightly altered part of the slate; B the greatly altered white part of the same specimen. The alteration has proceeded first along the bedding planes, which there undulate in a vertical direction, and from these along the cleavage, which dips only about 12°. These analyses, when compared with analysis A of fresh black slate from the Slatington quarries (see p. 108), 14 miles farther north-northeast, show a probable loss of 4 per cent of CaO during a still earlier stage of weathering.

Analyses of weathered slates from Pennsylvania.

	A	B
Silica (SiO_2)	65.56	68.81
Alumina (Al_2O_3) / Phosphoric oxide (P_2O_5)	17.06	16.44
Ferric oxide (Fe_2O_3) / Ferrous oxide (FeO)	4.19	3.14
Magnesia (MgO)	1.31	1.00
Lime (CaO)	.20	.20
Soda (Na_2O)	.26	.27
Potassa (K_2O)	3.81	4.32
Water (H_2O)[a]	7.09	5.33
Titanium dioxide (TiO_2)	.68	.77
Carbon dioxide (CO_2)	None.	None.
Sulphur (S)	.02=.04 FeS_2	....
	100.18	100.28

[a] Including carbonaceous matter.

A thin section of another specimen from the same ledge, made across both dark and light parts, shows under the microscope:

1. Absence of carbonate in both parts, the carbonate having been previously dissolved out.

2. Many spherules of pyrite in the dark part, some of which, altered to limonite, still remain in the white part.

3. Quartz grains, equally numerous in both parts.

4. Muscovite (sericite) much more conspicuous in the light than in the dark part.

To the above data should be added two analyses, by Dr. Hillebrand, of white "shale clays," which are regarded as the residual product of the weathering of the black slate.

Analyses of shale clays from Lehigh County, Pa.

	C	D
Silica (SiO_2)	64.50	75.77
Alumina (Al_2O_3)	[a] 21.67	[b] 15.30
Ferric and ferrous oxide (Fe_2O_3 and FeO)	1.83	....
Magnesia (MgO)	1.09	.81
Lime (CaO)	.18	.20
Soda (Na_2O)	.20	Trace.
Potassa (K_2O)	4.26	2.85
Water above and below 110° C. (H_2O)	[c] 5.65	4.69
Titanium dioxide (TiO_2)	.85	.36
	100.23	99.98

[a] Including P_2O_5. [b] With trace of Fe_2O_3 and (perhaps) P_2O_5. [c] Ignition loss.

C. White "shale clay" quarried for fire clay half a mile south of Fogelsville, Upper Macungie, Lehigh County, Pa.

D. White "shale clay" associated with limonite one-fourth mile northwest of Guth station, South Whitehall, Lehigh County, Pa.

The significance of these analyses and microscopic examinations is that this slate in weathering first loses its carbonate, then its carbonaceous matter, then its pyrite, and has its feldspathic material, if any, changed to kaolin, while its muscovite remains partly unaltered and its quartz largely so. The bleaching process in the slates of Lehigh and Northampton counties, Pa., apparently proceeds by these steps:

1. Removal of carbonates of lime and magnesia, accompanied by oxidation of the ferrous carbonate and deposition of limonite.
2. Oxidation and removal of carbon; also oxidation and removal of pyrite.
3. Removal of almost all limonite.

In general, therefore, while slate in weathering returns to a clay, this clay differs from that in which the slate must have originated, in some places by the absence of carbon and the small amounts of silica, potash, and soda, and in others by the absence or extremely low percentages of carbon, lime, and iron.

CHEMICAL COMPOSITION OF THE ROOFING SLATES OF EASTERN NEW YORK AND WESTERN VERMONT.

By W. F. Hillebrand.

Before the analyses of any of the slates were undertaken, it was well understood that the chief question of economic importance to be solved was the cause of fading observed in some but not all of the green slates after longer or shorter exposure to atmospheric influences. Attention was therefore primarily directed toward its elucidation, and the evidence accumulated will be herein set forth. Naturally, in the course of the work, opportunity was afforded for drawing conclusions as to the combination of certain chemical elements concerning which the microscope could furnish no satisfaction. A few remarks in this connection may therefore well be in place.

It soon became clear that there was no apparent connection between the percentage of iron sulphide (FeS_2) in any green slate and its liability to fade; that, furthermore, the visible sulphide was of an extremely resistant type, and often after years of exposure retained its original luster undimmed; that it was probably true pyrite. The possibility remained that there might be finely divided FeS_2 in the much more readily decomposable form of marcasite. Microscopical evidence made it clear that if present at all it was in amount altogether too trifling to produce the fading effect often observed.

It was found that the ferrous iron, other than that in the pyrite, was almost entirely in very soluble condition. Even when carbonates were absent, a large proportion of it dissolved in moderately dilute acids after very few minutes boiling. But the ferrous iron thus shown to exist in the silicate minerals could not be accepted as the cause of fading, because it exists in all slates; and some of the most ferruginous, as 314*f*,[1] are "unfading." Microscopical evidence is also opposed to oxidation of ferrous silicates as the cause of fading.

There remained as its sole probable cause the carbonate found in nearly all the slates. Its chemical behavior toward acids proves beyond question that this carbonate can be in no observed case calcite. Were it even in small part calcite, an instantaneous disengagement of gas would be apparent on adding acids, whereas their action is tardy and becomes pronounced only on application of heat. To those familiar with the behavior of different carbonates this evidence alone is decisive.

The carbonate is, therefore, an isomorphous mixture, and indeed the CO_2 found, as compared with the CaO, shows at once a great excess of the former. That $CaCO_3$ is one of the chief isomorphous constituents appears from the fact that absence of CO_2 uniformly accompanies the lowest percentages of CaO, and that increase of CaO carries with it an approximately corresponding increase of CO_2. The CO_2 is usually in molecular excess of the CaO, and in some slates of the MnO and FeO as well (compare analyses L, M, Q, R); hence $MgCO_3$ is indicated as the next most important isomorphous element of the carbonate. Analyses M, Q, and R, taken together in the order named, afford positive evidence that $MnCO_3$ is present either as an independent mineral or as a component of the complex carbonate, for as CO_2 decreases from the green center through the purple rim to the outer red, so does MnO, and at such a rate that with no carbon dioxide MnO would likewise disappear. In general, too, the slates high in CO_2 show a relatively high MnO content. Analysis 201*d* shows also that manganese carbonate is found as a vein formation in the slates, and Mr. Dale has found with the microscope some indications of its presence in the lenses of the red slate, at least. In order to be able to credit the fading to the carbonate, it is necessary still to show that it contains $FeCO_3$ as a constituent, for, while the manganese might produce discolorization by oxidizing, its amount is slight, and the color due to its oxidation products alone would be black rather than brown. Because of the above-mentioned ready solubility of the ferrous silicate or silicates in acids, chemical proof of the presence of ferrous carbonate is not obtainable, but from our general knowledge of its relations to those of magnesium and manganese it is in the highest degree probable that it does exist either as a distinct mineral or as a component of the dolomitic carbonate, and, in fact, it would be somewhat surprising if, with magnesium and manganese present as carbonates, iron should be

[1] Numbers refer to specimens whose analyses are given in the local descriptions.

absent. The needed proof, however, is supplied by the microscope, as detailed in the text of Mr. Dale's report (p. 140).

If it is objected that some green slates comparatively rich in carbonate fade less than others which are much poorer, it may be reasonably urged that the relative proportions of the several carbonates are doubtless subject to change in different slates, as in the natural order of things they must be, for the original composition of the slate-forming materials must have differed in each locality. This being so, it follows that a mere test as to the relative amount of CO_2 can furnish no guide in advance as to the fading qualities of a slate, as it might were the composition of the mixed carbonates always constant.

Though pyrite is never a visible constituent of the red slates, its presence seems necessary to account for the sulphur found, for careful tests failed to show an equivalent amount by far of SO_3. Hence pyrite is reported in all the analyses.

The phenomenal percentage of barium in 201*e* (K), as compared with other slates, has been of service as showing that, in this slate at least, it is mainly if not altogether a constituent of some silicate or silicates and not of barite only, which, according to Mr. Dale, has been observed on joint planes and in crystalline concretions, for the sulphur is totally inadequate to form barite with all the barium.

The condition of the nickel and cobalt has not been definitely ascertained. From the analysis of the manganese carbonate 201*d* it might appear as if they were constituents of the carbonate in the slates, but it is not impossible that they may be in combination with arsenic, or with arsenic and sulphur, as arsenides and sulpharsenides, even if the presence of arsenic has not been revealed, no test having been made for that element. In all the tests made for nickel and cobalt, both elements were found, and in one test their combined percentage as oxides, probably a maximum, was 0.025.

Heating of the slates in tubes closed at one end gave without exception alkaline vapors and whitish sublimates, and the latter reacted for SO_3, Cl, and strongly for NH_3. In eight tests the amount of ammonia thus given off in both conditions was ascertained by nesslerization and found to range from 0.0075 per cent for 760*a* (H) to 0.04 per cent for 305*d* (P). The latter is a black slate carrying nearly 0.5 per cent of carbon, but the ammonia obtained was not sensibly higher than in some of the green slates, as 645*a* (F) with 0.035 per cent NH_3, or 314 of 1895 (I); with 0.03 per cent NH_3.

Neither the condition nor the source of the nitrogen thus revealed can be stated with any degree of positiveness. It is found in the interior of fresh and unbroken masses and hence is not to be regarded as derived from infiltration of nitrogenous matter since the opening of the quarries. Whatever may be its manner of combination, nitrogen is coming to be recognized as a primary constituent of many rocks and minerals. It seems probable that its presence in these slates is to be attributed to the organic matter which was doubtless not wanting when the materials now composing the slates were originally laid down.

Chromium and vanadium are probably minor constituents of all the slates. They were not looked for in making the foregoing analyses, but in connection with some more recent work relating to the distribution of vanadium in the rocks of the earth's crust[1] the sea-green slate 230*a* (A) and the red slates 201*e* (K) and 397*e* (L) were examined. In 201*e* there was found 0.017 per cent of vanadium as V_2O_5 and 0.007 per cent of chromium as Cr_2O_3. A mixture of equal parts of the two red slates was found to contain 0.008 per cent V_2O_5 and about as much Cr_2O_3 as in 201*e*.

To the novice a cursory examination of the tabulated analyses might seem to indicate a greater diversity in essential composition than comports with the facts. Thus there seems to be, perhaps, little relation in composition, except qualitatively, between the red slates 358*d* (J) and 397*e* (L). Yet, after deducting all CaO as phosphate and carbonate, all MnO as carbonate, and enough MgO as carbonate to satisfy the remainder of the CO_2, also the trace of pyrite, amounting to 16.58 per cent in all, and calculating the remaining 83.80 per cent to 100, we obtain the figures given in the first column below, for comparison with which analyses 358*d* (J) and 201*e* (K) of slates naturally altogether or nearly free from carbonates are partly reproduced:

	397*e* (L).	358*d* (J).	201*e* (K).		397*e* (L).	358*d* (J).	201*e* (K).
SiO_2	67.40	67.61	67.55	K_2O	4.50	4.45	4.13
TiO_2	.57	.56	.58	Na_2O	.62	.67	.61
Al_2O_3	13.84	13.20	12.59	H_2O below 110° C.	.44	.45	.40
Fe_2O_3	4.15	5.36	5.61	H_2O above 110° C.	3.37	2.97	3.03
FeO	1.70	1.20	1.24				
BaO	.07	.04	.31		100.00	99.71	99.32
MgO	3.34	3.20	3.27				

When it is borne in mind that a portion of the FeO in 397*e* should doubtless be credited to the carbonate, whereby an equivalent of MgO would be released for the silicate, it will be seen that the agreement as to FeO in the above comparison would be much closer, and the three slates may be said to have almost identically the same composition when compared in this manner.

Applying a similar correction to the three analyses of 397*a* R, Q, and M, in the order named, we obtain the following corrected figures for the green spot, the purple rim, and the outer red, which bring

[1] Distribution and quantitative occurrence of vanadium and molybdenum of rocks in the United States, by W. F. Hillebrand: Am. Jour. Sci., 4th ser., vol. 6, p. 209, 1898.

into special prominence their relatively high silica contents as compared with all the other slates analyzed:

	397*a* (R).	397*a* (Q).	397*a* (M).		397*a* (R).	397*a* (Q).	397*a* (M).
SiO_2	76.04	73.64	71.59	K_2O	4.15	4.22	3.87
TiO_2	.60	.58	.53	Na_2O	.26	.26	.22
Al_2O_3	10.90	11.66	10.95	H_2O below 110° C	.29	.32	.30
Fe_2O_3	1.27	2.04	4.33	H_2O above 110° C	2.45	2.61	2.78
FeO	1.23	1.36	1.61				
BaO	.06	.05	.05		100.00	99.99	100.00
MgO	2.75	3.25	3.77				

The foregoing calculations for 397*e* and 397*a* (L and M) show at the same time the general dolomitic character of the carbonate, as appears from the following table, wherein the percentages of carbonates are given as calculated on the above-predicated assumptions:

	397*e* (L).		397*a* (R).		397*a* (Q).		397*a* (M).	
	Percentage.	Molecular ratio.	Percentage.	Molecular ratio.	Percentage.	Molecular ratio.	Percentage.	Molecular ratio.
$CaCO_3$	8.95	1.03	7.93	1.15	7.11	1.16	6.14	1.15
MgCO	6.93	1.00	5.36	1.00	4.77	1.00	4.22	1.00
$MnCO_3$	.48		.57		.47		.38	
	16.38	....	13.86	....	12.35	....	10.74	....

If, as is quite probable, a small fraction of the CaO should be charged to the silicates, the true dolomitic ratio would be more closely approached. It is of no consequence for the above calculations that an undeterminable portion of $FeCO_3$ should appear as $MgCO_3$. The ratios are not thereby affected.

PART II.—SLATE DEPOSITS OF THE UNITED STATES.

In Part II of this paper each State is taken up in alphabetic order. In the description of a deposit that has not been especially examined by the writer or some other geologist the result of the writer's microscopic examination is accompanied by such geologic data as could be found in the geologic literature of the region.

ARIZONA.

A specimen of roofing slate received from Arizona came from a deposit reported as about 6½ miles north of Phoenix and said to measure 800 to 1,000 feet in width and about 5,000 feet in length.

Lee[1] refers to the geology of this locality as follows:

In the Phoenix Mountains, immediately north of the city of Phoenix, occurs an extensive series of metamorphosed sediments, many thousands of feet in thickness. The layers rest in a nearly vertical position.

Lee's map shows areas of Algonkian rocks along the foot of the Phoenix Mountains at points ranging from 6 miles N. 25° E. to 7 miles north of Phoenix.

The examination of the specimen yielded the following results:

It is bluish gray with a lustrous surface, marked by two sets of minute wrinkles that lie at right angles to each other, a coarser set numbering from 25 to 40 per inch and a finer set numbering many more. The slate breaks along the finer set much more readily than along the coarser set. It has a marked argillaceous odor, shows considerable pyrite on the sawn edge, contains but little magnetite, does not effervesce in cold dilute hydrochloric acid, is sonorous, and has a fair grade of fissility.

Under the microscope this slate shows a matrix[2] consisting of muscovite (sericite) with a brilliant aggregate polarization.[2] Cleavage and bedding foliations are parallel but are crossed by two incipient slip cleavages (see p. 37 and Pls. VII, XI, A), the plications of which have not resulted in fractures but which give the slate a somewhat schistose structure. The finer of these slip cleavages has from 100 to 150 plications to the inch. There is considerable quartz, which appears to be mostly secondary. The conspicuous feature, however, is the great abundance of lenses and particles of pyrite and hematite. In the cross sections these measure from 0.0043 to 0.043 millimeter in length by 0.002 to 0.008 millimeter in width and number about 800 per square millimeter.[3] In parallel section they have irregular angular-roundish outlines.

There are also large plates of muscovite, a few crystals of tourmaline, a few lenses of decomposed crystals of an undetermined mineral up to 0.0425 by 0.025 to 0.075

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[1] Lee, W. T., Underground waters of Salt River valley, Arizona; U. S. Geol. Survey Water-Supply Paper 136, p. 96, Pls. VII, VIII, 1905.

[2] For definitions of technical terms see Glossary, pp. 213-215.

[3] The square millimeter referred to comprises the thickness of the thin section.

millimeter, and considerable rutile in very minute prisms. No carbonate was detected.

The constituents of this slate, arranged in descending order of abundance, appear to be muscovite, quartz, pyrite, hematite, kaolin, magnetite, rutile, and tourmaline.

If properly cut with reference to the direction of weakness this may prove a serviceable slate, but slip cleavage is generally objectionable. In this slate the slip cleavages are, however, only incipient.

ARKANSAS.

TOPOGRAPHY, GEOLOGY, AND CHARACTER OF DEPOSITS.[1]

The slate area of Arkansas covers part of the Ouachita Mountains, which lie south of Arkansas River and have a general east-west trend. The area extends from the vicinity of Little Rock about 100 miles westward nearly to Mena, and has an average width of 15 miles. The rocks include shales, slates, chert, novaculite (a deposit of extremely fine quartz grains), sandstone, and a little limestone. The entire sedimentary series is estimated at 11,400 feet in thickness, of which the upper 8,825 feet contains some commercial slate, as shown in the table below:

Section in Arkansas showing the relations of slates.

	Feet.
Carboniferous:	
Stanley shale: Greenish clay shale, locally black slate near the base, and greenish quartzitic sandstone	6,000
Unconformity.	
Age unknown:	
Fork Mountain slate: Gray slate with thin beds of siliceous material	125
Arkansas novaculite: Massive white and variegated novaculite with alternating flint and shale layers in the upper half	800
Missouri Mountain slate: Mainly red slate with green slate in basal part	75-300
Ordovician:	
Blaylock sandstone: Greenish quartzitic sandstone alternating with brownish-black shale	0-1,500
Polk Creek shale: Black fissile and sandy graptolitic shale	0?-100
Bigfork chert.	
	8,825

The areal distribution of these formations is shown on the geologic map (Pl. III) of Purdue's report on the slates published by the Geological Survey of Arkansas in 1909. The general situation of the slate district is shown in E. C. Eckel's map (Plate IX of this bulletin).

These strata lie in parallel close folds with the east-west axes which pitch alternately but always together east and west. The folds are either erect or overturned to the north or south. The peculiar

[1] Summary from Purdue, A. H., The slates of Arkansas: U. S. Geol. Survey Bull. 430, pp. 317-334, 1910.

topography of the region is due to these parallel pitching folds and to the unequal resistance offered to erosion by the soft shales and slates and by the hard quartzose beds.

Slate of possible economic value occurs in the four formations mentioned below.

The Polk Creek shale passes here and there into a black graptolitic sonorous slate, in places banded. The smallness of the amount of slate and the abundance of joints throughout the formation make the deposit of doubtful economic value.

The Missouri Mountain slate has been extensively prospected and is now quarried at Slatington. Its structure on Fork and Missouri mountains is shown in figure 4. It produces both red and green slate, the former predominating. In some places the cleavage is parallel to the bedding; in others it is oblique. The slate is defective in sonorousness and in many places shows two sets of slip cleavage.

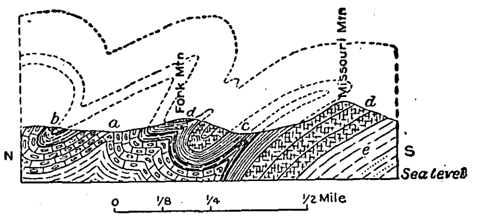


FIGURE 4.—North-south section through Fork Mountain, Ark., T. 3 S., R. 28 W., showing the folded structure of the Missouri Mountain slate. *a*, Bigfork chert; *b*, Polk Creek shale; *c*, Missouri Mountain slate; *d*, Arkansas novaculite; *e*, Stanley shale. From A. H. Purdue, U. S. Geol. Survey Bull. 430, fig. 6, 1910.

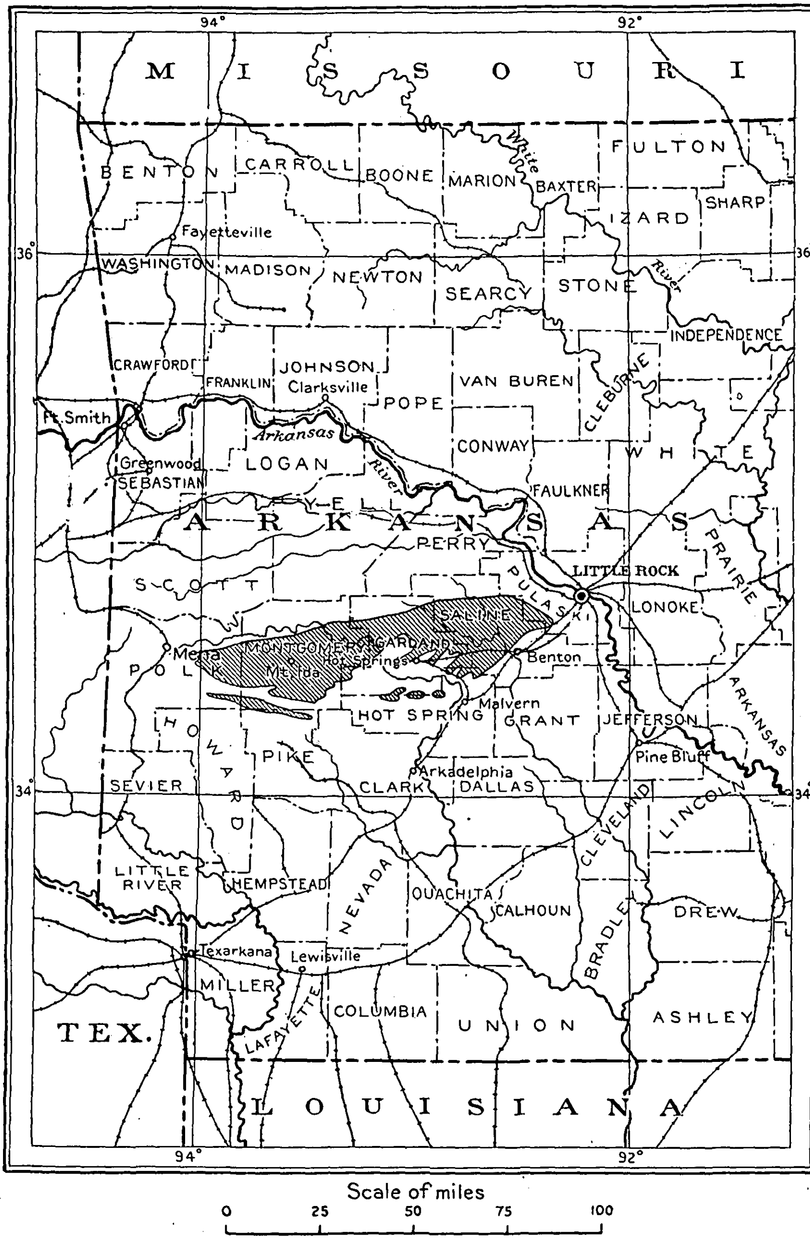
This slate is used for mill stock, particularly laundry tubs, lavatories, wainscoting, and electric switchboards. The results of tests of its electric conductivity are given beyond. In the preparation of millstock there is a certain loss from worked pieces cracking either along or at right angles to the cleavage.

The Fork Mountain slate consists of a hard slate, generally gray but weathering in places green or chocolate color and containing many thin sandy beds. The slate usually has a good cleavage and is ribboned, highly sonorous, strong, and tough. So far as prospected it is too much jointed to be of economic value.

The Stanley shale is almost everywhere a shale, rarely a slate. It has been extensively prospected near Slatington and in the southwestern part of Polk County. The color of the slate is blue to black and its cleavage remarkably fine, with very smooth cleavage surfaces. It is not regarded as sufficiently durable for roofing. Two quarries have been opened in it.

CHEMICAL COMPOSITION OF THE SLATES OF ARKANSAS.

The following analyses of slates from Arkansas, published in E. C. Eckel's note on slates of Arkansas in Bulletin 275, are fairly representative of the composition of some of these slates:



MAP SHOWING SLATE AREA OF ARKANSAS.

By E. C. Eckel.

Analyses of slates from Montgomery County, Ark.

[Analyst, W. G. Waring.]

	1	2	3	4	5	6	7
Silica (SiO_2)	66.16	68.79	69.04	69.07	67.90	64.00	63.22
Alumina (Al_2O_3)	8.62	14.26	12.66	11.40	10.42	11.59	16.76
Ferric oxide (Fe_2O_3)	9.04	5.90	8.55	7.66	6.22	13.71	9.54
Ferrous oxide (FeO)	3.44	1.16	1.30	1.04	....	....	....
Lime (CaO)	1.77	1.40	1.75	1.56	3.17	1.56	1.75
Magnesia (MgO)	.78	1.43	1.87	3.14	4.34	2.03	1.52
Potash (K_2O)	4.96	3.09	2.98	3.88	4.11	1.36	1.43
Soda (Na_2O)	.64	.09	.09	.96	.69	.64	.70
Sulphur in SO_3	.08	.44	.06	.02	.06	.05	.05
Sulphur in FeS_2	.02	.01	.01	.01	.01	.04	.03
Carbon (C)	2.10	2.01	Tr.	....	1.78	4.03	3.70
Carbon dioxide (CO_2)	.09	.11	.72	.11	.01	.01	.01
Water (H_2O)	.18	.47	.84	.24	.23	.57	1.01

1. Green slate, quarry No. 2.
2. Red slate, quarry No. 2.
3. Red slate from State House Cove.
4. Hard red slate from State House Cove.
5. Green slate from State House Cove.
6. Black slate from west end of Crooked Creek vein.
7. Black slate from Crooked Creek Falls.

MICROSCOPIC ANALYSES OF SLATES FROM ARKANSAS.

The microscopic analyses of slates from Arkansas published in 1904[1] are here repeated and supplemented by several others of specimens collected by Mr. Eckel during his visit to the quarries of that State in 1905. All have been revised.

Black slate from Mena, near Big Fork. This is a pure black slate, which to the unaided eye has an exceedingly fine texture and a remarkably smooth cleavage surface with a slight luster. It is both carbonaceous (or graphitic) and magnetitic; does not effervesce with cold dilute hydrochloric acid, is very sonorous and very fissile. Under the microscope this slate shows a matrix of muscovite (sericite), with a very brilliant aggregate polarization and an unusually fine texture and great homogeneity. Quartz grains are few and not over 0.01 millimeter in diameter. Rutile needles unusually minute. Many opaque particles of irregular shape, some of which are pyrite, others magnetite, and some coaly or graphitic matter. No carbonate.

The constituents, arranged in descending order of abundance, appear to be muscovite, carbonaceous or graphitic matter, quartz, pyrite, magnetite, and rutile.

This is a mica slate, with a remarkably fine cleavage and not liable to discolor on exposure, but its strength and its behavior under frost should be tested.

Dark-reddish slate from Mena, near Big Fork. In color this slate is somewhat darker than the "red" slate of New York. To the unaided eye it has a minutely granular texture and a roughish, speckled, almost lusterless surface. Contains very little magnetite, does not effervesce with cold dilute hydrochloric acid, is sonorous, splits readily, and has some argillaceous odor. Under the microscope it shows a matrix of muscovite (sericite), with brilliant aggregate polarization, quartz grains ranging up to 0.025 millimeter, muscovite and chlorite scales, and abundant hematite in minute dots. There are also rhombs, from 0.1 to 0.2 millimeter, of chlorite and rhodochrosite, probably pseudomorphs. No other carbonate.

The constituents, arranged in descending order of abundance, appear to be muscovite, hematite, kaolin, quartz, chlorite, rhodochrosite (?), and magnetite.

This slate compares favorably in texture with the "red" slate of New York.

Reddish slate from the Missouri Mountain slate ("Mammoth red" and "Lost Hannah" of quarrymen; exact locality not given). Color lighter than above, but not quite

[1] U. S. Geol. Survey Bull. 225, p. 414.

so red as the New York slate. To the unaided eye has a fine texture and a fine cleavage surface but no luster. Contains very little magnetite; does not effervesce with cold dilute hydrochloric acid, is sonorous and fissile, has some argillaceous odor.

Under the microscope it shows a matrix of muscovite (sericite), with brilliant aggregate polarization, quartz grains up to 0.03 millimeter, muscovite and chlorite scales, abundant hematite pigment, and no carbonate.

The constituents, arranged in descending order of abundance, appear to be muscovite, hematite, kaolin, quartz, chlorite, and magnetite.

This is a finer and softer slate than the dark red and should be tested for strength and frost resistance.

Greenish-gray slate from Mena. In color this resembles the sea-green slate of Vermont. To the unaided eye it has a fine texture, a roughish cleavage surface, and a waxy luster; does not show pyrite on sawn edge, contains very little magnetite; does not effervesce with cold dilute hydrochloric acid, and is somewhat sonorous.

Under the microscope it shows a matrix of muscovite (sericite), with a brilliant aggregate polarization and is of very fine texture and homogeneity, but the cleavage is crossed at an angle of 13° by a very close bedding foliation and also by an obscure slip or false cleavage at about 40°. Contains very few and very minute quartz grains, no carbonate, several pseudomorphic rhombs of chlorite, 0.08 millimeter, and has a slight argillaceous odor.

The constituents, arranged in descending order of abundance, appear to be muscovite, quartz, kaolin, chlorite, and magnetite.

The two extra foliations are likely to prove directions of weakness.

Light-greenish slate from the Missouri Mountain slate ("Mammoth red"), locality not designated. This is more greenish than the above; to the unaided eye has an exceedingly fine texture and a very fine, almost lusterless cleavage surface; shows pyrite on sawn edge; contains a little magnetite; does not effervesce with cold dilute hydrochloric acid, is sonorous, very fissile, and has a slight argillaceous odor.

Under the microscope it shows a matrix of muscovite (sericite), with a brilliant aggregate polarization and great evenness of texture. A very minute bed of quartz grains, chlorite, and muscovite lies in the cleavage, which is therefore the bedding also. The grain is indicated by the transverse position of some of the muscovite scales. Quartz not very abundant but occurs in grains up to 0.037 millimeter. Rutile needles abound from 0.0028 by 0.0009 up to 0.014 by 0.0014 millimeter. Muscovite and chlorite scales occur, the latter producing the green color. There are some opaque granules (limonite? and pyrite), occasional lenses, 0.14 millimeter long, of a central mass (probably rhodochrosite), with secondary muscovite at both ends. No other carbonate. Shows a number of tourmaline prisms up to 0.025 by 0.008 millimeter.

The chief constituents, arranged in descending order of abundance, appear to be muscovite, quartz, kaolin, chlorite, rutile, pyrite, magnetite, and tourmaline.

This mica slate probably possesses more petrographic interest than economic value. Its fissility, freedom from carbonate, and color are very favorable, but it will probably be found too delicate for use on a roof.

Very dark bluish-gray slate from sec. 25, T. 3 S., R. 29 W. (Specimen collected by E. C. Eckel.) To the unaided eye this slate has a fine texture and a smooth cleavage surface with a little luster, and shows a little pyrite on the sawn edge. It contains very little magnetite, considerable carbonaceous or graphitic matter, does not effervesce with cold dilute hydrochloric acid, is sonorous, and has a high grade of fissility. Under the microscope it shows a fine-textured matrix of muscovite (sericite) with good aggregate polarization, but somewhat obscured by carbonaceous matter. Quartz is not abundant, the grains measuring up to 0.047 by 0.02 millimeter. Pyrite spherules, measuring up to 0.008 millimeter in diameter, number about 120 per square millimeter. There are rutile needles but no carbonate.

The chief constituents, arranged in order of decreasing abundance, appear to be muscovite, quartz, pyrite, carbonaceous or graphitic matter, and rutile.

This slate has absence of carbonate in its favor. It is not so fine textured or so fissile as the black slate from Mena (p. 63), but may prove more durable.

Light-gray slate with a slightly greenish tinge from sec. 30, T. 3 S., R. 28. W. (Specimen collected by E. C. Eckel.) To the unaided eye this has a fine texture, but a lusterless, roughish surface, and shows a little pyrite on the sawn edges. It contains an insignificant amount of magnetite but no carbonaceous or graphitic matter, does not effervesce with cold dilute hydrochloric acid, and has an argillaceous odor and a fair degree of fissility and sonorousness.

Under the microscope it shows a fine-textured matrix of muscovite (sericite) with brilliant aggregate polarization, containing not abundant quartz grains, measuring up to 0.03 millimeter, scales of chlorite and of muscovite transverse to cleavage, some pyrite cubes up to 0.063 millimeter (generally with a rim of secondary quartz), passing into limonite and staining the matrix. Rutile needles abound.

The chief constituents, arranged in decreasing order of abundance, appear to be muscovite, quartz, chlorite, kaolin, pyrite, rutile, and limonite, with accessory magnetite.

Whether the limonitic staining from the decomposition of the pyrite will produce any appreciable discoloration in the course of years can be determined only by experiment.

Very dark-gray spangled slate from quarry operated by the Southwestern Slate Manufacturing Co. (Specimen collected by E. C. Eckel.) To the unaided eye this has a coarsish texture and a roughish, almost lusterless surface, spangled with minute scales of mica, shows pyrite on sawn edges, contains very little magnetite and little carbonaceous matter, does not effervesce with cold dilute hydrochloric acid, is somewhat sonorous, tolerably fissile, and has a slight argillaceous odor.

Under the microscope it shows a fine-textured matrix of muscovite (sericite) with brilliant aggregate polarization, containing roundish and angular grains of quartz of variable and large size, up to 0.27 by 0.17 millimeter; also a few of plagioclase feldspar, scales of muscovite and biotite up to 0.2 by 0.1 millimeter, some lenses of carbonate up to 0.4 millimeter long, a few grains of tourmaline, and lenses of secondary quartz. There is a faint incipient slip cleavage, not apparent, however, in the hand specimen.

The chief constituents of this slate, arranged in order of decreasing abundance, appear to be muscovite (including sericite), quartz, carbonate, pyrite, carbonaceous matter, and kaolin, with accessory biotite, plagioclase, tourmaline, and magnetite.

This slate combines some of the features of a metamorphic graywacke or grit with those of a mica slate. It is inferior to the dark bluish-gray slate described above.

PHYSICAL AND ELECTRIC TESTS.

The results of elaborate physical and electric tests of some of these slates, made for Purdue's report, will be found in full in Part III, pages 184–187.

CALIFORNIA.

ELDORADO COUNTY.

By Edwin C. Eckel.

Location and general relations.—Though roofing slate has at different times been quarried on a small scale in other parts of California, the only important slate-producing area in the State is located in

Eldorado County. The quarries which have been opened in this district are located along a line running about N. 15° W. from Placerville, at distances of 1 to 6 miles from that town. The location and geographic and geologic relations of the slate deposits and quarries can best be understood by reference to the maps included in the Placerville folio of the United States Geological Survey. The workable roofing-slate deposits of this district occur in a belt of the Mariposa slate, of Jurassic age. The quarries which have been opened are all situated near the western boundary of this belt of Mariposa slate where it is bordered by a large area of diabase. This diabase, according to Lindgren and Turner, is "of the age of the Mariposa slate, or older." A number of linear areas of amphibolite occur in the Mariposa slate. These amphibolites are described as being derived from diabase or gabbro. They are in part altered to serpentine.

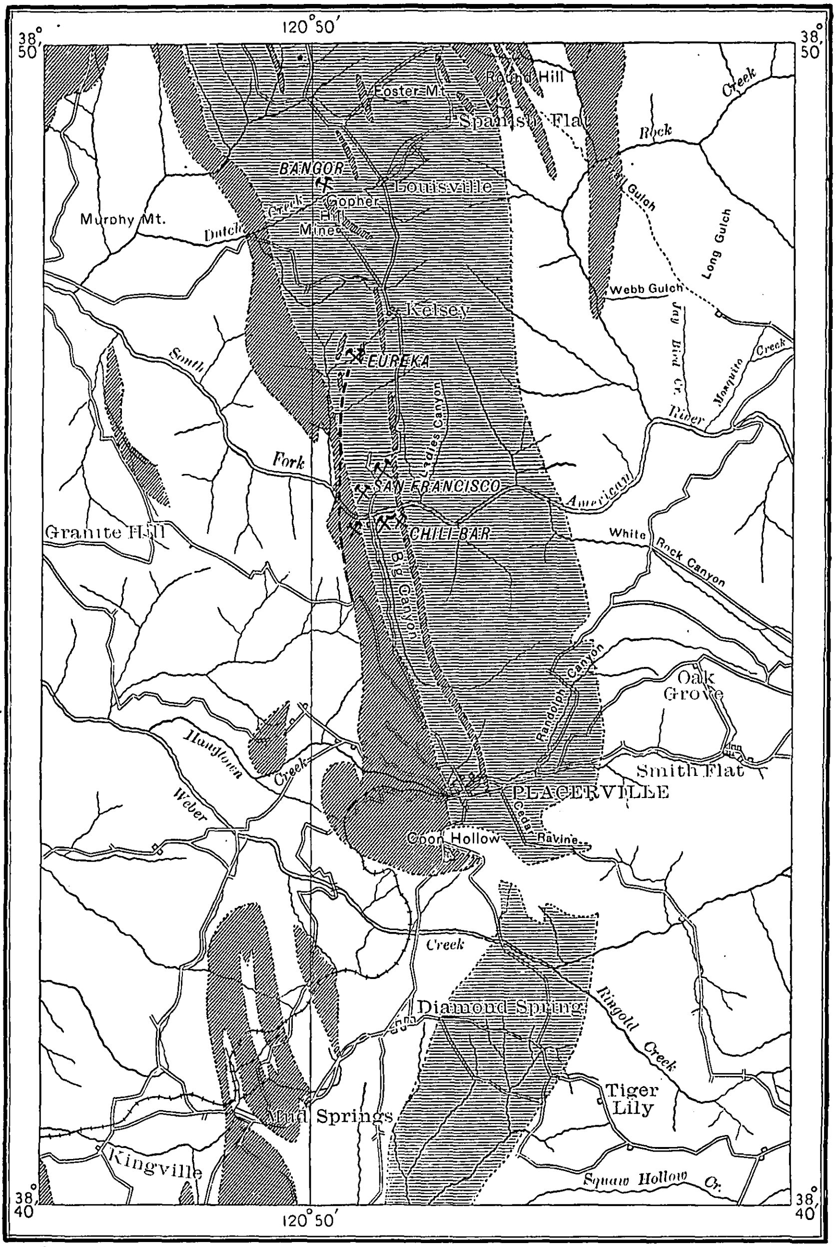
Previous work on the slate deposits.—The Placerville folio [1] contains the results of detailed geologic work by Lindgren and Turner in the area in which the roofing-slate deposits occur. At that date the roofing-slate industry had not assumed its present importance, though all the quarries now worked had then been opened. The existence of roofing-slate deposits is noted in the text of the folio, and the locations of the quarries are indicated on the map showing the economic geology of the area. No reference is made to the "green slates," or to the dikes cutting the Eureka quarry.

Excellent though brief descriptions of the different quarries and of the condition of the slate industry at various dates are to be found in the reports of the State mineralogist of California, particularly in the eighth and twelfth reports. The geologic relations of the slate-producing areas are shown on Plate X.

Structural relations in Eureka quarry.—At present the most important quarry is that of the Eureka Slate Co., and this is now being worked on a large scale. This quarry is at Slatington, about half a mile southwest of Kelsey. The cleavage planes of the slates strike N. 25° W. The dip of the cleavage is practically vertical, with slight local variations to 80° E. or 80° W. The upper weathered beds in the quarry are overturned by local pressure so as to give dips of 40° to 60° to the east or west, according to local conditions. This overturning is evidently due merely to the weight of the overlying soil and decomposed slate, and the effects are shown only for a depth of 3 to 15 feet. It is of interest, however, as a warning against accepting dip readings taken from surface beds of the slate.

The slate body shows rather numerous but narrow "ribbons." These ribbons are bands (from one-sixteenth to one-half inch thick

[1] U. S. Geol. Survey Geol. Atlas, Placerville folio (No. 3), 1894.



GEOLOGIC MAP OF PLACERVILLE SLATE DISTRICT, CALIFORNIA.

Scale

0 1 2 3 4 miles

Mariposa slates — Basic igneous rocks — Slate quarries — Line of cable

From U. S. Geol. Survey Geol. Atlas, folio 3.

usually, but locally as thick as 2 inches) of material differing in composition from the mass of the slate. They are in general more siliceous than the normal slate and do not furnish merchantable material. Their geologic interest arises from the fact that they represent differences in original sedimentation. The plane of the ribbons in a slate quarry is therefore the plane of original bedding. In the Eureka quarry and indeed throughout the roofing-slate belt the plane of original bedding seems to be usually within 10° of the plane of slaty cleavage.

The slate mass is cut by a series of joints parallel to the grain of the slates, striking N. 55° E. and dipping 70°–80° NW. Joints across the grain of the slate, which would be practically horizontal, do not occur in this quarry, but many of the thin quartz seams occupy this position.

Quartz and calcite occur in thin layers, filling joint spaces and some cleavage spaces. Pyrite also occurs in very much flattened nodules, which were apparently parallel to the original bedding.

Character of the normal slate.—The mass of the Eureka quarry product is a dense deep-black slate, splitting very finely and regularly, with a smooth glistening surface, much like that of the slates of Lehigh and Northampton counties, Pa. The abundance of the ribbons and of the pyrite nodules prevents the slate from being serviceable as mill stock, but as a roofing material it is excellent.

A specimen of the black slate, free from ribbon, was selected for analysis in the laboratory of the United States Geological Survey. The results of this analysis, by W. T. Schaller, follow:

Analysis of black slate from Eureka quarry, Slatington, Cal.

Silica (SiO_2)	63.52
Alumina (Al_2O_3) and titanic oxide (TiO_2)	16.34
Iron oxides (FeO, Fe_2O_3)	6.79
Lime (CaO)	.98
Magnesia (MgO)	2.50
Carbon dioxide (CO_2) Water	4.86

T. Nelson Dale has reported as follows on a sample of this slate:

This slate is very dark gray. To the unaided eye it has a fine texture and a smooth and lustrous cleavage surface. It contains considerable carbonaceous or graphitic matter but extremely little magnetite. The sawn edges show pyrite and lenses and streaks of lighter-gray material. There is no effervescence in cold dilute hydrochloric acid. It is sonorous and has a high grade of fissility.

Under the miscroscope it shows a matrix of muscovite (sericite) with a brilliant aggregate polarization and a general evenness of texture, interrupted, however, by lenses up to about 3 millimeters long by about 0.5 millimeter wide, consisting chiefly of quartz fragments (surrounded by a rim of radiating secondary quartz) with muscovite scales, plates, and rhombs of carbonate, and rarely a grain of plagioclase. These lenses have their long axes parallel to the cleavage, but in sections parallel to it some of them have such irregular outline and are so large as to appear like minute beds. The matrix contains many quartz fragments, measuring up to 0.09 by 0.03 millimeter, much less carbonate than the lenses, muscovite scales, chlorite scales, a little pyrite in spherules and crystals, carbonaceous or graphitic matter, rutile needles, a few grains of tourmaline, and rarely one of zircon.

The main constituents of this slate, arranged in order of decreasing abundance, appear to be muscovite, quartz, chlorite, carbonate, pyrite, carbonaceous matter or graphite, rutile, and magnetite, besides accessory tourmaline and zircon.

This ought to prove a serviceable slate. It will be noticed that carbonate, although present, is insufficient to produce effervescence.

Green slate of Eureka quarry.[1]—A band of green slate several feet wide crosses the Eureka quarry. On examination it is found that the borders of this band are not parallel to the ribbon of the black slate. The green band can not, therefore, be interbedded with the black slate. The probability that it represents a dike of massive igneous rock which has been changed to a slate by pressure subsequent to its intrusion is strengthened when the chemical composition of the green slate is considered. Two analyses of the green slates are presented below. The first is of a sample selected by the writer and analyzed in the laboratory to the United States Geological Survey by W. T. Schaller; the second was given by Mr. C. H. Dunton, manager of the Eureka quarry, but the name of the analyst is unknown. As the analyses show a close agreement in essential features, it is probable that they are fairly representative of the composition of the green slate, and that their average, which is given in the third column of the table, may be regarded as typical of this interesting and apparently unique type of roofing slate.

Analyses of igneous green slate from Eureka quarry, Slatington, Cal.

	1	2	Average.
Silica (SiO_2)	45.15	47.30	46.22
Alumina (Al_2O_3)	16.33	15.53	15.93
Iron oxides (FeO, F_2O_3)	8.42	8.00	8.21
Lime (CaO)	6.42	7.83	7.12
Magnesia (MgO)	8.72	7.86	8.29
Sulphur (S)	(a)	.12	.12
Alkalies (K_2O, Na_2O)	(a)	3.17	3.17
Carbon dioxide (CO_2), Water (H_2O)	11.28	9.92	10.60

a Not determined.

These analyses have been compared[2] with a series of 36 analyses of American roofing slates derived from clays by pressure, and remarkable differences in composition are apparent. The green slate, on the other hand, approximates closely in composition certain "basic"

[1] For a more detailed discussion of this interesting "igneous slate" the reader is referred to a paper by the writer in the Journal of Geology, vol. 12, pp. 15-29, 1904.

[2] Jour. Geology, vol. 12, p. 26, 1904.

igneous rocks of the district, and it is probable that it was derived from a gabbro or similar rock.

The "green slate" is in reality grayish green in color. It splits readily, though with not so smooth a surface as the black slate. It stands punching and trimming well and is sufficiently strong for roofing use. Considering its origin and composition, it is probable that it will be a highly durable slate, holding its color well. At present it is sold entirely for trimming and lettering on black slate roofs, for which purpose it is particularly well adapted, giving a strong but pleasant color contrast.

Chili Bar Slate Co.'s quarry.—This quarry is located about 3 miles north of Placerville, in sec. 36, T. 11 N., R. 10 E., on the south side of the South Fork of American River, a few hundred yards east of the Placerville-Kelsey stage road. It is the oldest quarry in the district, having been opened about 28 years ago. It has been shut down since 1897.

Several openings were made in a bluff forming the river bank at this point. In the easternmost of these openings, which is about 40 feet high and 30 feet wide, a rather poor slate with irregular joints is shown. The cleavage strikes N. 20° W. and dips 75° E. The westernmost opening is small and consists of a tunnel which was apparently run in on a band of better slate. The slate piled in the yard has kept its color fairly well.

It seems possible that this quarry may be flooded at high water. Both it and the one next mentioned (San Francisco quarry) are badly located, having no large dumping areas available near by. Neither quarry has gone deep enough to get really good slate, which might have been found at a greater depth.

San Francisco Slate Co's quarry.—This quarry is located in T. 11 N., R. 10 E., within a quarter of a mile of that of the Chili Bar Slate Co., but on the north side of the river and west of the Placerville-Kelsey road. The principal opening was located about 600 feet north of the river, at an elevation of 150 feet above its bank. A tramway led down to the dressing yard, which was situated at the river bank.

The cleavage of the slates in the large opening strikes about N. 30° W. and has an almost vertical dip. No slate has been quarried here since 1897. A large stock of trimmed slates is still piled in the dressing yard, and many of these have already discolored badly.

Transportation and market.—The slates of Eldorado County have practically no competition on or near the Pacific coast, and the Eureka quarry has recently placed large shipments in Hawaii and Guam. Until recently the principal problem has been the transportation of the slates from the quarry to the railroad. This was formerly done by wagon hauling over a 6-mile stretch of very hilly road. In 1905, however, the Eureka Slate Co. installed an aerial tramway system from its quarry to a point near Placerville. This tramway is an engineering feat of no mean order, the crossing of the South Fork of American River being the principal difficulty encountered.

MERCED COUNTY.

A slate deposit was discovered in 1912 about 11 miles east of Planada, probably the Mariposa slate and of Jurassic age.[1] It is reported as 1,500 feet in width at the surface, 3 miles in length, and 300 feet in vertical thickness. The California Slate Co., of Planada, has commenced to develop the property. A specimen of the slate examined by the writer yields these results:

This slate is of dark bluish-gray color, with a somewhat lustrous, very finely granular surface with minute striations along the grain. Its fissility is good. It is very sonorous, indicating a high degree of metamorphism, does not effervesce with cold dilute hydrochloric acid nor show any carbonate in thin section, indicating durability of color. It is graphitic and contains many bronze-colored magnetic particles. Magnetite is not certainly present.

Under the microscope it shows a matrix of muscovite (sericite) very even in the grain direction with brilliant aggregate polarization, also conspicuous lenses with a nucleus of black mica (biotite). The biotite scales lie mostly parallel to the grain direction and the lenses, partly biotite and partly quartz, are elongated in the grain direction, but the biotite nucleus is crossed by parallel bands of dark inclusions that lie in the cleavage direction. It also contains many bronze-colored metallic particles and minute lenses of a highly magnetic mineral, presumably pyrrhotite (magnetic pyrites). The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, biotite, kaolin, graphite, and pyrrhotite. Magnetite and rutile are not certainly present.

This is a mica slate of sedimentary origin, free from carbonate, with good cleavage. It should discolor but little if at all, but its content of magnetic particles makes it unsuitable for electric uses.

COLORADO.

The Colorado Slate Co. opened a quarry in 1910 in a deposit of black slate at Marble, in Gunnison County. The age of these slates is probably Ordovician. A specimen from this quarry examined by the writer yielded these results:

The slate has an extremely dark bluish-gray color. To the unaided eye its texture is fine, with a slightly uneven lusterless cleavage surface. It contains carbonaceous matter and extremely little magnetite. The sawn edge shows some pyrite. It effervesces with cold dilute hydrochloric acid, is sonorous, and has medium fissility.

Under the microscope it shows a matrix of muscovite (sericite) with feeble aggregate polarization. The cleavage is rendered uneven by alternating beds of fine and coarse particles, which are parallel to the cleavage. Carbonate is very abundant and helps to obscure the aggregate polarization. Pyrite is plentiful in spherules and irregular particles up to 0.16 millimeter across. Opaque carbonaceous matter also abounds, and there are several forms of organic origin. Rutile needles are very scarce or absent. Quartz grains measure up to 0.03 millimeter across.

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[1] See Turner, H. W., and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Sonora folio (No. 41), p. 2, 1897.

The constituents of this slate, named in descending order of abundance, appear to be muscovite, carbonate, quartz, carbon, kaolin, pyrite, chlorite, and rutile (?).

As shown by the defective aggregate polarization and confirmed by the scarcity of slate needles, this is an incompletely formed mica slate and it also belongs to the fading series. Its strength should be tested.

GEORGIA.

Roofing slates have been quarried in Bartow and Polk counties, in the northeastern part of Georgia.

BARTOW COUNTY.

Bolivar.—The Georgia Green Slate Co., of Fairmount, Ga., in 1910, opened a quarry in the northern part of Bartow County about 15 miles north-northeast of Cartersville and 3 miles northeast of Pinelog village, near Bolivar station of the Louisville & Nashville Railroad. The geologic age of the slate is as yet undetermined. It may be Cambrian.

The quarry lies in a hollow trending N. 60° W. along the south foot of a ridge about half a mile from the railroad. The opening is 175 by 50 to 100 feet in width, and in June, 1912, was idle and full of water. On the N. 60° W. side slate was exposed for 40 feet above the water and on the S. 60° E. side for 25 feet. As the hollow is narrow and the quarry was opened in the brook bed or close to it, the excavation soon fills.

The cleavage foliation strikes N. 30° E. and dips 5°–25° S. 60° E. The cleavage faces in the "top" are very limonitic and the region is thickly covered with rusty residual clays. The exact course of bedding could not be made out, but blocks on the dumps and the finished slates show ribbons intersecting the cleavage at 20°. Joints strike N. 63° E. and form a heading 15 feet wide at one end of the quarry, dipping 65° N. 27° W. Some of the slates show close joints filled with chlorite dislocating the ribbon but not affecting the cleavage. (See p. 39.)

The slate is of light blue-greenish gray color with some dark bluish-green ribbons, streaks, and lenses. It has a smooth to roughish, slightly lustrous surface, shows a little pyrite on the sawn edge, and contains extremely little magnetite. It effervesces slightly with acid test, is rather sonorous, and has a fair grade of fissility. The ribbons are somewhat calcareous.

Under the microscope it shows a matrix of muscovite (sericite) with marked aggregate polarization and a fine and regular cleavage, also abundant rutile needles. It contains a little carbonate in fine particles or rhombs and a little pyrite in spherules and irregular grains. There are lenses of chlorite up to 0.34 by 0.009 millimeter. The chlorite scales measure as much as 0.009 millimeter and the quartz grains 0.047 millimeter.

The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, pyrite, magnetite, and rutile.

This is a mica slate with a fair fissility and attractive color. Although the amount of carbonate is not so large as in the sea-green slate of Vermont (p. 140) it is probably sufficient to produce in time some discoloration. The slates about the quarry, exposed not over two years, show but slight discoloration.

The following analysis of slate from Bolivar by Dr. Edgar Everhart, chemist of the Geological Survey of Georgia, is here given for reference:

Analysis of slate from Bolivar, Bartow County, Ga.

Silica (SiO_2)	56.02
Titanium dioxide (TiO_2)	.74
Alumina (Al_2O_3)	21.61
Ferric oxide (Fe_2O_3)	1.36
Ferrous oxide (FeO)	5.97
Manganous oxide (MnO)	.05
Lime (CaO)	1.22
Magnesia (MgO)	2.96
Potash (K_2O)	2.83
Soda (Na_2O)	1.26
Water (H_2O)	.14
Phosphorus pentoxide (P_2O_5)	.02
Carbon dioxide (CO_2)	.91
Sulphur (S)	.35
Loss on ignition, less carbonic acid (CO)	4.76
	100.20
Less oxygen	.09
	99.11

POLK COUNTY.

Rockmart.—The Rockmart slate, which belongs to the Ordovician period, was described by Hayes[1] in 1902 in these words:

The Rockmart formation is confined to the Cedartown and Rockmart areas, in the southern portion of the Rome quadrangle. As stated previously, these rocks are contemporaneous with the upper portion of the Chickamauga limestone north of the Coosa Valley. The formation consists chiefly of black slate, originally calcareous shales, but sufficiently altered for the development of slaty cleavage. In addition to the slate, which occupies the lower portion of the formation, it contains beds of highly ferruginous sandstone and some cherty limestone. It also contains coarse conglomerates, made up of limestone pebbles embedded in an earthy matrix. This upper portion of the formation was evidently deposited near the margin of the sea, where the supply of sediment was abundant and variable in character. * * *

The formation in which the quarries are located, the Rockmart slate, extends across the border into the Rome quadrangle, but it is not certain that any workable slate will be found in this area. The formation is variable in composition, and to the north of Rockmart consists largely of unaltered clay shales with beds of ferruginous limestone and sandstone.

The portion of the formation which now produces roofing slate was originally a fine-grained homogeneous clay shale. Under the influence of metamorphism, connected probably with the extensive faulting which the region has undergone, a very perfect slaty cleavage was developed, which generally obscures, and in some cases entirely obliterates, the original bedding. East of the quadrangle, along the Cartersville fault, the slate is generally wrinkled near the fault, so that it does not cleave readily,

[1] Hayes, C. W., U. S. Geol. Survey Geol. Atlas, Rome folio (No. 78), 1902.

and at a considerable distance from the fault the cleavage is only imperfectly developed. Hence the best slate will be found within a comparatively narrow belt, from 1 to 5 miles from the fault.

East and southeast of the village of Rockmart, on Euharlee Creek, is an east-northeast ridge of slate rising 100 to 200 feet above the creek, or 900 feet above sea level. The prevalent strike of the beds is N. 20°–40° E. The limestone which underlies the slate occupies the valley on the northwest and crops out in contact with the slate at the disused easternmost quarry. The slate is covered in places with 20 to 30 feet of weathered slate and this is overlain by 5 to 10 feet of reddish clay. Within this weathered zone all transitions from a black mica slate to a bright-yellow ocher can be studied. In an early stage of decarbonization the slate consists of alternating ribbons of grayish slate from 0.02 to 0.2 inch thick and of a buff-colored material, and both are crossed diagonally by a pronounced slaty cleavage. In a later stage of alteration the little beds can still be traced by pale-yellow bands in the bright-yellow clay, which still splits most readily in the direction of the original cleavage. In the final stage the slate has passed into an almost homogeneous structureless yellow ocherous clay.

The most important economic consideration suggested by the stratigraphy is that as the slate is limited in depth by the underlying limestone and in places in height by the zone of residual ocher the actual thickness of workable slate can not be very considerable. It should be carefully determined at any point before commencing operations involving large expenditures.

The Rockmart Brick & Slate Co. is engaged in manufacturing shale brick out of the weathered slate with the possibility, when the supply of ocher fails, of quarrying the underlying fresh slate for roofing.

The slate has been extensively quarried for roofing on the southeast side of the ridge, but the quarries are now disused. Pritchard & Davis, however, in 1912, reopened a small quarry between the Hood and Southern Slates Co. quarries, in a small northwest-southeast ravine. The opening is 20 by 25 feet by 10 feet deep and the "top" consists of 2 feet of red clay and soil. The beds strike about N. 40° E. and dip 20°–25° S. 50° E. The ribbons are wide and in places extremely plicated, as explained on page 32 and shown in figure 1. The thickness between ribbons in the Rockmart quarries is generally reported as from 2 to 5 feet. The cleavage strikes with the bed but dips 40°–45° S. 50° E. Joints strike N. 10° E. and N. 75° W., dipping steeply or vertical, both sets being discontinuous and spaced 15 to 18 feet.

The slate is of very dark bluish-gray color and of slightly roughish, lusterless surface. It is sonorous and effervesces with acid test. The sawn face shows minute magnetite;

the powder shows very little magnetite but much carbon and effervesces very freely with acid test.

Under the microscope aggregate polarization is somewhat obscured by carbonaceous matter. The general texture is lenticular and somewhat coarse, the quartz grains measuring up to 0.047 millimeter. Small beds down to 0.12 millimeter thick (in the slates of fig. 1 to 0.1 inch), with quartz grains to 0.09 millimeter and much carbonate, intersect the cleavage at 14°. The matrix contains much fine carbon, much carbonate, chlorite scales interleaved with muscovite, abundant spherules and grains of pyrite, and rutile needles. The section parallel to cleavage is crowded with carbonate.

The constituents, named in descending order of abundance, appear to be muscovite, quartz (detrital), carbonate, carbon, chlorite, kaolin, pyrite, magnetite, rutile, and plagioclase (detrital).

This is a mica slate of the fading series, although some obtained from a tunnel at one of the quarries is reported to have kept its color for many years. Its fissility is fair.

MAINE.

The slate region of Maine lies about in the center of the State, in the southern part of Piscataquis County, south and southeast of Moosehead Lake and east and west of Sebec Lake, in the towns of Monson, Blanchard, and Brownville. (See map, fig. 5.) Commercial slate occurs also in the town of Forks, Somerset County.

Geologic relations.—The slate occurs in a belt consisting largely of slaty rocks, represented by Hitchcock as 15 to 20 miles wide and extending from Kennebec River, between Bingham and Dead rivers, northeastward to the sources of Mattawamkeag River. The rocks are probably of early Paleozoic age.[1] The portion of this belt now yielding commercial slate lies south of the central granitic area of the State. The general structure of this belt is unknown. At North Blanchard, on the west, the strike of the bedding is N. 25°–39° E. and the dip 80° ESE. Near Blanchard and Piscataquis River the strike is N. 55°–62° E., and the dip, 40 feet below the surface, is south-southeast at about 80°; but at the top, owing either to the glacier, which moved here S. 20°–40° E., or else to the beginning of an anticline, the dip curves to the north-northwest. Within 1½ miles southwest of Monson the strike is N. 60° E. and the dip 90°. A mile south the strike is N. 63° E. and the dip still 90°. At Monson the strike is N. 47°–54° E. and the dip 80° SE.; but at Brownville, 20 miles east of Monson, the strike is N. 78° E. and the dip 75° NNW. As the grain is horizontal at Brownville and at points 3½ miles west-southwest and 1½ miles southwest of Monson, a nearly vertical pitch may be assumed for the folds, but it is singular that the jointing in the quartzite beds should not furnish any clue to this pitch.

Monson.—In 1912 three companies were operating quarries in the township of Monson. The Monson Maine Slate Co. was operating two

[1] See Hitchcock, C. H., The geology of northern New England, 1886; also his Preliminary report on the natural history and geology of Maine, including geologic map of northern Maine, pt. 1, pp. 316, 319, 1861, and Second Ann. Rept., pt. 2, pp. 280, 282, 360, 1862.

quarries east-southeast of its Pond quarry; the Maine Slate Co. of Mònson its Mathews quarry, about 3½ miles west northwest of the village; and the Portland-Monson Slate Co. four narrow openings about a mile south of the village.

At the Monson Pond quarry the following series is exposed: Fifteen beds of slate, measuring altogether from 79 feet to 93 feet 6 inches, alternating with fifteen beds of dark-gray or black quartzite ("hards"), measuring altogether from 48 feet 5 inches to 49 feet 5 inches, both slate and quartzite aggregating from about 127 to about 142 feet. The deposit has been prospected for 200 feet farther southeast, but the

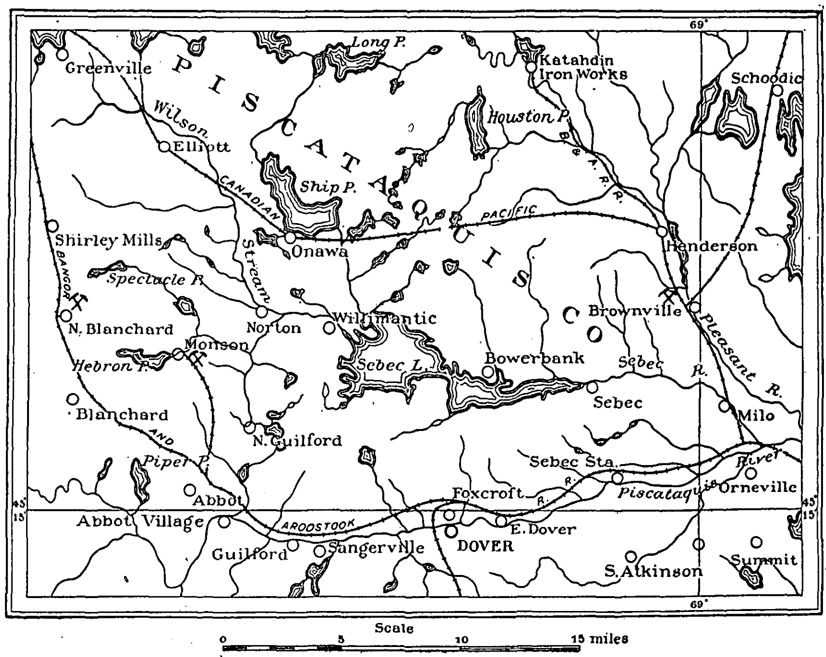


FIGURE 5.—Map of slate region in Maine. From post-route map. The chief quarrying centers are shown by crossed hammers.

slate beds range only from 4 inches to 2 feet in thickness and the quartzite beds vary considerably. The entire thickness explored here thus measures from 327 to 342 feet, and in that thickness there are no indications of duplication. This quartzite is usually very fine grained and under the microscope proves to be biotitic and pyritiferous, with a little magnetite and muscovite and a few grains of zircon. In order to convey an idea of the great irregularity of the interbedding which marks the entire belt the following measurements of the Pond quarry section at the north edge of the quarry are given.

Section at Monson Pond quarry, Monson, Maine.

[Furnished by the courtesy of Mr. F. H. Crane, superintendent.]

	Ft.	in.
Slate	7–18	0
Quartzite		6
Slate	1	8
Quartzite		2–8
Slate	1	10
Quartzite		8
Slate	2	0
Quartzite		3
Slate	4	0
Quartzite	1	6
Slate	4	0
Quartzite		8
Slate	4	0
Quartzite		6
Slate	15–18	0
Quartzite	4	0
Slate	5	0
Quartzite	1	4
Slate	7–8	0
Quartzite	4	0
Slate	3	0
Quartzite	1	2–4
Slate	3	0
Quartzite		8–12
Slate	3	0
Quartzite	20	0
Slate	7	0
Quartzite	2	0
Slate	6	0
Quartzite	11	0

Total slate, 79–93 feet 6 inches.

Total quartzite, 48 feet 5 inches to 49 feet 5 inches.

There is in places a transition from the quartzite to the slate, a quartzitic slate intervening. In the above section such beds are classified as quartzite.

The Pond quarry, now abandoned, measures about 500 feet along the strike and nearly 100 feet across at the top, and from 250 to 400 feet in depth. The beds strike N. 47° E. and dip 78°–80° SE., without any indication of turning, and the cleavage strikes N. 45° E. and dips 90°, thus intersecting the bedding at a very acute angle. The grain strikes N. 45°–50° W. and dips 90°. The slate is traversed at intervals by horizontal joints, which are more numerous in the quartzite—in places from 1 to 4 feet apart. The quartzite also has joints, striking N. 65° W. and dipping 25° N. 65° E., many of which are veined with quartz. There are also vertical diagonal joints striking about northwest and thus parallel to the grain. The northeast half of the quarry is much broken up by diagonal jointing and faulting, but in the southwest half conditions are more normal, although veining is there more common. The difference between the jointing of the quartzite and the slate results from the difference in their rigidity. Their behavior under the same stress must needs have been very dissimilar. Some of the quartz veins traversing the slate contain biotite, chlorite, and a little calcite. The surface of the formation is glaciated and covered with 5 to 10 feet of glacial clay and pebbles.

In 1909 a later and much longer opening next to the Pond quarry, on the east-southeast, had a length of 200 feet of its southern wall fall in, and the cost of removing the débris is reported to have been very great. It is difficult to see how such accidents can be avoided except by leaving supporting masses of unworked slate at short intervals. The horizontal close jointing of the quartzite greatly facilitates such falls.

The slate itself is very dark-bluish gray, but at the glaciated surface some of the beds have in bright sunlight a very slightly purplish hue. The fifth bed from the north edge is slightly brownish. To the unaided eye both texture and surface are fine, but the latter is almost lusterless. It is slightly graphitic and has very little magnetite. The sawn edge shows a little pyrite. No effervescence in cold dilute hydrochloric acid. It is very sonorous.

Under the microscope this slate shows a matrix of muscovite (sericite) with a brilliant aggregate polarization, but there is considerable irregularity in the size of the particles. Quartz fragments measure up to 0.017 by 0.008 millimeter. Some quartz lenses measure 0.094 by 0.047 millimeter. There are to each square millimeter about 100 scales of chlorite (interleaved with muscovite, rarely with biotite) measuring up to 0.047 by 0.03 millimeter and lying transverse to the cleavage; also about 18 scales of biotite to each square millimeter measuring up to 0.086 by 0.02 millimeter, lying both across and with the cleavage, and longish crystals and lenses of pyrite with their long axes parallel to the grain, numbering about 60 to the square millimeter and measuring up to 0.075 by 0.028 millimeter. These crystals are mostly distorted cubes, but mingled with them are probably some distorted octahedra of magnetite. Scattered throughout is dark-gray carbonaceous or graphitic matter in extremely minute particles, to which and to the biotite the slate owes its blackness. Finally, a few delicate rutile prisms, 0.001 millimeter long, some specks of hematite, and a few tourmaline prisms up to 0.036 by 0.004 millimeter. No carbonate detected.

The constituents of this slate, named in the order of decreasing abundance, appear to be muscovite, quartz, chlorite, biotite, pyrite, carbonaceous or graphitic matter, magnetite, rutile, and apatite.

The only available chemical analysis of this slate is that by L. M. Norton,[1] which shows 56.42 per cent of SiO_2, 24.14 per cent of Al_2O_3, and 0.52 per cent of CaO. This small percentage of lime, taken in connection with the occurrence of a little calcite in the quartz veins, points to the presence of an insignificant amount of carbonate, which the microscope fails to detect. But a little of this lime belongs to the apatite. The specific gravity is given by Bayley as 2.851. Tests of the crushing weight and strength made at the Massachusetts Institute of Technology show that a cubic inch of this slate yields to the pressure of 30,425 pounds when applied at right angles to the cleavage, and that a slab 12 by 6 by 1 inches, supported on knife edges 10 inches apart, breaks under a stress of 3,950 to 4,000 pounds applied at the center, with a steel rod, five-sixteenths inch in diameter, placed between the slate and the pressure block. This gives a modulus of rupture of 9,937 pounds to the square inch.

This slate is split to seven thirty-seconds of an inch for roofing. It is also used for electric purposes, register borders, blackboards, refrigerator shelves, etc.

At the Mathews quarry (Maine Slate Co. of Monson), opened in 1903, the thickest slate bed measures about 8 feet. The percentages of quartzite and slate are about 53.3 and 46.6. The strike of bedding and cleavage, taken 175 feet below the surface, is N. 62° E. and the dip 85° S. 28° E. There are two openings, the larger of which measures about 100 feet along the strike, 75 feet across it, and 180 feet in depth. On the north side of the east-northeast end is a tunnel extending 100 feet along the beds and 15 feet in width. Opposite

[1] See Bayley, W. S., U. S. Geol. Survey Bull. 150, p. 313, 1898, and Twentieth Ann. Rept., pt. 6 (continued), p. 394, 1899.

to it on the west-northwest side is another of the same width, 55 feet in length and 40 feet high. In such tunnels in nearly vertical slate reliance is placed on lateral compression contracting the walls sufficiently to make a keystone of the roof. The grain dips 5° N. 62° E. so that the slate has to be sawn in a northwest-southeast vertical direction and "sculped" horizontally. There are vertical dip joints, horizontal joints, and one diagonal joint. The product of this quarry is used for roofing.

The slate is very dark bluish gray; to the unaided eye it has a finer texture and finer cleavage surface than that of the Monson Pond quarry, and also more luster. It is slightly graphitic, has very little magnetite, but the sawn edges show considerable pyrite. It does not effervesce with cold dilute hydrochloric acid and is very sonorous.

Under the microscope this slate shows a matrix of muscovite (sericite), with a very brilliant aggregate polarization. There are lenses of biotite and quartz, or of quartz with a nucleus of pyrite, measuring up to 0.565 by 0.14 millimeter, rarely 1 by 0.075. Quartz fragments, unusually abundant in sections parallel to cleavage, measure up to 0.064 millimeter; biotite scales, about 63 to each square millimeter, measuring up to 0.13 by 0.028 millimeter, lie across as well as in the cleavage. A little less abundant than these are scales of chlorite interleaved with muscovite, lying across the cleavage, and measuring up to 0.13 by 2 millimeters. There are also about 1,160 lenses of pyrite to each square millimeter, with their long axes in the cleavage, and measuring from 0.002 to 0.094 millimeter in length, and up to 0.047 millimeter in width and breadth. This number probably includes a few crystals of magnetite. Some of these lenses are surrounded by secondary muscovite. Generally distributed is a dark grayish or black material, probably graphitic, to which the slate owes its blackness. Tourmaline prisms up to 0.047 by 0.009 millimeter. No carbonate was detected.

The relative abundance of these minerals appears to be, in descending order, muscovite, quartz, biotite, chlorite, pyrite, graphite, and magnetite.

The quarries of the Portland-Monson Slate Co., of 25 Central Wharf, Portland, are about a mile south of Monson village and 1,600 feet west of the railroad. (See Pl. XXVI, *A*.) The largest opening measures 225 feet along the bed, 18 feet across it, and 180 feet in depth; another is 90 feet long and of the same width and depth; and two others are 75 feet long, 18 feet wide, and 60 and 40 feet deep, respectively. The slate surface is glaciated and covered with 10 feet of gravel. The strike of the quartzite and the cleavage of the slate are both N. 63° E., the dip 90°, and the grain vertical and at right angles to the cleavage.

A channeler is used on horizontal joints for vertical cuts along and across the cleavage to obtain working faces. In order to avoid the falling in of the lateral walls, steel **I** beams 20 inches in height are used as braces in groups of three or four, set 2 feet into the wall on either side and inclosed in concrete. These reinforced braces measure about 5 feet square and are placed 30 feet apart and in alternate superposition. A supporting mass of slate, which can be tunneled later, is left every 60 feet.

The slate of these quarries is very dark bluish gray and has a lusterless roughish cleavage surface with marked grain. Its fissility is good. Pyrite very minute and sparse. The slate does not effervesce with acid test. The powdered slate effervesces slightly, is very graphitic, and shows some magnetite.

Under the microscope the matrix has a brilliant aggregate polarization, an even (not lenticular) texture, but with some passages of coarser quartz grains (up to 0.06 millimeter). Meandering incipient plications cross the cleavage and bedding at right angles in the grain direction. Quartz (detrital) is generally very minute, not over 0.04 and mostly under 0.03 millimeter; it appears to be less plentiful than in the slate of Northfield, Vt. (See p. 122.) Chlorite scales plentiful and larger than quartz grains. No rutile was detected, or carbonate, although test with powdered slate shows its presence. Rare tourmaline prisms. Sparse biotite scales, not over 0.06 millimeter across, number about 14 per square millimeter. Conspicuous magnetite crystals or lenses (with a few particles of pyrite), 0.047–0.094 millimeter long and 0.009–0.03 millimeter wide, number about 31 per square millimeter. The constituents, named in descending order of abundance, are muscovite, quartz, chlorite, magnetite, biotite, pyrite, carbonate, and tourmaline.

The slate is a mica slate of the unfading series and is used entirely for millstock, mostly for electric purposes. The president of the company states that electrical tests of this slate show that its insulating qualities are not affected by any magnetite content it may have. The amount of magnetite may also vary in different beds.

West Monson.—At the quarry of the Monson Consolidated Slate Co. is exposed a bed of black slate 9 feet thick, with a bed of quartzite 15 feet thick on its north side and small alternating beds of quartzite and slate on its south side, the whole series measuring perhaps 50 feet. The quarry in 1904 measured 300 feet along the strike, 15 feet across it, and 160 feet in depth. The walls are supported by three pillars of slate. Bedding and cleavage both strike N. 60° E. and dip 90°. There are vertical dip joints striking N. 15° W.; also horizontal joints, to which the grain is parallel. About 15 feet of till lies on the edges of the glaciated slate. As only one bed of slate is worked, the percentage of waste at this quarry is very small.

The slate is a very dark gray. To the unaided eye its texture and cleavage surface are very fine. It has more luster than the slate of the Pond quarry, but not so much as that of the Mathews quarry. It is slightly graphitic, has no magnetite, but shows pyrite on sawn edges; does not effervesce with cold dilute hydrochloric acid, and is very sonorous.

Under the microscope this slate shows a matrix of muscovite (sericite) with a brilliant aggregate polarization. There are a few lenses of quartz and biotite, measuring from 0.107 to 0.13 by 0.034 millimeter, some lying in the cleavage, others in the direction of the grain. The quartz fragments measure up to 0.02 by 0.012 millimeter. There are about 17 biotite scales to each square millimeter, measuring up to 0.08 by 0.02 millimeter; also about 248 chlorite scales, the larger ones measuring from 0.047 by 0.02 to 0.085 by 0.03 millimeter, with their longer axes and laminæ usually parallel to the cleavage and across the grain; and finally, 30 to 88 lenses and crystals of pyrite to each square millimeter, measuring, in sections across the cleavage, up to 0.066 by 0.02 millimeter, with their longer axes parallel to the cleavage, and the usual finely disseminated carbonaceous matter; also tourmaline prisms up to 0.007 by 0.008 millimeter. No carbonate was detected.

The probable relative abundance of these constituents, in descending order, is muscovite, quartz, chlorite, pyrite, biotite, and carbonaceous matter or graphite. Merriman's tests of this slate are given on page 183.

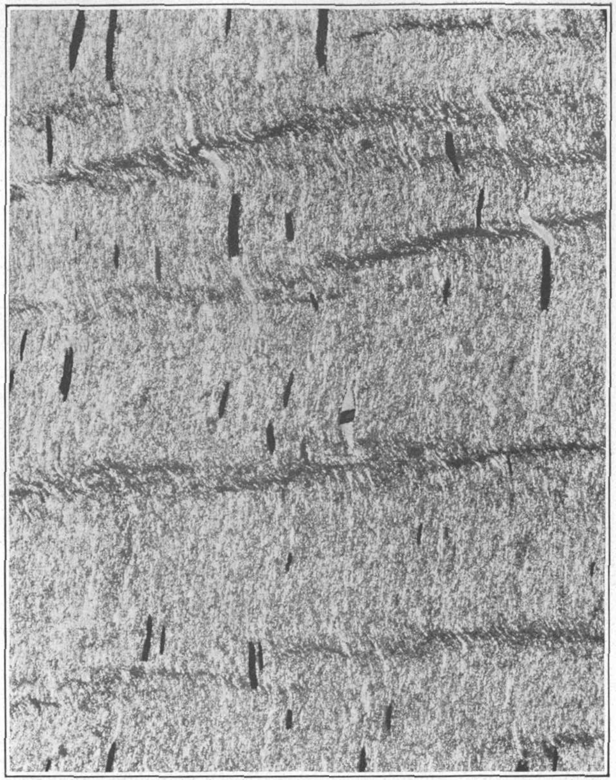
In 1904 the slate was used both for roofing and for electric purposes. The quarry was idle in 1912.

North Blanchard.—There are two quarries at North Blanchard which were both operated in 1904 by the Lowell Slate Co. At the State of Maine or Blanchard quarry 50 feet of slate and quartzite, 10 beds of each, in alternation, are exposed, and 200 or 300 feet more have been prospected east of the quarry. The quarry measures between 250 and 300 feet along the strike, 40 to 50 feet across it, and 200 feet in depth. Both bedding and cleavage strike N. 25° E. and dip 80° ESE. The slate has vertical dip joints striking N. 70° W. and diagonal ones striking N. 40° W. and dipping 32° SSW. There are also joints confined to the quartzite, dipping 65°–70° SSW. and also 65°–70° NNE. The grain strikes N. 65° W. and dips 90°, almost like the dip joints. The surface of the deposit is glaciated and covered with 10 feet of till. Some of the quartzite surfaces show faint traces of marine life. At the Moosehead quarry, which lies half a mile southwest or south-southwest of the last, more than 65 feet of slate and quartzite are exposed. The thickest beds of slate measure 4 and 7 feet. The quarry measures about 500 feet along the strike, 50 feet across it, and 125 feet in depth. Bedding and cleavage both strike about N. 37° E. and dip 80° ESE. Dip joints strike N. 55° W. and dip 90°. The quartzite on the west side of the quarry is broken up by undulating horizontal joints from 1 to 4 feet apart. The grain corresponds to the dip joints.

The slate from these quarries is a very dark gray. To the unaided eye the texture and cleavage surface are fine, but the latter is only slightly lustrous. The slate contains a little carbonaceous or graphitic matter and no magnetite, but the sawn edges show pyrite. No effervescence in cold dilute hydrochloric acid. It is very sonorous and very fissile.

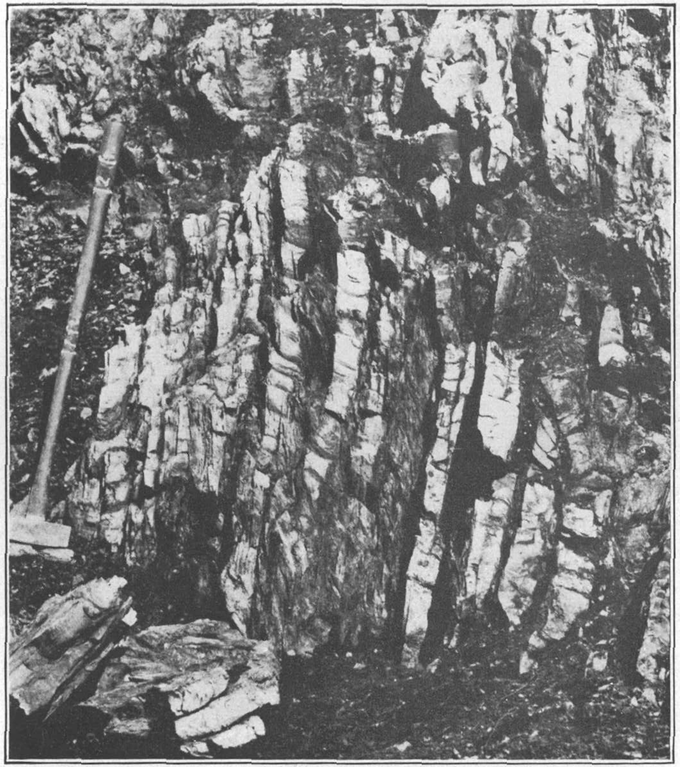
Under the microscope this slate shows a matrix of muscovite (sericite), with brilliant aggregate polarization. A thin section parallel to the cleavage shows muscovite scales sufficiently numerous and parallel to produce a slight aggregate polarization. This may be due to an unusually pronounced grain. The quartz fragments occasionally measure 0.028 millimeter and are not abundant. There are about 380 scales of chlorite, interleaved with muscovite or biotite, to each square millimeter, with their laminæ across the cleavage and measuring up to 0.066 by 0.028 millimeter; also, about seven biotite scales to each square millimeter, measuring up to 0.085 by 0.047 millimeter, many of them bordered by secondary quartz or muscovite in the direction of the slaty cleavage, but with their laminæ transverse to it. There are about 850 lenses of pyrite to each square millimeter, measuring from 0.004 to 0.03 millimeter in length and up to 0.01 millimeter in width; much dark-gray carbonaceous or graphitic matter in exceedingly fine particles; tourmaline prisms up to 0.07 by 0.009 millimeter are plentiful. No carbonate or slate needles found. The chief constituents, named in descending order of abundance, appear to be muscovite, chlorite, quartz, pyrite, graphite, and biotite.

This slate was used in 1904 for roofing and mill stock, including electric appliances. In 1912 the quarries were idle.



A. THIN SECTION OF BLACK ROOFING SLATE FROM MERRILL QUARRY, BROWNVILLE, ME.

Showing fine matrix of muscovite (sericite) with distorted octahedra of magnetite and (exceptionally for this quarry) a secondary plication resulting in slip cleavage. Lenses of chlorite and muscovite or of quartz and muscovite or of muscovite alone about some of the magnetite crystals. Enlarged about 50 diameters.



B. CLEAVAGE BANDING IN SHALES PARTLY ALTERED TO SCHIST, RUPERT, VT., NEAR THE HEBRON (N. Y.) LINE.

Showing alternate bands of finely cleft and uncleft rock, dipping 80° across the bedding foliation, which is visible at several points and dips at a low angle. Slip cleavage. The lower block in the foreground has three uncleft and two cleft bands. Sledge handle is 30 inches long.

MERRILL SLATE QUARRY, BROWNVILLE, ME.

Looking S. 60° W. The end wall, working face, has 42 beds of slate alternating with quartzite. The left wall is quartzite that is diagonally jointed.

Brownville.—The Old Merrill quarry at Brownville, operated in 1904 by the Merrill Brownville Slate Co., lies less than a mile about northeast of the station. (See Pl. XII.) Here are exposed 42 beds of slate, alternating with as many of quartzite, the whole measuring 165 feet in thickness. The slate beds range from 6 inches to 6 feet, and the quartzite beds from 6 inches to 5 feet 6 inches. Any quartzitic slate is considered quartzite in these calculations.[1]

At the Hughes quarry, owned by the same company, situated a mile northwest of the Merrill, there are 28 beds of slate alternating with 28 of quartzite, measuring in all 161 feet 6 inches. The slate beds range from 1 to 9 feet and the quartzite from 4 inches to 20 feet in thickness. There is no evidence of duplication in this series of beds. Some of the quartzite is grayish and medium grained. Under the microscope it proves to be chloritic, pyritiferous, and slightly biotitic, with rare grains of zircon.

The Merrill quarry measures about 450 feet along the strike, between 165 and 200 feet across it, and 250 feet in depth. The bedding strikes N. 78° E., and dips 75° NNW.; the cleavage strikes N. 68° E. and dips 70° NNW. Dip joints strike N. 20° E. and dip 82° WNW.; diagonal joints strike N. 60° W. and dip 90°. There are also horizontal joints, to which the grain is parallel. Quartz veins are not conspicuous, but there are some quartz lenses from 2 to 3 feet in diameter. These veins contain a little biotite. The south wall of the quarry (see Pl. XII), which is formed by a quartzite bed, is divided into rhombic blocks about 10 feet in their longer diameter, owing to the intersection of joints dipping 25° W. and 30° E. The surface of this bed has also what resembles a coarse ripple marking but is probably a minor effect of the rhombic jointing.

The slate is a very dark gray. To the unaided eye it has a very fine texture and a very smooth cleavage surface, with a very bright luster. It is slightly graphitic. When powdered, it yields considerable magnetite to the magnet. The sawn edges show lenses of pyrite a millimeter and less in length. Some of the cleavage and other surfaces on the dumps show a very dark purplish coating. There is no effervescence in cold dilute hydrochloric acid nor any discoloration whatever. It is very sonorous and fissile.

Under the microscope it shows a very fine grained matrix of muscovite (sericite), with a very brilliant aggregate polarization. It contains much quartz in fragments up to 0.076 by 0.02 millimeter; about five biotite plates to each square millimeter, measuring up to 0.076 by 0.03 millimeter, lying across the slaty cleavage. Many of these plates form the nuclei of quartz lenses which measure up to 0.4 by 0.03 millimeter. But the most conspicuous feature, next to the brilliant matrix, is the abundance of magnetite in tabular crystals, probably distorted octahedra, lying parallel to the cleavage, from 29 to 49 to each square millimeter, and measuring from 0.009 to 0.17 millimeter in length and up to 0.04 millimeter in width. Some of these crystals are bordered by secondary quartz and muscovite or chlorite, on one or

[1] Measurements obtained through the courtesy of C. H. Dunning, superintendent.

both sides, particularly wherever they happen to diverge from the cleavage direction. These secondary minerals occupy spaces resulting from a movement of the crystals after the commencement of slaty cleavage. There are also, but in less abundance, lenses of pyrite, up to 0.75 millimeter long and 0.12 millimeter wide, consisting of a nucleus of pyrite surrounded by secondary quartz or by this and biotite, these minerals forming the tapering part of the lens. There is also the usual abundance of dark-gray graphitic material in extremely fine particles. Not a few prisms of tourmaline occur, up to 0.043 by 0.008 millimeter. No carbonate.

Plate XI, *A*, will give some idea of the distribution of the magnetite crystals in this slate, but the "false cleavage" of the specimen is not typical of the product of the Merrill quarry—indeed it is quite exceptional. The specimen was selected to illustrate "false cleavage" as well as the fineness of slaty cleavage. The principal constituents, named in descending order of abundance, appear to be muscovite, quartz, magnetite, pyrite, graphite, biotite, chlorite, tourmaline. This is a highly crystalline mica slate of the unfading series with a bright cleavage face.

W. O. Crosby found that the slate of the East Brownville Slate Co. had an average crushing strength of 29.270 pounds to the square inch, the weight being applied perpendicular to the cleavage, and that it required 3,550 pounds to break a slab 6 inches wide, 1 inch thick, and 11 inches long between supports, the load being applied at the middle. This would give a modulus of rupture of 9,762 pounds to the square inch. The results of Merriman's recent tests of slate from Brownville will be found on page 183.

The product of the Merrill quarry was used exclusively for roofing purposes; its magnetite is thought to prevent its use for electric appliances. However, a piece 6 by 4 inches by one-half inch makes no impression whatever on the magnetic needle, and the section photographed in Plate XI, *A*, came from that piece. The quarry was idle in 1912.

Forks, Somerset County.—A slate prospect opened in the town of Forks in 1890 was visited by the writer in 1905. This prospect is about 18 miles west of the North Blanchard quarries, in the southwest corner of the town of Forks, about 3 miles northeast of Caratunk and about a mile northwest of Pleasant Pond. It is on Holly Brook, on land owned by Lawrence Hill. The nearest railroad is the Somerset Railway extension at Mosquito Narrows, 6 miles distant.

The cleavage strikes N. 55° E. and dips from 90° to steep northwest and southeast, owing to minor folding. The bedding is probably not far different.

The slate is bluish black, of fine texture and cleavage surface, with a luster not so great as that of the slate at Brownville. It is graphitic, contains a very small amount of magnetite, has no argillaceous odor, does not effervesce in cold dilute hydrochloric acid, is sonorous, splits, and can be perforated readily. Neither the ledge nor the fragments, said to have been exposed 15 years, show discoloration.

Under the microscope the section shows a matrix of muscovite (sericite) with a brilliant aggregate polarization, proving it to be a mica slate. The cleavage is fine and regular. There are about 52 lenses of pyrite to each square millimeter, measuring (in transverse section) from 0.02 to 0.06 millimeter in length and 0.004 to 0.016 millimeter in width. In sections parallel to the cleavage these lenses have a very irregular outline and many of them are as broad as long. These lenses account for the limonitic staining on cleavage surfaces of water-soaked specimens. Quartz is abundant but minute. No carbonate was detected. A few tourmaline prisms up to 0.11 millimeter in length. Some scales of chlorite with interleaved muscovite measure up to 0.09 millimeter. There are rare zircon fragments and aggregations of rutile crystals.

The constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, chlorite, pyrite, and graphite, with accessory tourmaline, zircon, and rutile.

This slate of Pleasant Pond differs from the slates of Monson in having a lustrous and smooth surface, and from the slate at Brownville in having much less magnetite and a little less luster. It would prove suitable for roofing or mill stock.

Whether, like the other slates of this State, it is interbedded with quartzite at frequent intervals could not be determined.

The more important features of the slates of Maine as brought out in the above descriptions are set forth in tabular form opposite page 188.

MARYLAND.

The slate of Cardiff, in Harford County, Md., about 30 miles northeast of Baltimore, extends up into Pennsylvania and will be considered under the heading "York and Lancaster counties" (pp. 110–115). Slate occurs also in Montgomery and Frederick counties, about 40 miles west of Baltimore and 33 miles northwest of Washington, where it has been prospected and quarried to a small extent. (See fig. 6.)

Geologic relations.—For the geology of the region the reader is referred to the writings of Williams,[1] Keyes,[2] and Mathews.[3] Keyes's section passes through Sugarloaf Mountain and along the Baltimore & Ohio Railroad (Metropolitan branch) to the northern corner of the District of Columbia. Its important features are these: Sugarloaf Mountain is a mass of eastward-dipping Cambrian sandstone passing toward the east into and under a belt of slaty or schistose rocks (phyllites), which Williams described as containing sericite, chlorite, quartz, hematite, and tourmaline. The phyllite area is traversed in several places by Mesozoic diabase dikes, and east of it are contorted gneisses.

This slate belt, whatever may be its exact bounds, is well exposed at Ijamsville, on Bush Creek and the Baltimore & Ohio Railroad, in Frederick County, where it has a well-defined strike of N. 10° E. Between Ijamsville and a point 2½ miles south-southwest of that place it is at least 1½ miles wide, and reappears west of Hyattstown, 3½ miles farther south, in Montgomery County; and from that point its

[1] Williams, G. H., The petrography and structure of the Piedmont Plateau in Maryland: Geol. Soc. America Bull., vol. 2, pp. 301-318, Pl. XII, 1891.

[2] Keyes, C. R., A geological section across the Piedmont Plateau in Maryland: Idem, pp. 319, 322, fig. 3.

[3] Mathews, E. B., On Ijamsville slate: Maryland Geol. Survey, vol. 2, pp. 231-232, Pl. XXX, 1898.

exposures and cleavage strike range from S. 20° W. to S. 37° W. It thus passes between Sugarloaf Mountain and the village of Mount

FIGURE 6.—Map of parts of Frederick and Montgomery counties, Md., showing (by dots) slate prospects and abandoned quarries.

Ephraim on the west and Hyattstown and Barnesville on the east, its minimum length and width being about 12 and 1½ miles respectively. Immediately east of this belt are chloritic schists and altered diabases.

E. B. Mathews [1] has recently concluded that some of the slates of Frederick County are of volcanic origin or contain material of such origin.

Ijamsville.—One-fourth mile west of Ijamsville station is an abandoned quarry in dark, slightly reddish purple slate.[2] The bedding, shown by light-green ribbons, strikes N. 10°–15° E. and dips 30°–40° W., but the cleavage strikes N. 40° E. and dips 50° SE. There are intermittent joints striking N. 15°–20° E., dipping 75° ESE., which have been parted a fourth of an inch, lined with quartz, and filled with calcite. Similar slate, but interbedded with light green, occurs also several hundred feet east and north of the station.

Thurston.—On Little Bennett Creek, about half a mile east-southeast of Thurston, in Frederick County, is another quarry (opening 70 by 50 feet) operated in 1885 but now abandoned. The slate is also dark purplish with light-green passages containing here and there a scaly bright-green mineral, pyrophyllite, which carries from 1 to 2 per cent of copper oxide. The bedding, indicated by coarsely plicated quartzose passages, appears to be about horizontal. A piece of this slate that is said to have been on a roof many years shows some lightening of the color, owing chiefly to the growth of lichens, but the change is only superficial. The cleavage strikes N. 20° E. and dips 60° E. There is a 2-foot quartz vein in the "top."

About 600 feet south-southwest of this quarry and half a mile southeast of Thurston is the quarry opened or reopened by the Bennett Creek Slate Co. about 1904, measuring 75 feet along the cleavage by 65 feet across it. In May, 1904, this quarry had a depth of 40 feet. The upper 25 feet is "top." The cleavage strikes N. 37° E. and dips 40° E., with green spots aligned in the same direction. Joints strike N. 30° E. and dip 40° W. The grain is almost at right angles to the cleavage.

The slate is dark purplish but has a bluer tinge than that of Ijamsville. To the unaided eye it has a slightly granular texture, a rather fine cleavage surface with distinct grain and a little luster. It contains no magnetite, does not effervesce with cold dilute hydrochloric acid, and is somewhat greasy to the touch. The sawn edges show light-green particles and more minute pyrite ones. The sonorousness is medium. Some of the slates on exposure develop dark spots, due to the oxidation of some mineral. The amount of quartz is so small that slabs half an inch thick may be easily sawn across the cleavage and the grain with a handsaw.

Under the microscope it shows brilliant aggregate polarization, but much irregularity in size of particles and very slight plications in the direction of the grain. The matrix of muscovite (sericite) contains abundant quartz fragments, measuring up to 0.094 millimeter. There are conspicuous scales of chlorite, often interleaved with muscovite lying transverse to the cleavage, measuring as much as 0.38 by 0.25 milli-

[1] Maryland Geol. Survey, vol. 8, pp. 133–136, 356–357, 1900.
[2] Idem, vol. 2, pp. 231, 232, Pl. XXIV, fig. 2, 1898.

meter, or exceptionally 0.66 by 0.14 millimeter, and forming the centers of lenses of sericite or talc (?)[1] measuring up to 1.5 millimeters in length. There are also lenses of sericite or talc (?)[1] measuring up to 0.56 by 0.09 millimeter with their long axes in the grain direction.

These scales and lenses number about 88 per square millimeter, of which about 18 are chlorite. Multitudinous minute dots of bright-red hematite occur throughout the slate, and to these and the chlorite it owes its purplish color. Among these dots are many particles of pyrite, some of which measure 0.038 millimeter. A few of these have passed into limonite. Slate needles (TiO_2) are somewhat plentiful. No carbonate. Tourmaline 0.076 by 0.009 millimeter. The important constituents of this slate, named in order of abundance, appear to be muscovite, chlorite, quartz, talc, hematite, pyrite.

Its deficient sonorousness is not due to the absence of a micaceous matrix, but to the presence of a large amount of chlorite and to about 5 per cent of talc. It is a slightly talcose mica slate.

Mount Ephraim.—About 4 miles southwest of the Bennett Creek quarries and a quarter of a mile south-southeast of the village of Mount Ephraim, in Montgomery County, east of the road to Barnesville and north of Little Monocacy River, on the property of Abraham Harris, a similar slate has been prospected. The cleavage strikes N. 30°–35° E. and dips 70° E. The bedding probably strikes N. 30° E.; the dip is uncertain.

The characteristics of the slates of Maryland are shown in the table facing page 188.

MINNESOTA.

By Edwin C. Eckel.

Deposits of roofing slate occur in northern Minnesota, a few miles west of Duluth. At present, however, all the quarries formerly opened here are abandoned, and the quality of the slate, as seen in specimens from the old dumps, is hardly such as to justify reopening.

The following reports and papers, while not economic in intention, contain data of interest on the distribution and character of the slates of Minnesota:

Hall, C. W., Keewatin area of eastern and central Minnesota: Geol. Soc. America, Bull., vol. 12, pp. 345–376, 1901.

Spurr, J. E., The stratigraphic position of the Thomson slates: Am. Jour. Sci., 3d ser., vol. 48, pp. 159–166, 1894.

Winchell, N. H., The geology of Carlton County: Minnesota Geol. Survey Final Repts., vol. 4, pp. 1–24, 1899.

——— The geology of the southern portion of St. Louis County: Idem, pp. 212–221.

——— The geology of the Carlton plate: Idem, pp. 550–565.

——— The geology of the Duluth plate: Idem, pp. 566–580.

[1] Mathews (Maryland Geol. Survey, vol. 2, p. 232), following some determination by G. H. Williams, regarded these slates as containing talc. A chemical test made by George Steiger at the United States Geological Survey laboratory shows 0.27 per cent of SiO_2 soluble in 1–20 solution of Na_2SO_3 before ignition, and 1.09 per cent after ignition. F. W. Clarke, chief chemist, notes that the difference, 0.82 per cent, corresponds to a splitting off of SiO_2 from the talc if talc is present. It would be one-fourth of the SiO^2 in the talc and thus represent a percentage of 5.17 of talc. As the only other silicates in the slate are crystalline quartz, chlorite, muscovite (sericite), and tourmaline, this result is reliable. The combination of chlorite and sericite alone would be sufficient to account for the "talcose" touch of the slate.

NEVADA.

The discovery of slate in the Blue Mountains in Humboldt County, Nev., was reported to the Geological Survey in 1908. The deposit occurs about 21 miles northwest of Winnemucca and is said to be extensive.

This slate may belong to the Mariposa slate, of Jurassic age. Clarence King [1] described a slate of the region in these words:

Over the Jurassic limestone on the northern points of the West Humboldt Range is a very heavy body of variable but generally argillaceous slate. The exposure on Humboldt Canyon is of over 2,000 feet and on the north side of the Humboldt valley the same slate group is exposed with even greater thickness.

On page 268 of the same work King correlates these Jurassic slates with similar rocks at Mariposa, Cal.[2]

Specimens reported as having been obtained from more or less weathered outcrops on the Gibraltar group of claims were examined with the following result:

The slate is of dark bluish-gray color. To the unaided eye it has an extremely fine texture and a very smooth, slightly lustrous cleavage surface. It contains some carbonaceous or graphitic matter and, as shown by the magnet, a little magnetite. The sawn edges show neither pyrite nor magnetite. It does not effervesce with cold dilute hydrochloric acid. It is sonorous and has a very high grade of fissility. The cleavage face shows traces of "grain," but the slate breaks usually at angles of 50° to 70° and 30° to the apparent grain.

Under the microscope this slate shows a matrix of muscovite (sericite) with well-defined aggregate polarization and is thus a mica slate. The cleavage is fine, although showing some minor irregularities in the size of particles. The quartz particles measure up to 0.06 millimeter in diameter; one plagioclase feldspar measured 0.04 millimeter. No pyrite was detected. The dark particles are nonmetallic and probably carbonaceous. Rather abundant scales of chlorite and of interleaved chlorite and muscovite measure up to 0.14 millimeter in length and to 0.05 millimeter in width. Rutile is very abundant both in single needles and more in net-shaped groups of twinned needles (sagenite) measuring 0.02 millimeter across. There is a little limonite proceeding possibly from the magnetite and due to incipient weathering. No carbonate could be found.

Its constituents, in descending order of abundance, appear to be muscovite, quartz (detrital), chlorite, carbon (probably graphite), rutile, magnetite, and plagioclase (detrital).

The fissility of this slate is equal to that of the slates of Pennsylvania, but its freedom from carbonate indicates that its color will prove more durable.

NEW JERSEY.

The slate belt of Lehigh and Northampton counties, Pa., is prolonged eastward into New Jersey, where roofing-slate quarries have been opened at several points, notably near Newton and Lafayette, in Sussex County.

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[1] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par., vol. 1, p. 295, 1878.

[2] See Smith, J. P., Age of the auriferous slates of the Sierra Nevada: Geol. Soc. America Bull., vol. 5, pp. 243-258, 1894; also Turner, H. W., and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Sonora folio (No. 41), p. 2, 1897.

Lafayette.—The quarry of the Lafayette Slate Co., of Newton, N. J., the only slate quarry in operation in this State in 1912, is about 2 miles N. 25° E. from Lafayette village and nearly 28 miles northeast of the Delaware Water Gap. The opening measures about 200 feet in a N. 20° W. direction by 85 feet across and 70 to 100 feet in depth. The "top" consists of 5 to 15 feet of weathered slate and till. The beds (ribbons) strike N. 45° E. and dip 20°–30° N. 45° W. The cleavage strikes N. 70° E. and dips 20° S. 20° E. There are two sets of joints. Those of one set strike N. 10°–45° E., dip 70° S. 63° E., and are spaced 2 to 20 feet. Those of the other set strike N. 30° W., dip 90°, and are spaced 5 to 40 feet. Owing to secondary motion the slate is more or less bent (not curved) at each ribbon. The weathered slate of the "top" is of light-brownish color.

The slate is very dark bluish gray. To the unaided eye it has a fine texture and a slightly roughish, lusterless cleavage surface. The sawn edge shows pyrite. It effervesces with acid test, and the ribbon still more. The powdered slate is very effervescent, carbonaceous, and but very slightly magnetitic. It has a high grade of fissility and is sonorous.

Under the microscope this slate shows a matrix of muscovite (sericite) with fair aggregate polarization somewhat obscured by abundant carbonate, and with very elongate lenticular texture. Beds 0.75 millimeter thick cross the cleavage at 36°. Quartz grains (detrital) up to 0.034 millimeter. Chlorite scales, some with interleaved muscovite, up to 0.08 millimeter, lie at right angles to the cleavage. Sparse pyrite spherules 0.004–0.012 millimeter across. Carbonaceous matter in short streaks parallel to beds. In these beds the carbonate is coarser and the quartz up to 0.66 millimeter. Rutile needles.

The constituents, named in descending order of abundance, appear to be muscovite, quartz, carbonate, chlorite, carbon, kaolin, pyrite, magnetite, and rutile.

This is a mica slate of the fading series. It is reported as being harder than slate of Bangor, Pa., and as preserving its color on the roof for at least 30 years.

It is supplied to the market in two qualities—No. 1, generally very slightly bent; No. 2, with one or two very obtuse bends, giving to each slate a zigzag outline in longitudinal section. When in full operation this quarry employs eight splitters.

There is an abandoned quarry about half a mile S. 70° W. from the quarry described above. The opening is triangular, about 75 feet on a side and about 90 feet deep. The beds strike N. 60° E. and dip 20° N. 30° W.; the cleavage strikes N. 55° E. and dips 35° S. 35° E. Although the quarry has not been worked for many years the slate on the dumps, which cover several acres, is generally very dark, but a quarried cleavage face at the edge of the quarry is light brownish gray.

NEW YORK.

GEOLOGIC RELATIONS.

The slates of Washington County, N. Y., are a continuation of those of Rutland County, Vt. The Lower Cambrian affords greenish and purplish slates, like those in Vermont described on page 139, which were once extensively quarried at Middle Granville and Jamesville. Overlying the Lower Cambrian, in isolated lenticular synclinal areas or in long, ramifying masses of complex structure, are Ordovician grits and black, red, and green shales; and these red and green shales pass here and there into roofing slates.[1] (See Pl. XX.)

Although the Lower Cambrian greenish and purplish slates are at present quarried almost exclusively on the Vermont side of the boundary, the red and green slates attain their best development on the New York side, particularly in the towns of Granville, Whitehall, and Hampton. The structural relations of the two slate-bearing formations on the New York side are shown in Sections I, II, VII of Plate XXII and are explained in detail on pages 125, 128, 132.

As to mode of occurrence, these red and green slates occur in places in proximity to white-weathering greenish or black, more or less quartzose shales or slates, and they also seem at several points to replace the Ordovician grit along the strike. Certainly these slates occur in as close proximity to the Cambrian slates as the grit. Black shales abounding with graptolites of the Normanskill fauna, as determined recently by Ruedemann, dip under the red slates on the west side of the now disused quarry a mile northeast of Middle Granville (locality 36, Pl. XX).

The red and associated bright-green slates are regarded as of the same general horizon as the Ordovician grits and their interbedded graptolite shales; and on the east the entire group (red and black slates and shales and grits) appears to pass along a meandering line extending from a point in Rupert, Vt., about a mile south of the Bennington County line, to the village of North Pawlet, Vt., on the north, merging gradually into the more highly metamorphosed sediments of the Taconic Range, the typical Berkshire schist, which is micaceous, chloritic, and in places also hematitic or graphitic. As the red slate appears to correspond to the lower part of the schist formation it is probably of middle Trenton age.

The cause of the abundant hematite to which the red slate owes its color may be sought in the beginning of a gradual elevation of a land surface that owing to long-continued weathering had become covered with somewhat thick deposits of rusty clays, which were then carried into the sea. These fine limonitic clayey sediments, when later subjected to the compression that metamorphosed the clay into fibrous muscovite and set up slaty cleavage, became reddish by the loss of the combined water and the change of limonite into hematite. The beds of bright-green slate may be attributed, like the spots and small greenish beds (p. 25), to the effect of decomposing marine organisms reducing the iron in the clays or to the original absence of iron therefrom.

[1] U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, Pl. XIII, 1899.

Beds of red and green slate alternate vertically and replace one another along the strike and also pass into shales of the same colors. The thickness exposed at the quarries reaches 50 and 75 feet, mostly red, with about 25 feet of green overlying, but after subtracting that which is too hard or too soft or badly veined, there remains in places but 10 feet, rarely more than 25 feet, and at a maximum 42 feet, of good red slate exposed at any one quarry. Owing to the character of the folds and their pitch, as well as the merging of the colors along the strike, it is not easy to ascertain the total thickness of the red and green. A few feet or inches of dark-red or purple slate is in some places interbedded with the red. Beds of greenish quartzite, locally calcareous, bordered by a purple slate, the whole ribbon measuring an inch or two in thickness, are not uncommon (Pl. II, *A*), also beds half an inch thick of rhodochrosite (manganese carbonate) with crystalline calcite.

An analysis of this slate (specimen D. XIV, 1895, 201*d*), made by George Steiger, yielded the following:

Analysis of rhodochrosite bed.

Al_2O_3	0.68	MgO	2.61
Fe_2O_3	.14	CO_2	25.06
FeO	1.13	Insoluble matter, including all silica from dissolved silicates	32.75
MnO	32.22		
NiO and CoO	.10		
CaO	3.81		98.50

Under the microscope thin sections of this bed show, with polarized light, a fine-grained bluish-brown matrix identical in color and texture with that of the small lenses in the red slate and with some of the lenses in the green slate; also large areas of calcite and some quartz.

Both red and green slates also contain veins of quartz, some of which is crystallized, and in the red slate are light-green spots with or without a purple rim. Both red and green slates are in many places speckled with lenses. (See p. 91.) The bedding planes are locally covered with glistening annelid trails and with impressions that may have been made by algæ. Thin films of barite and calcite occur on the joint planes.

The location of the more important red-slate quarries in the towns of Granville and Hampton is shown on Plate XX. The structure at two of the quarries is shown diagrammatically in figs. *H* of Plate XXIII and *U* of Plate XXIV, and the compass courses at the larger quarries, with reference numbers to their location on the map (Pl. XX), are given below, but Nos. 33, 39, and 41 lie west of the area mapped; 33 is 3½ miles north-northeast of Middle Granville, in Granville Township; 41 is 2⅘ miles northeast of Middle Granville, also in Granville; and 39 is 2¾ miles west of Jamesville, in Whitehall.

Compass observations at New York red-slate quarries.

Quarry No. on Plate XX.	Bedding.		Cleavage.		Strike joints.	
	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.
33	N.	30± E.				
34	N.	45° E.				
35	N.+	15° E.	N. 15° E.	20° E.		
36	N. 5° E.	45° E.	N. 5° E.	30° E.	N.+	55° E.
37	N. 12° W.	35° E.	N. 12° W.	35° E.		
38	N. 10° W.	25° E.	N. 5° W.	30° E.	N. 10° W.	25° E.
39	N. 5° E.	50° E.	N. 5° W.	45° E.		
40	N.	35° E.	N.	40° E.		
41	N.	30° E.	N.	40° E.	N. 15° W.	50° E.
64	N. 15° W.	22° E.	N.	25° E.		
66	N. 30° W.	20° E.	N. 15° W.	25° E.		

Quarry No. on Plate XX.	Dip joints.		Diagonal joints.		Shear zones ("hogbacks").	
	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.
33			N. 30° E.	70° W.		
34	N. 65° W.	90°				
35						
36	E.-W.	90°				
37						
38	N. 75° W.	90°				
39						
40					N. 7° E.	77° E.
41	N. 77° E.	90°				
64						
66	N. 80° W.	90°			N. 55° W.	70° NE.

THE SLATES.

Red slate.—The "red" slate is a decidedly reddish brown, becoming brighter on exposure. To the unaided eye its texture is fine, and its cleavage surface varies from slightly roughish to speckled with minute protuberances ("eyes" or "knots"), in either case without luster. It is magnetitic, sonorous, and has an argillaceous odor. Some of it effervesces with cold dilute hydrochloric acid. Under the microscope it shows a matrix of muscovite (sericite) with somewhat faint aggregate polarization, but this faintness is due partly to obscuration by carbonate and hematite, many of the plates of the former remaining light when all the mica is dark and the hematite darkening the mica when it is light. Distributed throughout the matrix are multitudinous bright-red hematite dots of circular or irregular oval outline, measuring from 0.0004 to 0.009 millimeter. There is much irregularity in the size of the particles, indicating but a fair grade of fissility. The larger particles consist of quartz fragments up to 0.06 by 0.03 millimeter, rare grains of plagioclase feldspar and of zircon, all detrital, considerable carbonate in rhombs or plates up to 0.047 millimeter, scales of chlorite interleaved with muscovite, up to 0.075 by 0.036 millimeter, a very variable number of lenses up to 0.34 by 0.15, rarely 0.5 millimeter long, consisting probably of rhodochrosite (carbonate of manganese) and chalcedonic quartz (containing carbonate rhombs and muscovite scales and in some places partial pseudomorphs of chlorite after carbonate), and finally some tourmaline prisms up to 0.005 by 0.001 millimeter.

The chief constituents of the red slate, named in descending order of abundance, appear to be muscovite, quartz, hematite, kaolin, carbonate, chlorite, magnetite, and rhodochrosite. For colored lithographs of magnified thin sections of this slate, as seen under both ordinary and polarized light, see Nineteenth Annual Report U. S. Geological Survey, part 3, Plate XXVIII, *A*, *B*, *C*. For a discussion of the causes of the green and purplish spots which occur here and there in this slate see page 23 of this bulletin. Associated with the red slate is generally a little purplish slate, some of it speckled, of no commercial importance. Under the microscope it shows less hematite and possibly more chlorite than the red slate. Analysis N, below, shows that it contains from 2½ to over 4 per cent less hematite and about one-third of 1 per cent more ferrous oxide than the red.

The following analyses were made in the chemical laboratory of the United States Geological Survey, the complete analyses by W. F. Hillebrand, the partial ones by George Steiger:

Analyses of red slates from New York.

	J	K	L	M	K[2]	N
Silica (SiO_2)	67.61	67.55	56.49	63.88		
Titanium dioxide (TiO_2)	.56	.58	.48	.47		
Alumina (Al_2O_3)	13.20	12.59	11.59	9.77		
Ferric oxide (Fe_2O_3)	5.36	5.61	3.48	3.86	7.10	1.02
Ferrous oxide (FeO)	1.20	1.24	1.42	1.44	1.00	1.67
Manganous oxide (MnO)	.10	.19	.30	.21		
Nickelous oxide (NiO)	Trace?	Trace.	Trace.	Trace.		
Cobaltous oxide (CoO)	Trace?	Trace.	Trace.	Trace.		
Lime (CaO)	.11	.26	5.11	3.53		
Baryta (BaO)	.04	.31	.06	.05		
Magnesia (MgO)	3.20	3.27	6.43	5.37		
Potassa (K_2O)	4.45	4.13	3.77	3.45		
Soda (Na_2O)	.67	.61	.52	.20		
Lithia (Li_2O)	Trace.	Trace.	Str. tr.	Str. tr.		
Water below 110° C (H_2O)	.45	.40	.37	.27		
Water above 110° C. (H_2O)	2.97	3.03	2.82	2.48		
Phosphoric oxide (P_2O_5)	.05	.10	.09	.08		
Carbon dioxide (CO_2)	None.	.11	7.42	5.08		
Pyrite (FeS_2)	.03	.04	.03	Trace.		
Sulphuric oxide (SO_3)	Trace.	Trace.	Trace.			
Carbon (C)	None.	None.	None.	None.		
	100.00	100.02	100.38	100.14		
Total sulphur (S)	.016	.02	.016			
Specific gravity			2.7839		2.8085	

J (D. XIV, 1895, 358*d*), red slate, H. H. Matthews's quarry, 1 mile west of Poultney, in Hampton, Washington County, N. Y.
K (D. XIV, 1895, 201*e*), red slate, Empire Red Slate Co.'s quarry, 1 mile north of Granville, in Granville, Washington County, N. Y.
L (D. XIV, 1895, 397*e*), red slate, National Red Slate Co.'s quarry, 1 mile north-northwest of Raceville, in Granville, Washington County, N. Y.
M (D. XIV, 1895, 397*a*), red slate, same locality as L, but near a green and purple spot.
K[2] (D. XIV, 1895, 201*h*), red slate, same as K, but finer grained.
N (D. XIV, 1895, 284*a*), purple bed in red slate at Fair Haven Red Slate Co.'s quarry (not worked), 2 miles north of Truthville, in East Whitehall, Washington County, N. Y.
For presence of chromium and vanadium in these see Dr. Hillebrand's note, p. 58.

Some points in these analyses are discussed by Dr. Hillebrand on pages 58, 59.

As these red slates do not discolor and yet show a considerable amount of carbonate under the microscope, and as the discoloration of the "sea-green" slates of Vermont is due to the oxidation of a ferrous carbonate, it may be inferred that the carbonate here is chiefly one of lime and magnesia, but the effect of a very small percentage of ferrous carbonate would probably be masked by the brightness of the hematite.

J. F. Williams reported for this slate a modulus of rupture of 7,310 pounds to the square inch, and Merriman 126.66 foot-pounds of work to the pound of slate as a result of impact tests. The results of Merriman's other tests of this slate are given on page 183.

Bright-greenish slate.—The reddish slate is usually interbedded and exceptionally passes along the strike into a light bluish-green slate, brighter in color than the "unfading green" Cambrian slates of Vermont. Its color is peculiarly bright by lamplight; its texture and surface are similar to those of the "red," and the surface is also in places speckled with minute lenses. It is magnetitic, effervesces very slightly with cold dilute hydrochloric acid, is sonorous, and is said to be unfading.

Under the microscope it shows a matrix of muscovite (sericite) with a more brilliant aggregate polarization than that of the red slates, which may be due to the absence of the hematite, but the coarseness of the particles does not indicate a superior fissility. There are quartz grains up to 0.084 by 0.056 millimeter, chlorite scales up to 0.043 millimeter, some carbonate rhombs from 0.002 to 0.056 millimeter, and lenses measuring up to 0.385 by 0.128 millimeter, that consist either of rhodochrosite or chalcedonic quartz inclosing very minute carbonate rhombs and chlorite scales. Sections parallel to the cleavage show these lenses with a more roundish outline. There are also particles of pyrite, tourmaline prisms, rutile needles, and grains of zircon.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, magnetite, rutile.

Its color is due to the abundance of chlorite and is permanent.

The following analysis (specimen O=D. XIV, 1895, 397c), by W. F. Hillebrand, is of a bright-greenish speckled slate from the National Red Slate Co.'s quarry, 1 mile north of Raceville, in Granville, Washington County, N. Y.

Analysis of bright-greenish slate from New York.

Silica (SiO_2)	67.89	Soda (Na_2O)	.77
Titanium dioxide (TiO_2)	.49	Lithia (Li_2O)	Trace.
Alumina (Al_2O_3)	11.03	Water below 110° C. (H_2O)	.36
Ferric oxide (Fe_2O_3)	1.47	Water above 110° C. (H_2O)	3.21
Ferrous oxide (FeO)	3.81	Phosphoric oxide (P_2O_5)	.10
Manganous oxide (MnO)	.16	Carbon dioxide (CO_2)	1.89
Nickelous oxide (NiO)	Trace?	Pyrite (FeS_2)	.04
Cobaltous oxide (CoO)	Trace?	Sulphuric oxide (SO_3)	Trace.
Lime (CaO)	1.43	Carbon (C)	None.
Baryta (BaO)	.04		
Magnesia (MgO)	4.57		100.08
Potassa (K_2O)	2.82	Sulphur, total (S)	.022

Specific gravity, 2.7171.

The relatively high percentage of magnesia is attributed to the abundance of both dolomite and chlorite.

The results of Merriman's tests of the bright-greenish slates quarried by the Mathews Consolidated Slate Co. are given on page 183.

Black slate.—Black roofing slate of Ordovician age was quarried many years ago, in a small way, 3 miles south of Hoosick Falls, near Hoosick, and also, at a later time, 2 miles south of Stephentown, near Lebanon Springs, in Rensselaer County, N. Y., but did not prove to be of economic importance at either locality.[1]

The principal features of the slates of New York as brought out in the above descriptions will be found in tabular form opposite page 188.

PENNSYLVANIA.

GENERAL FEATURES.

The slates of Pennsylvania, aside from those of Lancaster County and the southeastern part of York County, which are known as the Peach Bottom slate (pp. 110–115), occur chiefly in Northampton and Lehigh counties in a strip from 2 to 4 miles wide on the south side of Blue Mountain, extending from Delaware Water Gap in a west-southwest direction to a point 4 miles west of Lehigh Gap, a distance

[1] Pl. CI and fig. 26, Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1892, show the structure at the Lebanon Springs quarry.

of about 32 miles. The chief centers of the slate industry here are at Bangor and Slatington. The geographic relations of these places and of the other groups of slate quarries in these counties are shown on the maps of the Second Pennsylvania Geological Survey, in Merrill's "Stones for building and decoration" (third edition), and in Merriman's article in Stone for July, 1898.

The map, Plate XV, compiled from that of the Second Pennsylvania Geological Survey by C. A. Bonine, shows the quarry sites of Northampton County as approximately determined by him in 1911.

The general geologic relations of this slate are these: On the southeast, forming an east-northeasterly belt between Easton and Reading and beyond, are the pre-Cambrian gneisses, etc., of South Mountain, flanked and dotted over with strips of Lower Cambrian quartzite and sandstone. Northwest of this belt and parallel to it is a great Cambrian and Ordovician dolomite and limestone plain from 3 to 6 miles wide, under which the quartzite dips. Still farther northwest is a slightly hilly belt of Ordovician shales, grits, and roofing slates (the Martinsburg shale), from 6 to 8 miles wide. At the southeast these shales and slates overlie the limestone, and at the northwest they dip under the Silurian conglomerate and sandstone of Blue Mountain. The boundary between the shale and slate formation and the limestone is roughly parallel to the general course of the Shawangunk conglomerate boundary but passes a little north of Nazareth. In Carbon County, northwest of Blue Mountain, lies a strip of shales and slates, much resembling the Ordovician beds which dip under the Silurian conglomerate on the southeast, but which Rogers (section 2, Pennsylvania Survey) represented as overlying that conglomerate conformably and thus as of Silurian age. Slate has also been prospected in Dauphin County about 55 miles southwest of Lehigh County and southeast of Blue Mountain.

The shale and slate formation measures from a minimum exposure of 1,600 feet to an estimated maximum of 6,000 feet, but of this only a few hundred feet is commercial slate. In structure this formation consists of a succession of minor close folds, generally overturned northward, so that their axial planes have a general southerly dip, but usually the synclines so formed have a steeply inclined southern and a gently inclined northern limb. In places the fold is extremely close and the overturn so complete that its axial plane has a very low southeasterly dip. The cleavage dips southward at various angles, as low as 5°, pointing, like the curvature of cleavage and jointing, to a secondary movement. These folds vary greatly in width and their axes also pitch alternately east-southeast and west-northwest at angles ranging from 5° to 10°. They also bend laterally from north to south. These folds have been more or less truncated by surface erosion, and in places the cleavage foliation has been crushed and bent over to the south by the friction of the southward-moving ice sheet.

"Ribbons," or small beds of grit, measuring from a fraction of an inch to 2 feet in thickness, characterize the slate belt throughout. (See Pls. V, *B*; VI, *A*; XVII; and XVIII.) This grit consists mostly of more or less angular grains of quartz and feldspar, rarely of shale and quartzite, together with scales of muscovite and lenses of chlorite, spherules of pyrite, and carbonaceous matter, all in a cement of calcite and sericite with rhombs of carbonate more or less altered to limonite. The ribbons, as explained on page 11, represent coarse sediments, brought in, probably, by local marine currents.

Commercial slate is obtained along two belts. The upper and northerly one, known as the "soft vein," which is separated from the overlying Silurian conglomerate by an uncertain thickness of shale and slate, consists of beds of relatively soft slate of sufficient thickness between the ribbons to furnish large slabs suitable for mill stock or roofing. The lower and southerly belt, the "hard vein," near the base of the Ordovician formation ("Hudson"), consists of small beds of harder slate separated by small ribbons which are not coarse enough to interfere with their use either as mill stock or roofing slate.

The Bangor, East Bangor, Pen Argyl, Danielsville, Slatington, and Slatedale quarries are in the "soft vein" belt and the Belfast and Chapman are in the "hard vein." To judge from the map of the Second Geological Survey of Pennsylvania, which represents a limestone area, presumably anticlinal in structure, as extending from the Delaware near Portland to the vicinity of East Bangor, the "hard vein" ought to recur there near the limestone.

The following notes on the general stratigraphy of this slate belt and on the relations of the slate to the overlying Silurian conglomerate are contributed by C. A. Bonine, of this Survey, from his Lehigh University thesis on "The slate deposits of Northampton County, Pa.," written in 1912:

In going up either the Delaware or the Lehigh River at right angles to the strike it is evident even to the most superficial observer that there are three lithologically different types represented in the formation. Farthest south the beds of slate are hard and close together, possess a good cleavage, and are occasionally interbedded with sandstone. Northward the formation changes gradually into beds of almost pure sandstone with very few shaly beds, and still farther north up to the Shawangunk conglomerate the material is again nearly all slate, which is soft, thick bedded, highly fissile, and interlayered with only occasional sandy beds. In the lower portion the "hard vein" slate is found and in the upper the "soft vein." The Delaware River section, along which the most reliable exposures were found, shows clearly that the Martinsburg shale is divisible into three parts—a lower hard thin-bedded shale and slate, a middle member of sandstone, and an upper member of shale and slate, which is soft and thick bedded. From this section it will be seen that the "soft vein" slate is found only near the mountains, because the land farther south along the axis of the syncline has been reduced by erosion to such an extent that the upper soft member of the formation has been entirely removed, leaving exposed only the middle sandy portion.

A close examination of the beds of the Shawangunk conglomerate near the base shows included fragments of the underlying shale. The contact between this formation and the Martinsburg shale underneath is well exposed in a new cut of the Lehigh & New England Railroad at Lehigh Gap. The dips here are not conformable, that of the conglomerate being 20° N. 45° W. and that of the slate 40° N. 45° W. There are also strong indications of a considerable erosional interval, as shown by the transitional bed of soil material and pebbles.

All the more important features of the slates of Pennsylvania are set forth in tabular form in the section on the comparative characteristics of slates (p. 188). The literature of the slate of Northampton and Lehigh counties is listed in the bibliography on pages 205–212, under the names Chance, Lesley, Merrill, Merriman, Rogers (H. D.), and Sanders.

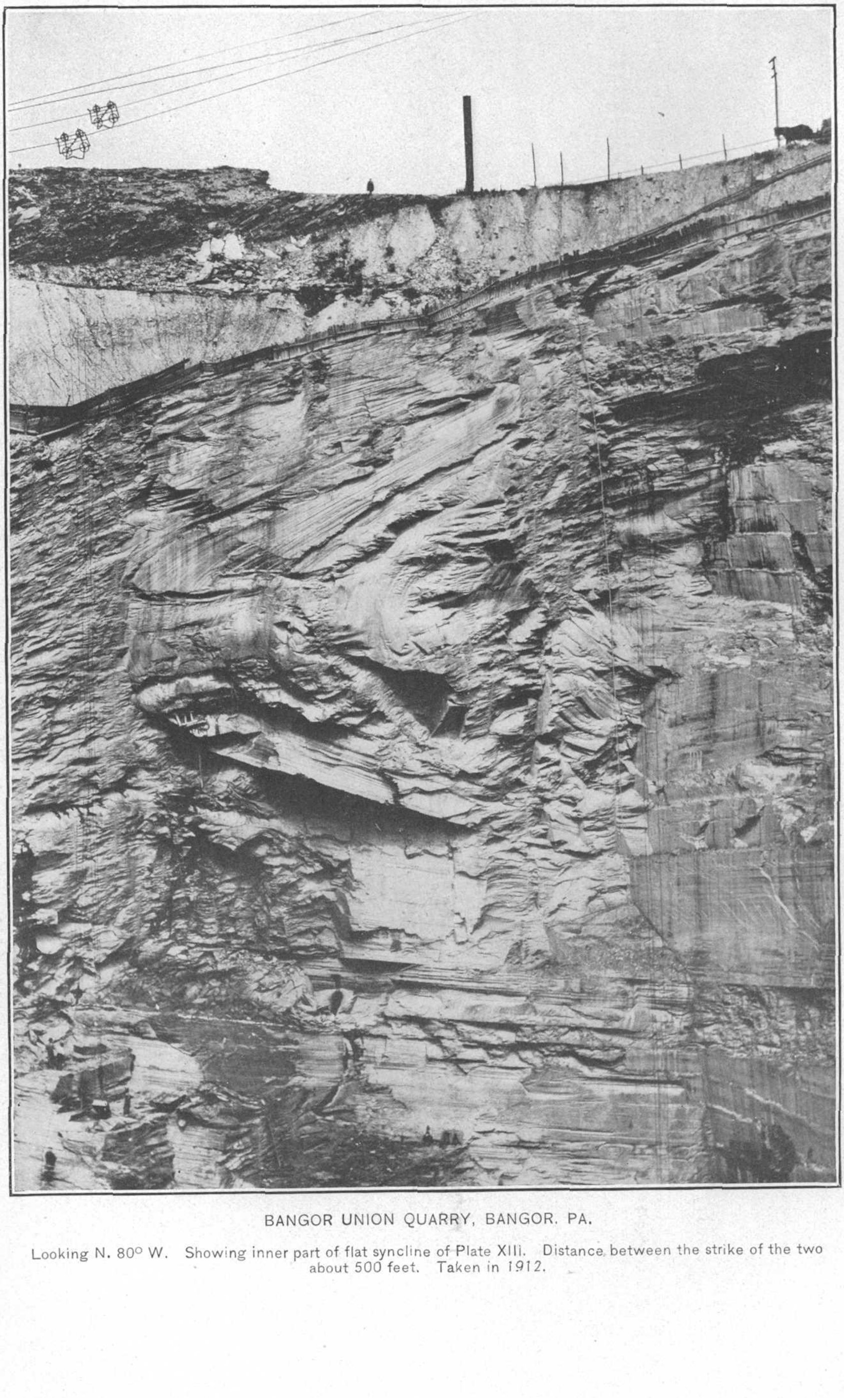
A few typical quarries and slates from these belts will now be described.

NORTHAMPTON COUNTY.

Bangor.—The "Old Bangor" quarry at Bangor, now operated by J. S. Moyer & Co., is the largest slate quarry in the United States and the oldest one in this region. It is regarded as being near the top of the "soft vein" belt. It measures over 1,000 feet along the strike, 500 feet across it, and from 200 to 300 feet in depth. (See Pl. XIII and map of Delaware Water Gap quadrangle, United States Geological Survey.) The general structure is that of a close overturned syncline, striking about N. 25° E., with an axial plane dipping east-southeast at a low angle and pitching 5°–10° SSW., crossed by cleavage dipping 5°–10° S. 32° E. The same gritty bed appears at both the top and the bottom of the quarry, and this bed is regarded as the lower limit of the slate, drill cores from a depth of 200 feet below the quarry having failed to show any good slate. The thickest bed of good slate is 9 feet thick. In 1912 that part of the gritty bed overlying the good slate of the syncline was being blasted out and thrown down upon the gritty bed below it as fast as the good slate was quarried out. Vertical diagonal joints striking N. 52°–57° E. are conspicuous. There are also vertical dip joints and horizontal joints. Curvature of the cleavage occurs here and there. Certain diagonal or longitudinal joints intersecting the bedding planes at the northern corner of the quarry produced an optical illusion, for the beds there seemed to curve over to the west-northwest instead of the east-southeast, and thus, in connection with the syncline on the east-southeast wall, to form a complete ellipsoid. This peculiar feature, however, is fast disappearing with the growth of the excavation. The ribbons are markedly more calcareous than the slate and in weathering become white from incrustation of lime. Veins

OLD BANGOR QUARRY (NORTH-NORTHEAST END), BANGOR, PA.

Showing close, flat syncline crossed by nearly horizontal cleavage. Taken in 1912. The shanty at the foot of the working face shows the scale.



BANGOR UNION QUARRY, BANGOR, PA.

Looking N. 80° W. Showing inner part of flat syncline of Plate XIII. Distance between the strike of the two about 500 feet. Taken in 1912.

of white calcite and quartz, 4 inches thick, occur in the strike joints. Crystalline films of gypsum form on the horizontal joint faces.

Mr. Bonine obtained the following names and order of the beds at this quarry from the foreman in 1912:

1. Surface (glacial débris, weathered slate).
2. Hard roll.
3. Big bed, 4 feet.
4. Thirteen beds.
5. Seven beds, 25 feet.
6. Five beds.
7. Hogback run, 10 feet.
8. Gray bed run, 13 feet.
9. Big bed, 3½ feet.
10. Schuman run.
11. Feathery run.
12. Black ribbon run.
13. Five beds.
14. Mill run, 3 feet.
15. Big bed, 4 feet.
16. Nine-foot bed, 9½ feet.

Sand slate rock.

The slate from the "Old Bangor" quarry is very dark gray and to the unaided eye has a fine texture and a fine cleavage surface, almost without any luster. The sawn edge shows pyrite. It contains very little magnetite, is carbonaceous or graphitic, effervesces with cold dilute hydrochloric acid, is sonorous, and has an argillaceous odor.

Under the microscope this slate shows a matrix of muscovite (sericite), with a brilliant aggregate polarization, somewhat obscured by abundant carbonate in plates and rhombs. The cleavage is regular, but the particles are coarse. There are scattered chlorite scales up to 0.124 by 0.066 millimeter; quartz grains not very abundant up to 0.047 millimeter. Pyrite spherules number about 14,000 per square millimeter, measuring up to 0.01 millimeter in diameter. Rutile needles are very plentiful. Carbonaceous or graphitic matter occurs in fine particles throughout.

A transverse section of a coarse ribbon from this quarry showed, under the microscope, bedding crossed by cleavage at an angle of 27°, a matrix of sericite in irregular stringers, without any aggregate polarization, and carbonate and carbonaceous matter, containing angular quartz grains up to 0.17 by 0.12 millimeter, feldspar grains (plagioclase, orthoclase) up to 0.14 by 0.09 millimeter, the quartz and feldspar together making up no more than 25 per cent of the ribbon; also spherules of pyrite up to 0.07 millimeter, some of them in lenses of chlorite; some large plates of muscovite and of chlorite interleaved with muscovite, up to 0.06 millimeter, and rarely a zircon fragment, 0.03 millimeter.

The constituents of this slate, named in descending order of abundance, appear to be muscovite, carbonate, quartz, kaolin, pyrite, chlorite, rutile, magnetite, and carbonaceous matter.

The final results of Merriman's physical and chemical tests of slate from the "Old Bangor" quarry are given here for convenience of reference: Strength (modulus of rupture), 9,810 pounds to the square inch; toughness (ultimate deflection on supports 22 inches apart), 0.312 inch; density (specific gravity), 2.780; softness (amount in grains abraded by 50 turns of a small grindstone), 128; porosity (per cent of water absorbed in 24 hours), 0.145; corrodibility (per cent of weight lost in 63 hours in acid solution composed of 98 per cent H_2O, 1 per cent HCl, 1 per cent SO_3), 0.446. Per cent of lime, 4.38; computed carbonate of lime, 7.82 per cent; computed carbonate of magnesia, 5.65 per cent.[1]

The product from the large beds is used for roofing, but that from the ribboned beds goes into mill stock.

The Bangor Union quarry, now operated by William E. Lloyd, of Bangor, lies about 500 feet northwest of the northwest wall of the "Old Bangor" quarry. The opening, estimated by Mr. Bonine as measuring 400 by 200 feet, exposes a completely overturned close fold on its northwest wall, crossed by an almost horizontal cleavage, as shown in Plate XIV. This fold is regarded as the inner northwesterly part of that exposed on the northeast wall of the "Old Bangor" quarry, shown in Plate XIII. The general strike is about N. 45° E.

Mr. Bonine has furnished the following note on the beds:

This quarry has some beds that are not present in the "Old Bangor" quarry because it is farther up in the fold. These new beds are:

1. Bangor Union big bed.
2. Spar ribbon.
3. Waste, 4 feet.
4. Pinhead run.
5. Magpie run.
6. Waste, 6 feet.
7. Black ribbon big bed.
8. Shellbark run.
9. Spar ribbon.
10. Waste, 4 feet.
11. One-length factory.
12. Waste, 4 feet.
13. School and factory.
14. Hard roll.
15. Factory.
16. Three beds.
17. Two beds.
18. Hard roll.
19. Fine ribbon.

Below this the beds occur as named in the "Old Bangor" (p. 97). At the present time this quarry has only been worked down as far as the "Gray bed run," No. 8 of the "Old Bangor" section.

The ribboned slates from this quarry reach the market in two grades. In grade No. 1 the ribbons occur only in one-half of the surface, which on the roof can be covered by the overlapping tier. Grade No. 2 has ribbons all over and the cleavage is likely to be bent slightly at the ribbon.

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[1] Am. Soc. Civil Eng. Trans., vol. 27, pp. 342–347, 1892.

North Bangor.—The large quarry of the North Bangor Slate Co. is about 200 feet square and 350 feet deep. The folded beds strike about N. 60° E. and the cleavage dips 15° SW. The total thickness of good slate here, measured across the cleavage, is 300 feet. In the smaller quarry the thickest bed measures 9 feet and is reserved for blackboards. It is thought that the gritty bed which underlies and overlies the good slate at the "Old Bangor" quarry has been struck at the bottom of this one.

The slate from these quarries is very dark gray and to the unaided eye has a fine texture and a very smooth cleavage surface, with but slight luster. It is somewhat carbonaceous and contains some magnetite. The sawn edge shows pyrite. It effervesces somewhat freely with cold dilute hydrochloric acid, is sonorous, and has an argillaceous odor.

Specimens from the North Bangor Slate Co.'s quarry show, under the microscope, a matrix of muscovite (sericite) with a somewhat brilliant aggregate polarization and a general uniformity in size of particles. The aggregate polarization is partly obscured by the very abundant carbonate. Quartz fragments are not very abundant and measure up to 0.04 millimeter. There are some chlorite scales up to 0.09 millimeter and about 10,000 spherules of pyrite, measuring up to 0.01 millimeter, to each square millimeter, also carbonaceous matter or graphite and very abundant rutile needles.

The constituents, named in descending order of abundance, appear to be muscovite, carbonate, quartz, kaolin, pyrite, chlorite, magnetite, rutile, and carbonaceous matter or graphite. In a black-ribboned piece from the same quarries the half-inch ribbon shows much carbonaceous matter and many spherules of pyrite. The quartz particles and the plates of carbonate are larger in the ribbon than in the adjacent slate.

The product of this company's quarries is used for blackboards, billiard tables, fireboards, stationary tubs, well covers, tiles, lathe work, etc.

East Bangor.—The large quarry of the East Bangor Consolidated Slate Co. measures 350 feet along the strike and 700 feet across by 130 feet in depth. The beds dip 5° NNE. and the cleavage 15°–20° SSW. The main joints strike north and undulate in a general vertical direction. The grain strikes N. 50°–60° W. Ribbons are numerous.

The slate is very dark bluish gray and to the unaided eye has a fine texture and a somewhat fine but almost lusterless cleavage surface. It is both carbonaceous, or graphitic, and magnetitic. The sawn edge shows a little pyrite. It effervesces slightly with cold dilute hydrochloric acid, is sonorous, and has a scarcely perceptible argillaceous odor.

Under the microscope a specimen taken between "ribbons" shows a matrix of muscovite (sericite) with a brilliant aggregate polarization, somewhat obscured by carbonate, a texture a little finer than that of the slate of the "Old Bangor" quarry, but carbonate as abundant as in that. Not very much quartz in grains measuring up to 0.04 by 0.02 millimeter; about 250 scales of chlorite, with interleaved muscovite, to each square millimeter, measuring up to 0.07 by 0.03 millimeter, exceptionally 0.08 by 0.04 millimeter; about 12,400 spherules of pyrite to the square millimeter, measuring up to 0.008 millimeter; rutile needles very abundant; carbonaceous or graphitic matter in fine particles.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, carbonate, quartz, pyrite, chlorite, kaolin, rutile, carbonaceous matter or graphite, and magnetite.

The product of this quarry is used both for roofing and for mill-stock, but not for blackboards, as the 9-foot bed is crossed by ribbons. The roofing slates are said to show comparatively little discoloration after 30 years' exposure.

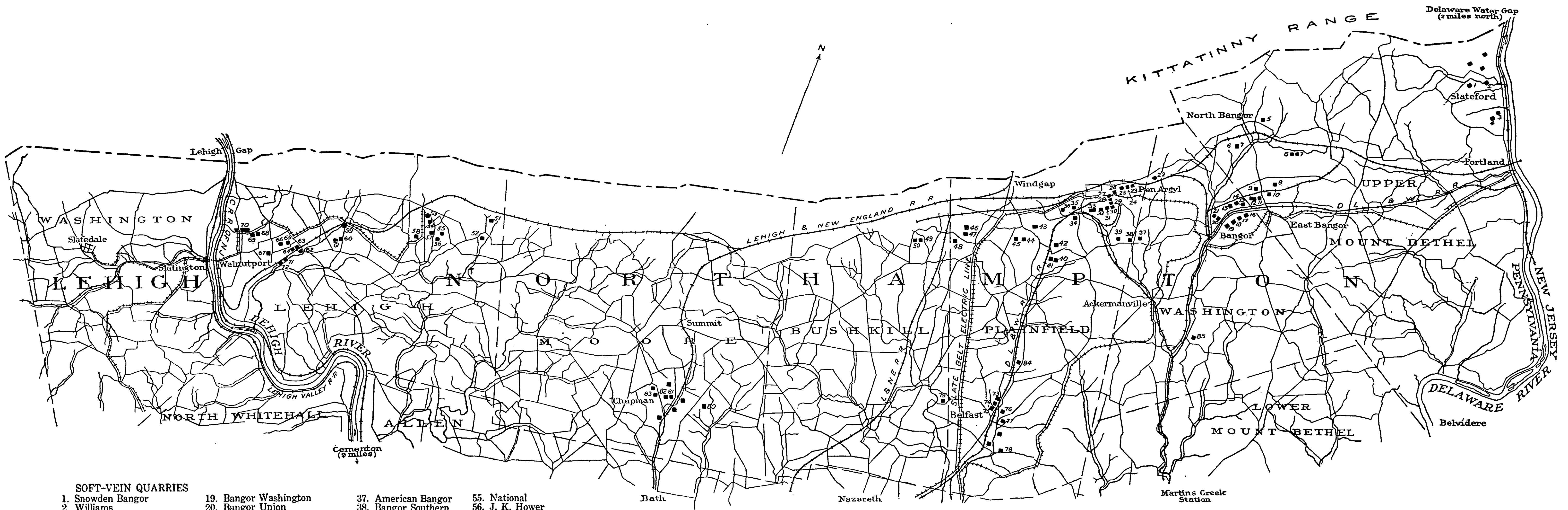
Windgap.—The group of quarries known as the Windgap quarries is about a mile from the saddle in Blue Mountain known as the Windgap, which is about 11 miles southwest of the Delaware Water Gap. (See Pl. XV.) Three of these quarries were visited by the writer in 1912.

The Alpha Slate Manufacturing Co.'s quarry, about a mile S. 35° E. from the gap, is about 200 feet square and 70 to 150 feet deep. The light-buff "top," of decomposed slate, is 50 feet thick. The beds strike N. 55° E. and dip 70° N. 35° W. The cleavage strikes N. 75° W. and dips 25° S. 15° W. Beds free of ribbon are from 2 to 25 feet thick. About three-fourths of the product is used for mill stock and the rest for roofing. Channeling machines are used for both horizontal and vertical cutting.

The Imperial quarry, operated by William Harding & Co., is about S. 30° E. from the gap and measures 175 feet along the bed by 150 feet across it and 200 feet in depth. The "top" consists of 75 feet of decomposed and bad slate. The beds curve northward at a depth of 40 feet below the "top." The thickest clear bed measures 11 feet along the cleavage. The grain is diagonal to the ribbon. The product is used mostly for mill stock, including blackboards. Channeling machines are used altogether for vertical cuts, but powder is used for cuts along the grain.

The Phœnix quarry of the Phœnix Slate Co., of Windgap, Pa., is about S. 20° E. from the gap and measures about 300 feet along the bed by 175 feet across and from 70 to 170 feet in depth. The decomposed slate of the top is 10 feet thick. The thicker beds free of ribbons measure 11 and 14 feet along the cleavage. The grain is diagonal to the ribbon. As shown in Plate V, *B*, the beds begin to curve southward at the rock surface. Slabs of banded (ribboned) slate from this quarry are shown in Plate VI, *A*. The product is nearly all used for mill stock, including blackboards. At least one of the beds has been found suitable for electric switchboards.

Heimbach.—The Heimbach quarry, about 1½ miles northeast of Slatington, in Northampton County, is operated by Jay S. Moyer & Co. There is a thick bed here known as the "Heimbach big bed," which is very dark gray and less bluish than the slate of the "Old Bangor" quarry.



SOFT-VEIN QUARRIES

1. Snowden Bangor
2. Williams
3. Northampton
4. Cooper's
5. New York
6. Bangor Vein
7. Hoboken
8. Bangor Ridge
9. Shimer's
10. Consolidated No. 3
11. Consolidated No. 2
12. Consolidated No. 1 and Star
13. Bangor Eclipse
14. Bangor Central
15. Bangor Royal
16. Columbia Bangor
17. Bangor Excelsior
18. Old Bangor
19. Bangor Washington
20. Bangor Union
21. North Bangor
22. West Bangor
23. Bangor Superior
24. Crown
25. Old Dorney
26. Old Pennsylvania
27. Master's
28. United States
29. Diamond
30. Valley No. 5
31. Valley No. 6
32. Valley No. 7
33. Stephen Jackson and Albion
34. West Albion
35. Parson's.
36. New Diamond
37. American Bangor
38. Bangor Southern
39. Delabole
40. Grand Central
41. Doney's
42. Harding's
43. Alpha
44. Imperial
45. Phoenix
46. Excelsior
47. Penn Bangor
48. Pelican
49. Avon
50. Blue Mountain
51. Bangor Rock
52. Dexter
53. Cambria
54. Gem
55. National
56. J. K. Hower
57. Hower
58. Seip's
59. Bryan
60. Prudential No. 1
61. Prudential No. 2
62. Washington
63. Berlin's
64. Kester's
65. Henry
66. Peters
67. Washington Standard
68. Old Heimbach
69. Heimbach Slate
70. Heimbach Quarries
71. Oak Hill
72. Laurella

HARD-VEIN QUARRIES

73. Lehr's
74. White Oak
75. Globe
76. Pennsylvania
77. Northampton
78. Whitesell's
79. Belfast
80. Chapman Superior
81. Keystone
82. Chapman
83. Chapman Standard
84. Valley
85. True Blue

LEGEND

Road
Electric railroad
Steam railroad
Slate quarry

Compiled from Atlas of the Second Geological Survey of Pennsylvania with additions and quarry locations by C. A. Bonine (Dimensions of quarries not exact) 1914

MAP SHOWING LOCATION OF QUARRY SITES IN NORTHAMPTON COUNTY, PA.

To the unaided eye it has a fine texture and a somewhat fine but almost lusterless cleavage surface. It contains an exceedingly small amount of magnetite, effervesces with cold dilute hydrochloric acid, and is sonorous.

Under the microscope it shows a matrix of muscovite (sericite), with but faint aggregate polarization owing to the abundance of carbonate, which much exceeds that in the slate of the "Old Bangor" quarry. The cleavage is considerably finer and there is greater regularity in the size of particles than in that slate. There are a few chlorite scales up to 0.06 by 0.04 millimeter. Very little quartz is seen, in grains reaching only 0.036 millimeter. Pyrite spherules measure up to 0.012 millimeter and number about 18,000 to the square millimeter. Rutile needles are very abundant. The usual carbonaceous matter is seen.

The constituents of the "Heimbach big bed," named in descending order of abundance, appear to be muscovite, carbonate, quartz, pyrite, chlorite, rutile, carbonaceous matter, and magnetite, but the carbonate is more plentiful than in some slates in which its relative position is the same.

There is also in the same quarry a 6-foot bed, which is blacker than any of the other slates of Northampton and Lehigh counties. It has to the unaided eye a somewhat fine texture and cleavage surface with a slight luster. It shows pyrite on the sawn edge, is carbonaceous or graphitic and very slightly magnetitic, effervesces in cold dilute hydrochloric acid, is sonorous, and has a slight argillaceous odor.

Under the microscope the "Heimbach black bed" shows a fine matrix of muscovite (sericite), with but faint aggregate polarization owing in part to the very large amount of carbonate and carbonaceous matter. The number of quartz fragments is relatively small and they measure up to 0.028 millimeter. There are chlorite scales up to 0.06 millimeter. Spherules of pyrite measure up to 0.008 millimeter, exceptionally 0.017 millimeter, and number about 6,800 to the square millimeter. Rutile needles abound. Rarely a scale of hematite is seen.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, carbonate, quartz, carbonaceous matter and graphite (?), pyrite, chlorite, rutile, and magnetite. The percentage of carbonate is large.

The principal difference betwen the slates of the Heimbach and "Old Bangor" quarries is in the larger amount of carbonate, lesser amount of pyrite, and the fine structure of the former, to judge from the microsopic evidence.

Pen Argyl.—The Albion quarry, at Pen Argyl, is regarded as being near the bottom of the "soft vein" belt. It measures 650 feet along the strike, 600 feet across it, and 390 feet in depth. In 1904 it was operated by two companies, Wm. Lobb & Sons at the west end and Stephen Jackson & Co. at the east end. The structure is that of an S-shaped fold overturned to the north-northwest. The bedding strikes N. 58°–60° E.; cleavage at the north-northwestern edge dips 10° S., halfway down about 10° N., and at the bottom about 40° S. The grain is at right angles to the ribbon. At the north-northwestern edge of the quarry is a series of hard beds 40 feet thick. Under the microscope this rock shows no aggregate polarization and is seen to consist of the following minerals, named in order of diminishing abundance: Carbonate, quartz, chlorite, carbonaceous matter, muscovite, pyrite, and rarely plagioclase feldspar. It is a clay slate. Some of the beds are said to measure 20 feet between ribbons. There is an exceptional bed, 44 inches thick, of a dark, slightly greenish-gray slate of superior quality, described beyond. Vein matter on the dumps consists of vein quartz and calcite, the former predominating. Associated with these veins are plicated, very quartzose ribbons traversed by a coarse slip cleavage and also brecciated. Black slaty material has been pressed into the faults of the slip cleavage. One of these quartz masses was 20 feet thick and extended the entire length of the quarry.

The chief product of the Albion quarry is a very dark-gray slate which to the unaided eye has a fine texture and a roughish, almost lusterless cleavage surface. It is somewhat carbonaceous and magnetitic, shows pyrite on the sawn edge, effervesces slightly with cold dilute hydrochloric acid (considerably in the ribbon), and is sonorous.

Under the microscope this slate shows a matrix of muscovite (sericite), with brilliant aggregate polarization, somewhat obscured by abundant carbonate in plates and rhombs. The amount of carbonate is less than in the specimens from the "Old Bangor" and North Bangor quarries. Quartz is not very abundant, in grains measuring up to 0.04, rarely 0.09 millimeter. Scales of chlorite, interleaved with muscovite, are conspicuous, lying transverse to the cleavage, in places forming lenses with their long axes parallel to the cleavage, measuring up to 0.14 by 0.07 millimeter and numbering about 310 to the square millimeter. Pyrite spherules occur up to 0.01 millimeter and average about 1,085 to the square millimeter. There is finely disseminated carbonaceous (or graphitic) matter and a great abundance of rutile needles.

The mineral constituents, named in descending order of abundance, appear to be muscovite, carbonate, quartz, chlorite, pyrite, rutile, carbonaceous matter, and magnetite. The carbonate, although second, is not as abundant as in specimens from the "Old Bangor" quarry.

The results of Merriman's physical and chemical tests of the dark-gray ("black") slate from this quarry are here given for convenience of reference: Strength (modulus of rupture), 7,150 pounds to the square inch; toughness (ultimate deflection on supports 22 inches apart), 0.270 inch; density (specific gravity), 2.775; softness (amount in grains abraded by 50 turns of a small grindstone), 80; porosity (per cent of water absorbed in 24 hours), 0.238; corrodibility (per cent of weight lost in 63 hours in acid solution), 0.547; per cent of lime, 4.09; computed carbonate of lime, 7.40 per cent; computed carbonate of magnesia, 4.41 per cent.[1]

The dark greenish-gray slate of the Albion quarry has to the unaided eye a somewhat granular texture and a roughish and almost lusterless cleavage surface. It is not perceptibly carbonaceous or graphitic but is somewhat magnetitic. The sawn edges show pyrite. It effervesces slightly with cold dilute hydrochloric acid and is sonorous.

Under the microscope it shows a matrix of muscovite (sericite), with brilliant aggregate polarization. Quartz fragments measure up to 0.09 millimeter. There is considerable carbonate. There are chlorite scales, interleaved with muscovite, lying transverse to the cleavage and parallel to the grain; also chlorite scales transverse both to grain and cleavage, with inclusions of needlelike crystals, probably rutile, crossing one another, usually at 60° or 120°. All these chlorite scales average about 28 to the square millimeter, and measure up to 0.17 by 0.1 millimeter. The pyrite spherules measure up to 0.01 millimeter, and average about 968 to the square millimeter. Rutile needles also occur.

These constituents, named in descending order of abundance, appear to be muscovite, carbonate, quartz, chlorite, pyrite, rutile, and magnetite.

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[1] Merriman, Mansfield, loc. cit.

The product of the Albion quarry, at least that of the west end, is used for roofing.

Some of the other quarries at Pen Argyl show the passage of the black slate by weathering into a yellowish light-brown or even white shaly substance. The dumps afford specimens showing all gradations from black slate to white rock. The weathered zone in these quarries measures up to 40 feet in thickness. At one of them the beds of the truncated southern limb of an overturned syncline dip about 55° S. and the cleavage dips less than 10° in the same direction. The weathered top measures between 30 and 40 feet and is covered with 5 to 10 feet of subsoil. The weathering acids, taking advantage of the position of the bedding, have followed one of the ribbons and penetrated the workable slates to a depth of 60 feet below the weathered zone and have also commenced to work horizontally along the cleavage. This has resulted in the formation along the ribbon of a central bed of reddish-yellow ocher about 1 foot thick, with a 6-inch band of white on either side of it. The white portions here probably represent less ferruginous parts of the original sediment and not a later stage of weathering, for similar alternations of yellowish and white belts of weathered material occur in hand specimens crossing the cleavage. The workable black slate is thus traversed here by a 2-foot bed of yellow and white ochraceous material at an angle of 65° to the cleavage as the effect of weathering upon material and structure. The process here is mainly decarbonization. (See further, on the subject of weathering, p. 53.)

In this connection it should be stated that in the "soft vein" quarries generally, to judge from the dumps, the amount of iron and lime in the ribbon varies greatly. In some places pyrite or siderite predominates and limonitic staining ensues; in others lime is more abundant and a white calcareous crust forms. The slate flags on the sidewalks in the village of Bangor wear along the ribbons more rapidly than along the slaty portions.

Chapman.—The principal quarry at Chapman, which is in the "hard vein" belt, is operated by the Chapman Slate Co. It measures from 700 to 800 feet along a longitudinal joint striking N. 63° E. across it and is about 200 feet wide and 300 feet deep. In the center of the quarry is a completely overturned close syncline or anticline, still visible on the south-southeast wall of the quarry, striking N. 75°–78° E. and pitching gently eastward; but the lower limb of this fold opens out on the east-northeast and west-southwest walls so as to dip steeply northwest. This fold is crossed by cleavage striking N. 65° E. and dipping 14°–15° SSE. The principal joints are longitudinal, striking N. 63° E. and dipping 90°, forming two of the sides of the quarry. The grain strikes N. 37°–53° W. and dips 90°. The largest bed, which, although containing very small ribbons, can be used for roofing slate, measures 16 feet. The number of ribbons exposed on the east-northeast wall, where the fold opens out, is 112, averaging a little over two to each foot of slate.[1]

Some quartz veins lying in the cleavage show a columnar structure parallel to the side of the vein. The "top" in an adjacent quarry of the same company measures fully 50 feet.

The slate is very dark gray but is crossed by many ribbons a trifle darker and measuring from one-eighth to one-half inch, which, however, scarcely deflect the cleavage.

To the unaided eye it has a fine texture and a slightly roughish and slightly lustrous cleavage surface. It is both graphitic (or carbonaceous) and magnetitic. The sawn edge shows pyrite. Under cold dilute hydrochloric acid there is a slight effervescence, but more in the ribbon. It is sonorous and discolors but slightly in 30 years' exposure. E. H. S. Bailey gives the specific gravity as 2.79. For Merriman's recent tests of this slate see page 182.

Under the microscope the Chapman slate shows a matrix of muscovite (sericite) with a brilliant aggregate polarization not obscured by carbonate. A ribbon of coarse materials, 0.62 millimeter wide, crossing the cleavage at an angle of 14°, possesses aggregate polarization. There are some large lenses of coarse quartz and carbonate in the cleavage. There is considerable carbonate throughout, in plates and rhombs, but less than in the slate of the "Old Bangor" quarry. Quartz up to 0.06 millimeter, pyrite spherules up to 0.02 millimeter and numbering about 4,250 to the square millimeter; about 263 scales of chlorite, with interleaved muscovite to the square millimeter, lying across the cleavage and measuring generally up to 0.08 by 0.04 millimeter; graphitic or carbonaceous matter in fine particles; abundant rutile needles; rare grains of plagioclase feldspar. The ribbon contains more abundant and coarser quartz, carbonate, chlorite, and carbonaceous matter than the rest.

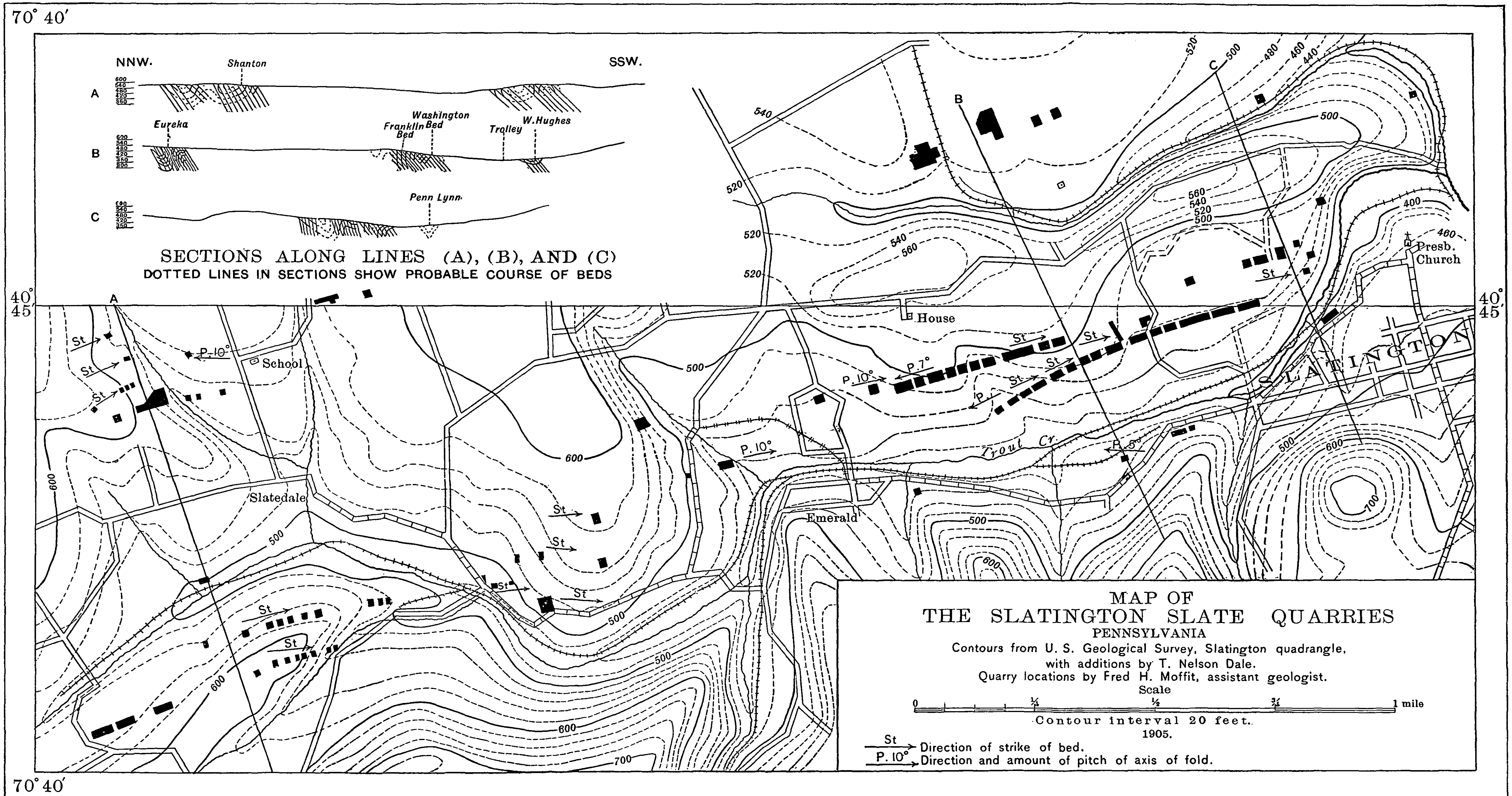
The important constituents, named in descending order of abundance, appear to be muscovite, quartz, carbonate, pyrite, chlorite, rutile, carbonaceous matter or graphite and magnetite.

The product of this quarry was formerly used largely for flagging, posts, steps, etc., and because of its hardness had to be cut with diamond saws which operated horizontally, but owing to the competition of sandstone flagging and the high price of diamonds this outlet is closed and the product is now used exclusively for roofing slate, for which, however, only selected material is available.

LEHIGH COUNTY.

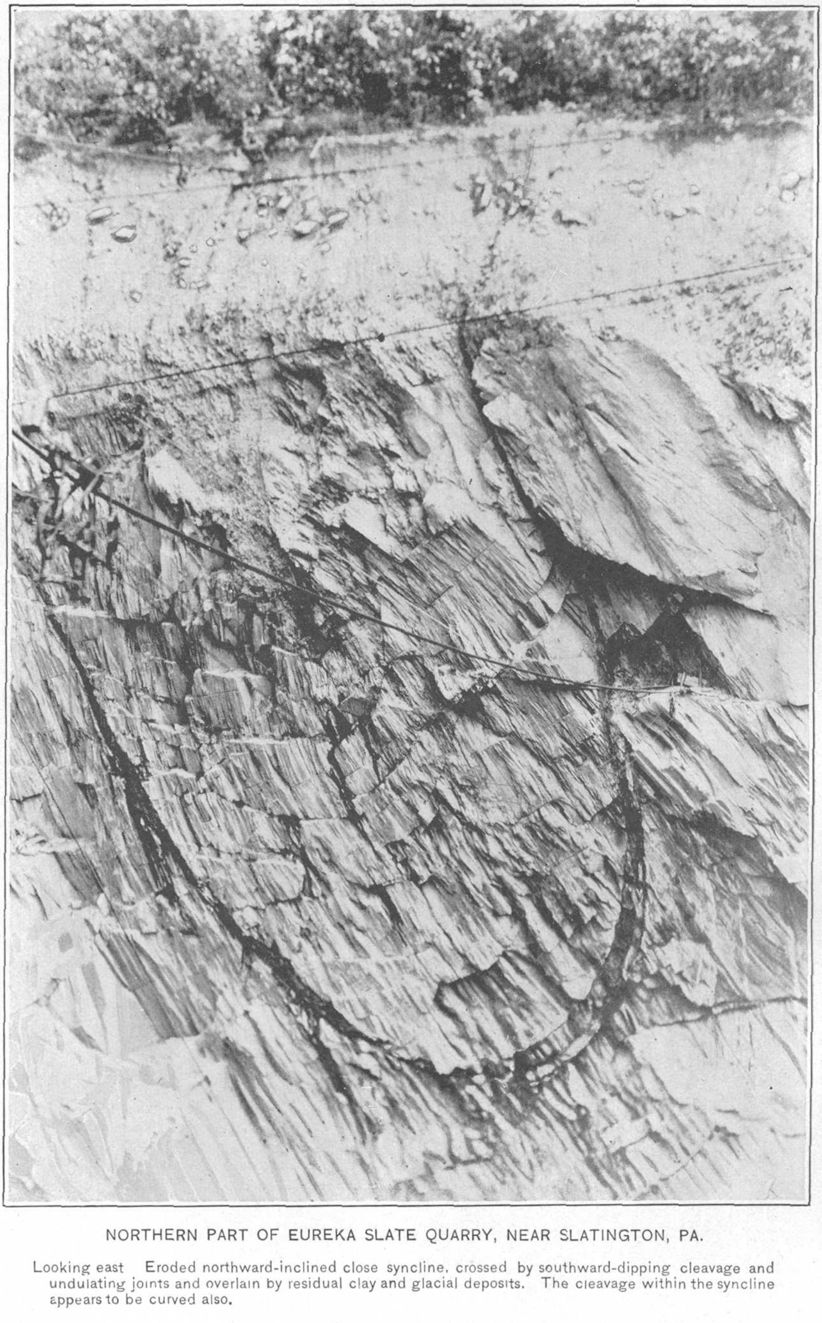
Geologic relations.—The slate quarries of Lehigh County all belong in the "soft vein" belt. The relation of the "soft vein" slate to the shale of the same formation is well exposed near Lehigh Gap, on the border of the county. On the east side of the gap the outcrop of the Martinsburg ("Hudson") shale, of Ordovician age, that is nearest to the so-called "Oneida" conglomerate is a black shale that occurs in alternating thick and thin beds. The thick beds, being entirely devoid of cleavage, weather into shelly fragments, and the thin ones,

[1] Figures obtained through the courtesy of Mr. Richard Chapman, superintendent.


70° 40′
40° 45′
NNW.
SSW.
Shanton
Eureka
Franklin Bed
Washington Bed
Trolley
W. Hughes
Penn Lynn
SECTIONS ALONG LINES (A), (B), AND (C)
DOTTED LINES IN SECTIONS SHOW PROBABLE COURSE OF BEDS
School
Slatedale
Emerald
House
Presb. Church
SLATINGTON
Trout Cr.
MAP OF
THE SLATINGTON SLATE QUARRIES
PENNSYLVANIA
Contours from U. S. Geological Survey, Slatington quadrangle, with additions by T. Nelson Dale.
Quarry locations by Fred H. Moffit, assistant geologist.
Scale
0 ¼ ½ ¾ 1 mile
Contour interval 20 feet.
1905.
St → Direction of strike of bed.
P. 10° → Direction and amount of pitch of axis of fold.

BLUE MOUNTAIN SLATE QUARRY, NEAR SLATINGTON PA.

Looking east. Showing the character of the syncline, its relation to the cleavage, and the southward bending of the cleavage at the surface, a bending probably due to glacial action.



NORTHERN PART OF EUREKA SLATE QUARRY, NEAR SLATINGTON, PA.

Looking east Eroded northward-inclined close syncline, crossed by southward-dipping cleavage and undulating joints and overlain by residual clay and glacial deposits. The cleavage within the syncline appears to be curved also.

owing to the intersection of an incipient slaty cleavage with the bedding foliation, break up into sticklike fragments. Under the microscope the thin beds prove to be an aggregate of muscovite scales, quartz grains, and carbonaceous particles, with some pyrite spherules and limonite specks. Here and there the beginning of a slaty cleavage foliation is indicated by short stringers of fibrous muscovite lying at right angles to the bedding, but otherwise there is no alignment of particles and the rock is a typical shale. A hundred feet farther south a southward-dipping slaty cleavage predominates, and the northward-dipping bedding is shown only by an occasional ribbon. Therefore within a space of 200 feet the transition from a shale to a slate can be observed. In the slate the amount of secondary mica has greatly increased and the clastic particles of the shale have been forced into the same parallelism of arrangement.

In weathering the slates of Lehigh County undergo the same transformations as those of Northampton County. The black slate first passes into a soft yellowish-brown ocherous rock, which later becomes nearly white and finally passes into a white micaceous clay, the "shale clay" of the limonite and fire-clay pits. But these changes probably required many centuries. See discussion of chemistry of slate, page 53.

Slatington quarries.—The slate quarries of Lehigh County are now confined to an area comprising about 3 square miles along Trout Creek and its tributaries. This stream empties into the Lehigh from the west at Slatington. The accompanying map (Pl. XVI) includes all the quarries about Slatington which were in operation in 1902, 45 in number, together with 50 abandoned ones. The older quarries had in 1902 reached a depth of about 300 feet. The map shows the exact location of these quarries, their approximate dimensions at the surface, the strike of the beds, and both the direction and angle of the pitch of the folds. The lateral deflection of the strike amounts in places to 10°, if not a little over, and the pitch ranges from 5° to 10°.

The character of the folds in these quarries is shown in Plates XVII and XVIII and figures 7, 8, 9, 10. The relation of the workable beds to the ribbons is shown in Plate XVII. The strike ranges from N. 40° E. to east and to N. 86° W. The cleavage strike is N. 74°–85° E., and its dip 35°–75° S. 5°–16° E.

In places there is a difference in the angle of the cleavage dip in adjacent beds. The curvature of the cleavage at the "Old William Hughes" quarry amounts to a change of 20° in 25 feet of slope. There is usually a little curvature of the cleavage on either side of the ribbon. There is a conspicuous system of dip joints striking about north-south, some of which are shown in Plate XVII; also strike joints which locally undulate like bedding planes, as at the Eureka quarry (Pl. XVIII).

The quarrymen's names of the slate beds in the Slatington area are, from south to north, Williamstown, Blue Mountain, Trout Creek, Washington, Little Franklin, Big Franklin, Mammoth, New Bangor,

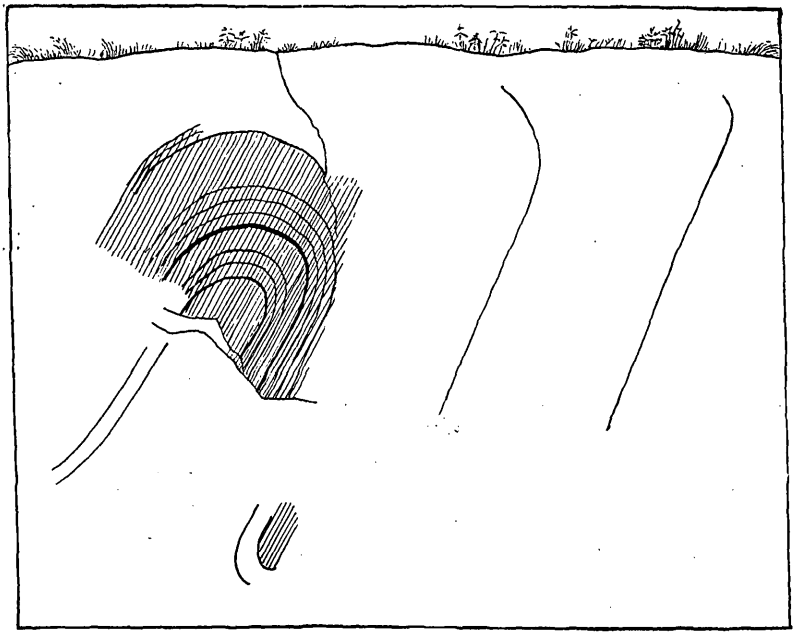


FIGURE 7.—Sketch of anticline in Provident Slate Co.'s quarry, near Slatington, Pa., looking west. Width represented, 50 feet.

Snowdon, and Eureka. It is uncertain whether some of these beds are not duplications, for the structure of the belt, as shown in the section on Plate XVI, indicates that they may be, and their relations

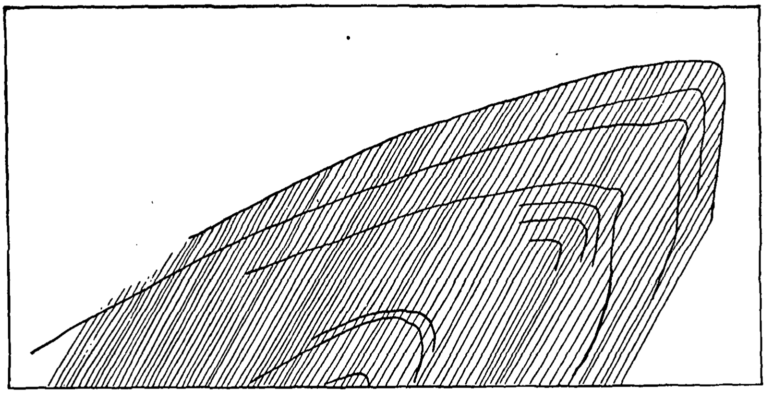


FIGURE 8.—Sketch of anticline in old quarry north of Slatington, Pa., looking west. Height represented, 25 feet.

have never been worked out mathematically. Examples of these beds ("veins") are the "Washington," which at the Hazel Dell quarry averages 27 feet in thickness or 40 feet measured along the cleavage, and the "Franklin," at the "Old Franklin" quarry, which consists of an upper bed of 28 feet and a lower one of 35 feet, separated by about 25 feet of small ribboned material, the measurements being taken

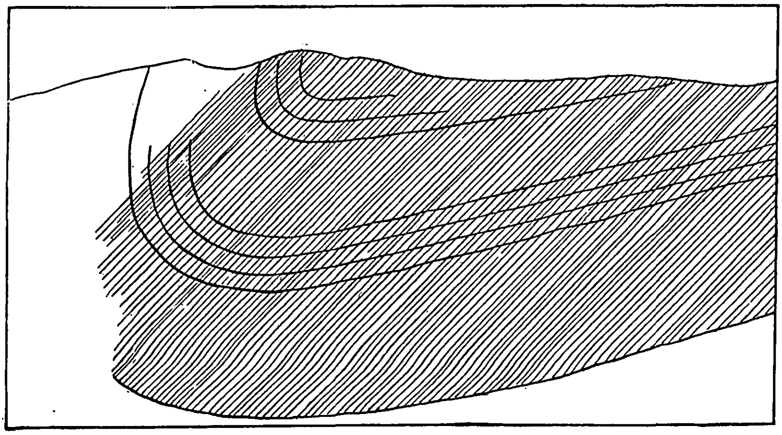


FIGURE 9.—Sketch of syncline at William Hughes's quarry, near Slatington, Pa., looking west. Length, 80 feet. Upper bed over 10 feet thick; lower bed 15 feet thick, but with marked curvature of cleavage.

along the cleavage. In general the beds range from 3 to 30 feet in thickness, measured at right angles to the bedding.

The slate of the Slatington area is very dark-bluish gray. To the unaided eye it has a somewhat fine texture and cleavage surface, but it is almost lusterless. It is carbonaceous and slightly magnetitic. The sawn edges show little if any pyrite. It

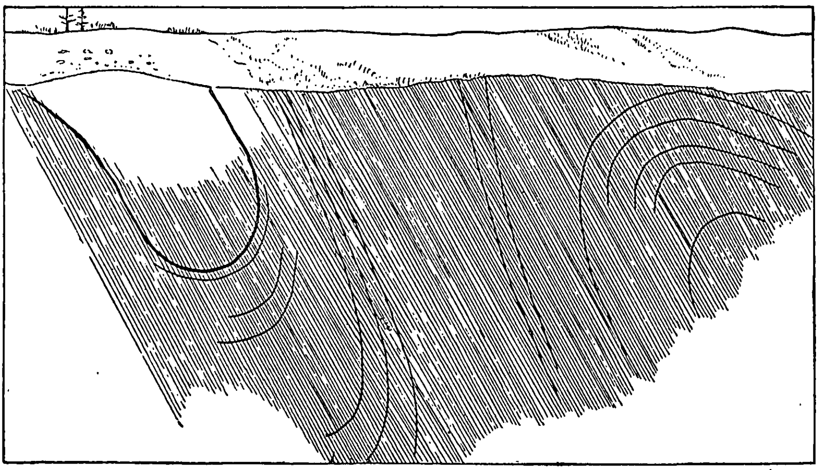


FIGURE 10.—Sketch of folds at Eureka quarry, near Slatington, Pa., looking east. Length, 350 feet; depth, 225 feet. The upper part of the syncline is shown in Plate XVIII.

effervesces in cold dilute hydrochloric acid, is sonorous, and has some argillaceous odor. After prolonged exposure this slate becomes at first a dark gray and finally various shades of cream and coffee color, but the rapidity and degree of discoloration differ in different beds. Fissility fine.

Under the microscope it shows a matrix of muscovite (sericite) with a brilliant aggregate polarization, obscured, however, by much carbonate and carbonaceous matter. There are many angular grains of quartz up to 0.04 millimeter; rarely one of plagioclase; a few scales of chlorite, interleaved with muscovite, or of each separately, up to 0.08 millimeter, and numbering about 7 to the square millimeter, spherules of pyrite up to 0.012, rarely 0.02 millimeter., numbering about 11,000 to the square millimeter; very abundant rutile needles.

The principal constituents, named in descending order of abundance, appear to be muscovite, carbonate, quartz, kaolin, pyrite, chlorite, rutile, carbonaceous or graphitic matter and magnetite.

The following analyses were made by Dr. W. F. Hillebrand—A from the "Lower Franklin bed," Old Franklin quarry, Slatington; B from the "Washington bed," Hazel Dell quarry No. 1, Slatington.

Analyses of slates from Lehigh County, Pa.

	A (complete).	B (partial).
Silica (SiO_2)	56.38	56.85
Alumina (Al_2O_3)	15.27	[a] 15.24
Ferric oxide (Fe_2O_3)	[b] 1.67	[c] 5.52
Ferrous oxide (FeO)	[b] 3.23	
Magnesia (MgO)	2.84	2.93
Lime (CaO)	4.23	4.24
Soda (Na_2O)	1.30	1.38
Potassa (K_2O)	3.51	3.34
Water below 110° C. (H_2O)	.77	.45
Water above 110° C. (H_2O)	4.09	Not est.
Titanium dioxide (TiO_2)	.78	.84
Zirconium dioxide (ZrO_2)	Trace?	....
Carbon dioxide (CO_2)	3.67	3.58
Phosphoric oxide (P_2O_5)	.17	(d)
Chromium oxide (Cr_2O_3)	Trace?	Trace?
Manganous oxide (MnO)	.09	Not est.
Baryta (BaO)	.08	Not est.
Strontium oxide (SrO)	Trace.	Not est.
Lithia (Li_2O)	Trace.	Not est.
Pyrite (FeS_2)	[e] 1.72	[e] 1.72
Carbon of carbonaceous matter (C.)	.59	Not est.
	100.39	96.12
Specific gravity (21° C.)	2.783	2.780

[a] Including P_2O_5.
[b] Approximate.
[c] As Fe_2O_3.
[d] Included in Al_2O_3.
[e] Including 0.92 of sulphur.

The considerable amount of carbonate indicated both by the analyses and by the microscopic examination and the discoloration due probably to the ferrous part of that carbonate are objectionable features in the slates of Slatington, but their fine cleavage and the relative facility with which they are quarried make it possible to supply them at low figures. On the other hand they are remarkably well adapted by their softness and the thickness of the beds for mill stock and particularly for blackboards and other indoor objects.

CARBON COUNTY.

Aquashicola.—The only quarry in Carbon County is that of W. M. Bray, of Palmerton, Pa., less than one-fourth mile northeast of Aquashicola village, northeast of Lehigh Gap, and nearly 2 miles east-northeast from Palmerton station. The opening now worked is about 275 feet along the cleavage by 150 feet across and from 90 to 155 feet deep. The "top" is about 40 feet thick, of which a thickness of 17 feet is bent southward by glacial friction (creep) and is decomposed.

The beds strike N. 70° E. and dip 80° N. 20° W. The cleavage strikes N. 70°–75° E. and dips 75° S. 17° E. On the west wall, at the north side, are curved joints striking about east, spaced 3 to 6 feet. Similar joints are very abundant on the east wall. The weathered "top" is buff, as in the quarries of Lehigh and Northampton counties, and decarbonization has operated chiefly along the bedding foliation. The course of the bed is shown in places by undefined calcareous nodules weathering light brown, which in thin section show very faint aggregate polarization, much carbonate in minute particles, quartz, chlorite, pyrite spherules up to 0.03 millimeter in diameter, and fine carbonaceous matter.

The slate is very dark bluish gray. To the unaided eye it has a very fine and finely banded texture and roughish lusterless cleavage surface. It contains much carbon and a little magnetite. The sawn edge shows pyrite. The rough edge effervesces with acid test. It is sonorous and has a high grade of fissility. The ribbons do not appear to be lines of weakness.

Under the microscope this slate shows a matrix of muscovite (sericite) with fairly good aggregate polarization. The cleavage is fine, crossing the bedding at a small angle. Quartz particles (detrital) measure up to 0.02 millimeter and abundant spherules of pyrite to 0.017 millimeter in diameter. Carbonate is plentiful but not excessive. Chlorite and rutile are present. The constituents, named in descending order of abundance, appear to be muscovite, quartz, carbonate, chlorite, carbon, kaolin, pyrite, magnetite, and rutile.

This is a mica slate of the fading series.

DAUPHIN COUNTY.

Some slate cores obtained in 1908 near Derry Church, in Dauphin County, were examined, with the following results:

The slate is of dark bluish-gray color, with very fine, even, and somewhat lustrous cleavage surface. It shows pyrite on the sawn edge, is graphitic, contains no magnetite, and effervesces freely with cold dilute hydrochloric acid. It is sonorous and has a superior grade of fissility.

Under the microscope it shows fine aggregate polarization and abundant rutile needles, much carbonate in rhombs and irregular plates up to 0.06 millimeter, also abundant pyrite in spherules from 0.004 to 0.017 millimeter in diameter but mostly under 0.008 millimeter. The cleavage foliation is crossed by a fine zigzagging vein of calcite. It contains nodules of carbonate up to 0.1 by 0.04 millimeter and of chlorite up to 0.1 by 0.04 millimeter. The quartz grains measure up to 0.06 millimeter and there are a few prisms of black tourmaline.

Its constituents, named in descending order of abundance, appear to be muscovite, quartz, carbonate, pyrite, chlorite, graphite, rutile, and tourmaline.

This is a true mica slate of fine fissility but of the fading series. The cores show some variation at different depths in the abundance of carbonate veinlets and also in what appear to be "ribbons," but the general quality of the slate is the same.

YORK AND LANCASTER COUNTIES.

The slate deposit of York and Lancaster counties is known as the Peach Bottom slate. The name seems to have been derived from that of a small village one-fourth mile west of Susquehanna River, formerly a sort of a port in the now disused canal which follows the river. This village is in a triangular township of the same name, which is bounded by the Maryland line on the south, the river on the northeast, and in part by Muddy Creek on the northwest, and which forms the southeast corner of York County.

PEACH BOTTOM SLATE.

Geologic relations.—The only available geologic maps of the region are those of the two Pennsylvania geological surveys and of the Maryland Geological Survey.[1]

The slate forms a belt and low ridge from one-fifth to one-half mile wide, which extends from a point about a mile northeast of the Susquehanna, in the town of Fulton, in Lancaster County, in a southwest direction across the river and across Peach Bottom Township in York County, and continues for about 3 miles in the same direction into the town of Cardiff, in Harford County, Md. Its total length is about 10 miles, of which 1 mile lies in Lancaster County, Pa., 1½ miles is submerged by the Susquehanna, 4½ miles is in York County, Pa., and about 3 miles is in Harford County, Md. Most of the quarry population is congregated along one street, which follows the western foot of the ridge. The northeastern part of this street is Delta, Pa.; the southwestern part is Cardiff, Md.

For the literature of Peach Bottom slate the reader is referred to the writings of Rogers, Lesley, Frazer, Williams, Mathews, Merrill, and Merriman.[2]

The slate belt has on its northwest side a sericite-chlorite-quartz schist (containing rounded grains of zircon), with a foliation striking N. 45° E. and dipping 75° SE. About midway between Delta and Bryansville this schist is calcareous. According to the reports of the Second Pennsylvania Survey similar schists recur on the southeast side of the slate belt, and the whole schist formation overlies in synclinal structure the older gneisses and serpentines which occur on

[1] Rogers, H. D., Geology of Pennsylvania, 1858. Frazer, Persifor, jr., York and Lancaster county sheets, Second Geol. Survey Pennsylvania, vol. CCC, Atlas, 1878, 1879. Mathews, E. B., Maryland Geol. Survey, vol. 2, Pl. XXX, 1898.

[2] Rogers, H. D., Geology of Pennsylvania, vol. 1, pp. 188, 189, 1858. Frazer, Persifor, jr., Geology of Lancaster County: Second Geol. Survey Pennsylvania, vol. CCC, pp. 179–190, Pls. VII, VIII, 1880. Williams, G. H., The petrography and structure of the Piedmont Plateau: Geol. Soc. America Bull., vol. 2, p. 304, 1891. Lesley, J. P., Second Geol. Survey Pennsylvania Final Rept., vol. 1, pp. 136–141, 1892. Mathews, E. B., Maryland Geol. Survey, vol. 2, pp. 215–231, 239–241, 1898. Merrill, G. P., Rocks, rock weathering, and soils, p. 229, 1897; Stones for building and decoration, 3d ed., 1903. Merriman, Mansfield, The strength and weathering qualities of roofing slates: Am. Soc. Civil Eng. Trans., vol. 27, pp. 331–349, 1892; vol. 32, pp. 529–539, 1894.

either side of it. These schists and the associated slate are classified as Cambrian, although no typical Cambrian fossils have as yet been found in them. A good exposure of the relations of the slate to the rocks on the southeast (referred to by Rogers) may be seen on the east side of Slate Point on the towpath along the Susquehanna. The slate here conformably underlies about 50 feet of slightly muscovitic quartzite, which was formerly quarried for canal construction, both rocks striking N. 45°–50° E. and dipping 70° SE. A little farther east this quartzite is succeeded by a coarsely plicated gneiss consisting of quartz, plagioclase, muscovite, hornblende, and epidote and having the same strike and dip. Still farther east, nearly a quarter of a mile from the contact of the slate and quartzite, slightly muscovitic quartzite about 70 feet thick crops out with a strike of N. 45°–50° E. and a dip of 42° SE. and is followed conformably by a gneiss like that previously described. These quartzites and gneisses apparently continue into Lancaster County, for in looking across the Susquehanna from Slate Point a considerable thickness of light-colored rock can be seen overlying the slates there with a steep easterly dip.[1]

The structure of the slate belt proper is difficult to make out. The quartzite of the southeast side was not found on the northwest side during the reconnaissance. At Foulk Jones & Sons' Slate Hill quarry, 2 miles northeast of Delta, there are some indications of anticlinal structure. Apparent bedding planes dip 30°–40° SE. on the southeast side of the quarry, and similar planes curve over steeply to the northwest on the northwest side, both crossing the cleavage, which is nearly vertical. Whether this is a minor anticline in a conplex syncline or anticline or the anticlinal axis of the entire belt could not be determined. There is also danger of confounding curved joints and bedding. Frazer's section along the right bank of the Susquehanna in York County (sheet 4, vol. CCC) represents the slate as interbedded with chlorite schist and forming part of the northwest limb of a syncline several miles wide.

Characteristics.—The color of the Peach Bottom slate is very dark gray with a slightly bluish tinge. To the unaided eye it has a minutely granular crystalline texture and a slightly roughish but lustrous cleavage surface. It is markedly graphitic and contains magnetite. The sawn edges show a little pyrite. There is no effervescence in cold dilute hydrochloric acid. It is very sonorous and does not discolor.[2] Under the microscope it shows a matrix of muscovite (sericite) of rather coarse, almost schistose texture, but with brilliant aggregate polarization. There is much graphitic material in fine particles and also much quartz, some of which is probably secondary, in grains measuring up to 0.05 and some of them 0.12 by 0.03 millimeter. In some specimens chlorite can be made out mingled with the muscovite. There are tabular crystals of magnetite measuring up to 0.11 by 0.02 millimeter, and also lenses of magnetite of larger size, but the most conspicuous feature is the abundance of crystals of andalusite

[1] See also Frazer, Persifor, jr., op. cit., pp. 133, 134.

[2] The apparent contradiction of this last statement with the passage of this slate into red clay in weathering is explained on page 53.

($Al_2O_3.SiO_2$, silicate of alumina) measuring from 0.008 by 0.001 millimeter and under up to 0.11 by 0.03 millimeter and exceptionally 0.2 by 0.02 millimeter, and numbering from 9 to the 310 square millimeter. These crystals contain opaque inclusions arranged diagonally to their vertical axes, and many of them are in lenses measuring from 0.04 to 0.25 millimeter long by 0.04 to 0.1 millimeter wide, which consist variously of chlorite interleaved with muscovite with some quartz at the ends, or mainly of quartz, the andalusite crystal having a plate of muscovite parallel to it on one or both sides; or the lens consists of muscovite, the crystal being bordered by quartz, or, finally, entirely of secondary muscovite. Where not in lenses, the andalusites generally have a plate of muscovite on one or both sides. These crystals lie with their long axes across the cleavage at various angles and with or across the grain, but the axes of the lenses which inclose them are usually parallel to the cleavage. (See fig. 11.) Pyrite is difficult to distinguish under incident light from the andalusite when this is rendered opaque by inclusions. Rutile occurs in irregular crystalline masses

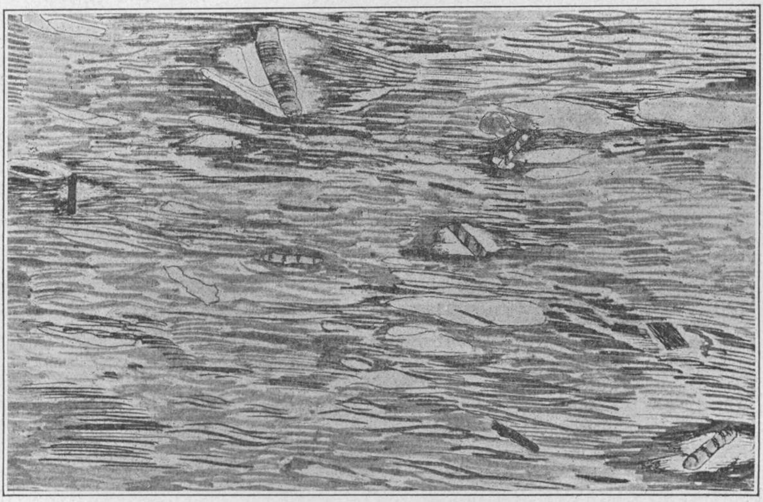


FIGURE 11.—Transverse section of Peach Bottom slate, showing andalusite crystals in a rather coarse micaceous matrix. Enlarged about 113 diameters. Some of these crystals are in lenses of quartz and muscovite and several show inclusions.

up to 0.09 by 0.04 millimeter, but no needles were detected. There is rarely a rounded grain of zircon; no carbonate was detected.

The important constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, graphite, andalusite, magnetite, and pyrite, with accessory rutile and zircon. Figure 11 will serve to show the andalusite crystals which are so characteristic of this slate. The highly crystalline character of the matrix and the absence of carbonate indicate a very durable slate.

The partly weathered slate of the "top" and "hems" shows, under the microscope, the magnetite crystals and lenses passing into hematite and the andalusite becoming limonitic from the oxidation of its inclusions, which must, therefore, be ferruginous and the matrix stained with hematite and limonite from the alterations.

Peach Bottom slate has been thoroughly tested by Merriman,[1] with results as follows: Modulus of rupture in pounds to the square inch, 11.260; ultimate deflection in inches on supports 22 inches

[1] Op. cit.

apart, 0.293; specific gravity, 2.894; softness (grains abraded by 50 turns of a small grindstone), 0.90; porosity (per cent of water absorbed in 24 hours), 0.224; corrodibility (per cent of weight lost in 63 hours in acid solution, consisting of 98 per cent H_2O, 1 per cent HCl, 1 per cent SO_3), 0.226.

The three published analyses show the following percentages of lime: 0.155,[1] 0.3,[2] 0.48.[3] That by the Second Pennsylvania Survey will be found in full on page 50 (analysis 7). This lime may be referable to the phosphate, apatite, which the analyses show to be present.

The Peach Bottom slate is now used almost exclusively for roofing. It also makes excellent gravestones. The chief features of this slate are stated in tabular form in the section on the comparative characteristics of slates (p. 188).

Delta and Cardiff quarries.—In 1912 seven concerns were operating quarries in the Peach Bottom slate belt. In June, 1904, there were 11. Five of these quarries or sets of quarries are located in Pennsylvania and six in Maryland. They lie in three parallel northeast-southwest lines and range from 75 to 120 feet across the cleavage and up to 200 feet in depth. The structural relations of these three belts of commercial slate are not yet apparent. The cleavage is uniformly vertical or dips steeply southeast with a strike ranging from N. 37° E. to N. 55° E. There is usually a horizontal joint—"big flat joint"—pitching gently south, locally from 40 to 60 feet below the surface and including 2 to 3 feet of crushed slate, which is evidently the result of a secondary crustal movement. Commercial slate occurs only below this joint. The "top" varies from 6 to 65 feet in thickness and in places includes 10 feet of slate in small fragments. Other flat joints dip about 20° NE. or 25° SW. Longitudinal joints strike N. 48° E. and dip 90°. Diagonal joints strike N. 25°–30° W. and also N. 45° W., dipping northeast at angles ranging from 45° to 90° or 50° to 80°. Conspicuous dip joints strike about at right angles to the cleavage and stand vertical or dip 25° or 45° SW. At Foulk Jones & Sons' quarry there are vertical diagonal joints striking N. 10° E. to N. 10° W. The grain dips 20°–50° NE. Quartz veins meander in the cleavage direction. The slate commonly has along the joint planes toward the surface a brownish rim, called a hem, from 1 to 2 inches wide and more or less parallel to the joint face. The slate breaks off at the inner side of the "hem," and this part is discarded. Some of the joints are parted and contain red clay half an inch to an inch thick. The hems represent simply the initial stage of weathering caused by the percolation of water from the joints,

[1] Second Pennsylvania Geol. Survey Rept. Progress for 1877, Vol. CCC, 1880; analyses by A. S. McCreath, pp. 269, 270.

[2] Analyses by Booth, Garrett, and Blair, 1885; see Maryland Geol. Survey, vol. 2, p. 226, 1898.

[3] Merrill, G. P., Rocks, rock weathering, and soils, 1897, p. 229.

and of this process the final result is the red clay. The slate of the top has generally a reddish hematitic hue, and the whole belt is covered with reddish clay. The chemical processes involved in the passage of Peach Bottom slate into red clay as determined by Merrill are given on page 53. The effect of weathering, as shown under the microscope, will be discussed after the microscopic analyses of the slate.

The quarrymen complain of the occurrence of what they call "black stuff," a hard material up to an inch thick, occurring locally in vertical planes diagonal to the cleavage. This material proves to be an aggregate of much pyrite, carbonaceous matter, quartz, chlorite, and muscovite, and is probably vein matter segregated from the adjacent slate.

The Baltimore Peach Bottom Slate Co., of Delta, Pa., has recently adopted the tunnel method in its Cardiff quarry in order to save the expense of removing the "top." It is found that this method also has the advantages of affording not only a shelter to the workmen but a uniform temperature of 60° both day and night and of preserving the moisture in quarried blocks for an indefinite period. The tunnel is 6 or 7 feet high, 12 feet wide, and about 600 feet long at right angles to the cleavage. It has lateral chambers, one on each side, measuring, respectively, 70 and 30 feet in length and 60 and 50 feet in width. One is 60 feet deeper than the tunnel floor; the other is 12 feet higher than its roof. Channeling and overcutting machines operated by compressed air are used.[1]

Lancaster County prospect.—Evidently belonging to the Peach Bottom slate is a deposit prospected in 1910 by P. B. Shank near Peters Creek, in Lancaster County. A specimen examined yielded these results:

The color of this slate is very dark gray, slightly bluish. The cleavage surface is fairly smooth, with minute striations in the grain direction and lustrous. The fissility is fair, grade (2). It is very sonorous. There is no effervescence with cold dilute hydrochloric acid nor any carbonate in thin section. It is very graphitic and shows no pyrite on sawn edge; there was a little magnetite in the powdered slate and in thin section.

Under the microscope it shows a matrix of muscovite (sericite), very even in grain direction, with marked aggregate polarization and containing considerable quartz and finely disseminated graphite. Its most conspicuous feature is the abundance of groups of intergrown rutile crystals (sagenite). These groups measure up to 0.04 millimeter in diameter and average about 15 to the square millimeter of thin section. A chemical analysis of the slate would probably show an unusually high percentage of TiO_2 (titanium dioxide) for a slate. There are also andalusite prisms (aluminum silicate) up to 0.066 by 0.009 millimeter, more or less darkened by inclusions and lying mostly with their long axis in the grain direction. A little tourmaline is present and probably chlorite. The constituents, named in descending order of abundance, appear to be muscovite, quartz, graphite, andalusite, rutile, chlorite (?), magnetite, tourmaline, pyrite, and zircon.

[1] These particulars obtained through the courtesy of Mr. C. F. Guild, general manager.

This is a graphitic mica slate free from carbonate. It will not discolor and ought to prove very durable. Its cleavage appears to correspond with that of the Peach Bottom slate, which it generally resembles.

TENNESSEE.

Slate deposits occur in eastern southeastern, and northeastern Tennessee.

BLOUNT COUNTY.

The slate deposits southeast of Knoxville were described by Keith [1] in 1895 as follows:

Two formations in this region contain beds of slate—the Wilhite and Pigeon slates. The Wilhite slate is too calcareous and soft for commercial use in the vicinity of Little Tennessee River but has the necessary hardness, evenness, and cleavage along Little Pigeon River. Along this stream the slate is well exposed over great areas but has never been developed. Quarries have been opened in the Pigeon slate along the Little Tennessee River at many points, and slates and flags taken out for local use. Recently a quarry has been opened on a small creek 2 miles from the river and much good material taken out for shipment. The slates are of fine, even grain and split into slabs an inch thick, of any desirable size, or into roofing slates. In this particular quarry the cleavage crosses the bedding and produces ribbons in much of the slate. An old quarry about 2 miles north of this shows the cleavage and bedding coincident, and flags of great size are readily loosened. Some of the slate layers contain pyrite, necessitating selection of the material for use. There are a great number of available places for quarrying in the bluffs along the river and the adjacent small streams on either side. That this slate resists weathering is amply proved by the high, sharp slate cliffs that border the river along most of its course.

The Southern Slate Co., of Columbus, Ohio, quarried a little slate near Chilhowie in 1910. There is also a slate prospect on the Virgil Grant farm, 3½ miles from Chilhowie.

The following analyses of slate quarried by the Southern Slate Co. at Maryville were made by Gilbert McCulloch, of the University of Tennessee.

Analyses of Tennessee roofing slate.

	1	2		1	2
Silica (SiO_2)	58.45	59.00	Potash (K_2O)	1.60	2.04
Alumina (Al_2O_3)	21.88	23.44	Soda (Na_2O)	2.34	1.78
Iron oxide (Fe_2O_3)	6.04	6.28	Sulphur trioxide (SO_3)	.65	.23
Lime (CaO)	1.86	1.30	Water	6.66	4.64
Magnesia (MgO)	.46	.50			

MONROE COUNTY.

Several outcrops and prospects on Tellico River and its tributaries were visited by the writer in 1912. The localities are among the western foothills of the Great Smoky Mountains at elevations between 800 and 1,000 feet above sea level and in the drainage basin of

[1] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Knoxville folio (No. 16), p. 6, 1895.

Tennessee River.[1] According to the folios on the Cleveland quadrangle,[2] on the west, and the Nantahala quadrangle,[3] on the east, the nearest areas that have been geologically mapped by the United States Geological Survey, these slates probably belong in the Hiwassee slate (Pigeon or Wilhite slate of Hayes) and are of Cambrian age. They consist of purplish, greenish, and black mica slates, interbedded here and there with quartzite and fine conglomerate.

The openings all lie within a radius of 3 miles of Tellico Plains station, the terminal of a branch of the Louisville & Nashville Railroad, and were made by the Tellico Co., of Tellico Plains.

Falls Branch prospect.—This is 3 miles S. 5° E. of Tellico Plains station, on Falls Branch, a brook flowing northward into Laurel Creek, a tributary of Tellico River. It is on the east side of Tellico Mountain, 400 feet above Tellico Plains station and about four-fifths of a mile south of the point where the Murphy pike crosses the branch. The opening is only 10 feet square and deep. Both bedding and cleavage strike N. 55° E. and dip S. 35° E., but the dip of the bedding is 25° and that of the cleavage 50°. The thickness exposed is about 40 feet, but the total thickness may be much greater.

The slate is very dark bluish gray with a lustrous ribboned cleavage face of more or less smoothness. It does not effervesce with acid test, even when powdered. The sawn edge shows black metallic grains; the powder some magnetite and much graphite.

Under the microscope the matrix shows brilliant aggregate polarization and lenticular texture. Small ribbons cross the cleavage at an angle of 14°. These contain coarser particles of carbonate, much quartz, pyrite in particles and spherules, and here and there a plagioclase grain. The matrix has many lenses of chlorite and muscovite, mostly 0.04–0.14 millimeter, detrital quartz grains up to 0.22 millimeter, some lenses of carbonate as much as 0.14 millimeter, of pyrite up to 0.09 millimeter, and a lens of pyrite, quartz, and muscovite 0.56 millimeter. The section with the cleavage shows much carbonate in very minute rhombs and plates. Rutile is plentiful in short needles, also fine graphite, tourmaline, and zircon.

The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, graphite, magnetite, pyrite, rutile, tourmaline, zircon, and plagioclase—the last two and the quartz being detrital.

This is a mica slate of the fading series, but the discoloration will probably be slight.

Lyons Creek prospect.—About 1½ miles southeast of Tellico Plains station, on the southwest side of Lyons Creek half a mile above its junction with Tellico River, is a cliff 40 to 50 feet high, of black slate, with a rusty-faced cleavage striking N. 50° E. and dipping 80° S. 40° E. Curved joints or beds in the upper part of the cliff correspond to ribbons below, which dip about 20° N. The slate crops out for 200 feet across the strike of the cleavage. About 325 feet N. 25° W. of the prospect is a bed of quartzite over 50 feet thick striking N. 50° E.

[1] See map of Murphy quadrangle, U. S. Geol. Survey.
[2] Hayes, C. W., U. S. Geol. Survey Geol. Atlas, Cleveland folio (No. 20), 1895.
[3] Keith, Arthur, idem, Nantahala folio (No. 143), 1907.

and dipping 55° S. 40° E. The cleavage faces along the cliff are limonitic.

The slate is bluish black with more or less lustrous cleavage face. It is sonorous and does not effervesce with acid test but contains little whitish granular pyritiferous beds up to 0.1 inch thick which effervesce strongly with acid and appear to be calcareous sandstone.

Under the microscope this slate has a brilliant aggregate polarization. A 0.2-inch bed of coarser particles zigzags at right angles across the cleavage and abounds in quartz grains (mostly under 0.09 millimeter) and carbonate, has pyrite on the edges, and contains chlorite, a plagioclase, and a zircon grain. The matrix is more carbonaceous than the sandy beds and in sections with the cleavage shows lenses of pyrite to 0.5 millimeter, with secondary fibrous quartz on opposite edges, much carbon and carbonate, some tourmaline, and rutile.

The constituents, named in descending order of abundance, are muscovite, quartz, carbonate, graphite, pyrite, chlorite, plagioclase, tourmaline, zircon, and rutile. Of these, most of the quartz and all the zircon and plagioclase are detrital.

This is a mica slate with much carbonate and pyrite and will probably discolor badly.

Laurel Creek quarry.—This is but little over a mile southeast of Tellico Plains station on the southeast side of Laurel Creek about a fourth of a mile from its junction with Tellico River. The opening is 25 feet square and 50 feet deep. The cleavage, which appears to coincide very nearly with the bedding, strikes N. 35° E. and dips 55° S. 55° E. The slate is purple but incloses a bed of green 5 feet thick.

The purple (specimens D. XXXIV, 9, a–d, g) is of dark purplish-gray color and of lusterless smooth cleavage surface, in places with minute dark-green lenses. Some very delicate brownish beds and lenses up to 0.3 inch thick are calcareous, but the slate itself does not effervesce with acid test. The powdered slate effervesces strongly but shows no magnetite. Under the microscope it shows brilliant aggregate polarization and fine texture, with little beds of coarser material up to 0.37 millimeter thick crossing the cleavage at an angle of 5°. It has a very chloritic lens 0.62 millimeter thick. Minute irregular dots of very dark red hematite are scattered throughout and are coarser in the little beds, where they appear to be black and metallic. Much chlorite; no carbonate except in the little beds. The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, hematite, carbonate, kaolin, and rutile.

The green (specimen D. XXXIV, 9, h) is of light-blue to greenish-gray color and has a lusterless smooth cleavage surface with lenses of darker green 0.1 inch long and very thin, also brownish-weathering lenses effervescing much with acid test. The slate effervesces some, as does the powdered slate, which shows extremely little magnetite. The sawn face shows fine grayish bands and lenses. Under the microscope this slate shows a fine texture and brilliant aggregate polarization, but many lenses and beds up to 0.4 millimeter thick parallel to the cleavage containing quartz grains to 0.12 millimeter and much carbonate in a matrix of chlorite. The general matrix contains much chlorite and fine quartz but no carbonate; also oxidized pyrite and abundant slate needles. The grain is well marked. The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, pyrite, magnetite, and rutile.

These are mica slates. Although both contain carbonate, slates of both colors exposed for 10 years on the dumps have suffered scarcely any discoloration. The quarry was given up because of the high cost of splitting, possibly caused by the acute intersection of bedding and cleavage and the little lenses.

Tellico River prospects.—These are about half a mile east-southeast of Tellico Plains station on the north bank of the river a little east of a conspicuous road angle. The section seems to consist, beginning on the northwest, of 250 feet of slate, mostly purplish, striking N. 15°–22° E. and dipping 45° S. 70° E., underlain by a bed of slightly limonitic quartzite 25 feet thick, and that in turn underlain by 75 feet of green and purple slate, under which is still another bed of quartzite, all with the same dip and strike. The cleavage and bedding of the slate appear to be nearly identical, although the dip of the first bed of quartzite at the contact is 55°.

The purple slate (specimens D. XXXIV, 6, b, c, e) is of medium purplish-gray color and has an almost lusterless cleavage surface. It is dotted with minute lenses and contains very delicate limonitic films which do not effervesce with acid. The sawn slate shows pyrite and the powdered slate effervesces slightly and does not show magnetite. Under the microscope this has a brilliant aggregate polarization and a fine but somewhat uneven texture. There are chloritic lenses up to 0.5 millimeter thick and limonitic streaks up to 0.25 millimeter thick. The section with the cleavage shows no carbonate but dots of dark-red hematite, black metallic particles, and some pyrite, with limonite from both; rutile exceedingly minute. The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, hematite, kaolin, pyrite, carbonate, limonite, and rutile.

The green slate is light greenish gray and otherwise corresponds to the purple. Its color is identical with the green of the Laurel Creek quarry described above and its composition presumably not far different.

SULLIVAN COUNTY.

A slate deposit 1¼ miles south of Kingsport was visited in 1909 by C. H. Gordon, of this Survey. The following note is taken from his written report:

The slate belongs to the Athens shale of the Ordovician [1] and is exposed along a small branch that rises on the north slope of Bays Mountain and flows into Holston River. The bedding, to judge from the relations to the underlying and overlying formations, probably dips 15°–20° S. 10° E. The cleavage strikes N. 50° E. and dips 60° S. 40° E. The two principal sets of joints, both nearly vertical, strike N. 60° E. and N. 30° W. The slate is "black," homogeneous, and even grained and effervesces with acid. In some places graptolites are very abundant. Small masses of pyrite are occasionally seen.

Thin sections of this slate, examined by the writer, yield these results:

Cleavage fair, but aggregate polarization feeble owing to incomplete micasization. Very carbonaceous; not graphitic. Carbonate very abundant; much pyrite in spherules, little quartz, rare grains of plagioclase, chlorite scales. Veinlets of calcite in the cleavage foliation.

This is not far from a clay slate, resembling somewhat that of Martinsburg, W. Va. (See p. 165.) It will probably fade badly. Its large percentage of carbonate and small content of quartz and mica make its commercial value doubtful.

[1] U. S. Geol. Survey Geol. Atlas, Estillville folio (No. 12), 1894.

WASHINGTON COUNTY.

Specimens of "black" slate from the vicinity of Austin Springs, 4 miles north of Johnson City, and also of the Athens shale, were examined microscopically with these results:

Better aggregate polarization than the slate near Kingsport, with much less carbonate and also more quartz. Some pyrite; carbonaceous matter probably graphite.

This is a mica slate the commercial value of which will depend mainly on the uniform quality of the cleavage and the distribution of the joints. There are no data as to the structure of the deposit.

UTAH.

By Edwin C. Eckel.

For some years past a small amount of slate has been annually quarried, chiefly for samples and trial shipments, at various points in Utah. Deposits of slate, believed to be of workable extent and of good quality, have been described as occurring on the islands in Great Salt Lake, and some attempt has been made to develop these deposits.

The locality which has been most widely discussed, however, is that near Provo. This has been exploited to some extent by F. W. C. Hathenbuck, of Provo. The slate deposits occur about 2 miles southeast of Provo station, in Slate Canyon. The slate here covers a considerable area, but that exposed at the surface is so badly broken up that large slabs can not be obtained. It is possible, however, that this condition will disappear if the deposits are worked deeper.

The deposits furnish green and purple slates, the latter being apparently present in greater quantity. The green slates show little tendency to cleavage in their surface outcrops and will probably be less satisfactory for roofing than the purple. The green slates rub very smooth, however, and would make good slabs or mill stock if obtainable in masses of sufficient size.

The purple slates split well, with a surface about as smooth as that of the Peach Bottom slate of Pennsylvania and Maryland. From samples seen it appears that they also bear punching well.

A specimen of the purple slate selected by the writer was analyzed by W. T. Schaller in the laboratory of the United States Geological Survey, the results being as follows:

Analysis of purple slate from Provo, Utah.

Silica (SiO_2)	54.05
Alumina (Al_2O_3)	20.95
Iron oxides (FeO, Fe_2O_3)	.28
Lime (CaO)	.22
Magnesia (MgO)	9.12
Carbon dioxide (CO_2) Water	3.90

Of a series of 36 analyses of American roofing slates collected and discussed[1] by the writer, the above analysis of the slate from Provo stands lowest in its percentages of silica and magnesia, and its lime is very far below the average.

Nothing definite is known as to the geologic age of these slates, though they are supposed to be Ordovician, or even older.

VERMONT.

GEOGRAPHIC RELATIONS.

There are at least four distinct slate districts in Vermont. The most easterly extends along Connecticut River for more than two-thirds the length of the State. The slate is black or dark gray and has been worked in Guilford, in Windham County, at the extreme south end of the State, and also in Thetford, in Orange County, and at Waterford, in Caledonia County. The next district extends along the east flank of the Green Mountain range from the Canada line to about the middle of the State, and its slate has been extensively worked at Northfield, in Washington County. The most important district, which furnishes the well-known "green" and "purple" slates, lies between the Taconic Range and Lake Champlain, extending from the town of Sudbury, in Rutland County, southward to Rupert, in Bennington County, a distance of 26 miles. This belt also passes south-southwest into Washington County, N. Y., where, however, it has thus far proved of less economic importance. The fourth district is an area of black slate, as yet undeveloped and covering only from 2 to 3 square miles in the town of Benson, in Rutland County, near Lake Champlain.

NORTHFIELD DISTRICT.

The Vermont geologic map[2] represents a belt of clay slate, from 1 to 7 miles wide, extending from Lake Memphremagog along the east side of the Green Mountain axis as far south as Barnard, in Windsor County, a distance of 90 miles. A paper and map by Richardson[3] represent a portion of this slate belt 52 miles long, extending from North Calais, in Washington County, to a point in Windsor County nearly 10 miles west of White River Junction. The age of this slate formation was thought to be probably Devonian by the authors of the earlier report,[4] but Richardson regards it as lower Trenton. Conclusive paleontologic evidence on the subject is yet lacking.

[1] Eckel, E. C., Jour. Geology, vol. 12, p. 26, 1904.

[2] Hitchcock, C. H., and Hager, A. D., Report on the geology of Vermont, vol. 2, Pl. I, p. 794, 1861.

[3] Richardson, C. H., The terranes of Orange County, Vt.: Vermont State Geologist Rept., new ser., vol. 3, pp. 77–79, Pls. IX, IX, *A*, 1902.

[4] Hitchcock, C. H., and Hager, A. D., op. cit., vol. 1, p. 497, 1861.

This slate has been quarried at Montpelier and Northfield, which are 10 miles apart. The strike of bedding at both places ranges from N. 10° E. to N. 25° E. At the Vermont Black Slate Co.'s lower quarry, 2 miles south of Northfield, the beds occur in minor very acute folds, which strike N. 10° E., while the cleavage, with an almost identical strike, dips 75° W. At that company's upper quarry, a quarter of a mile to the east, the beds strike N. 25° E. and dip 75° N. 65° W., and the cleavage likewise. The interpretation given by Richardson of Plate XV in his paper, referred to above, requires corroborative microscopic evidence. The low easterly (by error printed west) dipping planes resemble a secondary cleavage, and the steep westerly ones have the characteristics of bedding.

The slate continues about 300 feet west of this quarry and about a third of a mile east, making its total width in that vicinity about 2,000 feet. The general relations of this slate on the west are these: The western part contains a bed of novaculite up to 12 feet thick and is followed by slate of no commercial value, which is followed at the foot of the range, about three-fourths of a mile southwest of the village, by a sericite-chlorite-quartz schist containing grains of plagioclase, with a vertical slip cleavage striking about north and a plicated bedding having a northerly pitch. Beyond a covered interval, at a point on the range 2 miles west of the village, there is a large exposure of thin-bedded, more or less muscovitic quartzite, containing grains of zircon and plagioclase, so intricately folded as to strike N. 20° E., N. 20° W., N. 50° E., and due east. An area of a few acres of muscovite granite (formerly quarried, Moses King property) lies within this quartzite, or at least with this quartzite on both its east and west sides.

In 1904 but one quarry was in operation in Northfield Township, that of the Vermont Black Slate Co., which then measured about 100 feet along the strike, 60 feet across it, and 55 feet in depth. The company later reopened the "Clark quarry," on the ridge, a quarter of a mile east and 100 feet above the first. In 1909 both quarries became idle, and they were still idle in 1912. The Clark quarry has an east-west working face 100 feet long and 35 feet high and the beginning of a north-south face.

At the lower of these quarries the cleavage strikes N. 12° E. and dips 75° W. There are three sets of joints—(*a*) striking N. 15° E., dipping 50° N. 75° W.; (*b*) striking N. 77° W., dipping nearly 90°; 90°; (*c*) striking N. 55° E., dipping 65° N. 35° W. The grain dips 70° N. An exceptional slip cleavage dips 15°–20° N.

At the Clark quarry the cleavage and beds strike N. 25° E. and dip 75° N. 65° W. Slip cleavage, which is confined to certain beds and to certain horizontal zones, strikes N. 60° E. and dips 15° N. 30° W. A quartz vein half an inch thick cuts the beds from east to west, meandering horizontally, and then dips about 45° W. across them. East of it is an 8-foot heading, much veined with quartz. In a height of 30 feet there are but three horizontal joints, and these undulate. The slate beds here, from 6 inches to 3 feet thick, are separated by quartzose beds one-fourth inch to 3 inches thick and some very pyritiferous beds 1 or 2 inches thick, all of which weather a muddy brown, are void of cleavage, and effervesce freely with acid. In thin section these are a uniform compound of (1) carbonate plates and rhombs, (2) detrital quartz grains, (3) muscovite scales, and (4) fine carbonaceous material, with (5) a few lenses of secondary quartz, some with a nucleus of pyrite, these being numbered in descending order of abundance.

The slate itself is very dark gray and has a very lustrous cleavage face, smooth or dotted with minute lenses or with longish crystals of pyrite pointing in the grain direction. It is very sonorous, very fissile, does not discolor, does not effervesce, even when powdered, with cold dilute hydrochloric acid, and contains much graphite, more or less magnetite, and some magnetic iron pyrites ($Fe_7 S_8$) with here and there a nodule of it as much as half an inch in diameter. Where slip cleavage occurs the plications that give rise to it average about 20 to the inch and, in the sections examined, cross the cleavage at nearly 60°.

Under the microscope the matrix of sericite has a brilliant aggregate polarization and a very even texture. Porphyritic crystals or lenses of magnetitite or of pyrite (some with rim of secondary quartz, or of chlorite, radiating to 0.08 millimeter along the cleavage) average 4 or 5 in a square millimeter, and measure 0.05 to 0.24 by 0.02 to to 0.06 millimeter, some with their long axis in the grain direction; rare lenses of carbonate up to 0.37 millimeter; and some entirely of rutile crystals. Detrital quartz up to 0.06 millimeter (mostly), and chlorite scales, some with interleaved muscovite, are plentiful. There are prisms of tourmaline, 0.36 by 0.008 millimeter, and of rutile, up to 0.04 by 0.006 millimeter, but no rutile needles.

The constituents named in descending order of abundance, appear to be muscovite, quartz, graphite, chlorite, magnetite, pyrite and magnetic iron pyrites, chlorite, rutile, carbonate, tourmaline, and limonite stain.

This is a superior mica slate of the unfading series resembling that of Brownville, Me. Its content of magnetic minerals is too high to make it suitable for electric uses. Owing to the scarcity of horizontal joints the company gave its attention almost entirely to the production of mill stock. The true method of operating such a quarry would be to use channelers for horizontal cuts and to make roofing slates of the blocks that have little or no slip cleavage and use the rest for mill stock. Roofing slates from the Clark quarry with not a little "false cleavage" are yet strong.

The following data were gathered at the abandoned quarry of the Union Slate Co. half a mile east-southeast of Northfield; bedding strike, N. 10° E., dip 80° W.; cleavage strike, N. 4° E., dip 70° W. Strike joints dip, undulating, low west; diagonal joints strike N. 60°–65° W. and dip 75° NE.

At the abandoned quarry three-fourths of a mile southeast of Montpelier and about 10 miles north-northeast of the Vermont Black Slate Co.'s quarry at Northfield the strike of both bedding and cleavage was found to be N. 15°–20° E., and the dip 70°–75° W. This quarry was operated by means of three wide openings at intervals across the strike, communicating with with one another by a 10-foot open cut, which also served as a drain. The quarry is said to have been abandoned on account of the large percentage of waste, which may have been the result of the complex opening. The slate appears to be essentially the same as that of the Northfield quarries.

WESTERN VERMONT.

GEOLOGIC RELATIONS.

The broader geographic and geologic relations of the slate belt of western Vermont are shown in the map of the slate belt of eastern New York and western Vermont.[1]

The Ordovician (Berkshire) schist of the Taconic Range is bordered on the west, except along a stretch of 6 miles in Pawlet and Rupert, by a belt of Lower Cambrian rocks estimated as at least 1,400 feet in thickness, which include about 240 feet of greenish and purplish roofing slates. In Pawlet and Rupert the schists of the Taconic Range merge at the west through decrease of metamorphism into an irregular area of shales and grits of Ordovician age, not less than 1,200 feet thick, which include about 50 feet of commercial reddish and greenish slate. These have long been quarried in Granville and Hampton, N. Y., and are described in detail on pages 89–93. In some places the Lower Cambrian slate protrudes through the Ordovician slate; in others lenticular remnants of Ordovician slate overlie the Lower Cambrian slate. The relations of these two formations are more intricate in the New York part of the slate belt than in the Vermont part. In Plates XX and XXI their relations in the vicinity of the chief quarrying centers are shown, as well as the location and form of nearly all the slate quarries opened before 1904.[2]

The Lower Cambrian slates of western Vermont are greenish gray, purplish, and "variegated"—that is, greenish gray and purplish mixed. These colors occur in alternations, in which, as is shown by the quarry diagrams (Pls. XXIII and XXIV) there is little regularity. In the main, however, the beds at this horizon seem to consist of 100 to 140 feet or even 200 feet of greenish and purplish slates, the greenish beds predominating, with 40 to 50 feet of variegated or mottled slate overlying but possibly replacing the purple in places. On the west

[1] The slates of western Vermont were fully described by the writer in U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, 1899, and the matter appears here in revised form, but the general map, Pl. XIII, is not republished.

[2] It will be noticed that Plate XXI fits onto the eastern half of the north end of Plate XX. The scale of these maps is so large that they can be used for prospecting purposes by studying the relations of the quarry locations to the symbols which designate the strike of the beds. (See also p. 169.)

side of Lake Bomoseen purple slate nearly 100 feet thick is exposed. The purple slate in places contains a few inches of dark-reddish slate not unlike the red of the Ordovician. There is some difference in the shade of the different beds of green in the same quarry, some being more greenish, others more grayish. There are also differences in the amount of discoloration produced by weathering in beds of the same locality. Although some quarries produce only the so-called "unfading green" and others only the "sea-green," these differences appear to occur not in strata of different ages but at different points in strata of the same age.

Interbedded with the slates are strata of calcareous quartzite ranging in thickness from a few inches up to 5 feet. This quartzite contains a few grains of plagioclase and more muscovite scales and is veined with quartz, which crystallizes in cavities. Here and there the quartzite weathers brown; its calcite, therefore, probably contains some siderite.

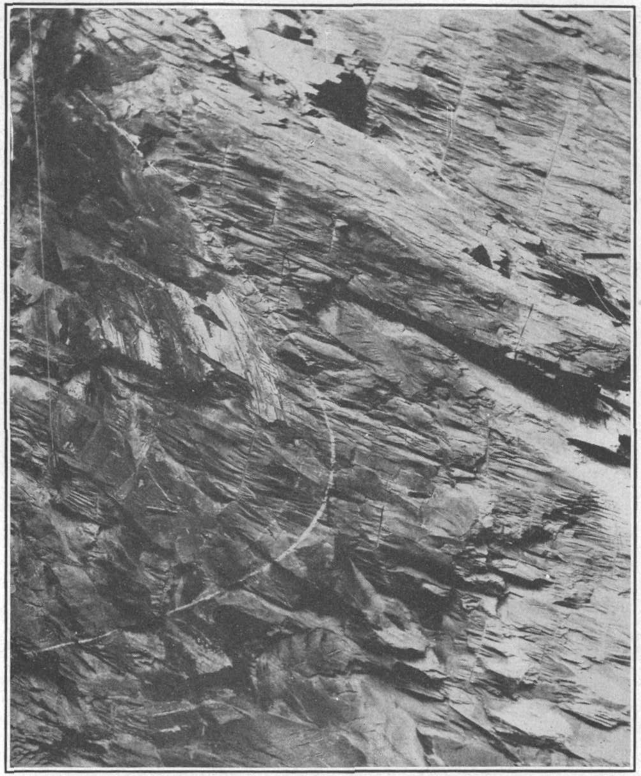
Associated with the slates are also beds of limestone conglomerate or breccia ranging from a few feet to 40 feet in thickness, carrying the trilobite Olenellus and other fossils characteristic of the Lower Cambrian. One of these beds of limestone breccia is of common occurrence in the quarries, overlying the slate. (See quarry diagram *P*, Pl. XXIV.)

The slate-bed surfaces are generally covered with annelid trails or impressions of algæ, or both. Many of the purple slates are ribboned or banded with light-green slate beds an inch or more in thickness or have oval or roundish light-green spots, frequently in rows. Similarly the "sea-green" slates are crossed by grayish ribbons.

The position of these commercial slates in the Lower Cambrian series is shown in the following table, in which the beds are arranged in their natural order:

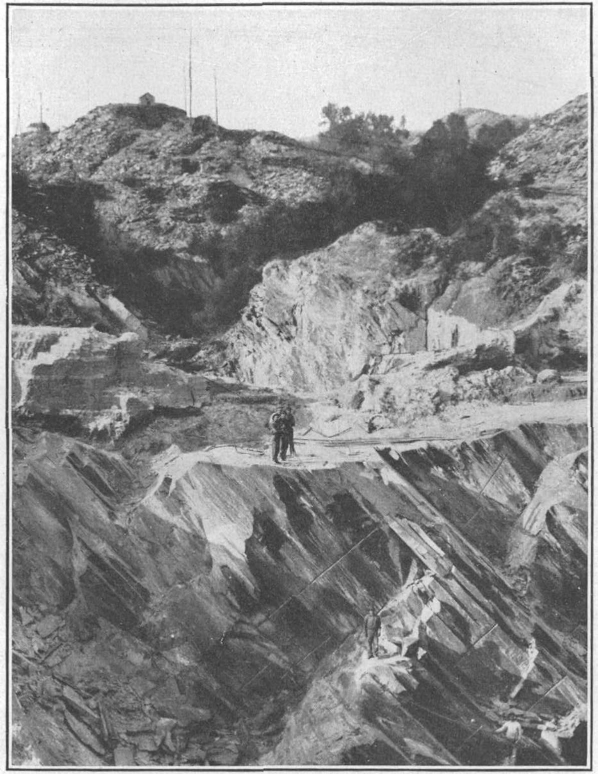
Lower Cambrian rocks of slate belt of western Vermont.

	Feet.
E. Ferruginous quartzite and sandstone	25–100
D. Black shale and slate with Lower Cambrian fossils	50–250
C. Black patch grit; a dark-gray grit or sandstone with black shaly patches, locally with calcareous nodules carrying Lower Cambrian fossils	10– 40
B. Roofing slate, grayish green, purplish or mixed green and purplish, alternating with beds of calcareous quartzite and of limestone breccia up to 40 feet thick, the breccia carrying Lower Cambrian fossils	200–240
A. Olive-colored grit or graywacke, more or less massive, with minute scales of hematite or graphite, containing some small quartzite beds, much of it calcareous, generally weathering a pale brick-red. Under the microscope shows grains of quartz, feldspar, and large scales of muscovite and of chlorite interleaved with muscovite. Associated with this is a bed of quartzite 12 to 55 feet thick	50–200



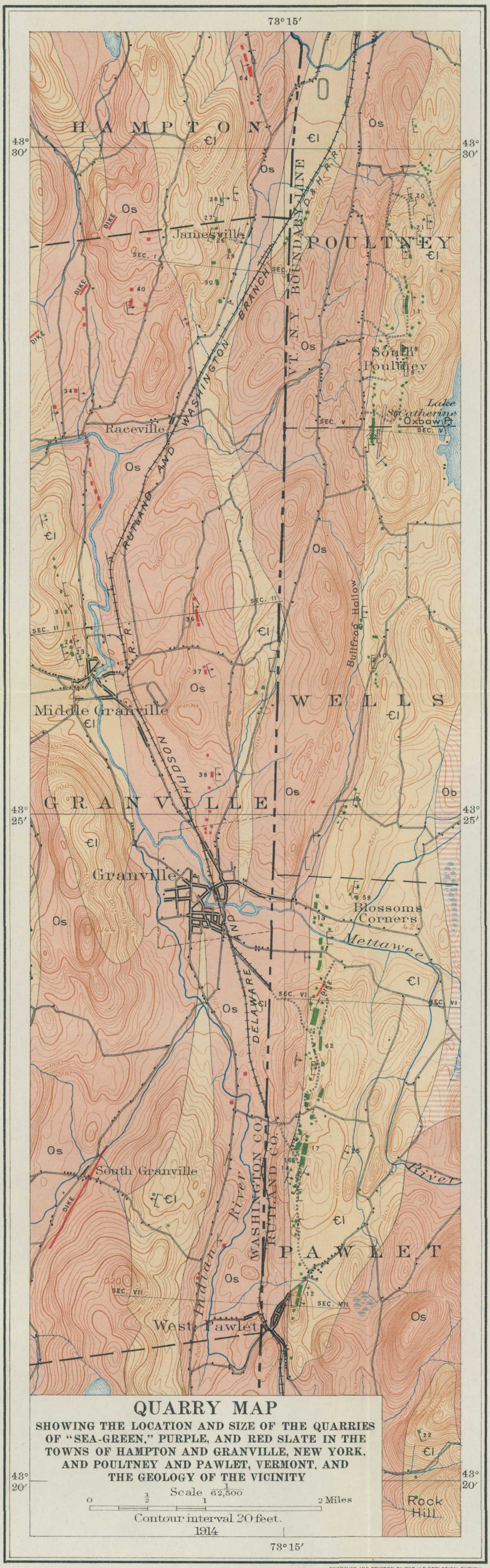
A. CEDAR POINT QUARRY, ON LAKE BOMOSEEN, CASTLETON, VT.

North face, showing good mill-stock slate in cross fracture. The flat syncline has a slight southerly pitch and the cleavage dips 15°-20° E. The board on the wall is 3½ feet long. Compare Plate XXIV, N.



B. CLAY QUARRY, PAWLET, VT.

North face, showing, in cross fracture, about 50 feet of good roofing slate, with bedding and cleavage parallel. The four men in a group are standing upon a freshly exposed glaciated surface. At the left is a 10-foot remnant of thin-bedded horizontal postglacial clay, from which the quarry is named.



QUARRY MAP

SHOWING THE LOCATION AND SIZE OF THE QUARRIES OF "SEA-GREEN," PURPLE, AND RED SLATE IN THE TOWNS OF HAMPTON AND GRANVILLE, NEW YORK, AND POULTNEY AND PAWLET, VERMONT, AND THE GEOLOGY OF THE VICINITY

Scale $\frac{1}{62,500}$

0 ½ 1 2 Miles

Contour interval 20 feet.

1914

LEGEND

Os — Ordovician slate, shale, grit, etc. (*Slate, red, bright green, black*)

Ob — Ordovician Berkshire schist

SAME AGE

€l — Lower Cambrian slate, quartzite, grit, limestone, and shale (*Slate, green, purple, or variegated*)

Quarries of red slate with some bright-green slate

Quarries of "sea-green" or purple slate (including variegated)

Strike and dip of bedding (*The shorter the arrow the steeper the dip*)

Strike and dip of cleavage (*The shorter the lines the steeper the dip. Cleavage and bedding symbols are in places combined*)

Strike of "hogback" or shear zone

Dike of camptonite or augite camptonite (*Basic eruptive*)

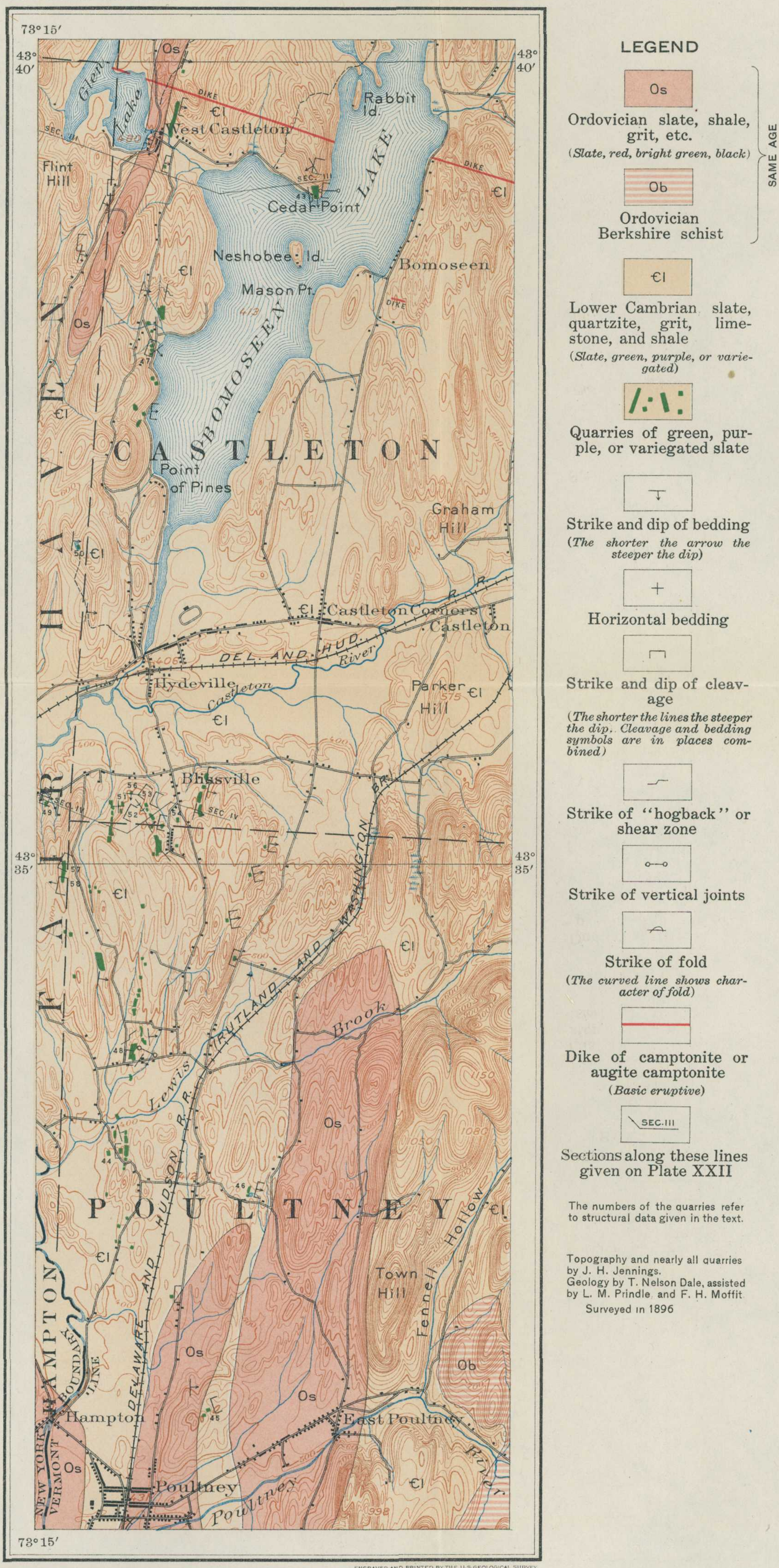
SEC. VI — Sections along these lines given on Plate XXII

The numbers of the quarries refer to structural data given in the text.

Topography by J. H. Jennings, G. E. Hyde, and Jas. McCormick. Quarries mostly by J. H. Jennings. Geology by T. Nelson Dale, assisted by L. M. Prindle and F. H. Moffit

Surveyed in 1895-96

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY



QUARRY MAP

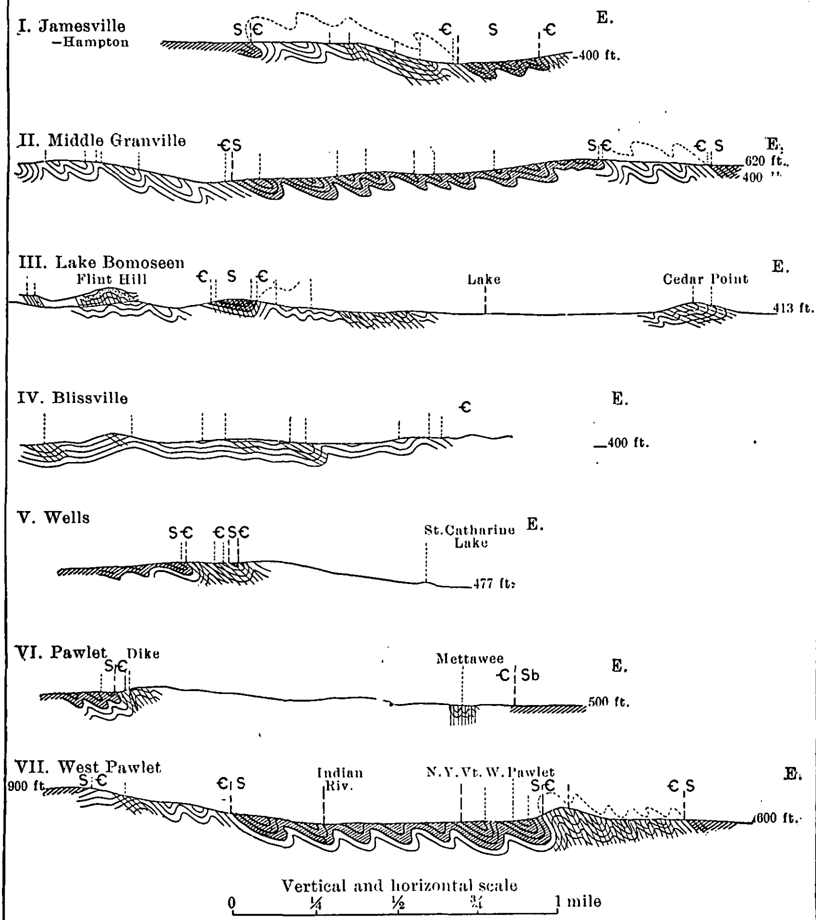
SHOWING THE LOCATION AND SIZE OF THE MORE IMPORTANT SLATE QUARRIES IN THE "UNFADING GREEN" SLATE BELT BEWEEN POULTNEY AND WEST CASTLETON, VERMONT, AND A FEW OF THE "SEA-GREEN" SLATE QUARRIES NEAR POULTNEY

Scale $\frac{1}{62500}$

0 ½ 1 2 Miles

Contour interval 20 feet.

1914



LEGEND

Section lines on Quarry maps, Pls. XX and XXI.

Vertical dotted lines indicate places where dip was observed; otherwise hypothetical.

Vertical dashes indicate boundaries between Cambrian and Silurian, or refer to names.

=Ordovician (Lower Silurian) shales, grits, and red and green slate.

All other areas =Lower Cambrian shale, limestone, quartzite, and green and purple slate.

SECTIONS ACROSS THE NEW YORK AND VERMONT SLATE BELT.

The base of the formation is not certainly exposed. There may be a bed of commercial slate in the olive-colored grit.

The probable structure and structural relations of the two slate formations of western Vermont are shown in Plate XXII. Each section is described beyond in detail. Those parts of the sections which are well substantiated are indicated by vertical dotted lines. The typical features of the region are finely shown at certain points, and these have been utilized in drawing the hypothetical parts of the sections. Symbols showing the structure at a number of the quarries are given on the large-scale quarry maps (Pls. XX and XXI), on which the section lines have been drawn.

GEOLOGIC SECTIONS.

SECTION I. JAMESVILLE-HAMPTON.

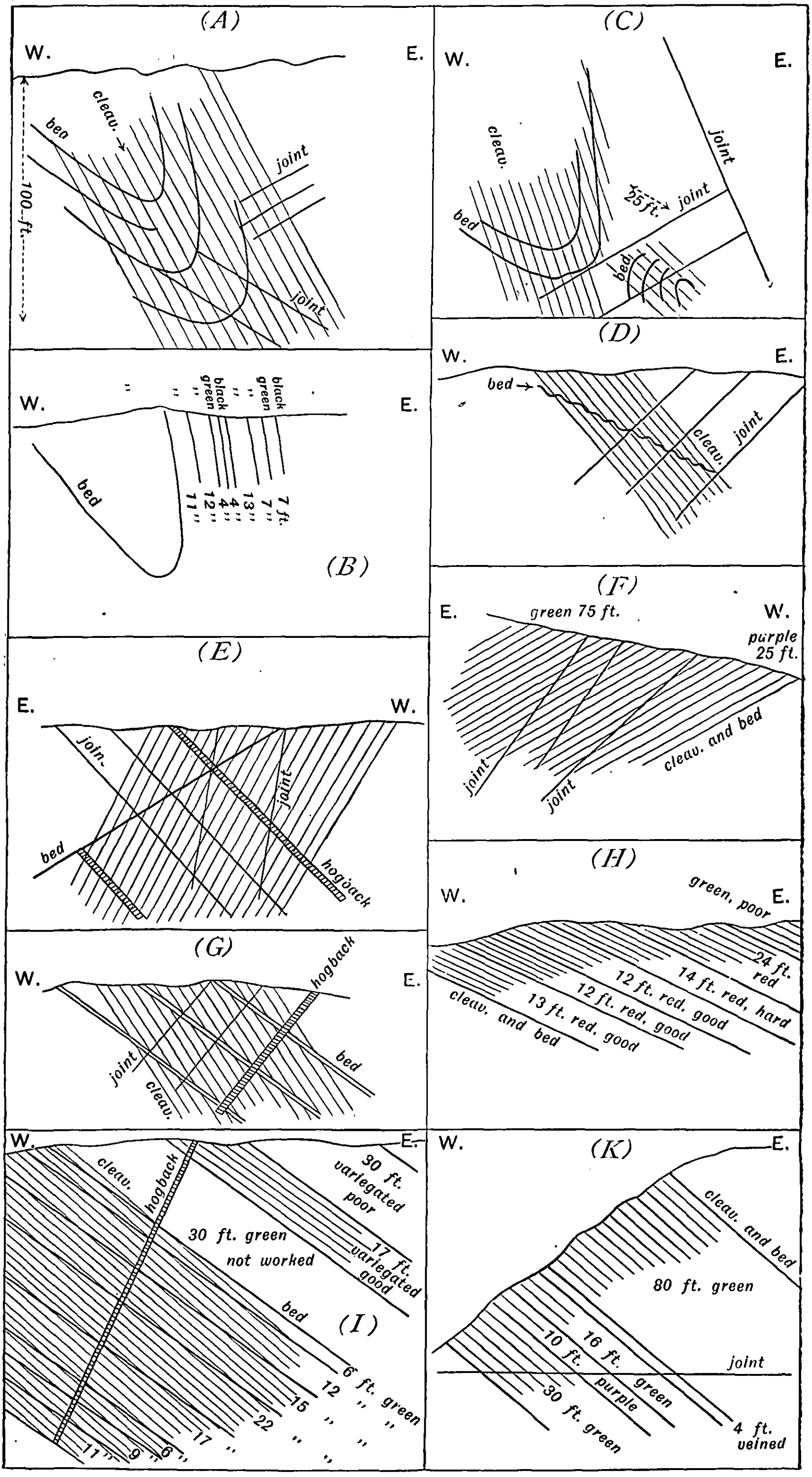
Section I crosses the Jamesville Cambrian slate belt. The occurrence of the Ordovician red slate on the east of the Jamesville belt is shown at the Matthews quarries, a mile west of Poultney, in Hampton, and on the west at those of the National Red Slate Co., about a mile north-northwest of Raceville, in the town of Granville. About a mile due north of Raceville there is a small opening in red slate in close proximity to the Cambrian. The red slate dips easterly under the Cambrian by overturn. From 500 to 600 feet north-northwest of this opening the Ordovician grits crop out, and a mile north-northwest, on the east side, three-fourths of a mile north of the section, Mr. Walcott found Ordovician graptolites in eastward-dipping shales.

The eastern base of the Jamesville Ridge consists of the Cambrian black slates and shales with small beds of limestone (D in section on p. 124). These also crop out at the bend in the road south of the section. These slates and shales form the uppermost strata of the ridge, the quartzite and sandstone (E) being absent, but that outcrop probably belongs to those on the west side of the ridge. Arising from beneath the black slates and shales are the green and purple roofing slates (B), with 10 feet of limestone carrying Lower Cambrian fossils. There are seven or eight old quarries on the hillside. In the largest one 20 feet or more of black and gray slates overlie the green and purple slates, which dip 22° E., with a cleavage of 35° E. A low easterly bedding and a steeper easterly cleavage (up to 45°) are well shown at several quarries. Beds of calcareous quartzite occur. The purple slates here underlie, not overlie, the green. In the main the ridge appears to be an anticline of the roofing slates (B) and the black slates (D), very much overturned to the west, with the red slates and the Ordovician graptolite shales and Ordovician grits on both sides of it. In Section I the only well-observed features are the relations of cleavage and bedding on the eastern slope. The overturn at the

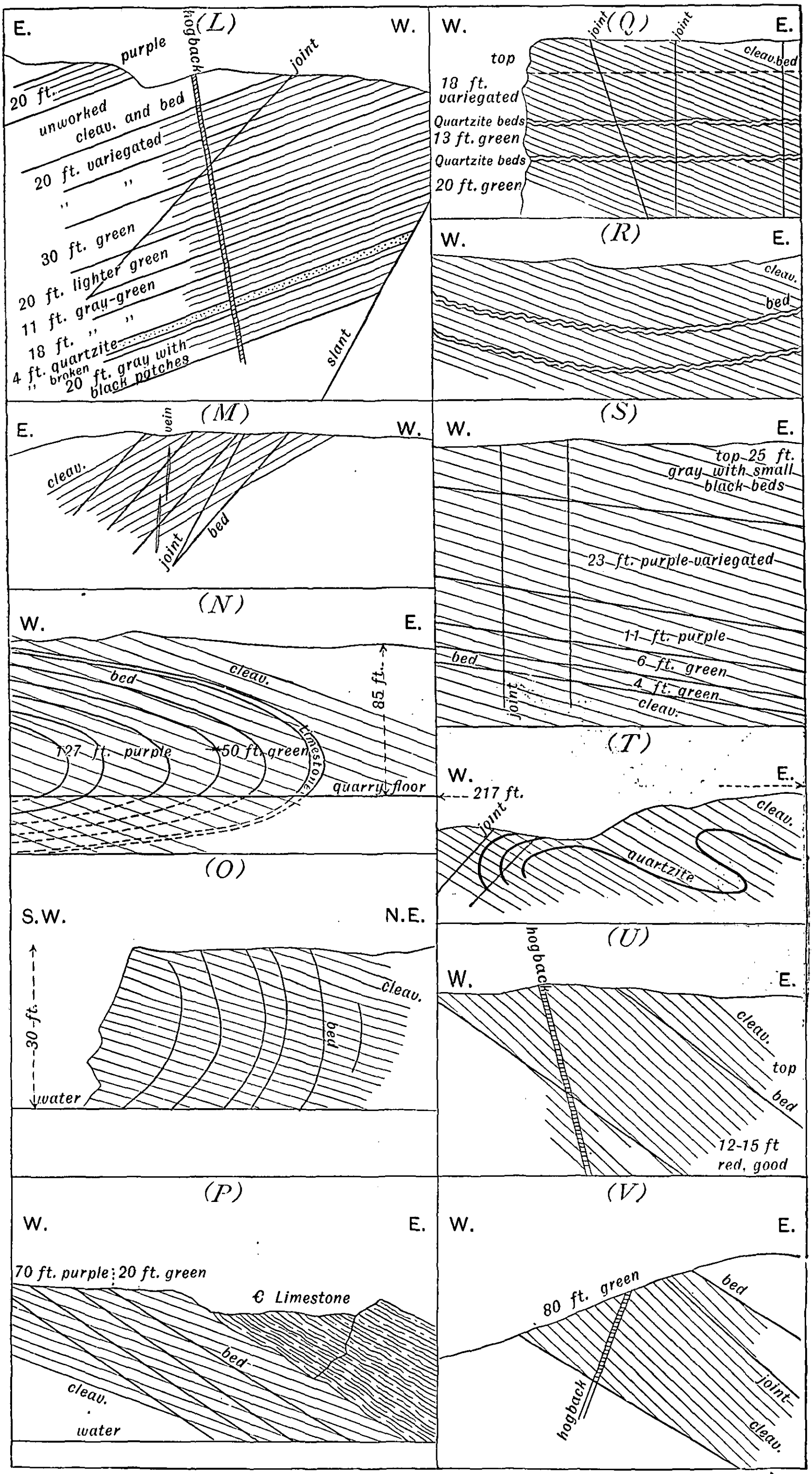
PLATE XXIII.

Structural Diagrams of Slate Quarries in Eastern New York and Western Vermont.

A. Rising & Nelson's "sea-green" quarry No. 2, West Pawlet, Vt.
B. Rising & Nelson's "sea-green" quarry No. 2, West Pawlet, Vt., with measurements.
C. Hughes's "sea-green" quarry No. 7, West Pawlet, Vt.
D. Roberts R. Roberts's "sea-green" quarry, Pawlet, Vt.
E. Hughes's western quarry "sea-green," Pawlet, Vt.
F. McCarty's "sea-green" and purple quarry, Poultney, Vt.
G. Schmidt & Williams's "sea-green" quarry, Pawlet, Vt.
H. Empire slate quarry (red), Granville, N. Y.
I. Auld & Conger's quarry ("sea-green" and variegated), Wells, Vt.
K. Griffith & Nathaniel's quarry ("sea-green" and purple), Poultney, Vt.



QUARRY DIAGRAMS, NEW YORK AND VERMONT SLATE BELT.



QUARRY DIAGRAMS, NEW YORK AND VERMONT SLATE BELT.

PLATE XXIV.

STRUCTURAL DIAGRAMS OF SLATE QUARRIES IN EASTERN NEW YORK AND WESTERN VERMONT.

L. Eureka slate quarries ("unfading green" and variegated), Poultney, Vt.
M. Valley Slate Co. ("unfading green"), Poultney, Vt.
N. Lake Bomoseen Slate Co. (mill stock, purple and green), Cedar Point, Castleton, Vt.
O. Old quarry (purple with green ribbons), near Blissville, Castleton, Vt.
P. Old quarry near and north of Eagle quarry, purple with green ribbons, Blissville, Castleton, Vt.
Q. Meadow Slate Co.'s quarry (mill stock, variegated and green), Fair Haven, Vt. Calcareous quartzite beds 4 to 12 inches thick and 18 inches apart.
R. Meadow Slate Co.'s quarry, Fair Haven, Vt., at north end.
S. Scotch Hill Slate Quarry Co.'s quarry (mill stock, purple, variegated, and green), Fair Haven, Vt. Dark beds are said to underlie the green.
T. Old quarry (purple), 1 mile south of West Castleton, Vt.
U. National Red Slate Co.'s quarry, southwest of Jamesville, in Granville, N. Y.
V. Williams & Edwards's quarry ("sea-green"), Wells, Vt.

west where the Ordovician underlies is inferential, and the other folds are hypothetical.

SECTION II. MIDDLE GRANVILLE.

Section II crosses the Middle Granville "sea-green" and red-slate quarries. Judging from the dovetailing of the Cambrian and Ordovician a few miles south of Middle Granville, we should expect, immediately west of Middle Granville, first, an anticline, then a syncline. The Jamesville belt crossed by the east end of the section would be, as in Section I, anticlinal, and the intervening broad Ordovician belt would be synclinal in structure.

There are about a dozen Cambrian slate quarries north of the village. Some measurements were taken about these quarries by the writer, but the locality is perplexing. There is a fault, and possibly much folding and faulting. The following succession, however, is clear, beginning above: Black shale and slaty shale (D), 70–100 feet; limestone with Lower Cambrian fossils, 4 feet; green and purple slate (B), 50–60 feet. An open drainage cut 213 feet long, east of one of the larger quarries, crosses the black shales and exposes one fault plane. There is a tunnel 180 feet long west of the quarry, with a shaft at the end in black shales, and the men who worked in the tunnel report that it also traversed black shales. West of the shaft is another slate quarry, and southeast of the east end of the open cut still another. There appear, therefore, to be two masses of black beds and three of roofing slate. Mr. Prindle finds some evidence of an Ordovician area at the top of the hill. It would seem possible that between that point and the red slate of the valley on the east there is an anticline consisting of several minor folds, and that the Cambrian green and purple slate occupy the centers of the lesser anticlines and the black shales the sides, as shown in the section. But the structure might be interpreted as consisting of two beds of green and purple slates alternating with two of black shale, or a fault could be supposed between the central body of green slate and the black slate west of it. Several quarries in this line show about 70 feet of the black rock (D).

Only scattered observations were made in the valley east of the ridge, and these all indicate low easterly dips, and so do most of the observations at Nixon's and Pritchard's quarries, there being slight indications of a westerly dip at one of the latter. The folds are probably all overturned to the west, but their dimensions may vary greatly from those shown in this part of the section. The only data as to the Cambrian ridge at the east end of the section are easterly dips on both its east and west sides, indicating the usual overturn.

SECTION III. LAKE BOMOSEEN.

Section III crosses Cedar Point and extends to Glen Lake. At the Lake Bomoseen Slate Co.'s quarry, Cedar Point, purple slate 127 feet thick is overlain by 50 feet of green slate, and this, in turn, by 5 to 10 feet of limestone, but all doubled over into a close syncline with an axial plane almost if not quite horizontal and traversed by a cleavage foliation dipping 20° E. (See Pl. XXIV, *N*.) For that part of the section which lies east of the Ordovician strip and west of the bend in the section line the data have been taken from the old quarries a mile south. (See Pl. XXIV, *T*, and Pl. XXII.) The folds, are many and small and overturned to the west. At the West Castleton quarries, north and south of this section and east of the Ordovician strip, the slates dip 45°–50° E., and consist of about 25 feet of purple slate overlain by 8 feet of green slate and 8 feet of limestone, followed by poor slates and quartzite beds. The relations of the Ordovician and Cambrian rocks are not well exposed. The Cambrian slates must either turn steeply to the west or be faulted. At the extreme north end of the Ordovician strip Mr. Prindle made out the following relations: The black Cambrian slates (D, p. 124) and the ferruginous quartzite (E) occur between the Cambrian limestone and roofing slates (B) and the Ordovician graptolite shales. About half a mile north of West Castleton the graptolite shales occur 300 feet west of the Cambrian slates, with some thin quartzités.

The structure of the Ordovician strip itself is beautifully shown at a ledge by the roadside between West Castleton and Glen Lake. (See Pl. III.) The rock is a grayish, more or less calcareous shaly or arenaceous slate, banded with black beds from a fraction of an inch to 2 inches in width. On the west side of the syncline the beds dip very slightly east or are horizontal. Farther east, at the top, the dip is 55° W., and still farther east it is 90°. The cleavage throughout is about 35° E. The ledge is evidently the center of the syncline and gives the key to the structure of the whole strip, which is 3½ miles in length, while the fossils leave no doubt as to its age.

SECTION IV. BLISSVILLE.

Section IV crosses several lines of quarries near Blissville, in Castleton, Vt. There are 20 quarries hereabouts, including the old Eagle quarry. The northeasterly line of quarries shows a minimum of about 50 feet of green and variegated slate (strike N. 10°–15° E., dip 20°–30° E.), overlain by 20 feet of black slate and shale and thin-bedded limestone (D, p. 124), a few feet of green slate, and a bed of quartzite 10 to 12 feet thick (E), which is exposed for 350 feet along the strike. The quartzite contains calcareous nodules which weather out. It overlies and, at the south, runs into a few feet of a green grit like that of Flint Hill. The black shales crop out at several points along the road south, and also on the ridge east of it.

Between this line of quarries and the road running south the olive-colored grits (A) crop out at several points and extend to the road corner north—all with an easterly dip. The first quarry on the west side of the north-south road shows a very gentle syncline at its south end and the beginning of an anticline at its northeast corner. The next line of quarries to the west includes the Eagle. The strike here changes to N. 15°–40° W. The dips are 25°–30° E. and SE. The cleavage strikes N. 5° E. and dips 20° E. The beds include about 70 feet of purple slate, overlain by 10 feet of green slate and 15 feet of thin-bedded Olenellus-bearing limestone. At the most northerly quarry but one of this line the beds are folded and overturned almost as much as at Cedar Point. (See Pl. XXIV, *O*.) The strike of the axis of the fold is N. 40° W.; the cleavage dips at a low angle to the east. Small beds of light-green slate, with or without a quartzose limestone in the center, produce bands on the cleavage surface.

At a quarry intermediate between the second and third lines of quarries, one-fourth of a mile north of this section, the strike changes to N. 75° W., dip 15°–20° S., and the cleavage strike to N. 35°–50° E., dip 15° E. The complication is probably due to a southerly pitch.

In the third line of quarries the beds are nearly horizontal. The fourth line, half a mile south of the section, shows very low westerly dips, and at the extreme west end of the section a gentle syncline is exposed crossed by a cleavage dipping 35° E.

SECTION V. WELLS.

Section V starts at the west shore of Lake St. Catherine and crosses the slate ridge to the west.

The portion of the slate belt most largely worked of late years is the ridge between West Pawlet and Poultney. Away from the quarries it is difficult to obtain satisfactory observations, and within the quarries bedding is generally obscured by cleavage.

Beginning at the lake, purple and green Cambrian slates dip 45° E. To judge from scattering observations along the west side of the ridge, it must be composed largely of roofing slate. From a point about half a mile west of the lake there is a line of quarries and prospect holes extending northward for 2 miles. The cleavage dip is uniformly east. Farther west the section crosses a strip of red Ordovician slate almost half a mile long and 180 feet wide at the broadest part but tapering out both north and south. The dip is

35° E. This is probably a small compressed and overturned syncline. The Ordovician grit is absent here, but some of the small quartzite beds occur between the Cambrian slates and the red slates. All the slates exposed between the strip of red and the road on the west should recur on the east of the red slate, but in inverse order. At Auld & Conger's quarries 170 feet of slates of various qualities, green and variegated, are exposed. The strike here is N. 5° W. and the dip 35° E.; the cleavage dips 40°–45° E. Dipping toward and under the slate, but with greenish and grayish beds intervening, are the Ordovician grits, which strike N. 5° E. and dip 40° E. Between the syncline of red slate and the Ordovician grits there is probably an anticline, as drawn in the section, and all the slates on the west side of the red ought to recur east of the grits in inverse order. The folds in the grit shown in the section are hypothetical, but the first one west of the slate would naturally be a syncline.

SECTION VI. PAWLET.

Section VI begins near Mettawee River and crosses the slate ridge. The boundary between Ordovician and Cambrian at the east end of the section is uncertain. In the gorge of the Mettawee green and purple Cambrian slates of no commercial value are finely exposed. At the sawmill the axial planes of the folds stand erect and the anticlinal parts of some of the folds have been pinched out. The cleavage is vertical. The east side of the ridge for a mile and more to the south consists of folded schists interbedded with quartzite, possibly belonging to A of the section on page 124. West of this is a strip three-fourths of a mile wide of unknown character, but from the situation of two quarries about 2¼ miles south of a point half a mile west of the Mettawee sawmill, and from the direction of the strike of the slate at these quarries, slate probably occurs in the western half of this blank space of the section. The roofing-slate quarries from this latitude to West Pawlet lie almost all within a strip one-fourth of a mile wide along the east side of the Ordovician grits on the western slope of the ridge. The structure at the quarries is difficult to make out. Bedding, where observed, dips east, as does also the cleavage. From the observed relations of the Cambrian and Ordovician wherever they occur very near each other in this region, the Cambrian overlies the Ordovician through an overturn. An anticline should therefore occur on the Cambrian side of the boundary and a syncline on the Ordovician side of it. Not far from the Columbia quarry is a dike of camptonite, 5 feet 9 inches wide, running northeast and dipping 90° or steeply to the northwest. The slate on the east side of the dike strikes north and dips 70° E. and that on the west side dips 55° E. The dike has a rough jointing parallel to its sides and weathers in spherical nodules. The cleavage at the quarries dips about 55° E. West of the quarries are greenish shales and schists with small quartzite beds striking N. 5° E. and dipping 45°–50° E., measuring, apparently, about 125 feet, but possibly less, if closely folded. These beds probably belong in the Ordovician. West of them come the Ordovician grits, dipping 65° E.

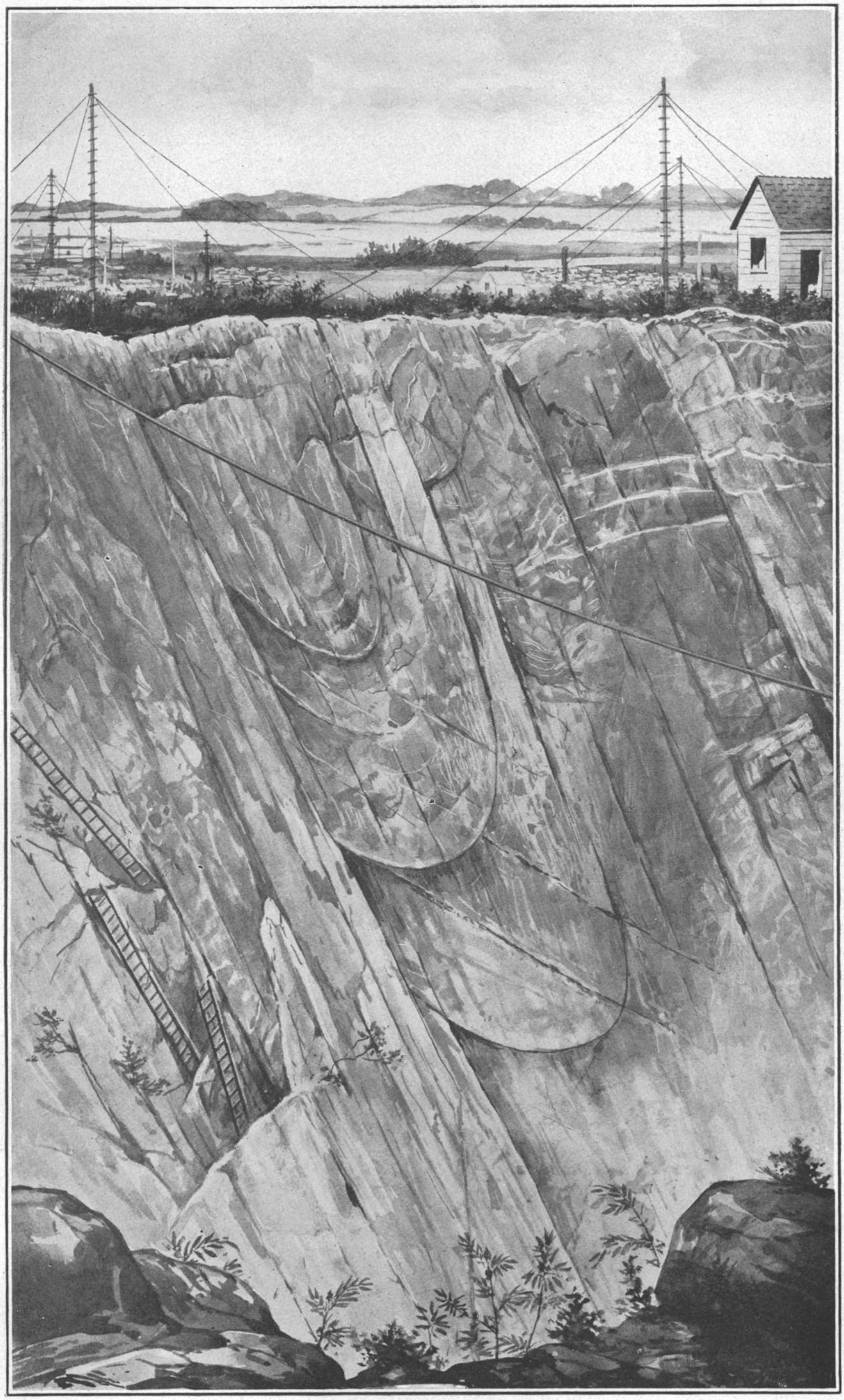
SECTION VII. WEST PAWLET.

Section VII crosses the West Pawlet quarries and reaches the other Cambrian belt west of Indian River. The West Pawlet belt ends abruptly south of the village, with Ordovician grits south, east, and west.

Some of the quarries are more than 175 feet in depth. At the Hughes quarry No. 7 there is a syncline with an anticline east of it (see Pl. XXIII, *C*), and the foreman stated to the writer that another one was found later east of it. The pinching out of the material between the folds observed at the Mettawee gorge recurs here. At the Rising & Nelson quarry No. 2 the syncline is finely shown (Pl. XXV and Pl. XXIII, *A*). We have here an isoclinal syncline with its axial plane dipping east with the cleavage. In such a structure the same beds of course occur on each side of the fold in opposite order and also at the bottom, but there they are thicker. The structure indicated is a syncline with an anticline on each side of it, but unless faulting occurred these must be parts of an anticline, and the Ordovician grits, which crop out in the village and at the foot of the dumps, should be part of a syncline. The strike of the slates ranges from N. 12° E. to N. 25° E., and that of the cleavage from N. 5° W. to N. 5° E., the dip is generally 70°, but in places 40°–50° E. The thickness exposed, measured across two synclines and one anticline, is about 100 feet. There are on the east side of the syncline some dark-gray or "black" beds which, according to this construction, would belong not on top, but within the roofing slates (B, p. 124). The Ordovician grits west of the Cambrian slates strike N. 10°–20° E. and dip 55°–60° E., but at the West Pawlet railroad station the strike changes to N. 5° W. and the dip to 80° E.

In the Indian River valley neither the few red-slate quarries nor the scattering outcrops afford very satisfactory data. The folds are probably numerous and overturned so as to give only easterly dips. Mr. Walcott has indicated a graptolite locality on the west side of the valley.

The Cambrian ridge at the west has a few old purple-slate quarries. Some Cambrian fossils occur in the limestone. Along the east side of the ridge lie the Cambrian shales (D). About half a mile east of South Granville, near the Ordovician boundary, west of this Cambrian belt, the purple slates dip 40° W. and have a cleavage



SLATE SYNCLINE, WEST PAWLET, VT.

North face of Rising & Nelson's "sea-green" slate quarry No. 2, showing eroded eastward-inclined syncline. Depth, 100 feet to lower syncline.

dipping 30° E. and striking N. 15° E., the bedding forming green bands on the cleavage surfaces. The second Cambrian ridge is clearly anticlinal in structure.

GENERAL STRUCTURAL FEATURES.

From the sections above described, necessarily more or less incomplete, the general structural characteristics of the western Vermont and eastern New York slate belt can be grasped. The structure of the Cambrian slate mass, which usually adjoins the Ordovician schist, is illustrated in sections VI and VII. It lies in close folds, more or less overturned to the west, with eastward-dipping slaty cleavage obscuring the bedding. The folds are so close and the cleavage is so pronounced that the cores of adjoining synclines and anticlines are brought very near together, or the anticlinal portions of several adjacent folds do not appear. In the northern part of the Cambrian area quartzite beds within the roofing slates are more abundant than in the southern part. Although the entire mass of slate and quartzite is in places thrown into folds so greatly overturned that their axial planes are nearly horizontal, yet the slate itself is less distorted in the direction of the cleavage and the cleavage itself is also less perfect in the northern than in the southern area. Series of such various folds form compound anticlines, and these minor Cambrian anticlinoria alternate with Ordovician synclinoria overlying Cambrian ones in apparent but not real conformity. As the Ordovician areas consist of shales, slates, grits, and small quartzite beds, the beds are more heterogeneous and slaty cleavage is less prevalent, but the folds are also overturned toward the west. (See Sections I, II, V, VI, VII, Pl. XXII.)

A north-northwesterly strike appears in the Cambrian rocks about Blissville and again at Cedar Point. (See map, Pl. XX.) Large beds of quartzite overlie the roofing slate and are typical of this portion (Section III, Pl. XXII).

The slate folds have suffered much erosion (Pls. III, XXV). The surfaces when freshly exposed are finely striated and in places deeply grooved by glacial action. The glaciated edges are covered either by morainal deposits or by finely bedded clays dating back to the postglacial submergence. (See Pl. XIX, *B*.)

GEOLOGIC AND GEOGRAPHIC DISTRIBUTION.

The quarry maps (Pls. XX and XXI), show that the slate quarries situated within the Cambrian areas are generally very near to or not far from the edge of the Ordovician belts. In some places (as in Pawlet, Wells, and West Castleton) the Cambrian slates occur within 100 or 200 feet of the Ordovician grits. This proximity of the two formations occurs in such a variety of situations that it can hardly be explained by faulting. The Cambrian roofing slates are therefore regarded as occurring not far from the top of the Lower Cambrian series as exposed in this region and very near the overlying Ordovician. As the Cambrian belts are made up of numerous folds generally close and overturned, the slates also occur toward the center of the belts, but their stratigraphic position is still the same. The first place to look for the Cambrian roofing slates is near the Cambrian-Ordovician boundary. Where the red slate occurs in close proximity to and on the west side of the Cambrian green and purple slates and the dip is easterly, as it usually is, the red slate may be found underlying the "sea-green," "unfading green," or purple slates, and on the east side of the Cambrian areas the green and purple slates of the Cambrian may be found underlying the red of the Ordovician when both dip easterly. At several points (Blissville, Eureka, etc.) away from the Ordovician boundary the rock which appears to immediately underlie the Cambrian slates is the olive-colored grit (A, p. 124), one of the so-called "wild rocks" of the quarrymen. It is uncertain whether there may not be one or more beds of slate interbedded with this. The rock which overlies the Cambrian slate is either the "black patch" grit (C) or the Cambrian black shale (D) or the ferruginous quartzite and sandstone (E). Perhaps most generally there is a bed of limestone conglomerate or breccia, followed by black shales or slates (D). (See p. 124). These vertical relations are pretty well established.

The areal relations of the "sea-green" and the "unfading green" are not at all clear. Nothing has yet been found to show that the stratigraphic position of these two varieties of Cambrian slates is not identical. It seems probable that, at the latitude of a point within 2 miles north of Poultney, a change in the sediments occurred in Cambrian time sufficient to account for the diminished percentage of carbonate and the increase of chlorite and pyrite. Whether this difference in composition is alone sufficient to account for the difference in the cleavage is uncertain. There may have been some difference in the resistance to pressure which would account for more perfect cleavage at the south than at the north. Possibly, as has already been suggested, the greater abundance of grains of quartz at the north may have restrained the cleavage structure, and so with more lime deposited at the south and more quartz sand at the north the whole structural difference may be traced back to changes in sedimentation.

Even this demarcation between the areas of "fading" and "unfading" green slate is not absolute, for "fading green" slates occur well within the "unfading green" area, as at an old quarry 1½ miles southwest of West Castleton and again 1¼ miles south of Castleton and half a mile south of Bomoseen. Slates which fade little are reported as occurring on the ridge west of Lake St. Catherine. In an old quarry about half a mile east of Jamesville, in a belt that seems to be directly continuous with that in which lies the Eureka and adjacent quarries, the slates fade comparatively little. In the Jamesville belt, at a quarry about 180 feet above the road and west of the chapel, there is a purple bed, probably overlying a green one; both purple and green fade badly, but on the west side of the purple—that is, underlying it—is a green bed which scarcely fades and which, under the microscope, shows very few carbonate rhombs.

The "sea-green" slate at two newly opened quarries in Bullfrog Hollow, in Wells, 2½ miles east-northeast of Middle Granville, has less carbonate than many slates of that belt, but it fades. Some old quarries reopened in 1911 in the "unfading green" belt in Fair Haven, near Carvers Falls, contain even less carbonate than that of the same sort in Poultney. The most southerly outcrop of the "unfading green" observed by the writer occurs 2½ miles N. 25° E. of Poultney and three-fourths of a mile east of the railroad.

A few things should be noted. The continuation of the slate of West Pawlet is to be looked for in the lenticular Cambrian area which begins 2 miles south of West Pawlet and stretches across the New York State line into Hebron. "Sea-green" and purple slates also occur in the Cambrian area southeast of West Pawlet. The Jamesville belt continues south into the village of Granville. About the north end of Lake St. Catherine the Cambrian slate belt divides in two, one part passing half a mile east of Poultney and the other half a mile east of East Poultney, where it crops out in the small gorge of Poultney River. In many places north of Castleton the strikes change to the northwest or the north-northwest, and the beds of slate locally follow this direction. Barker Hill and Wallace Ledge both have Cambrian slates about them.

QUARRY STRUCTURE.

The types of structure exposed at the quarries are shown in diagrams *A–G*, *K–T*, and *V*, on Plates XXIII and XXIV, and also in Plates XIX, *A*, and XXV.

The table on pages 137–138 contains the more important compass observations taken at the quarries. The numbers in the first column will be found on the maps, Plates XX and XXI. Where cleavage is given but not bedding, the bedding is very nearly or quite the same as the cleavage. The usual dip joints may be assumed where not given. Approximations are indicated by the signs plus (+), minus (−), more or less (±). Close jointing in the dip direction occurs in places. Such joints are spaced 4 to 24 inches over a length of 200 feet on the west wall of the Norton No. 6 quarry in Pawlet.

To the data given in the table should be added a few observations at quarries outside of the areas shown on the maps. An abandoned quarry three-fourths of a mile south of Fair Haven shows 24 feet of purple slate overlain by about 9 feet of greenish slate, dipping 15°–20° E. and containing three beds of quartzite, each 2 inches thick. The cleavage strikes N. 10° W. and dips 25°–30° E. Joints strike N. 35° E., dip 60° E.; also N. 50° E., dip 90°. There is a fatal secondary cleavage—"false cleavage"—here, striking about north. (See Pl. VII, *A*, and p. 37.) At the Meadow Slate Co.'s quarry (Pl. XXIV, *Q*, *R*), and at the quarry just north of it the bedding strikes N. 15° E. and the cleavage strikes N. 7°–15° W., and dips 15°–20° E. Vertical strike joints strike N. 15° E. and vertical dip joints N. 85° W. Diagonal joints strike northwest, dip 65° NE.; also N. 58° E., dip 90°. The grain strikes N. 35° W. At the Scotch Hill quarries (Pl. XXIV, *S*), 2 miles north-northeast of Fair Haven, the beds strike N. 25° W. and dip 5° E., and the cleavage has the same strike and dips 15° E. The joints are vertical, striking N. 5°–17° E. and N. 67° W.

At the Hampshire Slate Co.'s quarries, about one-third of a mile east-southeast of Carvers Falls, in Fair Haven, the beds strike N. 15° E. and dip 33° S. 75° E., but the cleavage strikes north and dips 40° E. At the Cedar Point quarry (No. 43, Pl. XXI) there is a marked southerly pitch, the syncline being found to rise as quarrying proceeds northward. There is also here a slip cleavage parallel to the axis of the fold, which prevents the slate from being used for roofing but does not interfere with its use for mill stock. On the hill north of the quarry this slip cleavage is vertical. At the now disused quarries 4 miles southwest of Brandon, in Sudbury, the beds strike N. 55° E. and dip 35° S. 35° E., and the cleavage is in places parallel, but some adjoining slate ledges have a slip cleavage that strikes N. 25° W., with the neighboring Ordovician schists.

Slate-quarry observations in Vermont.

Quarry No. on Pl. XX or XXI.	Bedding.		Cleavage.		Strike joints.		Dip joints.		Diagonal joints.		Grain strike.	Shear zones ("hog-backs").		Faults.	
	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.		Strike.	Dip.	Strike.	Dip.
10	N.+	30° E.	N.	42° E.	N. 5° W.	40° E.						N. 37° E.	65° NW.		
11	N. 5° E.	40° E.	N.	40° E.	N. 15° E. N.	65° E. 45° W.	N. 75° W.	90°			(Bottom joints.)				
12	N. 20° E.	(?)	N.	40°-70° E.	N. 15° E. N. 10° E.	62° E. 30° W.	N. 75° E.	90°							
13	N.+	E. low.	N.	40° E.	N. 5° E.	65° E.	E.-W.	90°							
14	N. 25° E.	25° E.	N. 15° E.	50° E.	N. 7° E. N. 25° E.	50° E. 45° W.									
15	N.+	37° E.	N. 15° E.	55° E.								E.-W. NE.	S. high NW.		
16	N.+	30° E.±	N.+	50° E.±	N.+	E. high.						NE. or N.	40° NW. or W.		
17	N.+	20° ± E.	N.+	40° ± E.	N.+ N.+	90° 30° W.									
18		50° E.?	N.	37° E.	N. 12° W.	60° E.	E.-W. E.-W.	55° W. 90°							
19			N.	35° E.	N. 10° E. N.	55° E. 40° E.	N. 82° E.	90°			Feeble.	N.	50° E.		
20	N.+	30° E.	N. 10° W.	50° E.	N.	60° W.	E.-W.	90°			N. 45° E.	NE.±	57° NW.		
21	N.+	17° E.	N. 5° W.	42° E.			E.-W.	90°							
22	(?)	(?)	N. 20° W.	40° E.	N. 5° W.	55° W.	N. 80° E.	90°			N. 80° W.	N. 45° E.	70° NW.		
23	N. 25° W.	30° E.	N. 25° W.	32° E.	N. N.+	75° E. 45°±W.									
24	(?)	(?)	N. 17° W.	40° E.	N. 10° W.	50° E.	N. 65° E.	90°							
25	(?)	(?)	N. 25° E.	65° E.											
26	N.	−45° E.	N. 15° E.	45° E.	N.+	42° W.			N. 50° W.	70° SE.					
27	N.+	20° E.	N. 12° E.	40° E.			N. 70° W.	70° ESE.							
28	N.	25° E.	N. 15° E.	37° E.											
29	N.+	20° E.	N.+	27° E.											
30	N.+	22° E.	N.+	35° E.											
31	(?)	(?)	N. 10° W.	45° E.	N.	75° E.	E.-W.	90°				N. 10° W.	45° E.		
43	N. 10° W.	Fold.	N. 10° E.	20° E.											
44	N. 7° W.	45° E.	N.	30° E.	N. 18° E.	45°+	E.-W.	90°							
45	N.+	35°-65° E.	N. 7° W.	50° to 65° E.	N	90°	E.-W.	90°							
46	N. 15° E.	60° E.	N. 15° E.	60° E.											
47	N. 55° E.	20° E.	N. 30° E.	25° E.	N. 20° E.	60° E.									
48	N. 25° E.	20° E.	N. 7° E.	25° E.	N. 25° E.	45° E.	N. 80° W.	80° N.	N. 30° E. N. 40° E.	45° E 50° SE.	N. 60° W.	N. 55° E. N. 40° E.	87° NW. 80° NW.	N. 80° E.	35° S.

Slate-quarry observations in Vermont—Continued.

Quarry No. on Pl. XX or XXI.	Bedding.		Cleavage.		Strike joints.		Dip joints.		Diagonal joints.		Grain strike.	Shear zones ("hog-backs").		Faults.	
	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.	Strike.	Dip.		Strike.	Dip.	Strike.	Dip.
49			N. 25° W.	20° E.			E.-W.	90°	N. 35° E.	60° SE.					
50	N.	20° E.	N. 27° E.	30° E.	N. 5° W.	30° E.	N. 65° W.	90°							
51		0°	N.+	17° E.											
52		0°	N. 25° E.	15° E.			N. 70° E.	90°						Along cleavage.	
53	N. 40° W.	Fold.	N. 15° E.	E. low.											
54	N. 17° W.	30° E.	N. 5° E.	20° E.											
56	N. 75° W.	17° S.	N. 42° E.	15° E.	N. 22° E.	60° E.									
57	N.+	7° W.	N.+	17° E.											
58	N.+	15° W.	N. 10° E.	17° E.											
59	N.	35° E.	N.	42° E.											
60	N.	35° E.													
61	N. 5° W.	37° E.	N.	37° E.											

MINOR STRUCTURAL FEATURES.

The purplish slates in many places include greenish ribbons—calcareous, quartzitic, and chloritic—an inch or two in thickness, and such ribbons run into rows or planes of green spots. The cause of these colored beds and spots has been discussed on page 23. The ribboned slates here, as elsewhere, are used for flagging.

In some of the quarries there are pyritiferous quartzite nodules a few inches in diameter, of lenticular form, lying in the bedding foliation and of sedimentary origin. (See p. 49.)

Faults of no great displacement are not uncommon. These may be reversed or normal. (See Pl. IV, *C*, *E*, and p. 43.)

Veins of milky quartz are abundant, and some of them attain large dimensions. (See Pl. V, *A*, and p. 48.) Their course is in places very irregular. They generally contain calcite and chlorite. The west wall of the Briar Hill quarry (No. 62, Pl. XX), in Pawlet, has many parallel curved tapering veins evidently due to shearing motion and tension.

As shown by the maps (Pls. XX, XXI) the region is traversed by dikes. These measure from 12 to 40 feet or more in width and as much as several miles in length. They are probably of Triassic date and are usually made up of camptonite, consisting chiefly of plagioclase feldspar and hornblende, with or without augite.[1] These dikes are locally parallel to the strike or the dip joints, but more commonly to the diagonal joints.

Shear zones ("hogbacks") are numerous, as is shown by the quarry diagrams (Pls. XXIII, XXIV). From their parallelism to the dikes and some of the joints they may all be due to the same earth movement. (See, on shear zones, Pl. VIII and p. 44, and on their relation to dikes, p. 169.)

The quartzite beds, veins, dikes, shear zones, "posts," faults, and diagonal joints add seriously to the difficulties presented by the overturned close folding and the pinching out of folds which characterize this region. False cleavage is, however, exceptional.

The general aspect of good commercial green slate as seen in a large mass broken across the cleavage is well shown in Plate XIX, *A* ("sea-green," quarried for roofing) and *B* ("unfading green," quarried for mill stock).

THE WESTERN VERMONT SLATES.

"Sea-green" slate.—When freshly quarried, the "sea-green" slate varies from a light gray to a slightly greenish gray. In some beds it is crossed by ribbons of a dark gray or, where bedding and cleavage are parallel, it bears traces of organisms in dark gray.

[1] See Bascom, F., U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 223-226, 1899.

To the unaided eye the texture is fine and the cleavage surface somewhat so, with a waxy luster. The sawn edges show a little pyrite. It is very slightly magnetitic, effervesces a little under cold dilute hydrochloric acid applied to the edges and much under acid applied to the powdered slate, is sonorous and very fissile. After a few years' exposure it changes its color to a brownish gray, and as the slates from different beds discolor differently a roof covered with "sea-green" slates from different beds acquires a mottled color.

Under the microscope it shows a matrix of muscovite (sericite), with brilliant aggregate polarization and of very fine texture, crossed here and there by obscure traces of bedding or with very minute more quartzose beds parallel to the cleavage. This matrix incloses more or less angular grains of detrital quartz measuring from 0.05 to 0.34 by 0.004 to 0.035 millimeter, but usually 0.035 by 0.013 millimeter, and an occasional grain of plagioclase (lime-soda) feldspar up to 0.04 by 0.05 millimeter. Sections parallel to the cleavage show many plates and rhombs of carbonate, the rhombs measuring from 0.003 to 0.03 or even 0.05 millimeter in diameter. Some of these consist of two crystals, an inner rhomb and an outer one, with different orientation, possibly in twinned position. In some of the double rhombs the inner one has fallen out; in others the rhomb has an opaque mineral nucleus which is not pyrite but may be magnetite or graphite. There are also a few scales of chlorite with interleaved muscovite up to 0.13 millimeter, their laminæ crossing the cleavage and mostly in the grain direction, and some equally large muscovite scales, possibly of sedimentary origin. There are some irregularly distributed pyrite spherules from 0.003 to 0.02 millimeter, also minute lenses of pyrite. Rutile needles, measuring from 0.0017 to 0.009, rarely 0.012, by 0.002 millimeter average about 65,000 to the square millimeter, which is equivalent to about 40,000,000 to the square inch of thin section. Here a and there is a grain of zircon or prism of tourmaline 0.022 by 0.008 millimeter.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, carbonate, chlorite, rutile, pyrite, and magnetite.[1]

In order to ascertain the cause of the discoloration thin sections across the discolored surface of a slate which had been exposed three years were examined and it was found that while the carbonate rhombs within the body of the slate were transparent in ordinary light those at the surface were changed to the color of limonite. These rhombs measured 0.047 millimeter. A cleavage surface of the same slate was also affixed to the glass slide and the other side was ground down. This showed a multitude of rhombs, generally ranging in size from 0.008 to 0.013 millimeter, entirely or partly altered to limonite. In some places there was a yellowish-brown zone of alteration surrounding an unaltered nucleus. These rhombs are regarded by Dr. Hillebrand (see p. 55) as an isomorphous mixture of dolomite and siderite—that is, a carbonate of lime, magnesia, and iron, in which the iron (ferrous carbonate) oxidizes into limonite. The only way to prevent this discoloration would be to coat the slate with some preparation which would protect it from oxidation.

Some of the "sea-green" slates are termed hard, others soft. The difference, judging from microscopic evidence, seems to be due to the

[1] For colored lithographs of magnified thin sections of this slate as seen under both ordinary and polarized light, see U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, Pl. XXXV, 1899.

greater percentage of carbonate in the soft ones and the larger size of the quartz grains in the hard ones.

The following complete analyses of "sea-green" slate were made by W. F. Hillebrand:

Analyses of Vermont "sea-green" roofing slate.

	A	B	C	D
Silica (SiO_2)	67.76	62.37	59.84	65.29
Rutile, titanium dioxide (TiO_2)	.71	.74	.74	....
Alumina (Al_2O_3)	14.12	15.43	15.02	....
Ferric oxide (Fe_2O_3)	.81	1.34	1.23	....
Ferrous oxide (FeO)	4.71	5.34	4.73	....
Manganese oxide (MnO)	.10	.22	.34	....
Nickelous and cobaltous oxide (NiO, CoO)	Trace?	Trace.	Trace.	....
Lime (CaO)	.63	.77	2.20	....
Baryta (BaO)	.04	.07	.09	....
Magnesia (MgO)	2.38	3.14	3.41	....
Potassa (K_2O)	3.52	4.20	4.48	....
Soda (Na_2O)	1.39	1.14	1.12	....
Lithia (Li_2O)	Strong trace.	Trace.	Strong trace.	....
Water below 110° C. (H_2O)	.23	.34	.41	....
Water above 110° C. (H_2O)	2.98	3.71	3.44	....
Phosphoric oxide (P_2O_5)	.07	.06	.09	....
Carbon dioxide (CO_2)	.40	.87	2.98	....
Pyrite (FeS_2)	.22	.06	.05	....
Sulphuric oxide (SO_3)	Trace.	Trace.	Trace.	....
Carbon (C)	None.	Strong trace.	Trace.	....
Fluorine (Fl)	....	....	.11	....
	100.07	99.80	100.28	....
Total sulphur (S)	.12	.032	.024	....

A (=D. XIV, 1895, 230*a*). Rising & Nelson's quarry No. 2, West Pawlet, Vt.; 13-foot bed.
B (=D. XIV, 1895, 225*f*). Griffith & Nathaniel's quarry, 9 miles north of A, South Poultney, Vt.
C (=D. XIV, 1895, 256*e*). Wm. H. Hughes's quarry No. 10 (Brownell), 2 miles north of A, Pawlet, Vt.
D (=D. XIV, 1895, 35*l*). Auld & Conger's quarry, 8 miles north of A, in Wells, Vt.; 22-foot bed. Determination of silica only.
These are all from the West Pawlet and South Poultney belt. Specific gravity: C, 2.7910; D, 2.7627.

This slate is used exclusively for roofing. The results of Merriman's tests of it are given on page 183.

"Unfading green" slate.—The slate called "unfading green" is greenish gray in color.

To the unaided eye it has a somewhat fine texture and a roughish lusterless cleavage surface. The sawn edges show some pyrite. It is magnetitic, does not effervesce with cold dilute hydrochloric acid, even when powdered, and is sonorous. Several years' exposure produces so little change of color that only when a fresh slate is put beside it is any change perceptible, and that is but slight. Its fissility is inferior to that of the "sea-green."

Under the microscope it shows a matrix of muscovite (sericite), with a brilliant aggregate polarization but considerable inequality in texture, coarser quartzose bands, with imperfect cleavage, alternating with finer more sericitic ones. In both there is irregularity in the size of the particles. Angular quartz grains measure from 0.01 by 0.008 to 0.04 by 0.017, rarely 0.07 by 0.017 millimeters. There are a few lenses up to 0.2 by 0.1 millimeter of quartz fragments and muscovite scales, also lenses up to 0.4 by 0.1 millimeters of chalcedonic quartz (?) A few grains of plagioclase feldspar; scales of chlorite up to 0.039 by 0.006 millimeters parallel to the grain, and also scales of muscovite in similar position; not a few specks and lenses of pyrite, some octahedra of pyrite with rim of chlorite; carbonate rhombs—0.026 to 0.065 millimeter—but in very much smaller number than in the "sea-green" slate; abundant rutile needles from 0.003 to 0.008 millimeters long.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, rutile, pyrite, and magnetite.[1]

These slates are relatively unfading, because they have fewer rhombs and plates of carbonate. (See Dr. Hillebrand's note, p. 55.) The sections also show why they cleave less perfectly than the "seagreen" slates.

The following analyses were made in the laboratory of the United States Geological Survey by W. F. Hillebrand:

Analyses of Vermont "unfading green" roofing slates.

	E	F		E	F
Silica (SiO_2)	59.27	59.48	Lithia (Li_2O)	Trace.	Trace.
Titanium dioxide, rutile (TiO_2)	.99	1.02	Water below 110° C. (H_2O)	0.32	0.17
Zirconia (ZrO_2)	....	Trace?	Water above 110° C. (H_2O)	3.98	4.05
Alumina (Al_2O_3)	18.81	18.22	Phosphoric oxide (P_2O_5)	.11	.10
Ferric oxide (Fe_2O_3)	1.12	1.24	Carbon dioxide (CO_2)	.21	.39
Ferrous oxide (FeO)	6.58	6.81	Pyrite (FeS_2)	.15	.13
Manganous oxide (MnO)	.13	.07	Sulphuric oxide (SO_3)	Trace.	....
Nickelous oxide (NiO)	Trace?	Trace?	Carbon (C)	None.	None.
Cobaltous oxide (CoO)	Trace?	....	Fluorine (Fl)	....	.08
Strontia (SrO)	....	Trace?			
Lime (CaO)	.42	.56	Total	99.98	100.23
Baryta (BaO)	.05	.05			
Magnesia (MgO)	2.21	2.50			
Potassa (K_2O)	3.75	3.81	Total sulphur included above (S)	.08	.07
Soda (Na_2O)	1.88	1.55	Specific gravity	2.795	....

E (=D. XIV, 1895, 314*f*). Eureka quarries, 3½ miles north of Poultney, in Poultney Township, Vt.
F (=D. XV, 1896, 645*a*). Valley Slate Co. quarry, 2½ miles north of Poultney, in Poultney Township, Vt.

The results of Merriman's recent tests of Vermont unfading green slate will be found on page 183.

This slate is largely used for roofing. The mill stock slate is described beyond.

"Purple" and "variegated" slate.—The "purple" slate is dark-purplish brown; the "variegated" is like the "sea-green" and the "unfading green" but is irregularly patched with purplish brown. These purplish slates are interbedded both with the "sea-green" and the "unfading green," as shown in the quarry diagrams (Pls. XXIII, XXIV).

The texture, surface, and luster correspond generally to those of the slates with which they are interbedded. The "purple" slate of the "sea-green" areas discolors less than the "sea-green" but effervesces with cold dilute hydrochloric acid and is very slightly magnetitic. The "variegated" slate of the Eureka quarry does not effervesce with cold dilute hydrochloric acid. All these slates are sonorous.

Under the microscope the purplish slate closely resembles the green, with which it is associated, both in structure and composition, excepting that the purplish contains a large amount of hematite (Fe_2O_3) in irregular bright red dots from 0.001 to 0.003 millimeter in diameter, exceptionally in hexagonal scales. This mineral obscures the aggregate polarization. There are quartz fragments up to 0.047 and even 0.07 millimeter, rare plagioclase grains; lenses of quartz a millimeter long; muscovite and chlorite scales lying at an angle to the cleavage, others without arrangement. Carbon-

[1] For colored lithographs of magnified thin sections of this slate, as seen both under ordinary and polarized light, see U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, Pl. XXXVI, 1899.

ate is less abundant than in the green slates. Spherules of pyrite from 0.007 to 0.027 millimeter, rutile needles in abundance, a few prisms of tourmaline, and rare fragments of zircon.

The chief constituents of the "purple" slate, named in descending order of abundance, appear to be muscovite, quartz, chlorite, hematite, carbonate, rutile, pyrite, and magnetite. The purplish color is due to the mixture of the red from the hematite and the bluish green from the chlorite.[1] In the "variegated" slates the mottling is produced by the irregular distribution of the hematite.

The following analyses were made by W. F. Hillebrand in the laboratory of the United States Geological Survey:

Analyses of Vermont "purple" and "variegated" roofing slates.

	G	H	I	H 2
Silica (SiO_2)	61.63	60.96	60.24	
Titanium dioxide, rutile (TiO_2)	.68	.86	.92	
Zirconia (ZrO_2)		Trace?	Trace?	
Alumina (Al_2O_3)	16.33	16.15	18.46	
Ferric oxide (Fe_2O_3)	4.10	5.16	2.56	5.28
Ferrous oxide (FeO)	2.71	2.54	5.18	2.36
Manganous oxide (MnO)	.09	.07	.07	
Nickelous oxide (NiO)	Trace?	Trace.	Trace.	
Cobaltous oxide (CoO)	Trace?	Trace.	Trace.	
Lime (CaO)	.50	.71	.33	
Baryta (BaO)	.06	.04	.03	
Magnesia (MgO)	2.92	3.06	2.33	
Potassa (K_2O)	5.54	5.01	4.09	
Soda (Na_2O)	1.26	1.50	1.57	
Lithia (Li_2O)	Str. tr.	Trace.	Str. tr.	
Water below 110° C. (H_2O)	.31	.17	.18	
Water above 110° C. (H_2O)	3.24	3.08	3.81	
Phosphoric oxide (P_2O_5)	.16	.23	.11	
Carbon dioxide (CO_2)	.41	.68	.08	
Pyrite (FeS_2)	.04	None.	.16	
Sulphuric oxide (SO_3)	Trace.			
Carbon (C)	None.	None.	None.	
	99.98	100.22	100.12	
Total sulphur (S)	.02	.07	.087	
Specific gravity	2.8064		2.8053	

G (=D. XIV, 1895, 260*a*), purple roofing slate, McCarty quarry, east of center of Lake St. Catherine, South Poultney, Vt.
H (=D. XV, 1895, 760*a*), purple roofing slate, Francis & Sons' quarry, nearly a mile south of Hydeville, in Castleton, Vt.
I (=D. XV, 1895, 314), variegated roofing slate, from Eureka quarry 3¼ miles north of Poultney, in Poultney Township, Vt., "unfading green" area.
H 2 (=D. XIV, 1895, 614*a*), dark-reddish bed a few inches thick in purple of "sea-green" area, west of Lake St. Catherine; determination of iron oxides only.

The results of certain tests of the strength of Fair Haven "purple" slate are given on page 183. The "purple" and "variegated" slates are used mainly for roofing.

Mill-stock slate.—In the northern and western parts of the green-slate belt those beds which have a less perfect cleavage are used as mill stock and find a market as blackboards, billiard-table tops, electric switchboards, tiles, vats, mantels, etc., and for some purposes are subjected to the process known as "marbleizing." They are purple or green. Much of the purple is paler than the "purple" roofing slate and also spotted with green, and some of the green is brighter than the "unfading green" roofing slate.

[1] For colored lithographs of magnified thin sections of the "purple" slate, as seen under both ordinary and polarized light, see U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, Pl. XXXVII, 1899.

Specimens from the Scotch Hill quarries, 2 miles north-northeast of Fair Haven; from the Meadow quarry, one-fourth mile east of Fair Haven; from the Lake Bomoseen Slate Co.'s quarry at Cedar Point, on Lake Bomoseen;[1] and from the J. Jones quarry, 2½ miles north of Castleton, were examined miscroscopically, with these results:

The matrix is muscovite (sericite), with aggregate polarization, but shows a cleavage much inferior to that of the "sea-green" slate and somewhat inferior to that of the Eureka of the "unfading green." There are about six chlorite plates, interleaved with muscovite, to each square millimeter, measuring up to 0.087 by 0.043 millimeter, and lying at right angles to the cleavage. Quartz fragments are very abundant, measuring up to 0.06 by 0.03 millimeter, with a few of plagioclase feldspar; muscovite scales in various orientations; a few carbonate rhombs, the usual abundance of rutile needles, and, finally, pyrite, which seems to be more abundant in the purple than in the green. The purple differs from the green by the addition of hematite.

The chief constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite (hematite in the purple), carbonate, rutile (kaolin in the purple, at least), pyrite, and, as shown by a magnet test, magnetite.

The specific gravity of the purple from Cedar Point was found to be 2.83 and of the green from the J. Jones quarry 2.84, both being a little higher than the figures for any of the other slates of western Vermont.

Slate-pencil slate.—In the portion of the belt containing the "unfading green" slate, about 1¼ miles north of Bomoseen and a little east of the lake, is an abandoned quarry where certain greenish slates were obtained and made into slate pencils. In Europe slate pencils have long been made by utilizing a secondary cleavage, which breaks the rock up into squarish sticks that are easily rounded. In the Vermont quarry the method used was to take tile-shaped blocks of slate and carve out first on one side, then on the other, by means of set gages, a whole series of hemicylindrical pencils which readily broke apart into roundish pencils.

A microscopic section of this rock shows essentially the same composition as that of the "unfading green" slates, except that sections parallel to the cleavage show no carbonate whatever, but a greater abundance and larger scales of muscovite (probably sedimentary), some limonite(?) specks, and a cleavage perhaps not quite so good as that of the Eureka quarries. The usual quartz, sericite, chlorite, rutile needles, and lenses are present.

The general substitution of paper tablets for school slates in this country has almost stopped the manufacture of slate pencils.

Minerals associated with the green and purple slates.—As the minerals of visible size associated with the slates throw light on the nature and origin of the microscopic constituents of the slate itself, they are here noted.

Quartz is the most common accessory mineral. It is usually segregated in the veins already described but occurs also as an infiltrated cement between the quartz grains in the beds of quartzite or in veins

[1] See Pls. XIX, *A*, and XXIV, *N*, for the structure at this quarry.

traversing the quartzite. In both of these modes it is crystallized wherever cavities admit of crystallization.

Next in abundance is calcite, occurring also in veins with or without quartz, or as delicate films on joint planes, or as a sediment in the beds of quartzite. Some of the quartzite beds contain minute rhombs which effervesce readily with hydrochloric acid and weather a limonite-brown and are therefore probably a double carbonate of iron and lime.

Squarish or oval concretions an inch by three-fourths of an inch and one-half inch thick, consisting of radiating crystalline lamellæ of barite, with the intervening spaces filled with slate and calcite and with many minute cubes of pyrite round about, occur in the Cambrian green slates of Middle Granville. Barite also occurs with calcite in crystalline films on joint planes.

Chlorite is common in quartz veins or almost alone makes up small veins or coats slickensided joint or bedding planes.

Pyrite occurs in cubes up to one-fourth inch across or in botryoidal concretions, coated with fibrous quartz (chalcedony) or with calcite or, more rarely, chlorite. This coating of chalcedony is in places confined to some of the sides, filling a space produced by motion or compression, as described by Renard. Pyrite may collect in the vicinity of calcareous and quartzose veins or beds, or form dendritic crystallizations on cleavage planes, or minute cubes on joint faces. That this mineral is pyrite and not marcasite is shown by its not decomposing readily after long exposure on the slate dumps.[1]

Rarely a little galenite occurs in the quartz veins.

It will be observed that nearly all the above-named minerals have already been mentioned as occurring in the slates, as shown either by the microscopic or the chemical analyses.

Black slate near Benson.—Half a mile east of Benson village and 7½ miles north-northwest of Fair Haven, in Rutland County, black roofing slate was quarried in 1895, but the quarry was abandoned not long afterward. The slate is probably of Ordovician age and belongs in a shale, slate, and schist belt which extends nearly 4 miles west to a point within a mile of Lake Champlain, and 4½ miles south-southwest to the village of West Haven, and also, with bends and ramifications, 20 miles north-northeast to Weybridge Center, in Addison County. The slate-bearing area, however, probably does not exceed 3 square miles.

At the quarry the beds dip about east at angles ranging from 15° to 20°; cleavage strikes about N. 7° E., dipping 35° E., and vertical joints strike N. 75° W.

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[1] See footnote on pyrite and marcasite, p. 174.

The slate is bluish black. To the unaided eye it has a somewhat fine texture and a rather smooth, slightly lustrous cleavage surface. It is carbonaceous or graphitic, contains a little magnetite, effervesces with cold dilute hydrochloric acid, is sonorous, and has a fair degree of fissility.

Under the microscope it shows a matrix of muscovite (sericite), with a brilliant aggregate polarization, somewhat obscured by much carbonate and carbonaceous matter in fine and coarse particles. The quartz fragments measure from 0.013 to 0.03 millimeter; carbonate rhombs from 0.004 to 0.035 millimeter. Pyrite spherules from 0.0017 to 0.007 millimeter number about 17,000 to the square millimeter, many of them occurring in rows along the cleavage. Rutile needles from 0.0017 to 0.0952 millimeter long are abundant; chlorite scales are very few and small, zircon fragments rare.

The constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, carbonate, pyrite, rutile, carbonaceous or graphitic matter, and magnetite.

This slate is thus closely related, both in composition and quality, to the "soft vein" slates of Lehigh and Northampton counties, Pa. Its large amount of carbonate indicates its probable discoloration on continued exposure. Its appearance in magnified thin sections under both ordinary and polarized light is very well shown in Plate XXXIX, Nineteenth Annual Report United States Geological Survey, part 3, a view which would answer almost equally well for many of the "soft vein" slates of Pennsylvania.

The following analysis (specimen P=D, XIV, 1895, 305*d*) of black slate from the abandoned quarry, one-fourth mile east of Benson Village, Rutland County, Vt., was also made by W. F. Hillebrand:

Analysis of black roofing slate from quarry near Benson, Vt.

Silica (SiO_2)	59.70	Lithia (Li_2O)	Strong trace.
Titanium dioxide, rutile (TiO_2)	.79	Water below 110° C. (H_2O)	.30
Alumina (Al_2O_3)	16.98	Water above 110° C. (H_2O)	3.82
Ferric oxide (Fe_2O_3)	.52	Phosphoric oxide (P_2O_5)	.16
Ferrous oxide (FeO)	4.88	Carbon dioxide (CO_2)	1.40
Manganous oxide (MnO)	.16	Pyrite (FeS_2)	1.18
Nickelous oxide (NiO)	Trace?	Sulphuric oxide (SO_3)	Trace.
Cobaltous oxide (CoO)	Trace?	Carbon (C)	.46
Lime (CaO)	1.27		
Baryta (BaO)	.08		100.05
Magnesia (MgO)	3.23	Total sulphur (S)	.63
Potassa (K_2O)	3.77	Specific gravity	2.7748
Soda (Na_2O)	1.35		

The more important features of all these Vermont slates, as brought out in the above descriptions, will be found in tabular form opposite page 188.

VIRGINIA.

W. B. Rogers,[1] in his reports to the legislature of Virginia during the years 1835 to 1841, called attention to the slate deposits east of the Blue Ridge in Buckingham, Fluvanna, and Fauquier counties.

[1] A reprint of annual reports and other papers on the geology of the Virginias [posthumous]; on the roofing slate of Buckingham County, pp. 78, 79; on that of Fauquier County, pp. 460, 461, New York, 1884.

Slate also occurs in the Blue Ridge in Amherst County and Albemarle County.

Recent field studies of these slate areas by T. L. Watson and S. L. Powell, of the Virginia Geological Survey,[1] have thrown more light on their geographic and geologic relations and their geologic age; and N. H. Darton's discoveries of fossils in the slate of the Arvonia district, announced in 1892,[2] determined the general geologic age of that belt. According to the studies of Watson and Powell and their map, reproduced in figure 12, there are three slate belts, of which the Amherst-Bedford County belt is the most westerly, the Buckingham-Fluvanna County and Quantico belt the most easterly, and the Albemarle-Fauquier County belt the central. Economically considered the slates in both the central and eastern belt vary considerably. The slate of the eastern belt is of Ordovician age; that of the central and western belts belongs to the Cambrian.

Geologic relations in Buckingham and Fluvanna counties.—Rogers's reference [3] to the slate of Buckingham and Fluvanna counties may well be repeated here:

> This [roofing slate] makes its appearance on both sides of the James River. * * * In Buckingham the bed is largely exposed in the neighborhood of New Canton, on Slate River. * * * In texture, density, and capacity of resisting atmospheric agents it can scarcely be excelled by a similar material in any part of the world. This quarry was first opened to procure slate for roofing the capitol, and notwithstanding it has been thus long known and its value established, but little further use has been made of it until the activity of the present owner has again brought it into notice. The building of the university will soon be furnished with a complete covering of slate from this quarry.

Slate River empties into the James about 40 miles west-northwest of Richmond and 52 miles northeast of Lynchburg. The extent and structure of the formation which includes these slate beds require further study, but figure 13 will serve to show some of its important features. The width of the formation north of the James, as far as explored by the writer during a very brief visit, extends from a point half a mile west of Bremo Bluff to a small creek entering the James 1⅔ miles east-southeast of Shores, a distance of 1⅔ miles. It strikes about south-southwest across the James and extends at least a mile south of Penlan, or 5¼ miles from the south bank of the James. This, on the scale of the map, would be three-fourths of an inch beyond its lower margin. South of the James its eastern boundary lies about 3,000 feet west of the toll bridge opposite Bremo Bluff, and its western boundary is roughly one-fourth mile east of the Virginia Mills, on Slate River. The bluffs on the north and south

[1] Watson, T. L., and Powell, S. L., Fossil evidence of the age of the Virginia Piedmont slates: Am. Jour. Sci., 4th ser., vol. 31, pp. 33–44, and map, fig. 1, 1911.

[2] Darton, N. H., Fossils in the "Archean" rocks of central Piedmont, Virginia: Am. Jour. Sci., 3d ser., vol. 44, pp. 50–52, 1892.

[3] Op. cit., p. 79.

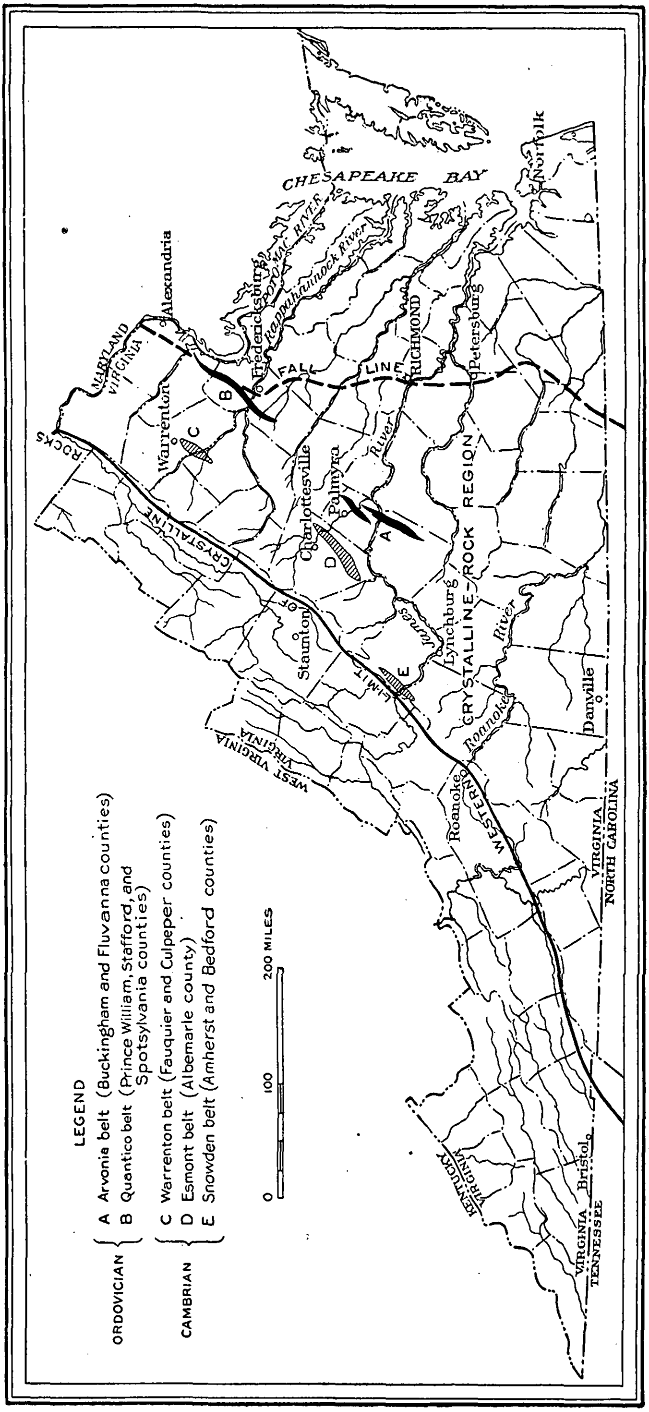


FIGURE 12.—Map of Virginia, showing distribution of slate areas in the crystalline region. After Watson and Powell.

sides of the James at Bremo Bluff, New Canton, consist of quartzite with like strike and dip—on the north, strike N. 17°–23° E., dip 65° E. and 90°; on the south, strike N. 13°–18° E., dip 90°. The exposure of quartzite on the north is about 950 feet across the strike

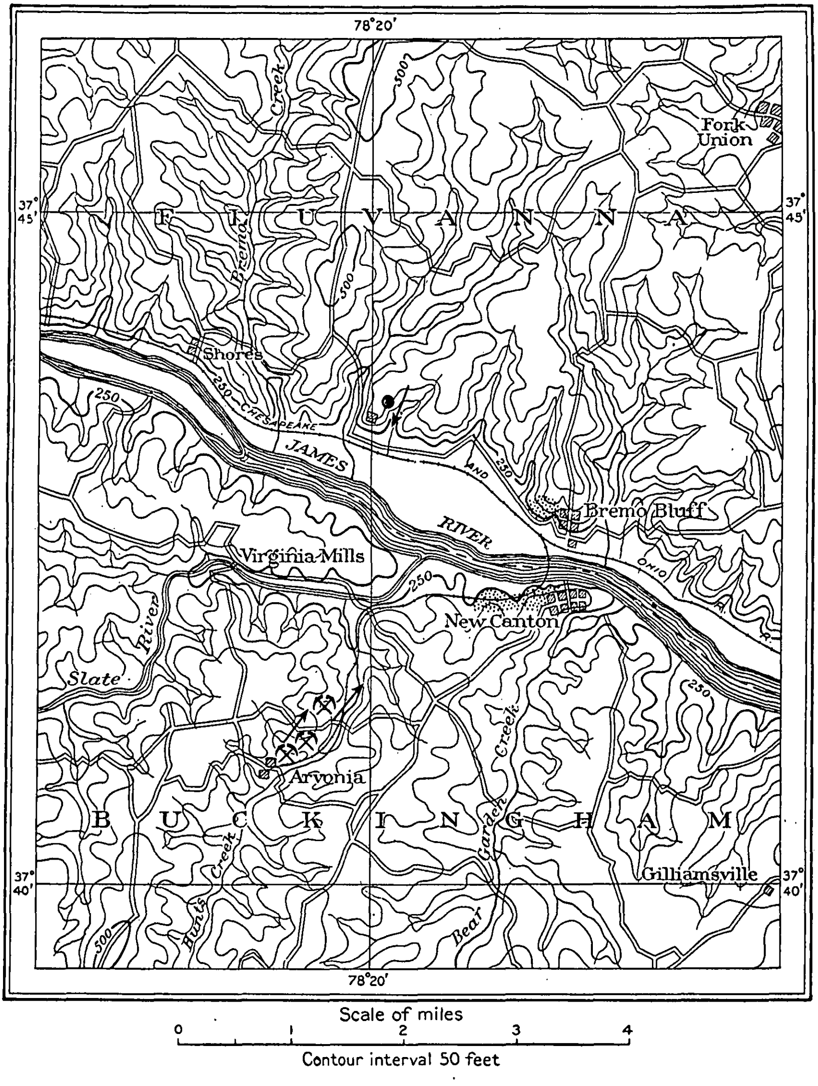


FIGURE 13.—Map of slate region in Buckingham and Fluvanna counties, Va. Quarries shown by crossed hammers; slate prospect by round dot; strike of commercial slate by arrows; quartzite areas by fine dots.

and on the south about 3,000 feet. These facts and the jagged structure of the Bremo Bluff, which is 75 feet high, show that the James here flows through a broad transverse cut in the quartzite and the slate formation west of it. This quartzite is fine grained, muscovitic, and biotitic, with scattered plates of calcite and a few fragments of plagioclase. It is interbedded here and there with a few inches of slate, consisting of muscovite (sericite), quartz, chlorite, and biotite and containing garnets and lenses of quartz, muscovite, and chlorite, some of which are probably altered garnets. The quartzite also has slate of this character on both sides of it. On the east the quartzite, dipping 80° E., is followed conformably by 40 feet of such slate, about 300 feet of micaceous quartzite, and an undetermined thickness of ferruginous slate full of pseudomorphs or crystals of mica (muscovite?) 1½ millimeters across, the plates of which lie across the foliation of the rock. This slate was originally bluish gray but weathers a hematite-red.

The general structure of the belt in which the commercial slate beds lie, to judge from the railroad cuttings between New Canton and Slate River, appears to consist of minor folds. It is traversed by numerous dikes of olivine basalt, ranging from a few inches to 12 feet in thickness and consisting of plagioclase, olivine, magnetite, and augite. These dikes weather in conchoidal masses with a yellowish brown surface. The formation is bounded on the east by the quartzite cut by James River. If this quartzite is in a westward overturned syncline, it would overlie the slate; if in an anticline of like character, it would underlie the slate, in either case in apparent conformity. On the west of the formation at Virginia Mills there are chloritic, sericitic, quartzose, and feldspathic schists striking N. 25° E. and dipping 90°, crossed diagonally by a small basaltic dike, also certain chloritic, quartzose, and feldspathic schists that weather bright red, possibly the same as the above, but both of uncertain age.

The commercial slate itself appears to occupy a belt two-fifths of a mile wide along Hunts Creek, which is a southern tributary of Slate River. At Penlan its strike is N. 30° E. At Arvonia its course is N. 35° E., roughly like that of Hunts Creek, which meanders through it; but on the north side of the James, 3½ miles north-northeast of Arvonia, the strike of the slate is N. 20° E., like that of the quartzite at Bremo Bluff. There appears thus to be a bend in the slate beds between Arvonia and the north side of the James. The discovery of certain crinoids and later of brachiopods, trilobites, etc., in the quarried slate at Arvonia shows it to be of Ordovician age. E. O. Ulrich, to whom collections of these fossils were referred, determines them as unquestionably of Ordovician age, but he finds that the fossils are of such strange types that it will require a very critical study to determine whether the beds are Mohawkian or Cincinnatian. The dikes are probably of Mesozoic age.[1] C. D. Walcott, as cited by Darton,[1] regards the crinoids from the slates at Arvonia as allied to the genera Schizocrinus, Heterocrinus, and Poteriocrinus. Mr. T. E.

[1] Darton, N. H., loc. cit.

Williams, of Arvonia, recently found in the Middle quarry an unusually well-preserved crinoid. The cup, as compressed, is 3 inches high and 2½ inches wide at the top. Seventeen tentacles, thickly fringed with pinnulæ up to an inch in length, cover an area of the slab 14 by 8 inches. The specimen is at the National Museum.

Arvonia.—The quarries near Arvonia are scattered along the sides of Hunts Creek for a mile northeast of that place. The principal quarries in operation in May, 1904, were the Old or Big quarry and the Middle quarry of the Williams Slate Co., and the Fontaine quarry of A. L. Pitts. Several others were being opened or were temporarily abandoned. One opened later near the mouth of Hunts Creek had been abandoned in 1912.

The Big quarry in 1904 measured 300 feet along the cleavage, 200 feet across it, and 125 feet in depth. Bedding and cleavage are identical, striking N. 37° E., and dipping 86° SE. There are vertical dip joints striking about northwest; strike joints trending northeast, dipping 75°–80° SE.; also two sets of diagonal joints, one dipping 30° E. and the other 55° W. The latter system had a "post" 5 feet thick full of shear zones. There are also gently undulating "flat joints," to which the grain is parallel. Quartz veins in this quarry contain calcite, chlorite, and biotite. The Middle quarry is 400 feet along the cleavage, 400 feet across, and in places 350 feet deep, with a wing 150 by 50 feet and 100 feet deep. Bedding and cleavage strike N. 33° E., dip 75° S. 57° E., and are crossed by northwesterly vertical joints. There are also horizontal joints spaced 1 to 25 feet. One of these meanders 10° from the horizontal in a distance of 50 feet. At the south end is a vertical dike of olivine basalt, 10 to 12 feet thick, trending N. 25° W., with horizontal joints, 4 to 6 inches apart, for a few feet on its north side and joints parallel to it on both sides. The slate is said to be of better quality a little beyond the zone of these joints than it is at a greater distance from the dike.

The slate from the Williams quarries is very dark gray, with a slightly greenish hue. To the unaided eye it has a minutely granular but very lustrous surface. It is slightly graphitic and magnetitic, shows pyrite on the sawn edge, does not effervesce in cold dilute hydrochloric acid, and is very sonorous and fairly fissile.

Under the microscope it shows a matrix of minute alternating beds, chiefly of fine muscovite, with coarser ones, chiefly of quartz, the former with a brilliant aggregate polarization, the latter with a faint one. These beds are parallel to the cleavage. The quartz fragments measure up to 0.085 millimeter. Scattered throughout both the more micaceous and the more quartzose beds are crystals, lenses, and particles of pyrite, numbering about 25 to each square millimeter and measuring up to 0.09 millimeter, rarely 0.15 and 0.42 millimeter, with their longer axes parallel to the cleavage. These probably include a little magnetite. There are also biotite scales transverse to the cleavage, about 39 to the square millimeter, and measuring up to 0.12, rarely 0.2 millimeter. Almost if not quite as abundant are plates and rhombs of carbonate. There are scattered scales of chlorite interleaved with muscovite, a few grains of plagioclase feldspar 0.047 millimeter, rarely one of zircon, some tourmaline prisms 0.014

millimeter long, much extremely fine graphitic (or carbonaceous?) material, a few particles of hematite, and some rutile needles. Sections parallel to the cleavage are unusually brilliant in polarized light, owing to the abundance of quartz, biotite, and carbonate.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite and sericite, quartz, biotite, carbonate, graphite, pyrite, chlorite, and magnetite, with accessory plagioclase, zircon, hematite, tourmaline, and rutile.

The Fontaine quarry of A. L. Pitts in 1904 had a length of 300 feet along the cleavage, a width of 200 feet, and a depth of about 100 feet. Bedding and cleavage strike N. 34° E., and dip 80° SE. The quartz veins also contain calcite.

The slate from this quarry is very dark gray with a greenish hue and to the unaided eye has a granular sparkling crystalline texture and a roughish but very lustrous cleavage surface. It is slightly graphitic (or carbonaceous). The sawn edge shows pyrite. It contains rare particles of magnetite, does not effervesce in cold dilute hydrochloric acid, and is very sonorous.

Under the microscope the slate of the Fontaine quarry shows alternating little beds of fine, more muscovitic, and coarser, more quartzose material, the former having a brilliant aggregate polarization. Much of the mica is in the form of muscovite rather than sericite, particularly in the quartzose beds. These beds are parallel to the cleavage. Quartz fragments are abundant, measuring up to 0.12 millimeter. Conspicuous scales of biotite lie across the cleavage, usually up to 0.2 by 0.09 millimeter and averaging about 12 to the square millimeter. Lenses and crystals of pyrite, many of them surrounded by secondary quartz, about 27 to the square millimeter and measuring up to 0.076 by 0.03, rarely 0.34 by 0.03 millimeter, with their longer axes in the cleavage. A few scales of chlorite, interleaved with muscovite, lying across the cleavage and up to 0.3 millimeter. Some carbonate in the coarser beds, here and there with inclusions of an opaque mineral (graphite, pyrite, or magnetite). Much graphitic matter in very minute particles. Some hematite and a few crystals of tourmaline, 0.02 by 0.006 millimeter.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite and sericite, quartz, biotite, carbonate, pyrite, graphite, chlorite, magnetite, and hematite, with accessory tourmaline.

A specimen from an exceptional bed in the same quarry shows a wrinkled surface from the abundance of biotite lenses measuring half an inch in length by a twentieth of an inch in width at the center. George H. Williams[1] found the joint faces at the old Roberts quarry covered with pyrite and crystals 1 millimeter long, which when analyzed proved to be TiO_2 and which he determined optically as anatase.

Although the slates of Arvonia, as shown by the above determinations, contain some carbonate, they do not include any appreciable amount of ferrous carbonate, for some of these slates put on the old Richmond Theater over 70 years ago did not show any discoloration whatever when removed, about 1902, and some have been on buildings near the quarries over a century without losing any of their

[1] Anatase from the Arvon slate quarries, Buckingham County, Va.: Am. Jour. Sci., 3d ser., vol. 42, p. 431, 1891.

blackness. Their highly crystalline character also implies strength and durability.

The results of Merriman's tests of slate from the Williams and Pitt quarries are given on pages 182–183.

Penlan.—Penlan station is 2 miles about south-southwest of Arvonia. The quarry of the Penlan Slate Co., of Penlan, is a mile farther south. It measures about 100 feet along the cleavage, 150 feet across it, and 100 feet in depth. At 50 feet from the west edge, on the south side, there is a tunnel, 30 feet wide and 50 feet high measured from the quarry bottom, and extending 40 feet along the cleavage. In its upper 10 feet the tunnel has been extended 40 feet still farther. Another tunnel has been made on the north side nearly in line with the west wall. This is 40 feet wide and 50 feet high and extends 40 feet northward along the cleavage. The company expects to extend the first tunnel 500 feet, to sink a shaft to meet its north end, and to work from both ends.

Both cleavage and bedding strike N. 30° E. and dip 80°–85° S. 60° E. There are three sets of joints—(*a*) horizontal, spaced 2 to 10 feet; (*b*) transverse, discontinuous, spaced 2 to 10 feet; (*c*) diagonal, open 3 inches and filled with quartz, graphite, or slate fragments (?). The weathered "top" is 50 feet thick. Whitish disks of calcite of extreme tenuity occur here and there on cleavage faces and have a diameter of 1 or 2 inches. They were evidently deposited by percolating water deriving the lime from the slate itself. These disks are easily removed with dilute muriatic acid and have no economic importance.

The slate has a very dark gray color with a faintly brownish, not bluish, hue. A specimen (D. XXXIV, 16, a), obtained from the company in 1912, and probably finer than the average, has a lustrous, very smooth cleavage surface, which only with a magnifier is seen to be very sparsely and minutely granular. It is very sonorous and very fissile, shows pyrite on the sawn edge, does not effervesce with acid test except when powdered, and contains graphite and some magnetite.

Under the microscope it shows a matrix of muscovite (sericite) with fine texture and brilliant aggregate polarization. Passages and little beds with more and coarser detrital quartz grains, parallel to the cleavage, make the texture somewhat uneven and show that bedding and cleavage are parallel. Particles and crystals of magnetite and of pyrite, 0.02–0.3 millimeter long, average about 5 to the square millimeter. Some of the pyrite is inclosed in secondary quartz. Neither biotite nor chlorite was detected. Fine graphite occurs throughout; considerable carbonate in minute rhombs and plates; tourmaline and rare detrital zircon and plagioclase. Rutile was not detected.

The constituents, named in descending order of abundance, appear to be muscovite, quartz, graphite, carbonate, magnetite, pyrite, tourmaline, plagioclase, and zircon.

This is a highly crystalline mica slate generally identical with that of Arvonia.

The following is a résumé of the results of physical and magnetitic tests of four specimens of this slate made for the company by C. W. Hudson at the Cooper Union Laboratory in New York in 1908:

Tests of slate from Penlan, Va.

Strength, modulus of rupture...pounds to the square inch..	8,000–11,720
Toughness, ultimate deflection, supports 18 to 22 inches apart..........inch..	0.266–0.366
Porosity, water absorbed in 24 hours............per cent..	0.152–0.235
Specific gravity..........	2.763–2.777
Content of magnetite..........per cent..	0.05

The recently opened quarry of the Arvon Slate Manufacturing Co., of Penlan, is about a quarter of a mile southeast of Penlan station and 1,000 feet east of the railroad. It measures about 130 feet along the cleavage, 50 feet across it, and 50 feet in depth. The weathered "top" is in places 10 feet thick.

The cleavage strikes N. 25° E. and dips 75° S. 65° E. and the attitude of the bedding is probably identical. The foliation has some slight plications, 6 to 12 inches wide, crossed by slip cleavage. There are transverse vertical joints spaced 1 to 10 feet with a heading 5 feet wide at the south end of the quarry. Irregular horizontal joints are spaced 10 to 20 feet and a diagonal joint strikes N. 20° W.

The slate is of very dark gray shade, like that of the Arvonia quarries, with a faintly brownish, not bluish, tinge, and a lustrous, very granular surface with marked minute plications. The slate is very fissile and sonorous, does not effervesce with acid test unless powdered, shows minute spangles on a rough edge and a little pyrite when sawn, and is graphitic and magnetitic.

Under the microscope this slate has a brilliant aggregate polarization. The cleavage is intersected at 36° by minute plications. Particles of magnetite and pyrite, the former far more abundant, 0.05–0.25 millimeter long, average about 5 to the square millimeter. Crystals and irregular scales of biotite, 0.05–0.3 millimeter long, average 5 or 6 to the square millimeter. The magnetite crystals lie mostly between plates of biotite, and these have secondary quartz on the outer side. Graphite in fine particles throughout; very little carbonate, 3 to 7 small plates to the square millimeter. Very little chlorite; tourmaline; rutile not detected.

The constituents, named in descending order of abundance, appear to be muscovite, quartz, graphite, biotite, magnetite, carbonate, pyrite, chlorite, and tourmaline.

This highly crystalline mica slate, although microscopically slightly different from that of the other Penlan quarry, is generally identical with that of Arvonia.

Bremo Bluff.—Slate has been prospected on the estate of the late Dr. Casey C. Cocke, 2 miles west-northwest of Bremo Bluff, in Fluvanna County. It occurs in the ravine east of the house and also on the hill northeast of it. The strike is N. 18°–23° E., and the dip nearly 90°. A little northwest of the house is a dike of olivine basalt 5 to 10 feet wide. The results of an examination of specimens obtained within a few feet of the surface and therefore belonging to the "top" are given on page 155.

This slate is dark gray, but its lightness of shade is in part the result of weathering. It will prove to be darker below the zone of weathering. To the unaided eye it has a fine texture, with a somewhat fine and very lustrous cleavage surface, more or less dotted with minute lenses or crystals. It is slightly graphitic but not magnetitic, shows pyrite on sawn edges, does not effervesce in cold dilute hydrochloric acid, has an argillaceous odor, and is sonorous and very fissile. The slate from one of the openings has exceedingly minute veins of muscovite.

Under the microscope the slate from the C. C. Cocke estate shows a matrix of muscovite (sericite), with a brilliant aggregate polarization. There are abundant quartz grains up to 0.09 by 0.03 millimeter and 0.13 millimeter long, the larger ones surrounded by secondary quartz radiating along the cleavage; about 35 lenses and crystals of pyrite to the square millimeter, measuring up to 0.09 by 0.02 millimeter (exceptionally the lenses are 1.5 millimeters long), with their longer axes in the cleavage. There are also square and rhombic spaces lined with secondary quartz, measuring up to 0.6 millimeter, left by the dissolution of cubes or distorted cubes of pyrite. In some specimens there are 65 such cavities to the square inch, in others none. There are lenses up to 0.56 by 0.11 millimeter, consisting of quartz and muscovite or of these and chlorite and pyrite, or of chlorite and muscovite, the folia of muscovite and chlorite lying across the cleavage; also muscovite scales up to 0.09 by 0.02 millimeter. Throughout the matrix much dark-gray material occurs in exceedingly fine dots (graphite?). There are also some dots of hematite. Rutile needles are not very plentiful up to 0.01 millimeter long; also a number of very irregular particles of rutile up to 0.05 millimeter, consisting of a network of crystals ("sagenite twinning") forming angles of 120° and 60°. A few fragments of zircon, an occasional crystal of dark tourmaline up to 0.05 by 0.02 millimeter; rare flakes of biotite; no carbonate.

The chief constitutents of the slate, named in descending order of abundance, appear to be muscovite, quartz, pyrite, kaolin, chlorite, graphite, rutile, with accessory tourmaline, zircon, biotite, and hematite.

This slate differs from the slate of the Arvonia area in its finer texture, probable slightly lighter shade, and slightly higher percentage of pyrite. It has less biotite and, at least in the "top," no carbonate. Core drilling or excavation deep enough to penetrate the "top" is amply warranted by the above determinations.[1]

Slate has also been prospected at several other points in Fluvanna County between James River and Palmyra, but no quarry was yet in operation in 1912. A company has been organized and a quarry opened at a point 2 miles northeast of the Bremo mansion and 7 miles south-southwest of Palmyra, a little south of the road, with a course generally parallel to that of the James. (See fig. 13.)

A specimen (D XXXIV, 92, *a*) from this locality, obtained in June, 1913, from J. O. Shepherd, of Palmyra, and reported as having been taken about 7 feet below the surface, is of medium bluish-gray color with a very slight purplish tinge. It has a lustrous roughish cleavage surface dotted with minute blackish lenses, is very fissile and sonorous, very graphitic and magnetitic, and with acid test effervesces very slightly in the powder, but not at all in the rock.

Under the microscope it shows a matrix of sericite with brilliant aggregate polarization. It contains lenses of carbonate up to 0.6 by 0.25 millimeter, numbering about

[1] Slate outcrops on this property were referred to by J. L. Campbell, Tenth Census, vol. 10, Special report on building stones, p. 181, 1884.

23 to the square inch of transverse section, also crystals and lenses, mostly of magnetite with some of pyrite, up to 0.5 millimeter long by 0.07 millimeter thick and numbering about five to the square millimeter of section with the cleavage but seven to the square millimeter of transverse section. The lenses have radiating secondary quartz and muscovite about them, also chlorite. The pyrite shows limonite stain. The slate also contains prisms of tourmaline and of rutile but no slate needles, also a few grains of zircon. There is much fine graphite but no carbonate besides that in lenses.

The constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, graphite, chlorite, magnetite, carbonate, pyrite, tourmaline, rutile, zircon, and limonite.

This is a highly crystalline graphitic mica slate of the unfading series, resembling that of Arvonia but of a little lighter shade. It may be found darker as quarrying deepens.

Esmont, Albemarle County.—The slate outcrops of the Esmont district lie east of the Blue Ridge and 10 to 12 miles west of the slate of

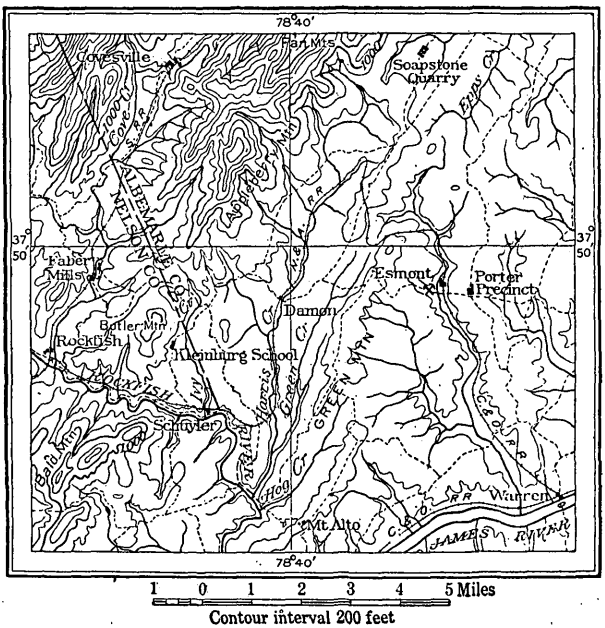
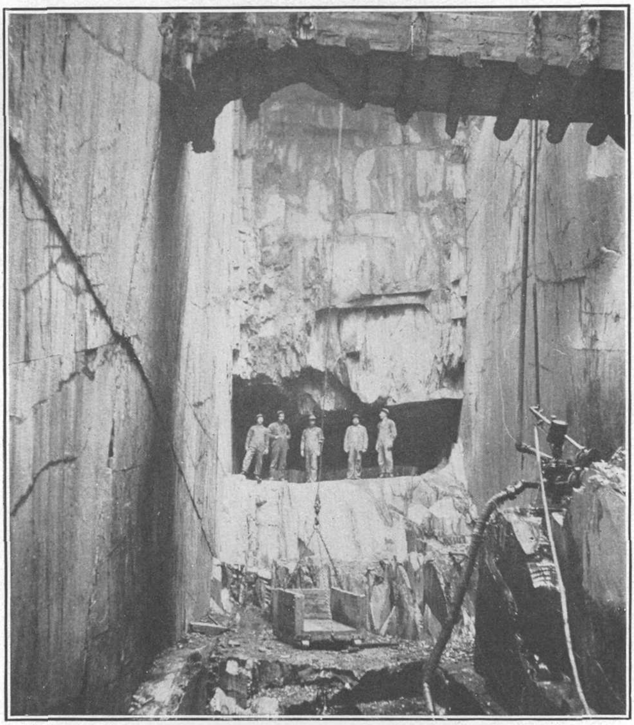


FIGURE 14.—Map of slate region in Albemarle County, Va. Quarry shown by crossed hammers. Course of railroad approximate.

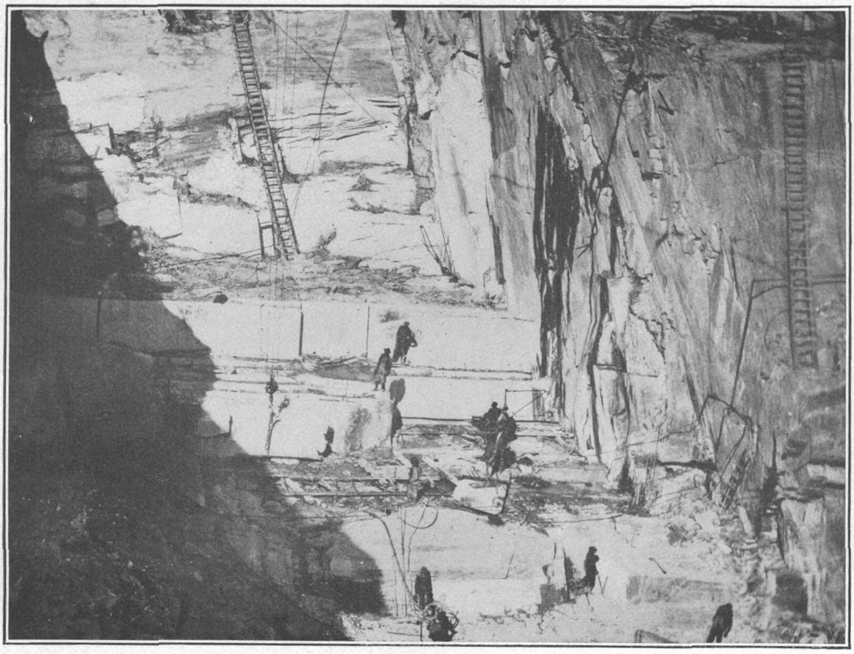
Buckingham and Fluvanna counties. The quarries are on Ballinger Creek, a small tributary of James River, 5 miles northwest of Warren, on the James, and a mile west of Porter Precinct, as shown on figure 14. A north-northeastward-trending ridge, Green Mountain, attaining an elevation of 800 feet, or 400 feet above the James, lies west of the slate. A diabase dike 50 feet thick, with a northerly course, cuts the slate east of the village and creek.

The quarry of the Standard Slate Corporation, of Esmont, lies west of Ballinger Creek and north of the road to Porter and measures



A. LOWER QUARRY OF PORTLAND-MONSON SLATE CO., MONSON, ME.

Showing lateral walls of jointed quartzite kept in place by steel and concrete brace and slate pillar (in background). This has flat joints and has been tunneled 30 feet to the next opening.



B. QUARRY OF STANDARD SLATE CORPORATION, ESMONT, VA.

Showing benches from use of channeling and undercutting machines about 200 feet east to west, 80 feet north to south, and 170 feet in depth. (See Pl. XXVI, *B*.) Although the general structure at this place is much obscured it seems to consist of an acute syncline in the center of the quarry and an acute anticline east of it, with probably another west of it and still another syncline beyond the west edge of the quarry—in all, two synclines and two anticlines. The strike of the cleavage is N. 17°–22° E. and the dip 70° S. 80° E. The limbs of the folds strike with the cleavage and dip 50°–60° S. 80° E. There are vertical discontinuous joints striking N. 58° W. and spaced 2 to 10 feet. Another set undulates horizontally and has a spacing of 3 to 30 feet. The slate within the upper part of the central syncline on the north wall is much broken up by many open joints of the horizontal set and the slate about the lower part of this syncline abounds in shear zones (see p. 44), slip cleavage, and quartz veins. A specimen from this place shows about eight planes of slip cleavage to the inch. From the somewhat uncertain structure exposed there seems to be about 50 feet of black slate overlain by about the same thickness of green and "variegated," but in close eastward-inclined folds so that within the length of the quarry and the uncovered area west of it each bed of slate is repeated, the green five times and the black four times. As quarrying proceeds more light will be thrown on the structure.

There are four varieties of slate, as described below:

"No. 1, blue-black" (specimens D, XXXIV, 11, *a*, *d*) is of dark bluish-gray color, the bluish tint being marked and in the wet slate resembling that of specular iron. It has a very lustrous granular surface with an obscure foliation crossing the grain. It does not effervesce with acid test; the sawn edge shows pyrite; the powdered slate shows very little magnetite and still less graphite. It is sonorous and rather fissile. Under the microscope this slate shows a matrix of sericite with brilliant aggregate polarization containing on the average 2½ lenses to the square millimeter and measuring 0.25–1.12 millimeters in length and up to 0.25 millimeter in thickness. These lenses consist of carbonate, mostly in rhombs with dark-brownish content, also of chlorite, muscovite, and quartz. In sections with the cleavage these rhombs and the muscovite are radially arranged, forming brilliant objects in polarized light. The proportions of the constituents of the lenses vary greatly. In one the carbonate amounted to 50 per cent, chlorite 25 per cent, and muscovite and quartz 12.5 per cent each. The matrix abounds in minute bluish-black metallic grains of irregular size and form that are probably metallic hematite (Fe_2O_3). The carbonate is largely confined to the lenses. There are a few stains of limonite. The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, specular hematite, carbonate, graphite, pyrite, magnetite, rutile, tourmaline, and limonite. This is a mica slate of superior quality with a considerable content of specular hematite, to which its peculiar sheen is due. Its content of carbonate is so slight as not to appreciably affect the durability of its color. The color can not easily be confounded with that of the slates of the Arvonia district.

The "dark-green" slate (specimens D, XXXIV, 11, *e*, *k*) is of medium greenish-gray color and of lustrous, finely spangled or coarsely and sparsely granulated surface. It does not effervesce with the acid test and is sonorous. The color is devoid of the bluish tinge which marks some green slates. On exposure the color darkens somewhat.

There is also a "light-green" variety of this slate which is a dingy green. The "dark green" contains a little magnetite and the spangles are magnetite. The sawn face shows pyrite. It is very sonorous and fissile. Under the microscope this slate shows a matrix of sericite with brilliant aggregate polarization, containing lenses of chlorite, carbonate, and quartz, or of each separately with a little muscovite. The chlorite (interleaved with muscovite) lies in the grain direction, transverse to the axis of the lens. The lenses are 0.25–2 millimeters long, 0.07–0.1 millimeter thick, and 0.17–0.7 millimeter wide and average 3 or 4 to the square millimeter. The carbonate and muscovite are concentrically and radiately arranged, the carbonate being within, as seen in sections parallel to the cleavage. There are secondary (?) quartz lenses up to 1.7 millimeters wide, also scales and elongated crystals of magnetite, 0.006–0.05 millimeter wide and as much as 0.2 millimeter long, averaging about 13 to the square millimeter. Slate needles are very plentiful; a little sagenite, tourmaline, and zircon. The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, magnetite, rutile, pyrite, tourmaline, and zircon. This is a mica slate with an amount of carbonate probably not large enough to affect the durability of its color appreciably.

The "variegated" slate is of purplish-gray color irregularly streaked with greenish gray, or of a peculiar very light brownish-purplish gray with meandering parallel bands ("ribbons") or beds of dark greenish gray, 0.1 to 0.3 inch wide. The banding and coloring vary greatly. The surface has but little luster and is granular. It is sonorous, does not effervesce with acid test, and has a very little magnetite and pyrite. Under the microscope this slate shows a matrix with brilliant aggregate polarization containing little beds that are less micaceous and contain more and coarser quartz and carbonate. Particles of specular hematite are plentiful but not so abundant as in the black slate. There are lenses of radiately arranged carbonate rhombs and of chlorite, 0.3 to 1.25 millimeter in diameter, in sections parallel to the cleavage and averaging nearly 2 to the square millimeter. Tourmaline, rutile needles, and limonite stains also appear. The bands are due to variations in the amount of quartz, chlorite, carbonate, and hematite. The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, specular hematite, rutile, magnetite, limonite, pyrite, and tourmaline.

The "ferrous" slate, a variety of the "dark blue" which discolors on continued exposure, has dark-brownish spots and indeed a general very slight brownish tinge, both attributable to a carbonate of iron, probably also of lime and magnesia. Its surface is lustrous and granular. It effervesces slightly with acid test and is sonorous. It contains much more carbonate than the black. Its strength is reported as fair.

The following analyses of the black and green slate, made for the company by the Lehigh Testing Laboratory at Allentown, Pa., are given here for reference:

Analyses of slates from Esmont, Va.

	Dark blue.	Dark green.
Silica (SiO_2)	56.33	53.58
Alumina (Al_2O_3)	22.26	24.53
Iron oxides (FeO, Fe_2O_3)	9.44	8.81
Lime (CaO)	.68	.42
Magnesia (MgO)	1.48	1.95
Alkalies (Na_2O, K_2O)	5.07	4.88
Sulphur (S)	.004	.008
Carbon dioxide (CO_2)	1.69	1.99
Combined water (H_2O)	2.86	3.39
	99.814	99.558

The following physical tests were made by the division of tests, United States Department of Agriculture, in 1907, for the company:

Physical tests of slates from Esmont, Va.

Specific gravity	2.90
Weight per cubic foot........pounds..	181
Water absorbed per cubic foot........do....	0.18
Toughness	18
Crushing strength with grain.......pounds to the square inch..	19,150
Crushing strength across grain........do....	29,500
Modulus of rupture, on a cross-bending test, load at right angles to grain........pounds to the square inch..	9,360

Machinery.—Channeling machines are used by this company for both horizontal and vertical cuts. The plant also includes a "carrier" with a continuous chain running through a trough into which the refuse slate from the cutters and splitters is thrown and is thus automatically carried to the dumps. The slate blocks are cut across the grain by circular saws, and a gang of saws is being put in to cut the large blocks obtained by channeling to the size required by the splitters.

An abandoned quarry east of Ballinger Creek and the dike and a little northeast of Esmont station is about 75 feet square and shows steep eastward-dipping cleavage.

The slate is light greenish gray and has a slightly lustrous surface, two intersecting striations, and minute dark spangles. The green is more bluish than the green slate of the Standard Slate Co.'s quarry. The sawn edge shows pyrite. Effervescence with acid test very slight. The pieces on the dumps show slip cleavage, which in this and the other quarry may possibly be related to the intrusion of the diabase.

Under the microscope this slate shows a matrix of sericite with brilliant aggregate polarization and abundant chlorite. There are lenses of chlorite and carbonate; sparsely distributed magnetite in plates; quartz and carbonate; a passage of coarser quartz, carbonate, and chlorite; an obscure plication diagonal to the cleavage.

The constituents, named in descending order of abundance, appear to be muscovite, chlorite, quartz, carbonate, and magnetite.

Snowden, Amherst County.—The slate deposit of Snowden is on the southeast side of the axis of the Blue Ridge, north of the cut through which James River flows. It is situated about 18 miles north-northwest of Lynchburg. (See map, fig. 15.) The slate crops out in a longitudinal valley between Rocky Row Mountain on the northwest and a spur of Big Piney Mountain on the southeast. It strikes N. 65° E. and is bordered by quartzite on the southeast. The general structure and the areal relations of the slate have not yet been exhaustively investigated.[1]

The only quarry in operation in 1904 was that known as the Williams Brothers slate quarry, on the property of the Virginia Slate

[1] See Campbell, J. L. and H. D., The Snowden slate quarries: The Virginias, vol. 5, pp. 162-163, 1884. Campbell, J. L., Geology of the Blue Ridge, near Balcony Falls, Va.: Am. Jour. Sci., 3d ser., vol. 28, pp. 221-223, 1884.

Mining Co., 3 miles north-northeast of Snowden station and about 1,200 feet above it, where Rocky Row Run enters James River. Slate about 250 feet thick is exposed with a bedding strike of N. 65° E., forming a flat-topped anticline, whose northern limb dips 35° at the surface but is vertical at the bottom of the quarry and for a few feet dips steeply south, indicating a possible overturn. The cleavage strikes N. 45° E. and dips 32° SE. The bedding forms finely plicated ribbons of quartz and calcite several inches wide on the cleavage surfaces. Joints strike N. 18° E., dip 70° W., also N. 18° W., dip 65° E. The grain makes an angle of 90° to 104° with the bedding and is said to be very marked.

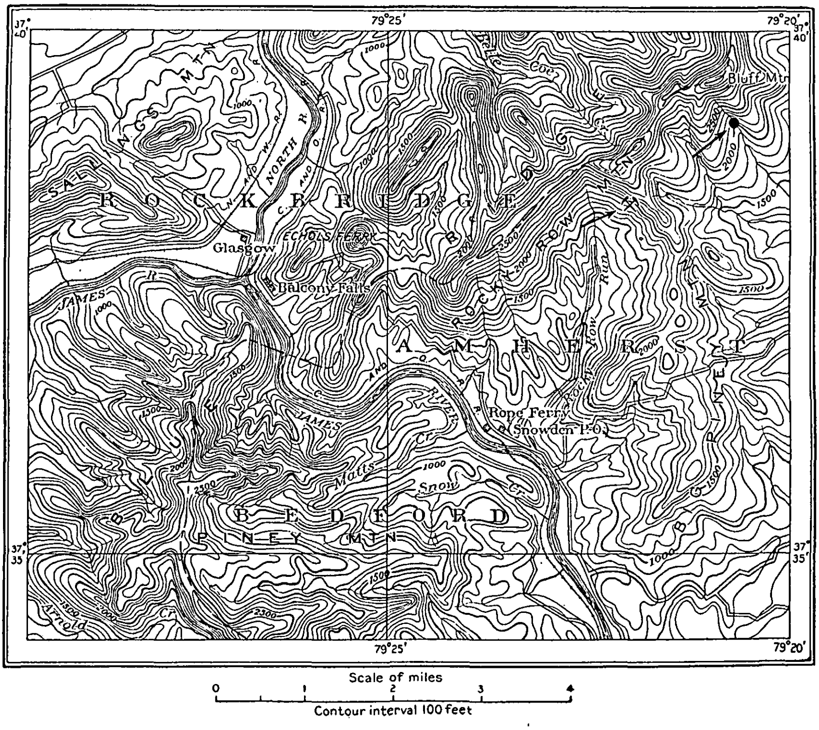


FIGURE 15.—Map showing location of slate quarries and prospects in Amherst County, Va. Quarries shown by crossed hammers; slate prospects by round dots; strike of commercial slate by arrows.

This slate is very dark gray. To the unaided eye it has a minutely granular texture and a moderately smooth cleavage surface, with very little luster. It is not graphitic, shows no pyrite on sawn edge, has no magnetite, does not effervesce with cold dilute hydrochloric acid, is fairly sonorous, has a very slight argillaceous odor, and is said not to fade.

Under the microscope it shows a matrix of muscovite (sericite), with aggregate polarization not very brilliant owing partly to the coarseness of many of the other constituents. Quartz fragments measure up to 0.08 millimeter; chlorite scales and lenses up to 0.28 millimeter in length, rarely 0.42 by 0.2 millimeter, numbering about 126 to the square millimeter; also muscovite scales up to 0.09 millimeter; some carbonate in exceedingly minute rhombs and plates; grayish carbonaceous (?) matter;

about 3,000 spherules and pyritohedrons of pyrite to the square millimeter, measuring up to 0.005 millimeter; abundant rutile needles, and scattered fragments of zircon.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite (sericite), quartz, chlorite, kaolin, pyrite, carbonate, rutile, and carbonaceous matter.

This is a superior slate, but is less crystalline than that of Arvonia. It is used exclusively for roofing, having been found less well adapted for mill stock. In 1912 this quarry was closed owing to litigation.

Thompson prospect.—About 1½ miles northeast of the Williams quarry slate was prospected in 1886 on the Thompson property, which lies on a small tributary of Otter Creek that flows into the James 1½ miles downstream from Snowden, as shown in figure 15. The thickness exposed is 20 feet; the bed strikes N. 53° E. and dips 20° S. 37° E.; the cleavage is nearly horizontal; joints strike N. 38° E. and dip 20° N. 52° W.

A reexamination of the specimens collected by the writer in 1904 shows an aggregate polarization probably obscured by lenticular texture and the distribution of carbon between the lenses as well as by the amount of carbonate. The quartz particles are noticeably angular; one detrital plagioclase; much carbonate; lamellæ of chlorite in grain direction; spherules of pyrite; abundant rutile needles.

The constituents, named in descending order of abundance, appear to be muscovite, quartz, chlorite, carbonate, carbon, pyrite, rutile, and plagioclase.

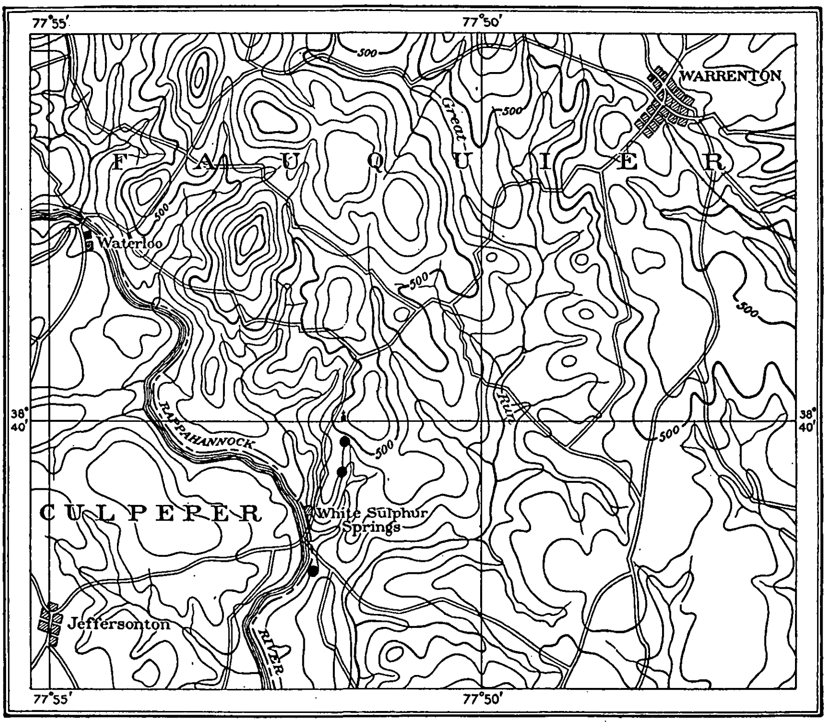
This is a mica slate, probably of the fading series, although it is asserted that slates obtained from this opening when it was made and then put on the courthouse at Amherst and on Kenmore College, in Amherst County, show no discoloration. In comparing the thin sections of this slate with those from the Williams quarry the latter are found to polarize less brightly. In sonorousness, color, and general characteristics this slate closely resembles that of that quarry.

Warrenton, Fauquier County.—There are several prospects in the neighborhood of White Sulphur Springs on the Rappahannock, 6 miles southwest of Warrenton, to which Rogers[1] referred and from which roofing slate was obtained as early as 1837. (See map, fig. 16.)

The following data afford some indications as to the geologic relations: About 1¼ miles south of the springs and 200 feet east and as far west of the road to Routsville there are outcrops of muscovitic quartzite with grains and pebbles of blue quartz up to one-fourth inch across. These beds have an apparent easterly strike and a gentle southerly dip. A little north of this point quartzite slate crops out and continues northward for 2 miles, nearly to the "colored church." Its cleavage strikes N. 25°–30° E., but the slate three-fourths of a mile south of the springs, at the river, strikes about east, like the quartzite farther south. Slate is also said to occur at points

[1] Op. cit., p. 460.

west of the road from the springs to the church. The minimum width of this slate belt is half a mile. North of the church is a greenish metamorphic eruptive consisting of actinolite, zoisite, titanite, and sericitized plagioclase. South of the quartzite are greenish schists, possibly of similar origin. Between the church and Warrenton greenish schists also crop out at several points. They are epidotic actinolite schists, in places with lenses up to 3 by 2 feet and stratiform masses of an epidotic rock containing actinolite, titanite, magnetite, chlorite, and quartz.



Scale of miles 0 1 2 3 4
Contour interval 50 feet

FIGURE 16.—Map of slate prospects in Fauquier County, Va. Slate prospects are shown by round dots.

All these hornblendic and epidotic rocks weather into a bright-reddish soil. This slate is thus related to a quartzitic formation, as well as to certain hornblendic and epidotic rocks, which must be regarded as metamorphosed eruptives.[1] The proximity of the slate to these other formations is so close that nothing can be assumed as to its thickness.

Slate has been prospected at three points, indicated by black dots on the map (fig. 16). One place is seven-eighths of a mile north-northeast of the springs, east of the road to Warrenton, and west of

[1] Rogers (op. cit.) refers to the epidotic rocks.

the beginning of a small brook flowing south into the Rappahannock. The cleavage strikes N. 30° E. and dips 25° W. The plowed fields on the south show a strip of dark-gray soil, from the weathering of the slate, which measures 125 feet across.

The slate is black and, to the unaided eye, has a rather coarse texture, a rough speckled cleavage surface with little luster. It is very carbonaceous, shows pyrite on sawn edges, and has about 220 cubes and lenses of pyrite to the square inch, measuring one-fiftieth of an inch and under; no magnetite; no effervesence with cold dilute hydrochloric acid. It has an argillaceous odor.

Under the microscope this shows no aggregate polarization, but a coarse cleavage, the matrix mainly of carbonaceous matter and quartz fragments with a little muscovite. The quartz grains measure from 0.009 to 0.3 millimeter; a number of plagioclase feldspar fragments up to 0.2 millimeter long. There are lenses and cubes of pyrite coated with quartz, about 4 to the square millimeter; a few scales of chlorite; rare fragments of zircon. No carbonate or rutile detected.

The chief constituents of this slate, named in descending order of abundance, appear to be carbonaceous matter, quartz, muscovite, feldspar, pyrite, and chlorite. This is a clay slate.

At a second locality about half a mile northeast of the springs, the cleavage strikes N. 25° E. and dips 20° W., and the bedding probably strikes N. 12° W. Strike joints trend N. 15° E. and dip 90°; dip joints strike N. 75° W. and dip about 90° but variable. The slate is here covered by 2 feet of black clay and 3 feet of brownish-yellow clay, both of which still show a lamination parallel to the cleavage of the underlying slate and therefore represent different stages in the decomposition of the slate.

This slate is bluish black. To the unaided eye it has a moderately fine texture and cleavage surface, with very few lenses of pyrite and but little luster. It is very carbonaceous, shows pyrite on sawn edge, has no magnetite, does not effervesce in cold dilute hydrochloric acid, is sonorous, and has an argillaceous odor.

Under the microscope this has a matrix of muscovite (sericite) with distinct aggregate polarization but abundant irregular quartz grains from 0.009 to 0.37 millimeter; also some lenses of secondary quartz, much carbonaceous matter, a few lenses of pyrite up to 0.14 millimeter, passing into limonite, and a few grains of plagioclase feldspar. No carbonate or rutile detected.

The chief constituents of this slate, named in descending order of abundance, appear to be muscovite, quartz, carbonaceous matter, and pyrite. Recent excavations are said to show a larger amount of pyrite at a depth of 20 feet than the specimen above described indicates. This is a mica slate.

The third locality is about half a mile south of the springs, on the east bank of the Rappahannock. "Slate" about 40 feet thick is exposed in a small cliff. The strike of cleavage and bedding (?) ranges from N. 80° E. to N. 85° W. and the dip from 12° to 15° S.

This slate is bluish black. It has a coarse crystalline texture and, as accurately described by Rogers,[1] a knotty, wrinkly surface. This is due to the presence of cubical and lenticular cavities once occupied by pyrite but now partly filled with quartz and graphite. These measure from one-fiftieth to three-fiftieths of an inch

[1] Op. cit., p. 460.

and number from 12 to 20 to the square inch. The surface has very little luster. The slate is carbonaceous or graphitic, shows pyrite on the sawn edge, has very little magnetite, contains in places scales of a micaceous mineral up to one twenty-fifth of an inch, does not effervesce in cold dilute hydrochloric acid, has an argillaceous odor, and is very sonorous.

Under the microscope it shows a matrix of carbonaceous or graphitic material, quartz, and muscovite. As the first two predominate the aggregate polarization is rather faint. The cleavage is serpentine, owing to the many large quartz grains (up to 0.14 millimeter) and the cubes and lenses or distorted cubes of pyrite already referred to; most of which seem to be partial pseudomorphs of quartz and graphite after pyrite, the remaining pyrite having been oxidized and dissolved. There are some grains of plagioclase feldspar almost as large as the quartz grains, with graphite inclusions parallel to the multiple twinning. Veinlets of quartz and lenses of secondary quartz occur, usually about or on either side of the cubes and lenses of pyrite; rare grains of zircon. No carbonate or rutile detected.

The chief constituents of this slate, named in descending order of abundance, appear to be carbonaceous matter and graphite, quartz, muscovite, kaolin, pyrite, and feldspar. It seems to be more metamorphic than that of the other two localities, yet to be less micaceous. This is properly a graphite-quartz-muscovite schist, or in process of becoming such.

A piece of this "slate" half an inch thick from the roof of one of the brick outbuildings at the White Sulphur Springs, where it was placed at least 75 years ago, does not show any decomposition but in places has a little limonite coating.

The pyritiferous character of the slate in all these prospects and the sulphurous character of the springs are probably intimately related. Such springs are common in the vicinity of pyritiferous shale and obtain their sulphur from the decomposition of the pyrite by surface water. The indications from the openings and the microscopic examinations are not sufficiently promising to warrant investments.

The principal features of the slate of Virginia, as given in the foregoing descriptions, will be found in tabular form opposite page 188.

WEST VIRGINIA.

The slate district near Martinsburg, in Berkeley County, W. Va., lies within the geologic belt designated Martinsburg shale in the Harpers Ferry folio of the United States Geological Survey. This belt lies about 13 miles west of the Blue Ridge and mostly on the west side of Opequon Creek, a small tributary of the Potomac. It measures at least 2 to 3 miles in width. This shale and clay slate formation, estimated at 700 to 1,000 feet in thickness, is of Ordovician age and overlies the Cambrian-Ordovician Shenandoah limestone in a series of folds represented in the folio as overturned to the west. The rock is generally a dark-grayish shale, weathering into a yellowish or white clay, known locally as "soapstone." At several points, usually near the Opequon or its tributary runs, where the mass has been denuded of its weathered zone, it has a well-marked eastward-dipping (exceptionally westward) slaty cleavage crossing the bedding at various angles, and pieces when struck with a hammer give the typical ring of a slate. The slatiness of the formation is, however, inconstant.

The now disused quarry of the Shenandoah Slate Co., about 3 miles northeast of Martinsburg, is near a small run flowing into the Opequon. In May, 1904, it measured about 100 feet along the strike, 70 feet across it, and 75 feet in depth, of which the "top" took up 25 feet. The bedding strikes N. 25° E. and dips about 15° S. 65° E. The cleavage, with the same strike, dips 75° in the same direction. There are joints striking with the cleavage and dipping 35° S. 65° E., also dip joints striking N. 50° W. and dipping 90°. The beds are small and are separated by darker ribbons. The thickest bed exposed measured 3 feet 6 inches. A diamond-drill core from a hole put down to 40 feet below the bottom of the quarry shows several 3-foot beds.

The slate is black, with a slightly brownish hue. The texture is somewhat fine and the cleavage surface roughish, without any luster whatever. The material is carbonaceous rather than graphitic, contains a little magnetite, shows pyrite on the sawn edge, effervesces with cold dilute hydrochloric acid but less in the ribbon, is somewhat sonorous, and has an argillaceous odor. Under the microscope it shows a matrix consisting of carbonate and carbonaceous matter, and therefore without aggregate polarization, but a cleavage consisting in the parallel arrangement of the carbonate and carbonaceous matter in alternating bands. A very carbonaceous bed (ribbon) crosses the cleavage at an angle of 36°. There are abundant angular quartz grains up to 0.05 millimeter; scales of chlorite interleaved with muscovite, and some of muscovite only; spherules of pyrite up to 0.01 millimeter, numbering from 6,500 to 11,000 to the square millimeter. Rutile was not observed. The amount of carbonate differs in different beds. It may be so abundant as to completely obscure the sericitic matrix. Some of the sections parallel to the cleavage show almost as much muscovite as carbonate and, curiously, a faint aggregate polarization parallel to the bedding or the grain.

The constituents of this slate, named in descending order of abundance, appear to be carbonate, muscovite (in places almost equal in amount to carbonate), quartz, kaolin, pyrite, carbonaceous matter, chlorite, and magnetite. This is a clay slate. The amount of CO_2 (carbon dioxide) in this slate was determined by George Steiger, of the United States Geological Survey, at 1.94 per cent.

An analysis of slate from this quarry, made for the company by Dr. W. C. Tilden, of Washington, shows SiO_2, 62.71; Al_2O_3, 19.40; CaO, 1.11 per cent. It was proposed to use the product of this quarry for mill stock, for which it seems better adapted than for roofing.

The following prospects were noted:

One 2 miles south of Martinsburg, on John Rowe's land, where an opening 30 by 20 feet has been made. Bedding strikes N. 32° E. and dips 60°–65° E.; cleavage strikes N. 23° E. and dips 80° E. A 3-foot bed is in sight.

Another opening has been made on the Opequon, on Light's land, half a mile south-southeast of Bedington. Bedding and cleavage strike N. 20° E., the former dipping 30° E., the latter 55° E. A 3-foot bed is in sight. Under the microscope this slate shows a faint aggregate polarization, fragments of feldspar, and rutile needles.

At an opening on T. F. Bowers's farm, about 4 miles northeast of Martinsburg, the cleavage strikes N. 27° E. and dips 73° W., but the bedding dips east. Under the microscope this also shows a faint aggregate polarization, but carbonate is unusually abundant and evidently obscures the cleavage.

In the brook on John Shedd's farm, 2½ miles south-southeast of Martinsburg, the cleavage strikes N. 20° E. Under the microscope the slate from this place shows a slight aggregate polarization and but little carbonate.

Clay slate has also been found on the McKown & Busey farm, 2 miles N. 10° W. from Middleway, in a brook 2½ miles southeast of Martinsburg, and also on land of J. W. Snyder on the Opequon, 3 miles southeast of Martinsburg, and it will be found in many other places.

Although the proportions of carbonate and muscovite vary in these slates, none of them show a complete sericitization of the matrix. They are all clay slates. The material can therefore hardly possess sufficient fissility or prove sufficiently strong or elastic to compete with mica slates for roofing. Furthermore, the amount of carbonate shown by the microscope, as well as the mode of weathering in the outcrops, indicates its probable discoloration on prolonged exposure, so that it belongs in the "fading" group of clay slates. But these characteristics do not affect its serviceableness for indoor uses.

The principal features of these West Virginia slates are stated in tabular form opposite page 188.

PART III.—ECONOMIC GEOLOGY OF SLATE.

DIFFICULTIES IN SLATE QUARRYING.

The difficulties in slate quarrying are many. Even after the commercial value and the grade of fissility of the slate itself have been fully determined by scientific and practical tests, the opening of a quarry offers serious problems. These concern the thickness of the deposit and of the weathered "top," the character of the jointing, and the presence of faults, shear zones, and dikes. There are also the practical matters of drainage, of the location of dumps, of transportation facilities, and of fuel. The cost of slate at some quarries is increased by the necessity of removing the dumps of former workings, which, for lack of capital or of good judgment, were placed on good slate. The only way to remove some of these old dumps is to throw them into the quarry on one side and hoist them up on the other. In places where the beds are steeply inclined or vertical, one of the walls falls in as the quarry deepens, and the removal of this material entails great expense. The occasional employment of a consulting engineer for the mathematical determination of the points at which supporting walls should be left would obviate mechanical accidents of this nature. (See pp. 76, 78.) The recent introduction of the method of tunneling from the slate quarries of Angers, in France, is a step in advance, as it avoids the cost of removing the "top," furnishes shelter for the workmen in winter and rain, and preserves the moisture in the exposed slate. (See pp. 114, 153.) When the tunnels attain large dimensions the French method of systematic daily inspection of marks set on the walls and roof to detect the slightest indication of any rock movement should also be adopted.[1]

There are also uncertainties of a stratigraphic nature which would be eliminated from many a slate-quarrying venture by the liberal use of the core drill.

BEDDING AND CLEAVAGE—HOW DISTINGUISHED.

Wherever the slates are traversed by "ribbons," or marked changes in color occur and persist through a thickness of several feet, or wherever strips of quartzite or limestone occur at intervals and continue longitudinally for several hundred feet, quarrymen of experience know that they have to do with beds and that the quality of the slate

[1] See Larivière, G., Angers et l'Anjou, Assoc. française avanc. sci., pp. 1-51, 1903.

of any one bed may be expected to continue along that bed, unless some change should occur in the character of the cleavage. The quality of the slate is primarily dependent on the character of the sediment. This changes less frequently in a horizontal than in a vertical direction. The changes in the character of the materials brought into the sea and deposited at one time throughout a moderately large area were fewer than between those brought in at different times at any one spot. Cleavage, being the result of a later compression, may traverse sediments of slightly different composition with little change in direction but will be very much affected by great changes in the material or the grain of the sediment. (See Pl. II, *B*.) The prime factor is, then, the bed; the second factor is the cleavage.

In the southern part of the slate belt of western Vermont, where beds of quartzite or limestone are few and inconspicuous and the difference of color is slight, the distinction between bedding and cleavage is not always easily made. Quarrymen and prospectors sometimes regard them as identical where they really differ. Where the strikes of the bedding and cleavage are divergent, if that of the cleavage is mistaken for that of the bedding, a new opening may easily be made at the wrong point and the bed looked for may be missed. (See fig. 17.) In such places the readiest means of distinguishing cleavage and bedding are as follows: (1) The fossil impressions, trails, or algæ ("wavers") are always on a bed surface; so also are crinoid stems and trilobites. (2) Minute plicated beds of quartz and calcite indicate bedding. (3) A microscopic section transverse to the cleavage, if other means fail, may indicate the amount of divergence between bedding and cleavage, as shown in Plate VII, *C*. Where both are parallel the course of the bedding may be shown by that of lenses or passages of coarser particles of quartz, carbonate, carbon, etc.

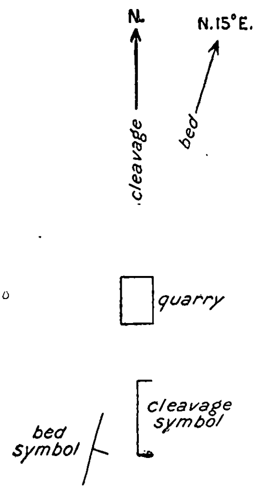


FIGURE 17.—Diagram illustrating the effect of divergence in strike of slate bedding and cleavage.

"FLINTS"—THEIR NATURE AND CAUSE.

Beds of quartzite, which may be calcareous, micaceous, or pyritiferous (see Pl. II, *A*), should never be confounded with veins of quartz (see Pl. V, *A*). In some regions they are both indiscriminately designated by the quarrymen "flints." The quartzite beds are sediments consisting mainly of quartz sand, and, although varying considerably in thickness, are generally more persistent than the quartz veins, which, as has been already shown, are chemical infiltrations into fractures produced at a much later time in consequence of various stresses. Ordinarily the quartzite has a more granular and less glassy surface than the vein quartz. A microscopic section under polarized light will almost always show the difference when ordinary means fail. The importance of not confounding the quartzite beds and the quartz veins lies in this—that while the quartzite beds indicate the direction and thickness of adjacent beds of slate and thus prove helpful, the quartz veins constitute perhaps the most fortuitous and the most pernicious element in slate quarrying. The strains which the slate masses have suffered have been so various that it is almost impossible to foretell the probable presence, course, extent, or thickness of a quartz vein. It should be noted, however, that while the fractures which occasioned the veins are to be looked upon somewhat as accidental, they are the result of stresses affecting large areas or of the complex interactions of pressure in a few definite directions. The course of a vein which is tapering out should be taken with a compass, and another should be somewhat expected in the same line or in directions parallel to it, or at nearly a right angle to it.

RELATIONS OF JOINTS, DIKES, AND SHEAR ZONES.

From the similarity in the courses of the diagonal joints and many of the dikes and shear zones in western Vermont and eastern New York there seems to be a close relation between them. They may all have been produced by the same stress at the same time, in some places the strain resulting in a "hogback," in others in a diagonal joint, and these joints, where very deep, may have given rise to dikes. The practical application of this statement is that the possibility of such a relation should lead the quarryman, whenever he finds diagonal jointing, to suspect the proximity of "hogbacks" and dikes with a similar course, and so with either a "hogback" or a diagonal dike, and this suspicion may sometimes save expenditure of time and labor.

USE OF GEOLOGIC MAP AND COMPASS IN PROSPECTING.

Although the following paragraphs refer particularly to the slate belt of western Vermont and eastern New York—and necessarily so because this is the only slate region that has been mapped by the writer in this way—the general principles and method of procedure are applicable to any slate region where the beds consist of close and more or less overturned folds.

The quarry maps, Plates XX and XXI, are designed to be of practical utility. The coloring shows where the Cambrian green and purple and the Ordovician red slates may be looked for or not looked for. The dovetailing of the Cambrian and Ordovician areas represents to a certain extent structural relations and not mere "accidents" of erosion. Thus, the Jamesville Cambrian belt is closely related to the Cambrian belt which lies east of South Granville.

On the quarry maps the course of bedding and cleavage at several quarries has been shown by special symbols. The scale of these maps is sufficiently large to admit the entry of many more quarries and symbols. By using a small geologic compass to determine the strike of any bed of good slate at any of the located quarries, and transferring the strike to the quarry map by means of a protractor, the probable direction of the recurrence of the bed can be ascertained, and so with joints, "hogbacks," or dikes. Such a compass should be provided with sights, spirit levels, and movable ring to set off magnetic variation and should have a clinometer attachment to indicate angle of dip.

Where, as at West Pawlet (see Section VII, Pl. XXII, and diagrams *A, B, C,* Pl. XXIII), the slate is closely folded, repetitions of the same series of beds may be looked for in an east-west direction at varying intervals. The possibility of the pitching of the axis of a fold in a northerly or southerly direction should be kept in mind. In such folds older or newer beds are traversed in following the direction of the pitch. Where an Ordovician belt abruptly cuts off a Cambrian belt on the north or south, the Cambrian must ordinarily be supposed to plunge under the Ordovician.

From the relations already explained, quarrymen need not be surprised, here and there, as the excavation proceeds, to come upon the Ordovician red and bright-green slates at the bottom of a "sea-green" or "unfading green" quarry, or to come upon these Cambrian slates at the bottom of a red-slate quarry (Sections I, II, V, VI, VII, Pl. XXII).

Quarrymen are very skilled in detecting the presence of good slate from the peculiar appearance of the weathered edge, and that skill appears to have been their only guide in prospecting in this region. It would be well if this skill were reinforced by the use of the following method in exploration:

1. Make reference to a geologic map for the areas in which the various slates may occur.
2. Determine on a quarry map or general map the good slate beds already exploited.
3. Make compass determination of the strike of such beds.
4. Explore along that strike.
5. Explore at right angles to that strike to see if the series is repeated by folding. (Note order of horizons in table on p. 124.)
6. Trench at promising localities across the strike to expose as large a series as possible.

7. Where surface indications are favorable, make an opening large enough to determine the angle of dip of both bed and cleavage and to obtain specimens sufficient for the tests given on pages 172–179.

8. Bore with diamond or steel-shot drill at 45° to cleavage dip, so that the core will split up into elliptical pieces sufficiently larger than diameter of core to be conveniently tested.

9. Measure thickness at right angles to bedding planes on the core.

The map of the slate district near Slatington, Pa. (Pl. XVI), upon which the quarries are carefully located and the strike and pitch shown, is also designed for practical use.

TECHNICAL DESCRIPTION OF A SLATE QUARRY.

The following outline of a description of a slate quarry is proposed as covering the features of practical geologic and economic importance, aside from the ordinary statistical matters as to amount and value of product, number of employees, etc.:

Quarry name or number.
Location (exact).
Geologic formation as given on the geologic map.
Distance from railroad and means of transporting product.
Diagram of plan of quarry to scale.
Depth of quarry.
Dimensions of working face.
Distance and direction of dumps from working face.
Means of drainage.
Number of hoists or of horse derricks.
Number of carriers.
Number of channelers.
Number of slate saws.
Capacity of air compressor.
Number of slate-trimming machines.
Kinds of slate produced.
Thickness of good and bad beds in natural order.
Diagram showing course of beds.
Strike and dip of beds.
Strike and dip of cleavage.
Bends or curvature of cleavage.
Strike and dip of strike, dip, and diagonal joints.
Curvature of joints.
Strike and dip of grain.
Strike and dip of slip cleavage.
Strike and dip of shear zones.
Location and diameter of "posts" and supports.
Proximity of dikes.
Course and thickness of veins.

METHODS OF TESTING SLATE.

Methods of testing the elasticity, absorption, fissility, and resistance of roofing slates have been in use for many years, and many more or less complete chemical analyses of slate have been published. In recent years, however, more exact methods of reaching these results have been devised. All such methods have here been brought together. If parts of one specimen, fairly representing the average quality of the product of any quarry or prospect, or if parts of each of a series of specimens, fairly representing all the different varieties and qualities there obtained, are subjected respectively to the tests described, such a slate or slates may be said to have been for all economic purposes exhaustively investigated. Several of these tests are of so simple a character as to be very easily applied. This list of methods is largely compiled from Böttinger, Fresenius, Hutchins, Jannetaz, Merriman, Reverdin and De la Harpe, Sorby, Umlauft, and J. F. Williams.[1] Although they all offer valuable suggestions, the most useful papers on the subject are those of Fresenius, Umlauft, and Merriman.

Sonorousness.—One of the first and most time-honored tests of roofing slate is to suspend a good-sized piece of the usual thinness and tap it with some hard object. If it possesses the molecular structure of a slate it will yield a semivitreous ring. A clay slate will be less sonorous than a mica slate, but mica slates with a large percentage of chlorite and possibly a little talc will be deficient in sonorousness. It is because of this property that when at the quarries refuse slates are thrown upon the dumps the sound produced is not unlike that made by the smashing of a large quantity of crockery.

Cleavability.—The test for cleavability should be applied by an experienced workman. The block should be freshly quarried, unfrozen, and moist. The chisel should be very thin and about 2 inches wide. The cost of slate is closely related to the degree of its cleavability. The cleavage face of a freshly cleft slate with a high grade of fissility usually shows extremely delicate partly detached scales of slate lying parallel with the cleavage.

Cross fracture (*"sculping"*).—This test to determine the character of the "grain" should also be applied by an experienced man to a large block several inches thick, with a stout chisel and a long-handled heavy mallet. Jannetaz[2] published a method for determining with scientific precision the direction of the grain in slate in which it is but obscurely shown on the cleavage surface. The slate is sawn in a direction parallel to its cleavage and one of the sawn surfaces is made exceedingly smooth and covered with an even and very thin coat of grease. The point of a red-hot platinum wire is applied to the slate opposite the center of the greased surface. The greased area reached by the heat will, in cooling, leave an oval outline, the long axis of which will show the direction of the grain, the heat having traveled

[1] Full titles are given in the economic bibliography, pp. 210–213.

[2] Jannetaz, E., Relation entre la propagation de la chaleur et l'élasticité sonore dans les roches, p. 417, 1877.

more rapidly within the slate in the direction of the grain than in any other. He also made a disk of slate 5 inches in diameter, of ordinary thickness, with a central perforation. This disk was fastened by the extremities of the diameter parallel to the grain and afterwards by that at right angles to the grain, and was made to vibrate by tapping the side of the perforation. The sound produced when the disk was fastened by the diameter at right angles to the grain was louder than when fastened by that parallel to it. In other words, the direction of the grain was that in which elasticity and vibration were greatest.

Character of cleavage surface.—The cleavage surface should be examined with an ordinary magnifying glass. If the grain is pronounced, it will appear in fine transverse lines. If slip cleavage, which is generally a cause of weakness, is present, it can usually be detected on the cleavage surface. Ribbons, which are sometimes lines of weakness, should be noted. There is great difference in the smoothness of the surface in slates of different regions. Ordinarily the constituent minerals ought not to be visible. Minute lenses or crystals are not necessarily detrimental, but they retain dust and thus afford a foothold for mosses and other cryptogams, which gather moisture and thus aid the decomposition of the slate.

Presence of lime.—The presence of lime can be determined by the application of cold dilute hydrochloric acid to the edges of a freshly quarried slate or still better to the powdered slate. Rapid effervescence implies the presence of carbonate of lime; slow, that of a lesser quantity of it or of dolomite—carbonate of lime and magnesia. Reverdin and De la Harpe [1] call attention to the fact that good slate may have a high percentage of calcium carbonate, while others free from it may be poor. But it is nevertheless true that slates containing a high percentage of lime must, other things being equal, in time be acted upon more powerfully by the acids of the atmosphere than those with little or no lime.

Color and discoloration.—The color of the freshly quarried slate should be noted and compared with that of pieces exposed for several years to the weather, either on a roof or on the quarry dumps, or with that at the top of the quarry close to the gravel, although this last comparison may not always be perfectly conclusive. The value of slates is somewhat affected by the extent of their discoloration.

Presence of clay.—By breathing upon a fresh and clean piece of slate and observing whether there is any argillaceous odor the presence of clay will be detected. The very best slate will not emit any such odor.

Presence of marcasite.—A slate containing lenses or crystals of a pale-yellowish metallic mineral which, on exposure, decomposes,

[1] Reverdin, F., and De la Harpe, C., Chem. Zeitung, vol. 14, pp. 64–65, 94–95, 126–127.

forming a yellowish-white film and rusty spots, is poor;[1] but pyrite in small quantity is not necessarily detrimental, for it does not decompose readily. It is present in nearly all slates, particularly in black slate.

Presence of magnetite.—Since slate has come to be used so largely in electric appliances the determination of the relative abundance of magnetite has become of practical importance. A cubic inch of the slate should be weighed, broken up, and reduced to a fine powder in an agate motor or else between sheets of zinc or copper and then spread on a flat surface and thoroughly traversed by a strong magnet and the extracted magnetite weighed. The quantity of magnetite, by weight, in a cubic inch of slate can thus be determined.

Electric resistance.—The electric resistance of slate is governed in part by the scarcity of magnetite and in part probably also by the character of bedding, cleavage, and grain. The tests applied by Prof. W. N. Gladson, of the University of Arkansas, to Arkansas slates can be used. The object of these tests is to determine the adaptability of the slate for electric switchboards.

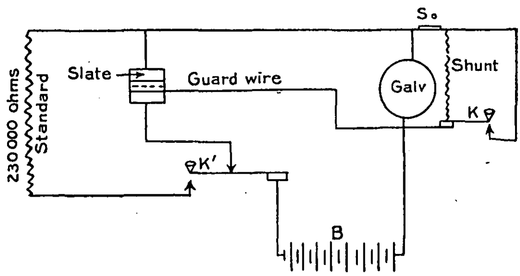


FIGURE 18.—Diagram showing electric connections made in testing slate, by W. N. Gladson.

The following description of these tests is taken from a report by Purdue:[2]

These pieces of slate were tested in comparison with three pieces of gray slate taken at random from old switch bases in the university electric laboratory. A piece 1 centimeter cube was cut from each sample and these were numbered consecutively from 1 to 9, Nos. 1, 3, and 4 being gray slate. In preparing the cubes metallic particles were found in samples 4 and 6, and Nos. 5 and 6 were so easily split that it was difficult to obtain a centimeter cube.

The pieces of red slate as received were smooth blocks 4 by 5 inches by five-eighths of an inch, neither varnished nor in any way filled. They were red or reddish brown, were much softer than the gray slate, and split much more readily. All samples tested were dry and appeared to be seasoned. The method of measuring the resistance of these centimeter cubes was as follows:

A block of paraffin wax was attached to the center of a glass plate, which in turn was thoroughly insulated from the table by glass strips piled across one another. In the top of the paraffin block an opening was cut 1 centimeter square and about 3 millimeters deep. In the bottom of the cavity thus formed four copper supports were embedded so that their top surfaces were in the same plane, about 1 millimeter below

[1] See Julien, A. A., On the variation of decomposition in the iron pyrites; its cause, and its relation to density: New York Acad. Sci. Annals, vol. 3, pp. 365-403, 1886; vol. 4, pp. 125-221 and Pls. VIII, IX, 1887. Brown, A. P., On marcasite and pyrite; a comparative study of the chemical behavior of pyrite and marcasite: Am. Philos. Soc. Proc., vol. 33, pp. 225-243, 1894. Stokes, H. N., On pyrite and marcasite: U. S. Geol. Survey Bull. 186, 1901.

[2] Purdue, A. H., The slates of Arkansas: U. S. Geol. Survey Bull. 430, pp. 329-330, 1910.

the top of the paraffin cup. A drop of mercury coming about flush with the copper supports in this cavity formed one terminal for making electric connection to the slate cube. Contact with the opposite face was made by placing a well-amalgamated zinc plate 1 centimeter square on top of the cube. This arrangement insured equal contact with each slate cube under test.

The galvanometer used was of the D'Arsonval type and had a working constant of 70,533 millimeters on the scale 1 meter distant through 1 megohm resistance. The electromotive force was furnished by storage cells and was kept constant at 42 volts during the experiment. The connections were made as shown in figure 18.

To avoid leakage over the surface of the slate a guard wire was connected as shown. All readings were taken after the deflections became constant; in some tests they did not become so until half an hour after electrification.

The results of the test are shown in the following table, from which we find the average resistance of all samples to be 1,224.2 megohms per cubic centimeter. The average resistance of the three gray samples was 1,180, and of the six red-slate samples 1,267.8 megohms per cubic centimeter. Each piece tested, except No. 7, shows a different resistance between each pair of opposite parallel faces, which seems to depend on the plane of cleavage. The gray-slate samples show a decidedly higher resistance between faces of cubes perpendicular to cleavage planes, but in individual samples the distribution of resistance would be greatly affected by the presence of foreign conducting particles or seams, which are likely to be present in all slate.

Results of tests of electric resistance of samples of slate from Arkansas.

Sample No.	Galvanometer scale deflections.			Resistance.[a]		
	Perpendicular to cleavage planes.	Parallel to cleavage planes.		Perpendicular to cleavage planes.	Parallel to cleavage planes.	
	D	D′	D″	R	R′	R″
	Mm.	*Mm.*	*Mm.*	*Megohms.*	*Megohms.*	*Megohms.*
1	39.0	40.0	44.0	1,808.5	1,763.3	1,603.0
2	98.0	174.0	625.0	719.7	405.3	67.1
3	171.0	185.0	283.0	414.9	381.2	249.2
4	35.0	94.0	43.0	2,015.3	750.4	1,640.3
5	104.0	47.7	39.9	678.2	1,476.3	1,767.1
6	338.9	28.0	88.0	208.1	2,519.0	801.5
7	91.0	91.0	48.0	775.0	775.0	1,469.4
8	57.0	51.0	27.0	1,500.7	1,383.0	2,612.3
9	45.0	33.0	36.0	1,567.4	2,137.3	1,959.2

[a] R, R′, and R″ correspond to the directions D, D′, and D″, respectively.

Average of Nos. 1, 3, and 4 (gray slate), 1,180.6 megohms per centimeter cube.
Average of Nos. 2, 5, 6, 7, 8, and 9 (red slate), 1,267.8 megohms per centimeter cube.
Average of all samples, 1,224.2 megohms per centimeter cube.

Strength.—Merriman's apparatus for testing the strength of slate is described in his paper:[1]

The pieces were supported in a horizontal position upon wooden knife-edges 22 inches apart, and these loads were placed upon another knife-edge halfway between the supports. This load was applied by means of sand running out of an orifice in a box

[1] Merriman, Mansfield, Am. Soc. Civil Eng. Trans., vol. 27, Nos. 3 and 6, 1892; vol. 32, pp. 529-539, 1894. An extended abstract of Merriman's paper is given by W. C. Day in part 6, continued, of U. S. Geol. Survey Nineteenth Ann. Rept., pp. 257-263, 1898. On p. 182 of this bulletin the results of his recent tests of 33 specimens of slate are given.

at the uniform rate of 70 pounds per minute, and by the help of an electric attachment the flow was stopped at the instant of rupture.

He computes the modulus of rupture by the use of the formula $S=\frac{3wl}{2bd^2}$, in which w is the load in pounds which causes the rupture, l the distance between the supports in inches, b the breadth, and d the thickness of the plate in inches. S is the number of pounds to the square inch. According to these tests the modulus of rupture in the best slate should range from 7,000 to 10,000 pounds.

J. F. Williams[1] made tests of compression and elastic limit on purple, red, and green slates from Rutland and Washington counties. His results give a modulus of rupture ranging from 7,310 to 10,800 pounds to the square inch. Campbell and Donald[2] give 20,000 pounds as the crushing weight for 1 cubic inch of slate. Wilkinson, in his "Practical geology of Ireland," gives 30,730 pounds as the crushing weight of the Killaloe slates.[3] Watrin[4] gives the maximum crushing weight of some French slates as 2,000 kilograms to the square centimeter, but 1,700 as the average.

Merriman has also devised an impact test for determining the strength of slates. He lets a wooden ball weighing 15.7 ounces fall 9 inches upon a piece of slate measuring 6 by 7¾ inches and from 0.20 to 0.28 inch thick, and repeats the blows until the slate breaks. The foot-pounds of work to the pound of slate are then calculated from the weight and thickness of the slate and the number of blows. The resulting figures range from 3.50 to 126.66.

Toughness or elasticity.—Merriman finds the ultimate deflection in certain Pennsylvania slates, when placed on supports 22 inches apart, to range from 0.270 to 0.313 inch. Certain blue-black slates of Eldorado County, Cal., when split seven to the inch and 18 inches square and fastened solidly at the two ends are said to bend 3 inches in the center without any sign of fracture.[5] J. F. Williams[1] tested beams of slate from Rutland and Washington counties, 1 inch square and 10 inches long, with supports 6 inches apart. Bending without breaking was effected by a pressure of 770 to 1,200 pounds, and when the supports were placed 3 inches apart by 1,710 to 2,400 pounds. The great elasticity of the slates of western Vermont and of Northampton and Lehigh counties, Pa., is apparent to anyone visiting the shanties where the splitting is done.

Density or specific gravity.—The specific gravity is determined in the usual way, by weighing a piece of the slate in and out of water and

[1] Van Nostrand's Eng. Mag., vol. 31, pp. 101-103, 1884.
[2] Encycl. Brit., 9th ed., 1887.
[3] Quoted by Hull, Edward, A treatise on the building and ornamental stones of Great Britain, etc., 1872.
[4] Watrin, N., Les ardoisières des Ardennes, pp. 192, 193, 1898.
[5] Crawford, J. J., California State Min. Bureau, Twelfth Rept., p. 400, 1894.

dividing its weight out by the difference between its weight in and out. All air should first be removed by boiling the piece of slate in distilled water. The specific gravity will be considerably affected by the amount of magnetite or pyrite.

Porosity.—The porosity is best determined by drying, then weighing, then immersing for 24 hours and weighing again, in order to ascertain the percentage of water absorbed. Merriman takes a piece 3 by 4 inches, with rough edges, dries it in an oven at 135° F. for 24 hours, cools to the normal temperature of the room, weighs, immerses it for 24 hours, and weighs again. His tests of Pennsylvania slates showed from 0.099 to 0.303 per cent of absorption. Porosity is sometimes roughly indicated by immersing a roofing slate edgewise one-half in water and observing how far the water ascends by capillary attraction. In good slates it ought to rise but very little.

Reverdin and De la Harpe [1] state that slates are liable to deterioration from the chemical action of gases arising from woodwork beneath the slate, as well as from the action of the atmosphere, and that they are also liable to an increase of porosity by the physical action of changes of temperature and by the unequal conductivity of heat in the direction of cleavage and of grain. They state that the porosity in a fresh slate should be below 0.1 per cent, or after treatment less than 0.2 per cent. Their somewhat elaborate method is this: For determining porosity as produced by acids the slate is treated with 10 per cent cold acetic acid and the flask is made vacuous from time to time. The piece is then washed, dried, weighed, and immersed in diphenylamine in a thick-walled tube 12 by 3½ centimeters. The tube is exhausted and then heated two hours in an oil bath at 170° C., air pressure is restored, and heating is continued for four to five hours at 150° C., after which the test pieces are removed, the diphenylamine wiped off with ether, and the increase in weight taken.

For determining porosity as produced by changes of temperature, the slate is heated in a wrought-iron tube for half an hour to 300° C., and the tube is then suddenly cooled by a stream of water for half an hour. This process is repeated 24 times, and the slate is then impregnated with diphenylamine and the procedure is as in the previous test.

Fresenius is accredited with a method of testing the effect of heat and cold on slate by saturating it with water and putting it for 24 hours in a freezing mixture and heating another piece from 250° to 350° for five or six hours and then immersing it in water. The porosity, strength, and elasticity of the pieces so treated should then be tested. Böttinger points out that the greater the porosity of a slate the more damaging is the action of frost likely to be. The effect of

[1] Op. cit.

frost on the microscopic structure has already been referred to (p. 35).

Hardness or abrasion.—Merriman has also devised a method of testing the relative hardness of slates by subjecting a piece of determined weight to the action of a grindstone revolved 50 times, the slate being held against it by a lever with a constant pressure of 10 pounds. The loss of weight in the process was then determined. As the softness depends largely upon the amount of quartz and mica, a microscopic analysis would also throw light upon this quality.

Corrodibility.—An important quality in roofing slates is their resistance to the acids of the atmosphere, particularly in cities, where gases increase the destructive power of these acids. Fresenius in 1868 suggested testing the weathering qualities of a slate by immersing it for three days in dilute sulphurous acid in a closed vessel. At the end of that time poor slates are softened or broken up into thin laminæ or easily fractured, but good ones preserve both their density and hardness.

Merriman for the same purpose prepared a solution consisting of 98 parts of water, 1 part of hydrochloric acid, and 1 part of sulphuric acid. Pieces of slate 3 by 4 inches were carefully weighed, then immersed in the solution for 120 hours, then dried for 40 hours, weighed, the solution strengthened, and the pieces reimmersed for another 120 hours and weighed again. This was repeated once more. The losses in weight ranged from 0 to 2.76 per cent.

Microscopic analysis.—One of the most satisfactory tests of slate is the examination of a thin section of it under the microscope. A cubic inch thus tested will suffice to show the character of the cleavage, the presence of slip cleavage, if any, the probable durability or non-durability of the color, as well as the presence of any mineral constituents likely to determine its other qualities. The specimen should be carefully selected, so as to fairly represent the general quality of the bed. It should be fresh, unfrozen, and half an inch thick across the cleavage. At least two sections should be prepared—although the more the better—one parallel to the cleavage and another at right angles to it, never diagonal to it. The sections should be exceedingly thin, much thinner than ordinary sections of eruptive rocks, and the slide cover should be of the very thinnest kind and should be fastened on with a minimum of balsam to admit the use of the highest objectives. Both slides should be examined first in ordinary light and then in polarized light, with powers ranging from 140 to 700 or even 1,100 diameters. The transverse section will show the quality of the cleavage, the slip cleavage, if any, and, under polarized light, whether the specimen is a mica slate or a clay slate, by the entire matrix becoming in a mica slate four times dark and four times light in complete rotation. The observer should not be misled, however, by the obscuration of aggregate polarization caused by the abundance of carbonaceous matter or carbonate or hematite. The carbonate, which extinguishes irregularly, is very troublesome. It could be eliminated by the application of hydrochloric acid to the bare section and then re-covering it. The aggregate polarization may also be obscured by the thickness of the section and the whole analysis thus vitiated. Sections parallel to the cleavage reveal the amount of carbonate and indicate the probable amount of discoloration by exposure. Both sections, under incident light, will show pyrite, if any exists. If the carbonate contains no ferrous carbonate a thin section cut parallel to the cleavage of a long-exposed roofing slate and ground down almost entirely from the back so as to bring the exposed surface next to the slide will show the carbonate free from brownish discoloration.

The following passage translated from an abstract of J. Hirschwald's exhaustive work on the testing of building stones[1] will be found useful in the microscopic examination of roofing slate:

The microscopic examination of roofing slates, which is best made with sections at right angles to the cleavage, shows that the textural variations of slate depend mainly on the development of the mica layers. The mica itself either occurs in thick-leaved lamellæ of dark color with the optical properties of biotite (magnesia mica) or it appears faint yellowish to colorless and then always makes up fine scaly aggregates, but sometimes very much streaked thin lamellæ. The scaly aggregates resemble phlogopite (the ironless magnesia mica); the streaked lamellæ resemble sericite (fibrous muscovite). Besides these there are chloritic varieties. Some of the mica is of uniform color, and some spotted to opaque. This may be due to magnetite or to coaly matter. In the latter case the black spots are not sharply bounded, but have merging outlines; and this is also true of the general outline of the mica lamellæ when strongly impregnated with coal. If the mica is in continuous layers, as it usually is in the good slates, it prevents access of water from the surface. It not only protects the other constituents that lie between the mica layers from the dissolving, softening, and decomposing effect of water, but the inner part of the slightly dampened slate is not as much exposed to the action of frost as it would be in slates greatly saturated with water. When the mica is less abundant it makes up discontinuous layers or in the inferior slates quite separate little lamellæ. These admit water freely from the cleavage face and consequently more solution takes place, more decomposition of any content of pyrite, and especially more frost action. Those slates that contain mica in separate scales, even where continuous mica layers have been developed, show an increased absorption and thus greater evidence of decomposition, and are therefore among the least valuable slates.

But there is still another difference in the development of the mica layers. In some slates these possess a remarkable parallelism of arrangement; in others they are more or less fibrous, the mica enveloping the other constituents in lenses, and in this way a close connection is brought about at short intervals between the separate mica layers. In the slates of the first type, water gains free access laterally from the edge of each slate by capillary attraction and distributes itself between the mica layers, and such slates easily scale under the action of frost. But in the slates of fibrous texture such lateral admission of water can occur only to a very slight extent, and as the

[1] Zeitschr. prakt. Geologie, vol. 16, pp. 387-389, 1908.

continuous and mostly well-developed layers of mica prevent the entrance of water from the cleavage surface any considerable frost action is shut out. When, after the lapse of centuries, such fibrous slates finally weather they show but little exfoliation and in many cases only scaly disintegration. Very micaceous slates of fibrous texture are among the best roofing materials if their mica is in homogeneous layers and not in the loose scaly aggregates above described.

But slates poor in mica may be tolerably durable if they are strongly silicified. The clayey material thus acquires considerable hardness and affords a corresponding resistance to the softening effect of water.

Coaly slates belong in a special class. In some the coaly substance is only interleaved with the mica layers, which, under the microscope, appear intensely black and opaque and have peculiar intergrown borders, while the other constituents are quite transparent. In others the coaly matter is distributed either evenly or in single irregularly disseminated spots throughout the slate mass. All coaly varieties of slate are inferior, because the coal is hygroscopic and thus opens the mica layers so that they fail to protect the intervening matter from the operation of water. As stated, the black inclusions may also consist of magnetite, which does not possess the deleterious property of the coaly constituent. As both of these substances and the usually associated pyrite are equally opaque it is important when other means fail to distinguish them microscopically. The simplest way is to examine the section under incident light, preferably lamplight. The coaly matter will then appear intensely black, the magnetite bright gray with metallic luster, but the pyrite a bright golden yellow. This method is also serviceable in distinguishing the other constituents of slate, as, for instance, quartz and feldspar. The quartz is water clear, but the feldspar is more or less cloudy according to its degree of decomposition.

The above extract is an important supplement to the microscopic notes in this bulletin. Although some of the slates described probably differ from the American slates, they may yet be found here, and the observations are discriminate and the methods suggestive.

Chemical analysis.—In order to give a correct idea of the composition of the slate, the chemical analysis should not be partial but complete.[1] Such analysis should then be compared with complete analyses of the best slates of like color. Its microscopic analysis and the results of the tests of its strength, elasticity, porosity, and corrodibility should be considered in connection with its chemical analysis. Merriman[2] concludes from six different kinds of tests applied to each of 24 specimens of slates from the "Old Bangor" and Albion quarries of Pennsylvania, as well as from the results of several general chemical analyses, that—

The strongest slate stands highest in weathering qualities, so that a flexural test affords an excellent index of all its properties, particularly if the ultimate deflection and the manner of rupture be noted. The strongest and best slate has the highest percentage of silicates of iron and alumina, but is not necessarily the lowest in carbonates of lime and magnesia. Chemical analyses give only imperfect conclusions regarding the weathering qualities of slates and do not satisfactorily explain their physical properties.

[1] See, on the advantages of complete analysis, Hillebrand, W. F., Principles and methods of analysis applied to silicate rocks: U. S. Geol. Survey Bull. 148, pp. 1-64, 1897; The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 422, 1910.

[2] Op. cit.

As the discoloration in slate has been shown to be probably due to the oxidation of the ferrous carbonate ($FeCO_3$), one of the chief objects of a chemical analysis should be to show the amount or absence of the carbonate, but this is just what a chemical analysis can not do with so complex a rock. It rarely happens that the chemical analysis of a slate affords conclusive evidence as to its commercial value. The value of such analysis is quite subsidiary to that of the microscopic examination. This was practically demonstrated in the West Virginia clay slate district, where investments were made and a quarry was opened largely on the basis of a chemical analysis, and what could have been learned from the study of a few thin sections was not ascertained until it was too late.

Hutchings[1] finds that the presence of chlorite minerals can be detected by heating the slate to dull redness, thus dehydrating and discoloring those minerals, then preparing a thin section of the slate so treated and comparing it with sections of the normal rock.

The most decisive of all these tests are probably those for strength and toughness, as applied by Merriman, and the microscopic analysis.

It should be added that shearing, compression, and expansion tests of slate were formerly made at the United States Arsenal at Watertown, Mass., and that transverse and absorption tests are now made by the United States Bureau of Standards. (See p. 189.)

TESTS OF CERTAIN MAINE, NEW YORK, PENNSYLVANIA, VERMONT, AND VIRGINIA SLATES.

By Mansfield Merriman.

Physical tests of some of the slates described in this bulletin were made for the United States Geological Survey at Lehigh University, South Bethlehem, Pa., in 1905.

The following is a report of the results of the tests of 33 specimens of roofing slate received at our laboratory from May 6 to May 13, 1905. The tests have been made according to the methods described in my paper on "The strength and weathering qualities of roofing slates."[2]

All the specimens were 12 by 24 inches in size. The following is a statement of the marks placed upon them and of their mean thicknesses:

C1, C2, C3, C4 designate four blue slates from the Chapman Slate Co., Chapman quarries, Pennsylvania, the mean thicknesses being 0.228, 0.204, 0.216, 0.222 inch, respectively.

W1, W2, W3, W4 designate four blue slates from the Williams Slate Co., Arvonia, Va., the mean thicknesses being 0.202, 0.195, 0.206, 0.263 inch, respectively.

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[1] Hutchings, W. M., Clays, shales, and slates: Geol. Mag., dec. 4, vol. 3, Nos. and 8, 1896.
[2] Am. Soc. Civil Eng. Trans., September, 1892.

P1, P2, P3, P4 designate four blue slates from A. L. Pitts, Arvonia, Va., the mean thicknesses being 0.232, 0.200, 0.204, 0.194 inch, respectively.

B1, B2, B3 designate three blue slates from the Merrill Brownville Slate Co., Brownville, Me., the mean thicknesses being 0.220, 0.195, 0.210 inch, respectively. A fourth piece sent by this firm was accidentally broken.

Mo1, Mo2, Mo3, Mo4 designate four blue slates from Monson Consolidated Slate Co., Monson, Me., the mean thicknesses being 0.238, 0.227, 0.237, 0.225 inch, respectively.

V1, V2 designate two green slates from Vermont Unfading Green Slate Co., Fair Haven, Vt., the mean thicknesses being 0.222, 0.262 inch, respectively. Two other pieces sent by this firm were found broken in the package.

R1, R2, R3, R4 designate four green slates from Rising & Nelson Slate Co., West Pawlet, Vt., the mean thicknesses being 0.260, 0.167, 0.224, 0.213 inch, respectively.

M5, M6, M7, M8 designate four green slates from Mathews Consolidated Slate Co., Boston, Mass., the mean thicknesses being 0.194, 0.222, 0.187, 0.205 inch, respectively. The labels on these slates were marked "Quarry N. E."

M1, M2, M3, M4 designate four red slates from Mathews Consolidated Slate Co., Boston, Mass., the mean thicknesses being 0.190, 0.180, 0.174, 0.186 inch, respectively. The labels on these slates were marked "Quarry E."

The following table gives the results of the tests of the 33 specimens for strength, toughness, density, softness, porosity, and corrodibility, and also the means for each of the nine different kinds of slate:

Tests of roofing slates.

Color and firm.	Mark on specimen.	Strength—modulus of rupture in pounds to the square inch.	Toughness—ultimate deflection in inches on supports 22 inches apart.	Density—specific gravity.	Softness—amount in grams abraded by 50 turns of a small grindstone.	Porosity—per cent of water absorbed in 24 hours.	Corrodibility—per cent of weight lost in acid solution in 63 hours.
Blue;[a] Chapman Slate Co.	C1	8,410	0.21	2,775	0.171	0.221	0.336
	C2	12,490	.24	2.780	.218	.290	.301
	C3	7,420	.16	2.734	.234	.150	.560
	C4	9,540	.24	2.766	.213	.263	.334
	Mean	9,460	.212	2.764	.208	.231	.383
Blue;[b] Williams Slate Co.	W1	8,590	.17	2.788	.073	.105	.281
	W2	8,250	.19	2.754	.038	.090	.801
	W3	10,700	.31	2.795	.097	.209	.223
	W4	8,620	.24	2.788	.033	.167	.270
	Mean	9,040	.227	2.781	.060	.143	.394

[a] Designated "very dark gray" in table opposite page 188.
[b] Designated "very dark greenish gray" in table opposite page 188.

Tests of roofing slates—Continued.

Color and firm.	Mark on specimen.	Strength—modulus of rupture in pounds to the square inch.	Toughness—ultimate deflection in inches on supports 22 inches apart.	Density—specific gravity.	Softness—amount in grams abraded by 50 turns of a small grindstone.	Porosity—per cent of water absorbed in 24 hours.	Corrodibility—per cent of weight lost in acid solution in 63 hours.
Blue;[a] A. L. Pitts	P1	8,540	0.25	2.805	0.095	0.332	0.248
	P2	9,010	.18	2.790	.159		.552
	P3	11,970	.25	2.788	.138	.154	.275
	P4	9,880	.22	2.781	.038	.163	.218
	Mean	9,850	.225	2.791	.108	.216	.323
Blue;[b] Merrill Brownville Slate Co	B1	8,860	.17	2.790	.243	.189	.366
	B2	9,050	.21	2.804	.360	.128	.284
	B3	11,720	.22	2.799	.192	.128	.264
	Mean	9,880	.200	2.798	.265	.148	.305
Blue;[b] Monson Consolidated Slate Co	Mo1	9,500	.24	2.796	.234	.181	.282
	Mo2	11,370	.22	2.795	.302	.181	.384
	Mo3	7,000	.19	2.794	.271	.206	.234
	Mo4	8,640	.17	2.791	.218	.186	.243
	Mean	9,130	.205	2.794	.256	.188	.286
Green; Vermont Unfading Green Slate Co	V1	6,250	.19	2.783	.326	.300	.277
	V2	6,580	.26	2.759	.356	.162	.313
	Mean	6,410	.225	2.771	.341	.231	.295
Green; Rising & Nelson Slate Co	R1	6,790	.24	2.750	.184	.429	.433
	R2	11,040	.22	2.740	.183	.220	.722
	R3	3,470	.13	2.733	.209	.365	1.067
	R4	7,700	.24	2.700	.185	.286	.849
	Mean	7,250	.207	2.736	.190	.325	.768
Green;[c] Mathews Consolidated Slate Co	M5	7,090	.22	2.783	.286	.376	.413
	M6	5,470	.15	2.782	.203	.409	.265
	M7	10,130		2.786	.244	.360	.428
	M8	9,490	.20	2.781	.172	.351	.409
	Mean	8,050	.190	2.783	.226	.374	.379
Red; Mathews Consolidated Slate Co	M1	6,850	.18	2.834	.069	.153	.249
	M2	9,870	.27	2.853	.099	.251	.425
	M3	11,340	.25	2.853	.119	.334	.507
	M4	8,820	.23	2.853	.304	.235	.311
	Mean	9,220	.232	2.848	.148	.243	.373

[a] Designated "very dark greenish gray" in table opposite page 188.
[b] Designated "very dark gray" in table opposite page 188.
[c] Designated "bright green" in table opposite page 188.

The results given, with the exception of those for softness, may be compared with the results for the slates of the Bangor, Pen Argyl, Lehigh, and Peach Bottom districts, given in my papers published in Transactions of the American Society of Civil Engineers for September, 1892, and December, 1894, and in Stone for July, 1898. The results above given for softness are comparable with one another, but can not be compared with those in the papers cited; this is due to the circumstance that the former grindstone has been destroyed by fire and that the one selected to replace it has a much smaller abrading capacity.

TESTS OF SLATES FROM ARKANSAS.

Specimens of slates from Arkansas, collected by Prof. A. H. Purdue, were subjected to various physical tests at the United States Geological Survey laboratory at St. Louis. The results of these tests, published in Survey Bulletin 430, are repeated here for reference.

Source and color of slate samples tested.

No.	Owner.	Locality.	Color.
1	Southwestern Slate Mfg. Co.	East line of NE. ¼ SE. ¼ sec. 33, T. 3 S., R. 27 W.	Red.
2	do	do	Green.
3	M. J. Harrington	Sec. 24, T. 3 S., R. 29 W.	Black.
4	Southwestern Slate Co.	SE. ¼ SE. ¼ sec. 33, T. 3 S., R. 27 W.	Red.
5	M. J. Harrington	Sec. 24, T. 3 S., R. 29 W.	Black.
6	M. W. Jones	do	Green.
7	do	do	Do.
8	do	do	Red.
9	do	do	Reddish brown.
10	do	do	Red.
11	C. B. Baker	NE. ¼ sec. 18, T. 3 S., R. 28 W.	Buff.
13	M. W. Jones	Sec. 24, T. 3 S., R. 29 W.	Red.

Results of physical tests on slates from Arkansas.

Field No.	Register No.	Individual specimen No.	Transverse tests. Dimensions. Width.	Depth.	Span.	Conditions at maximum load. Load at center.	Deflection at center.	Modulus of rupture.	Modulus of elasticity (constant nearly to maximum).	Absorption tests. Weight ratio of absorption. 30 minutes.	24 hours.	48 hours.	Volume ratio of absorption. 30 minutes.	24 hours.	48 hours.	Specific gravity. True.	Apparent.	Absolute porosity.[a]	Weight per cubic foot.
			Inches.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Lbs. per sq. inch.*											*Pounds.*
1	Misc. 141	1	2.00	0.95	9	322	0.0190	2,410	2,100,000	0.0017	0.0189	0.0189	0.0047	0.0511	0.0513	2.863	2.714	....	169.1
		2	1.98	.97	9	674	.0148	4,880	4,640,000	.0005	.0175	.0193	.0014	.0475	.0523	2.859	2.712	....	169.0
		3	1.98	.98	9	854	.0196	6,060	4,250,000	.0011	.0164	.0786	.0031	.0439	.0500	......	2.689	....	167.5
	Average	....	....	....	....	....	....	4,450	3,660,000	.0011	.0176	.0189	.0031	.0475	.0512	2.861	2.705	0.0545	168.5
2	Misc. 141	1	1.94	1.00	9	920	.0134	6,400	6,430,000	.0004	.0089	.0105	.0010	.0243	.0286	2.813	2.738	....	170.6
		2	1.97	.98	9	959	.0150	6,840	6,040,000	.0004	.0075	.0095	.0012	.0205	.0260	2.816	2.747	....	171.1
		3	1.99	.97	9	920	.0170	6,630	5,470,000	.0003	.0087	.0101	.0009	.0238	.0276	......	2.744	....	171.0
	Average	....	....	....	....	....	....	6,620	5,980,000	.0004	.0084	.0100	.0010	.0229	.0274	2.815	2.743	.0256	170.9
3	Misc. 143	1	1.98	.28	12	59	.0430	6,840	13,420,000	.0037	.0160	.0189	.0094	.0409	.0481	2.696	2.550	....	158.9
		2	1.95	.26	12	56	.0790	7,640	8,820,000	.0012	.0114	.0146	.0031	.0293	.0375	2.702	2.564	....	159.7
		3	2.05	.27	12	80	.0855	9.640	11,030,000	.0041	.0167	.0201	.0105	.0425	.0512	......	2.544	....	158.5
	Average	....	....	....	....	....	....	8,040	11,090,000	.0030	.0147	.0179	.0077	.0376	.0456	2.699	2.553	.0541	159.0
4	Misc. 144	1	2.07	.30	12	93	.0600	8,990	11,820,000	.0026	.0113	.0121	.0072	.0310	.0332	2.862	2.748	....	171.2
		2	1.98	.27	12	64	.0560	7,980	12,420,000	.0009	.0087	.0114	.0025	.0241	.0315	2.857	2.776	....	173.0
		3	1.99	.29	12	80	.0615	8,600	11,570,000	.0013	.0112	.0122	.0036	.0307	.0334	......	2.741	....	170.8
	Average	....	....	....	....	....	....	8,520	11,940,000	.0016	.0104	.0119	.0044	.0286	.0327	2.860	2.755	.0367	171.7
5	Misc. 145	1	1.94	.85	12	210	....	2,700	2,900,000	.0023	.0120	.0157	.0058	.0305	.0402	2,705	2.557	....	159.3
		2	2.04	.77	12	279	.0405	4,150	3,150,000	.0033	.0153	.0193	.0083	.0390	.0491	2.704	2.544	....	158.5
		3	1.94	.78	12	388	.0335	5,920	6,010,000	.0024	.0121	.0156	.0062	.0309	.0397	......	2.553	....	159.1
	Average	....	....	....	....	....	....	4,260	4,020,000	.0027	.0131	.0169	.0068	.0335	.0430	2.705	2.551	.0570	159.0

[a] Apparent specific gravity ÷ true specific gravity.

Results of physical tests on slates from Arkansas—Continued.

Field No.	Register No.	Individual specimen No.	Transverse tests. Dimensions. Width.	Transverse tests. Dimensions. Depth.	Transverse tests. Span.	Transverse tests. Conditions at maximum load. Load at center.	Transverse tests. Conditions at maximum load. Deflection at center.	Transverse tests. Conditions at maximum load. Modulus of rupture.	Transverse tests. Modulus of elasticity (constant nearly to maximum).	Absorption tests. Weight ratio of absorption. 30 minutes.	Absorption tests. Weight ratio of absorption. 24 hours.	Absorption tests. Weight ratio of absorption. 48 hours.	Absorption tests. Volume ratio of absorption. 30 minutes.	Absorption tests. Volume ratio of absorption. 24 hours.	Absorption tests. Volume ratio of absorption. 48 hours.	Specific gravity. True.	Specific gravity. Apparent.	Absolute porosity.[a]	Weight per cubic foot.
			Inches.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Lbs. per sq. inch.*											*Pounds.*
6	Misc. 146	1	2.04	1.09	12	400	.0252	2,970	2,620,000	0.0014	0.0076	0.0114	0.0040	0.0210	0.0314	2.860	2.771	....	172.6
		2	2.03	1.02	12	318	.0134	2,710	4,810,000	.0010	.0081	.0093	.0027	.0225	.0257	2.854	2.767	....	172.4
		3	2.03	1.01	12	791	.0233	6,880	6,920,000	.0015	.0080	.0093	.0041	.0221	.0257	......	2.769	....	172.5
	Average	......	......	......	......	......	......	4,190	4,780,000	.0013	.0079	.0100	.0036	.0219	.0276	2.857	2.769	.0308	172.5
7	Misc. 147	1	2.03	.24	12	35	.0660	5,390	9,240,000	.0010	.0089	.0109	.0028	.0243	.0300	2.805	2.739	....	170.6
		2	2.07	.23	12	57	......	9,370	10,290,000	.0013	.0089	.0107	......	......	......	2.810	......	....	......
		3	1.96	.24	12	40	.0740	6,380	8,060,000	.0011	.0090	.0113	.0029	.0246	.0310	......	2.733	....	170.3
	Average	......	......	......	......	......	......	7,050	9,200,000	.0011	.0089	.0110	.0029	.0245	.0305	2.808	2,736	.0256	170.5
9	Misc. 149	1	1.99	.17	7	48	.0317	8,760	13,150,000	.0010	.0073	.0088	.0029	.0203	.0244	2.849	2,764	....	172.2
		2	2.00	.14	7	47	.0358	12,590	19,530,000	.0010	.0081	.0091	.0029	.0227	.0256	2.845	2.806	....	174.8
		3	2.00	.22	4	120	......	7,440	......	.0009	.0082	.0091	.0026	.0229	.0255	......	2.789	....	173.8
	Average	......	......	......	......	......	......	9,600	16,340,000	.0010	.0079	.0090	.0028	.0220	.0252	2.847	2.786	.0214	173.6
11	Misc. 150	1	1.97	.53	9	139	.0181	3,390	4,720,000	.0183	.0410	.0410	.0467	.1045	.1045	2.828	2,552	....	159.0
		2	1.94	.51	9	155	.0181	4,150	6,090,000	.0185	.0402	.0404	.0471	.1023	.1029	2.830	2.546	....	158.6
		3	1.93	.52	9	140	.0206	3,620	4,500,000	.0084	.0365	.0365	.0216	.0941	.0941	......	2.576	....	160.5
	Average	......	......	......	......	......	......	3,720	5,100,000	.0151	.0392	.0393	.0385	.1003	.1005	2.829	2.558	.0958	159.4
8	Misc. 148	1	1.94	.15	7	20	.0265	4,810	9,820,000	.0016	.0094	.0101	.0045	.0263	.0283	2.863	2.801	....	174.5
		2	2.04	.17	7	36	.0330	6,410	9,410,000	.0010	.0081	.0096	.0028	.0227	.0272	2.866	2.822	....	175.8
		3	2.02	.17	7	32	.0250	5,760	15,810,000	.0010	.0089	.0098	.0027	.0252	.0279	......	2.838	....	176.8
	Average	......	......	......	......	......	......	5,660	11,680,000	.0012	.0088	.0098	.0033	.0247	.0278	2.865	2.820	.0157	175.7

[a] Apparent specific gravity ÷ true specific gravity.

10	Misc. 148	1	1.99	.12	7	9.75	.0430	3,570	5,730,000	.0088	.0251					2.854			
		2	1.93	.13	7	8	.0378	2,570	4,250,000	.0072	.0257	.0257	.0194	.0689	.0689	2.857	2.682		167.1
		3	1.97	.14	7	18	.0440	4,890	6,340,000	.0067	.0251	.0253	.0180	.0672	.0677		2.676		166.7
	Average							3,680	5,440,000	.0076	.0253	.0255	.0187	.0681	.0683	2.856	2.679	.0620	166.9
13	Misc. 148	1	2.03	.15	6	20	.0440	3,940	3,550,000	.0046	.0228	.0229	.0124	.0613	.0617	2.862	2.691		167.6
		2	2.00	.16	6	20	.0300	3,520	4,420,000	.0062	.0243	.0243	.0167	.0652	.0652	2.860	2.683		167.1
		3	1.93	.18	6	24	.0180	3,450	6,480,000	.0061	.0241	.0244	.0163	.0640	.0648		2.658		165.6
	Average							3,640	4,820,000	.0056	.0237	.0239	.0151	.0635	.0639	2.861	2.677	.0643	166.8

NOTE.—Specific gravities corrected at 70° F.

COMPARATIVE CHARACTERISTICS OF SLATES.

The accompanying table shows the principal mineralogic, chemical, and physical characteristics of 56 kinds of slate described by the writer in this bulletin, so far as these characteristics manifestly bear on their economic value. These slates are from Arkansas, California, Colorado, Georgia, Maine, Maryland, Nevada, New Jersey, New York, Pennsylvania, Tennessee, Vermont, Virginia, and West Virginia. For full particulars and for scientific details the descriptions should be consulted, by reference to the pages given in the third column. The columns headed "Strength" and "Toughness" refer to the tests by Merriman, whose methods of experimentation are described on page 175. "Microscopic texture" refers primarily to the matrix or body of the slate. By "crystalline" is meant that the matrix consists of interlacing and overlapping scales and fibers of muscovite and is therefore a mica slate or technically a phyllite slate, although it may inclose unaltered particles of sedimentary origin. Such a slate should have, other things being equal, greater elasticity (toughness) and strength than one in which there is no such texture or in which it is only incipient. The fineness or coarseness of this crystalline texture probably has a bearing on the strength and toughness of the slate, but physical data are not sufficient to show this. The coarse-textured Peach Bottom slate, which really approaches a mica schist, is the strongest of the twelve kinds of American slates tested, but it is less flexible than all the other kinds tested. In the grade of fissility 1 signifies a perfect slaty cleavage, 4 a very imperfect one. The column of "Chief minerals" includes only the four or five principal constituents which were seen under the microscope or whose presence has been otherwise determined, and these are given in the descending order of their probable abundance. In the column headed "Class" the technical economic designation of each slate is given with reference to the classification on page 10. To these comparative data should be added the results of a few tests not easily tabulated.

Merriman's later corrosion tests show the following percentages of loss in weight after immersion in acid solution for 360 hours: Pennsylvania slates (not including Peach Bottom slate), 1.68 to 2.76; Peach Bottom slate, 1.11 to 1.29; red slate of New York and Vermont, 0.25. During these tests the Pennsylvania slates became a grayish white, some of the Peach Bottom samples changed but slightly, others were almost unaffected; the red slates likewise remained almost unaffected.[1]

E. H. S. Bailey's tests of porosity give these indices of porosity: "Hard vein" Pennsylvania, Chapman, 0.11–0.14; Daniels quarry, 0.14; Belfast quarry, 0.25; red of New York and Vermont, 0.21.[2]

[1] Am. Soc. Civil Eng. Trans., vol. 32, p. 538, 1894.

[2] Idem, p. 542.

State.	Locality, quarry, bed.	Described on page—	Color.	Cleavage surface.	Luster.	Magnetite.	Microscopic texture.	Grade of fissility.	Chief minerals a (probable descending order of abundance).	Class.	Carbonate.	Lime by analysis.	Strength, pounds to the square inch. b	Toughness. c	Remarks.
Arkansas	Mena, Polk County	63	Black	Remarkably fine	Slight	Some	Crystalline, extremely fine, homogeneous.	1	Muscovite, carbon, quartz, pyrite, magnetite.	Mica slate, unfading	None				Strength, toughness, and behavior in freezing and thawing should be tested.
Do	do	63	Dark reddish	Roughish, speckled	Almost none	Very little	Crystalline, fine	3	Muscovite, hematite, kaolin, quartz	do	do				
Do	Missouri Mountain slate ("Mammoth red" and "Lost Hannah"), Polk County.	63	Reddish	Fine	None	do	do	1	Muscovite, hematite, kaolin, quartz, chlorite.	do	do				Do.
Do	Mena, Polk County	64	Greenish gray	Roughish	Waxy	do	Crystalline, extremely fine, homogeneous.	3	Muscovite, quartz, kaolin, chlorite	do	do				Specimen shows two extra foliations, which will prove directions of weakness.
Do	Missouri Mountain slate ("Mammoth red" and "Lost Hannah"), Polk County.	64	Light greenish	Very fine	Almost none	Little	do	1	Muscovite, quartz, kaolin, chlorite	do	do				Strength, toughness, and behavior in freezing and thawing should be tested. See p. 64.
Do	Sec. 25, T. 3 S., R. 29 W., Polk County.	64	Very dark bluish gray.	Fine	Slight	Very little	Crystalline, fine	2	Muscovite, quartz, pyrite, carbon	do	do				
Do	Sec. 30, T. 3 S., R. 28 W., Polk County.	65	Light gray	Roughish	None	do	do	2	Muscovite, quartz, chlorite, kaolin	Mica slate, unfading (?)	do				Some limonite staining from pyrite.
Do	Southwest Slate Mfg. Co., Polk County.	65	Very dark gray	Roughish, spangled	Almost none	do	Crystalline, coarse, granular.	3	Muscovite, quartz, carbonate, pyrite, carbon.	Mica slate, fading	Some				Between a metamorphic grit and a slate.
California	Eureka quarry, Eldorado County.	67	do	Fine	Bright	do	Crystalline, fine	2	Muscovite, quartz, chlorite, carbonate, pyrite.	Mica slate, fading (?)	do	0.98			See test, p. 176.
Do	Near Planada, Merced County.	70	Dark bluish gray	Very finely granular	Some	Magnetic pyrite.	do	2	Muscovite, quartz, biotite, kaolin, graphite.	Mica slate, unfading	None				
Colorado	Marble, Gunnison County	70	Extremely dark bluish gray.	Slightly uneven	None	None	Crystalline, irregular	3	Muscovite, carbonate, quartz, carbon, kaolin.	Clay-mica slate, fading	Much				
Georgia	Bolivar, Bartow County	71	Light blue-greenish gray.	Smooth to roughish	Slight	Extremely little	Crystalline, fine	2	Muscovite, quartz, chlorite, carbonate.	Mica slate, slightly fading	Little	1.22			
Do	Rockmart, Polk County	73	Very dark bluish gray.	Slightly roughish	None	Very little	Crystalline, lenticular, coarse	3	Muscovite, quartz, carbonate, carbon	Mica slate, fading	Much				
Maine	Merrill quarry, Brownville, Piscataquis County.	81	Very dark gray	Very fine	Very bright	Much	Crystalline, very fine	1	Muscovite, quartz, magnetite, pyrite	Mica slate, unfading	None		9,880	0.200	See p. 81 on amount of magnetite. See tests on pp. 82, 183.
Do	North Blanchard, Piscataquis County.	80	do	Roughish	Slight	None	Crystalline, fine	3	Muscovite, chlorite, quartz, pyrite	do	do				Very sonorous.
Do	Monson Pond quarry, Monson, Piscataquis County.	77	Very dark bluish gray.	do	Almost none	Very little	Crystalline, fine, but particles irregular.	3	Muscovite, quartz, chlorite, biotite	do	do	0.52			Do. See tests on p. 77.
Do	Portland-Monson quarry, Monson.	78	do	do	None	Some	do	3	Muscovite, quartz, chlorite, magnetite, biotite.	do	do				Do. See p. 79 on amount of magnetite.
Do	Maine Slate Co., of Monson	78	do	do	Bright	Very little	Crystalline, very fine	2	Muscovite, quartz, biotite, chlorite	do	do				Do.
Do	West Monson	79	do	Very fine	Somewhat bright	None	Crystalline, fine	2	Muscovite, quartz, chlorite, pyrite	do	do		9,130	0.205	Do. See tests on p. 183.
Maryland	Thurston, Frederick County	85	Dark purplish	Slightly granular	do	do	Crystalline, fine, particles irregular.	3	Muscovite, chlorite, quartz, talc	Talcose mica slate, unfading	do				Sonorousness very moderate; can be sawn with handsaw.
Nevada	Near Winnemucca, Humboldt County.	87	Dark bluish gray	Very smooth	Slight	Very little	do	1	Muscovite, quartz, chlorite, graphite (probably).	Mica slate, unfading	do				Sonorous.
New Jersey	Lafayette, Sussex County	88	Very dark bluish gray.	Slightly roughish	None	do	Crystalline, lenticular	1	Muscovite, quartz, carbonate, chlorite, carbon.	Mica slate, fading	Much				Reported as harder than Bangor, Pa., slate.
New York	Granville and Hampton, Washington County.	91	Reddish	Fine or roughish, speckled.	None	Some	do	3	Muscovite, quartz, hematite, kaolin, carbonate.	Mica slate, brightens on exposure.	do	0.11–5.11	9,220	0.232	Little or no ferrous carbonate. Impact test shows 126.66 foot-pounds of work to the pound of slate. See tests on pp. 92, 183.
Do	do	92	Bright greenish	do	do	do	do	3	Muscovite, quartz, chlorite, carbon, magnetite.	Mica slate, unfading	Less than red, usually.	1.43	8,050	0.190	See tests on p. 183.
Pennsylvania	"Old Bangor" quarry, Northampton County.	97	Very dark gray	Fine	Almost none	Very little	Crystalline, fine	1	Muscovite, carbonate, quartz, kaolin	Mica slate, fading	Quite a little	4.38	9,810	0.312	Impact tests of various slates from Northampton and Lehigh counties show from 3.50 to 5.44 foot-pounds of work to the pound of slate. See tests on p. 97.
Do	North Bangor, Northampton County.	99	do	do	do	Some	do	1	Muscovite, carbonate, quartz, kaolin	do	Much				Do.
Do	Albion quarry, Pen Argyl, Northampton County.	102	do	Roughish	do	do	do	1	Muscovite, carbonate, quartz, chlorite	do	Quite a little	4.09	7,150	0.270	Do. See p. 102.
Do	Albion quarry, gray bed, Northampton County.	102	Very dark greenish.	Roughish, granular	do	Little	do	1	Muscovite, carbonate, quartz, chlorite	do	do				
Do	Heimbach, big bed, Northampton County.	101	Very dark gray, not bluish.	Somewhat fine	do	Extremely little.	do	1	Muscovite, carbonate, quartz, pyrite	do	Very much				Do.
Do	Heimbach, black bed	101	Bluish black	Roughish	None	Very little	do	1	Muscovite, carbonate, quartz, carbon	do	do				
Do	East Bangor Consolidated, Northampton County.	99	Very dark bluish gray.	Somewhat fine	Almost none	Some	do	1	Muscovite, carbonate, quartz, pyrite, chlorite.	do	Much				In ribboned slate from this quarry the percentage of quartz would be higher than in the rest. Impact tests of various slates from Northampton and Lehigh counties show from 3.50 to 5.44 foot-pounds of work to the pound of slate.
Do	Slatington, Lehigh County	107	do	do	do	Little	do	1	Muscovite, carbonate, quartz, kaolin	do	do	4.23			Discolors on continued exposure. Impact tests of various slates from Northampton and Lehigh counties show from 3.50 to 5.44 foot-pounds of work to the pound of slate. See tests on p. 188.
Do	Chapman "hard vein," Northampton County.	104	Very dark gray	Slightly roughish	Slight	Some	do	2	Muscovite, quartz, carbonate, pyrite	do	A little	2.83–3.40	9,460	0.212	Discolors less readily than any of the above Pennsylvania slates. Impact tests of various slates from Northampton and Lehigh counties show from 3.50 to 5.44 foot-pounds of work to the pound of slate. See tests on p. 182.
Do	Aquashicola, Carbon County	109	Very dark bluish gray.	Roughish, finely banded.	None	Little	do	1	Muscovite, quartz, carbonate, chlorite, carbon.	do	Much				
Do	Derry Church, Dauphin County.	109	Dark bluish gray	Very fine	Somewhat bright	None	do	1	Muscovite, quartz, carbonate, pyrite, chlorite.	do	do				
Pennsylvania-Maryland.	Peach Bottom	111	Very dark bluish gray.	Minutely granular	Very bright	do	Crystalline, coarse	2	Muscovite, quartz, graphite, andalusite, magnetite.	Mica slate, unfading	None	0.155–0.48	11,260	0.93	Very sonorous. Impact tests show from 8.49 to 24.17 foot-pounds of work per pound of slate. See tests on p. 112.
Pennsylvania	Peters Creek, Lancaster County.	114	Very dark, slightly bluish gray.	Somewhat fine	Bright	Little	do	2	Muscovite, quartz, graphite, andalusite, rutile.	do	do				
Tennessee	Falls Branch, Tellico, Monroe County.	116	Very dark bluish gray.	Fine to roughish	do	Some	Crystalline, fine	2	Muscovite, quartz, chlorite, carbonate.	Mica slate, fading	Some				Sonorous.
Do	Laurel Creek, Tellico, Monroe County.	117	Purplish gray	Fine or speckled	None	None	Crystalline, crossed by beds at acute angle.	3	Muscovite, quartz, chlorite, hematite, carbonate.	Mica slate, unfading	do				Do.
Do	do	117	Light blue-greenish gray.	Fine	do	Extremely little.	do	3	Muscovite, quartz, chlorite, carbonate, pyrite.	do	do				Do.
Vermont	Northfield, Washington County.	122	Very dark gray	Very fine to speckled	Very bright	More or less	Crystalline, very fine	1	Muscovite, quartz, graphite, chlorite, magnetite.	do	Very little				Very sonorous. Contains magnetic iron pyrites.
Do	"Sea-green," Rutland County.	140	Gray greenish	Fine	Waxy	do	do	1	Muscovite, quartz, carbonate, chlorite	Mica slate, fading	Much	0.63–2.20	7,250	0.207	Becomes brownish gray on continued exposure. See tests on p. 183.
Do	Purplish of "sea-green," Rutland County.		Purplish brown	do	None	do	do	1	Muscovite, quartz, carbonate, hematite.	do	Some	0.50–0.71			Discoloration less pronounced than that of "sea-green."
Do	"Unfading green," Rutland County.	141	Greenish gray	Roughish	do	Some	Crystalline, irregular	2	Muscovite, quartz, chlorite, carbonate.	Mica slate, unfading	Very little	0.42–0.56	6,410	0.225	Preserves nearly all its color on continued exposure. See tests on p. 183.
Do	Purplish of "unfading," Rutland County.	142	Purplish brown	do	do	do	do	2	Muscovite, quartz, chlorite, hematite	do	do				Do.
Do	Benson (prospect), Rutland County.	146	Bluish black	Somewhat fine	Slight	Very little	Crystalline, fine	2	Muscovite, quartz, carbonate, pyrite	Mica slate, fading	Much	1.27			Sonorous. Probably "fading."
Virginia	Arvonia, Williams, Buckingham County.	151	Very dark greenish gray.	Minutely granular	Bright	do	Crystalline, irregular	2	Muscovite, quartz, biotite, carbonate, graphite.	Mica slate, unfading	Some		9,040	0.227	Very sonorous. See tests on p. 182.
Do	Arvonia, Fontaine, Buckingham County.	152	do	Granular	do	do	Crystalline, irregular, coarse.	2	Muscovite, quartz, biotite, carbonate, pyrite, graphite.	do	do		9,850	0.225	Very sonorous. See tests on p. 183.
Do	Penlan, Penlan Slate Co., Buckingham County.	153	Very dark gray, faintly brownish.	Minutely granular	do	0.05 per cent	Crystalline, irregular, fine	2	Muscovite, quartz, graphite, carbonate, magnetite.	do	do		8,000–11,720	0.266–0.366	Very sonorous. See tests on p. 154.
Do	Penlan, Arvon Slate Manufacturing Co., Buckingham County.	154	do	Very granular	do	Some	Crystalline, with minute plications.	2	Muscovite, quartz, graphite, biotite, magnetite.	do	Very little				Very sonorous.
Do	Bremo (prospect), Fluvanna County.	155	Dark gray	Fine speckled	do	None	Crystalline, fine		Muscovite, quartz, pyrite, kaolin? graphite.	do	None				
Do	Esmont, Albemarle County	157	Dark bluish gray, like specular iron when wet.	Granular	Very bright	Very little	Crystalline, lenticular	2	Muscovite, quartz, chlorite, specular, hematite.	do	Very little	0.68	9,360		Very sonorous. See tests on p. 159.
Do	do	157	Medium greenish gray.	Fine, spangled, sparsely granular.	Bright	Little	do	2	Muscovite, quartz, chlorite, carbonate, magnetite.	Mica slate, darkens a little on exposure.	do	0.42	9,360		Do.
Do	do	158	Purplish-brownish gray, banded.	Granular	Little	Very little	Crystalline, irregular	2	Muscovite, quartz, chlorite, carbonate, specular hematite.	Mica slate, fading?	do				
Do	Snowden, Amherst County	160	Very dark gray	Minutely granular	Almost none	do	Crystalline, fine, irregular	2	Muscovite, quartz, chlorite, kaolin	Mica slate, fading	Little				Very sonorous.
West Virginia	Martinsburg, Berkeley County.	165	Black, brownish hue.	Roughish	None	Little	Not crystalline or imperfectly so, coarse.	3	Carbonate, muscovite, quartz, kaolin, pyrite, carbon.	Clay slate, fading	From some to much.	1.11 and over.			Analysis by W. C. Tilden. In some specimens muscovite equals the carbonate in amount.

a Carbon=carbonaceous matter or graphite. b Tests by Merriman. c Deflection, in inches, on supports 22 inches apart; tests by Merriman and others.

J. F. Williams's tests of the compression of columns of slate 10 inches long by an inch in section, with the cleavage vertical, show that the purplish of the "unfading green" series of Vermont stands 20,000 pounds; the "unfading green," 16,020 pounds, and the red of New York and Vermont 17,730 pounds.[1]

The following results of various tests of slate from Monson, Maine, were made at the United States Arsenal at Watertown, Mass.:[2]

	Pounds.
Maximum fiber stress per square inch	7,671
Shearing test per square inch	2,192
Ultimate compressive strength per square inch	19,510

Coefficient of expansion, 0.000005.

In accordance with the scheme of classification of slates given on pages 10, 11 many of the slates whose characteristics are given in the preceding table are here arranged systematically.

A. Clay slates (fading) Martinsburg, W. Va.

B. Mica slates
- (fading)
  - (a) Carbonaceous or graphitic (blackish). Lehigh, Northampton, and Carbon counties, Pa.; Sussex County, N. J.; Benson, Vt.; Rockmart, Ga.
  - (b) Chloritic (greenish). "Sea-green," Vermont; green, Bartow County, Ga.
  - (c) Hematitic and chloritic (purplish). Purplish of Pawlet and Poultney, Vt.
- (unfading.)
  - (a) Graphitic (blackish).
    - Peach Bottom, Pa. and Md.
    - Arvonia and Penlan, Va.
    - Northfield, Vt.
    - Brownville, Monson, Me.
    - North Blanchard, Me.
    - Merced County, Cal.
    - Humboldt County, Nev.
  - (b) Hematitic (reddish). Granville, Hampton, N. Y.; Polk County, Ark.
  - (c) Chloritic (greenish). "Unfading green," Vermont; "bright green," Granville, N. Y.; green, Tellico, Tenn.
  - (d) Hematitic and chloritic (purplish). Purplish of Fair Haven, Vt.; Thurston, Md.; and Tellico, Tenn.
  - (e) Hematitic (specular) and graphitic (bluish black). "Blue-black" of Esmont, Va.

SLATE MACHINERY.

A description of all the various machines used in quarrying and finishing slate is not within the scope of this publication, but atten-

[1] Van Nostrand's Eng. Mag., vol. 31, p. 132, 1884.

[2] War Dept. reports, republished in Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (contd.), p. 395, 1899.

tion will be briefly called here to the growing substitution of cutting machinery for powder in quarrying slate and to the new devices for finishing it.

It will be noticed from the quarry descriptions that where the cleavage is nearly horizontal, as in some of the Pennsylvania quarries, or where it is nearly vertical, as in the Maine quarries, machines for vertical or horizontal cutting, constructed on the same principle as those used in the marble quarries, are being used, and in connection with them air compressors are also being introduced. The reduction of waste by these processes is obvious. The attempt, referred to on page 159, to do all the transverse cutting of large blocks by circular saws is of interest. Among the minor improvements is the automatic transportation of waste from the cutting sheds to dumps at a distance (p. 159) and the use of carborundum wheels in finishing slate moldings, etc.

The most important recent addition to the mechanical devices in the ndustry is the slate-splitting machine invented by Vincent F. Lake, which, in January, 1913, was on exhibition at the plant of the Genuine Washington Slate Co., at Berlinsville, Pa. The underlying principle of this machine is the substitution for the sudden jar given to the slate by the hand-splitter's hammer and chisel of a great number of blows, each of which moves the chisel a small fraction of an inch only, while the operator presses the vibrating chisel into the cleft slate as it parts. These vibrations, numbering as many as 16,000 a minute, are imparted to the chisel by means of a broad-edged iron cylinder 6 inches in diameter into which are sunk 24 small steel cylinders projecting but slightly above its edge. The rapid rotation of the main cylinder with its minor ones coming into contact with a single cylinder carried in a piston to which the chisel is attached imparts the vibratory motion. The slate block, preferably with one or more sawn edges, is placed with its long edge on an iron table and with its short edge facing the operator. (See Pl. VI, *B.*) The chisel, a very thin blade of vanadium steel, 9 inches or more in width but made flexible by splits at intervals and with its edge vertical, is set loosely in the piston socket. The edge of the slate is held between gages mechanically adjusted and operated by a treadle so that the exact center of the slab is brought before the chisel. The operator controls the intensity of the hammer blow by means of a trigger and pushes the chisel horizontally through the block.

This machine can be operated with little skill and makes commercial slate from blocks which now find their way to the dumps. It also makes slate of unusual thinness. Mr. Lake has also perfected a punch for making beveled holes of any shape in slate with a view of utilizing slates of various thicknesses as a foundation for plaster and stucco work. The perforated slates are nailed to the studding or furring, and the plaster, applied directly to the slate, passes through the perforations and clinches itself on the back.

The slate-splitting machine thus seems likely not only to reduce the cost of splitting but also the percentage of waste, and to make new demands for slate.

USES OF SLATE.

As will be seen by consulting the descriptions in this bulletin and the table opposite page 188, the slates of the United States have a very wide range of color, texture, and composition and therefore of adaptation. While nearly all of them possess one or two excellent features, few possess many such features and none possess them all. Several are so conspicuous for their well-nigh perfect adaptation to certain uses that the demand for them is likely to increase with the growth of the country. Such are the blackboard slates of the "soft-vein" region of Pennsylvania, the red roofing slates of New York, which increase in brightness of color on exposure, and the fadeless bright-green ones associated with them; the black unfading slates of the Peach Bottom district of Maryland and Pennsylvania, of Arvonia, Penlan, and Esmont, in Virginia, and of Monson and Brownville, in Maine; the almost unfading green slates of Vermont; and the mill-stock slates of Vermont, Maine, and Pennsylvania.

On account of their cheapness, which is due to their perfect cleavage, the "sea-green" slates of Vermont and the black slates of Lehigh and Northampton counties, Pa., will always be in demand in spite of their content of ferrous carbonate. Some architects are reported as preferring such fading slates for esthetic reasons.

The selection of a slate should manifestly be governed mainly by its adaptation to the purpose in view as well as by considerations of cost and transportation.

An increasing quantity of mill-stock slate is used for electric purposes, but this use requires a minimum content of magnetite. It would be well if the more durable slates were more widely used for inexpensive tablets and gravestones instead of marble. Facts showing the relative durability of inscriptions on slate and marble exposed to the weather will be found in Bulletin 521 of the United States Geological Survey.[1]

There are also many structures where thick slate slabs with their great transverse strength could be used to advantage instead of concrete beams. Finally should be mentioned the proposed substitution of slate veneers for laths, described on page 190.

[1] Dale, T. N., The commercial marbles of western Vermont, pp. 37-39, 1912.

SLATE WASTE.

The percentage of waste is generally high in slate quarrying. Watrin,[1] referring to the Ardennes region, gives the total waste at 70 to 75 per cent in weight, of which 20 to 25 per cent occurs in the quarry and 50 per cent in splitting. Merrill estimates the waste in the Peach Bottom region as 88 per cent. In the Maine quarries it is also large, owing to the interbedding of the slate with quartzite. Among the important practical problems in the slate industry is that of the reduction of this large percentage of waste and the utilization of the unavoidable remainder. The substitution, wherever practicable, of mechanical cutting for blasting is probably the most available method of effecting this reduction. Much ingenuity has been expended in devising methods of utilizing slate waste. The slate-splitting machine described above aims to make a contribution to this end. The growing use in roofing of "graduated slates," which near the ridge are one-fourth inch thick but at the cornice 1½ inches thick, consumes slates with imperfect cleavage. The Inlaid Slate Co. of Bangor, Pa., is utilizing slate 3 inches square embedded in a mixture of asphalt having a high melting point with a backing of roofing felt for covering flat roofs.[2] A demand for waste slate has also arisen from the use of powdered slate for filling in oilcloth, etc., and of granulated slate for roofing. The particles, averaging about 0.1 inch in diameter, are pressed into a tarred paper (Staco Mills, Whitehall, N. Y.). The bright-red slate waste of Granville, N. Y., is being used by the Algonkian Red Slate Co., of Truthville, N. Y., for roofing and bridge paint by being combined with several superior oils and a small quantity of white lead. An article by one of the editors of the Slate Trades Gazette (England) describes the use being made of powdered slate in Norway.[3]

At the present time in Norway waste slate is being ground into a fine powder and mixed with casein, * * * the nitrogenous constituent (curd) of milk. The casein may be either solid or liquid, the proportion varying according to the nature of the slate. Hard and soft slates obviously require different treatment. The casein may be pure or mixed with other substances—lime, soda, resins, or acids—according to the character of the product required. If the final resultant is required to be of any particular tint, coloring matter is introduced at this stage. The composition thus obtained is plastic and is placed hot or cold in molds and subjected to pressure. The material is then exposed to the drying action of the air. The final product has properties identical with those of slate except that the casein, if anything, renders it harder and tougher. The casein can be made insoluble by the application of formaldehyde. The compressed slate is then ready to undergo sawing, planing, polishing, etc. * * *
All manner of fancy designs may be imprinted on the plastic slate, which may be manufactured into blocks of uniform size or in large sheets, and the thickness may, of course, be regulated by the pressure. This material could be used as a covering for

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1 Watrin, N., Les ardoisières des Ardennes, 1898.
2 U. S. Geol. Survey Mineral Resources for 1910, pt. 2, p. 632, 1911.
3 Idem for 1909, pt. 2, p. 560, 1910.

walls, either internally or externally, in place of the ordinary wall paper or plaster, or to enhance the picturesqueness of the slate roof. Embossed mantelpieces could also be made and other uses would in course of time reveal themselves.

Chemists have also considered the feasibility of utilizing slate waste for the manufacture of aluminum, and when combined with lime for the manufacture of cement, but as clay would answer both purposes equally well and is abundant these schemes have been given up.

STATISTICS OF PRODUCTION, IMPORTS, AND EXPORTS.

By A. T. Coons.

PRODUCTION.

Although slate has been known and quarried in this country more or less since 1750 in Massachusetts, Maryland, and Pennsylvania and since about 1850 in New York, Vermont, Georgia, California, Virginia, and other States, no statistics of production for the entire United States are obtainable for any year preceding 1879.

In the tables here presented the production for the years 1879, 1881, 1882, and 1883 is largely estimated. The statistics for 1880 are taken from the Tenth Census and are very accurate. The figures from 1884 to 1888 are fairly reliable; those for 1889 are the figures of the Eleventh Census; and from 1890 to the present time the data as to production have been obtained directly from the slate quarries and are as accurate as can be procured. There is no record of production in New York from 1884 to 1890, but as the operations in this State are closely allied to those of Vermont the output is doubtless included in that of Vermont.

The statistics of the production of slate as here given represent the output of slate as reported by the slate quarrymen and include the quantity and value of roofing slate and of mill stock sold by them and the value of slate sold for other purposes. The values given for both mill stock and roofing slate represent prices f. o. b. at the point of shipment, the mill stock being classed as rough or manufactured, according to the condition in which it is sold by the quarrymen, whether as rough blocks to slate mills or in a finished or partly finished state from mills at the quarries.

The tables give the output of slate in the United States from 1879 to 1913 by States, showing as nearly as possible the number of squares of roofing slate produced, their value, and the quantity and value of slate used for other purposes so far as figures are obtainable.

Production of slate in the United States, by States and uses, from 1879 to 1913.

State.	1879 Roofing slate. Squares.	1879 Roofing slate. Value.	1880 Roofing slate. Squares.	1880 Roofing slate. Value.	1881 Roofing slate. Squares.	1881 Roofing slate. Value.	1882 Roofing slate. Squares.	1882 Roofing slate. Value.
Georgia	....	....	1,000	$4,500	500	$2,250	200	$900
Maine	14,000	$42,000	26,200	84,800	25,200	77,500	26,000	78,000
Maryland	8,000	36,000	12,280	56,700	12,000	54,000	15,000	67,500
Massachusetts	....	....	1,550	7,000	1,000	4,500	500	2,000
New Jersey	....	....	4,683	15,000	3,000	10,500	4,000	12,000
New York	9,000	45,000	19,850	95,500	19,000	95,000	21,000	105,000
Pennsylvania	245,500	826,093	271,313	862,877	272,000	877,978	292,000	1,002,000
Vermont	83,300	249,900	108,891	352,608	109,370	368,110	127,300	435,100
Virginia	8,057	32,228	11,500	51,000	12,000	54,000	15,000	51,000
	367,857	1,231,221	457,267	1,529,985	454,070	1,543,838	501,000	1,753,500

State.	1883 Roofing slate. Squares.	1883 Roofing slate. Value.	1884 Roofing slate. Squares.	1884 Roofing slate. Value.	1884 Other purposes than roofing slate.	1884 Total value.
Maine	30,000	$120,000	41,000	$215,000	....	$215,000
Maryland	15,000	67,500	a 10,000	45,000	....	45,000
Michigan	5,000	18,250	7,000	35,300	....	35,300
New Jersey	1,000	4,000	....	....	....	....
New York	10,200	51,000	....	....	....	....
Pennsylvania	325,000	1,147,500	329,004	1,162,560	....	1,162,560
Vermont	110,000	440,000	85,000	340,500	....	340,500
Virginia	10,000	50,000	9,000	45,505	....	45,505
	506,200	1,898,250	481,004	1,843,865	$8,000	1,851,865

State.	1885 Roofing slate. Squares.	1885 Roofing slate. Value.	1885 Other purposes than roofing slate.	1885 Total value.	1886 Roofing slate. Squares.	1886 Roofing slate. Value.	1887 Roofing slate. Squares.	1887 Roofing slate. Value.
Maine	34,000	$102,000	....	$102,000	36,000	$118,000	37,000	$81,000
Maryland	a 14,500	65,250	....	65,250	a 12,000	54,000	a 20,000	90,000
Michigan	10,000	40,000	....	40,000	12,000	46,000	7,000	25,000
Pennsylvania	331,160	993,080	....	993,080	348,805	979,415	370,439	1,111,317
Vermont	130,000	380,000	....	380,000	111,385	353,155	120,000	356,000
Virginia	17,300	58,137	....	58,137	16,600	59,800	19,000	57,000
	536,960	1,638,467	$10,000	1,648,467	536,790	1,610,370	573,439	1,720,317

a Includes Pennsylvania Peach Bottom.

Production of slate in the United States, by States and uses, from 1879 to 1913—Con.

State.	1888		1889			
	Roofing slate.		Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.	Squares.	Value.		
Arkansas						(a)
California			3,104	$18,089		$18,089
Georgia			3,050	14,850	$480	15,330
Maine	37,000	$111,000	41,000	201,500	18,000	219,500
Maryland	[b] 19,000	85,500	23,099	105,745	4,263	110,008
Michigan	7,000	24,000				(a)
New Jersey	6,000	22,000	2,700	9,675	1,250	10,925
New York			16,767	81,726	44,877	126,603
Pennsylvania	416,000	1,270,400	476,038	1,641,003	370,723	2,011,726
Utah						(a)
Vermont	160,000	480,000	236,350	596,997	245,016	842,013
Virginia	17,400	60,540	30,457	113,079		113,079
Other States			3,060	15,240		15,240
	662,400	2,053,440	835,625	2,797,904	684,609	3,482,513

State.	1891				1892			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
Arkansas	120	$480		$480				
California	4,000	24,000		24,000	3,500	$21,000		$21,000
Georgia	3,000	13,500		13,500	2,500	10,625		10,625
Maine	50,000	250,000		250,000	50,000	250,000		250,000
Maryland	25,166	123,425	$2,000	125,425	24,000	114,000	$2,500	116,500
New Jersey	2,500	10,000		10,000	3,000	12,000		12,000
New York	17,000	136,000	40,000	176,000	20,000	160,000	50,000	210,000
Pennsylvania	507,824	1,741,836	401,069	2,142,905	550,000	1,925,000	408,000	2,333,000
Vermont	247,643	698,350	257,267	955,617	260,000	754,000	260,000	1,014,000
Virginia	36,059	127,819		127,819	40,000	150,000		150,000
	893,312	3,125,410	700,336	3,825,746	953,000	3,396,625	720,500	4,117,125

State.	1893				1894			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
California					900	$5,850		$5,850
Georgia	2,500	$11,250		$11,250	5,000	22,500		22,500
Maine	18,184	124,200	$15,000	139,200	24,690	123,937	$22,901	146,838
Maryland	7,422	37,884		37,884	39,460	150,568	2,500	153,068
New Jersey	900	3,653		3,653	375	1,050		1,050
New York	69,640	204,776	206	204,982	7,955	42,092	2,450	44,542
Pennsylvania	364,051	1,314,451	157,824	1,472,275	411,550	1,380,430	239,728	1,620,158
Utah	75	450	400	850				
Vermont	132,061	407,538	128,194	535,732	214,337	455,860	202,307	658,167
Virginia	27,106	104,847	12,500	117,347	33,955	118,851	19,300	138,151
	621,939	2,209,049	314,124	2,523,173	738,222	2,301,138	489,186	2,790,324

[a] Included in other States.
[b] Includes Pennsylvania Peach Bottom.

Production of slate in the United States, by States and uses, from 1879 to 1913—Con.

State.	1895				1896			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
California	1,500	$10,500		$10,500				
Georgia	2,500	10,675		10,675	4,597	$20,388		$20,388
Maine	23,774	118,791	$21,363	140,154	23,078	99,831	$24,255	124,086
Maryland	13,188	59,157	1,200	60,357	15,557	70,194	1,948	72,142
Massachusetts							1,200	1,200
New Jersey	200	700		700	200	700		700
New York	13,624	90,150	1,725	91,875	16,002	78,612	3,880	82,492
Pennsylvania	426,687	1,437,697	210,054	1,647,751	431,324	1,391,539	334,779	1,726,318
Tennessee					160	640	780	1,420
Vermont	221,359	531,482	93,849	625,331	155,523	509,681	99,915	609,596
Virginia	27,095	92,357	19,000	111,357	26,863	92,163	15,700	107,863
	729,927	2,351,509	347,191	2,698,700	673,304	2,263,748	482,457	2,746,205

State.	1897				1898			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
California	1,000	$7,000		$7,000	400	$2,700		$2,700
Georgia					3,450	13,125		13,125
Maine	38,367	161,262	$39,855	201,117	29,834	131,752	$67,485	199,237
Maryland	11,592	53,049	890	53,939	18,332	80,786	1,454	82,240
Massachusetts							958	958
Minnesota	400	1,000	500	1,500	100	400		400
New Jersey	250	775		775	200	800		800
New York	9,197	52,799	1,000	53,799	7,160	46,744	1,950	48,694
Pennsylvania	657,692	2,034,958	330,341	2,365,299	571,256	2,097,735	394,021	2,491,756
Vermont	244,575	656,114	39,701	695,815	241,762	612,902	119,782	732,684
Virginia	38,375	130,495	14,875	145,370	43,745	142,446	8,500	150,946
	1,001,448	3,097,452	427,162	3,524,614	916,239	3,129,390	594,150	3,723,540

State.	1899				1900			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
California	928	$6,642		$6,642	3,500	$26,500		$26,500
Georgia	2,000	7,500		7,500	2,500	9,375		9,375
Maine	24,676	121,640	$60,126	181,766	21,771	103,949	$73,393	177,342
Maryland	20,196	90,897	2,698	93,595	27,158	126,271	2,402	128,673
Massachusetts			800	800				
Minnesota							700	700
New Jersey	400	1,600		1,600	3,600	13,600		13,600
New York	10,912	69,525	7,150	76,675	7,713	58,360	4,395	62,755
Pennsylvania	711,138	2,202,742	334,280	2,537,022	788,571	2,277,192	436,406	2,713,598
Tennessee	50	250		250	50	250		250
Utah	200	1,100		1,100				
Vermont	277,463	777,971	94,702	872,673	282,820	795,474	121,988	917,462
Virginia	52,550	174,950	8,160	183,110	56,365	185,211	5,000	190,211
	1,100,513	3,454,817	507,916	3,962,733	1,194,048	3,596,182	644,284	4,240,466

Production of slate in the United States, by States and uses, from 1879 to 1913—Con.

State.	1901				1902			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
Arkansas	....	....	....	....	500	$4,000	....	$4,000
California	2,500	$18,608	....	$18,608	4,500	31,500	....	31,500
Georgia	800	3,000	....	3,000	1,000	4,000	....	4,000
Maine	20,791	111,295	$91,030	202,325	26,468	143,832	$62,726	206,558
Maryland	20,153	104,781	1,017	105,798	22,569	117,155	929	118,084
Minnesota	....	....	1,400	1,400	....	....	....	....
New Jersey	7,500	30,000	....	30,000	8,000	32,000	....	32,000
New York	15,786	91,805	9,155	100,960	21,165	116,628	10,090	126,718
Pennsylvania	853,028	2,591,625	392,639	2,984,264	908,206	3,001,545	545,777	3,547,322
Vermont	330,191	984,317	177,874	1,162,191	400,029	1,338,817	126,101	1,464,918
Virginia	53,630	178,979	....	178,979	42,731	160,951	....	160,951
	1,304,379	4,114,410	673,115	4,787,525	1,435,168	4,950,428	745,623	5,696,051

State.	1903				1904			
	Roofing slate.		Other purposes than roofing slate.	Total value.	Roofing slate.		Other purposes than roofing slate.	Total value.
	Squares.	Value.			Squares.	Value.		
Arkansas	118	$709	$4,000	$4,709	1,750	$10,300	$4,000	$14,300
California	10,000	70,000	....	70,000	5,600	39,200	....	39,200
Georgia	....	....	....	....	1,000	4,500	....	4,500
Maine	27,377	157,911	73,319	231,230	20,789	120,838	60,330	181,168
Maryland	24,475	135,424	2,207	137,631	22,628	131,245	2,727	133,972
New Jersey	7,647	33,403	....	33,403	....	....	....	....
New York	15,690	89,548	22,450	111,998	10,022	64,102	7,441	71,543
Pennsylvania	871,875	3,378,804	581,102	3,959,906	778,825	2,922,259	710,987	3,633,246
Tennessee	....	....	....	....	115	607	....	607
Utah	....	....	....	....	50	300	....	300
Vermont	391,366	1,363,923	228,729	1,592,652	361,126	1,245,730	162,421	1,408,151
Virginia	29,646	115,356	....	115,356	31,852	130,208	....	130,208
	1,378,194	5,345,078	911,807	6,256,885	1,233,757	4,669,289	947,906	5,617,195

State.	1905				1906			
	Roofing slate.		Value of mill stock.	Total value.	Roofing slate.		Value of mill stock.	Total value.
	Squares.	Value.			Squares.	Value.		
Arkansas	50	$350	$9,650	$10,000	....	....	$5,000	$5,000
California	5,000	40,000	....	40,000	10,000	$80,000	....	80,000
Georgia	1,500	7,500	....	7,500	1,000	5,000	....	5,000
Maine	19,865	106,271	117,983	224,254	18,498	100,916	137,765	238,681
Maryland	25,845	149,315	1,900	151,215	25,288	129,965	1,004	130,969
New Jersey	1,340	5,360	....	5,360	....	....	....	....
New York	10,354	65,051	1,595	66,646	10,788	60,000	12,360	72,360
Pennsylvania	802,170	2,879,671	612,234	3,491,905	755,966	2,710,249	811,900	3,522,149
Vermont	339,001	1,174,246	178,295	1,352,541	354,134	1,189,799	251,531	1,441,330
Virginia	36,102	146,786	....	146,786	39,068	172,857	....	172,857
	1,241,227	4,574,550	921,657	5,496,207	1,214,742	4,448,786	1,219,560	5,668,346

Production of slate in the United States, by States and uses, from 1879 to 1913—Con.

State.	1907					
	Roofing slate.		Mill stock.		Other.	Total value.
	Squares.	Value.	Quantity.	Value.		
			Square feet.			
Arkansas					*a* $8,500	$8,500
California	7,000	$60,000				60,000
Maine	16,879	91,583	404,829	$145,023		236,606
Maryland	21,815	113,665			2,395	116,060
New Jersey	2,000	8,000				8,000
New York	11,908	81,535	13,000	1,950		83,485
Pennsylvania	793,466	2,987,740	4,597,884	620,753	*b* 247,147	3,855,640
Vermont	385,314	1,301,576	963,911	175,683		1,477,259
Virginia	39,172	173,670				173,670
	1,277,554	4,817,769	5,979,624	943,409	258,042	6,019,220

State.	1908						
	Number of operators.	Roofing slate.		Mill stock.		Other.	Total value.
		Squares.	Value.	Quantity.	Value.		
				Square feet.			
Arkansas	1					$2,500	$2,500
California	1	7,000	$60,000				60,000
Maine	5	20,151	115,682	285,299	$98,025		213,707
Maryland	6	18,521	101,204			982	102,186
New Jersey	2	} 18,485	130,439	1,500	180		130,619
New York	11						
Pennsylvania	102	825,078	3,070,906	3,565,083	498,188	*c* 333,864	3,902,958
Vermont	51	402,258	1,513,580	941,930	196,911		1,710,491
Virginia	7	41,678	194,356				194,356
	186	1,333,171	5,186,167	4,793,812	793,304	337,346	6,316,817

State.	1909						
	Number of operators.	Roofing slate.		Mill stock.		Other.	Total value.
		Squares.	Value.	Quantity.	Value.		
				Square feet.			
California	1						(*d*)
Georgia	1						(*d*)
Maine	6	18,024	$101,865	372,229	$126,017		$227,882
Maryland	6	22,563	128,227			$1,311	129,538
New Jersey	2						(*d*)
New York	8	18,098	106,175	6,043	1,261		107,436
Pennsylvania	98	626,228	2,281,779	3,389,119	441,464	*e* 169,115	2,892,358
Vermont	51	397,441	1,533,936	1,345,503	307,347	306	1,841,589
Virginia	7	40,880	180,775				180,775
Other States *f*		10,479	61,840				61,840
	180	1,133,713	4,394,597	5,112,894	876,089	170,732	5,441,418

a Used chiefly for electric supplies.
b Composed of 5,711,105 school slates valued at $48,152 and 1,531,330 square feet of blackboard material, valued at $198,995.
c Composed of 5,036,147 school slates, valued at $42,364, and 2,388,886 square feet of blackboard material, valued at $291,500.
d Included in "Other States."
e Composed of 3,650,831 school slates, valued at $32,319; 1,095,540 square feet of blackboard material, valued at $130,195; and $6,601 for slate used for structural and other purposes.
f Includes California, Georgia, and New Jersey.

Production of slate in the United States, by States and uses, from 1879 to 1913—Con.

1910

State.	Number of operators.	Roofing slate. Squares.	Roofing slate. Value.	Mill stock. Quantity.	Mill stock. Value.	Other.	Total value.
				Square feet.			
California	1						(a)
Georgia	2						(a)
Maine	6	16,708	$99,023	385,307	$149,982		$249,005
Maryland	4	14,529	77,791			$782	78,573
New Jersey	2						(a)
New York	6	17,618	84,089	2,933	733		84,822
Pennsylvania	104	777,190	2,809,593	3,476,526	539,572	b 391,641	3,740,806
Tennessee	1						(a)
Vermont	48	395,640	1,585,324	1,316,732	308,811	524	1,894,659
Virginia	7	31,787	148,721				148,721
Other States c		7,149	40,123			50	40,173
	181	1,260,621	4,844,664	5,181,498	999,098	392,997	6,236,759

1911

State.	Number of operators.	Roofing slate. Squares.	Roofing slate. Value.	Mill stock. Quantity.	Mill stock. Value.	Other.	Total value.
				Square feet.			
Arkansas	2						(a)
Georgia	1						(a)
Maine	5	14,879	$98,074	394,531	$165,442		$263,516
Maryland	4	14,816	74,692			$1,343	76,035
New Jersey	2						(a)
New York	9	21,452	120,359				120,359
Pennsylvania	97	699,344	2,508,435	4,029,663	574,966	d 347,950	3,431,351
Vermont	49	328,760	1,335,244	1,320,383	287,197	2,500	1,624,941
Virginia	7	40,040	188,808				188,808
Other States c		5,386	22,959			50	23,009
	176	1,124,677	4,348,571	5,744,577	1,027,605	351,843	5,728,019

1912

State.	Number of operators.	Roofing slate. Squares.	Roofing slate. Value.	Mill stock. Quantity.	Mill stock. Value.	Other.	Total value.
				Square feet.			
Arkansas	1						(a)
Maine	3	16,640	$96,079	428,689	$186,599		$282,678
Maryland	4	18,236	90,993			$1,191	92,184
New Jersey	2						(a)
New York	10	27,024	135,136			71	135,207
Pennsylvania	93	716,770	2,528,791	4,101,200	552,929	e 392,527	3,474,247
Vermont	54	373,638	1,576,294	1,234,384	273,582	99	1,849,975
Virginia	8	42,220	195,392				195,392
Other States c		2,760	13,500	1,000	110	25	13,635
	175	1,197,288	4,636,185	5,765,273	1,013,220	393,913	6,043,318

a Included in "Other States."
b Composed of 5,610,518 school slates, valued at $47,075; 2,821,689 square feet of blackboard material, valued at $334,070; and $10,496 for slate used for structural and other purposes.
c Includes, in 1910, California, Georgia, New Jersey, and Tennessee; in 1911, Arkansas, Georgia, and New Jersey; in 1912, Arkansas and New Jersey.
d Composed of 4,308,292 school slates, valued at $35,157; 2,636,650 square feet of blackboard material, valued at $300,034; and $12,759 for slate used for structural and other purposes.
e Composed of 4,482,571 school slates, valued at $38,852; 2,898,742 square feet of blackboard material, valued at $352,109, and $1,566 for slate used for structural and other purposes.

Production of slate in the United States, by States and uses, from 1879 to 1913—Con.

State.	1913						
	Number of operators.	Roofing slate.		Mill stock.		Other.	Total value.
		Squares.	Value.	Quantity.	Value.		
Georgia	2	(a)	(a)				(a)
Maine	4	15,593	$89,933	513,745	$234,065		$323,998
Maryland	3	15,913	82,981			$1,012	83,993
New Jersey	2	(a)	(a)			(a)	(a)
New York	10	29,868	139,970	21,342	4,912		144,882
Pennsylvania	90	678,396	2,605,882	4,210,515	648,216	b 479,483	3,733,581
Vermont	53	332,642	1,351,175	1,566,409	346,645		1,697,820
Virginia	7	38,330	175,774			56	175,830
Other States c		3,202	15,347			25	15,372
Total	171	1,113,944	4,461,062	6,312,011	1,233,838	480,576	6,175,476

a Included in "Other States."
b Composed of 6,174,526 school slates, valued at $51,313; 3,504,162 square feet of blackboard material, valued at $426,703; and slate used for structural and other purposes, valued at $1,467.
c Includes Georgia and New Jersey.

The following table shows the number of squares and value of roofing slate, average value per square, and value of mill stock, by years, from 1879 to 1913, inclusive:

Values of roofing slate produced in the United States, 1879–1912.

Year.	Roofing slate.			Mill stock.			Other uses (value).	Total value.
	Squares.	Value.	Average price per square.	Quantity.	Value.	Average price (square foot).		
				Square feet.				
1879	367,857	a$1,231,221	$3.35					a $1,231,221
1880	457,267	a 1,529,985	3.35					a 1,529,985
1881	454,070	a 1,543,838	3.40					a 1,543,838
1882	501,000	a 1,753,500	3.50					a 1,753,500
1883	506,200	a 1,898,250	3.75					a 1,898,250
1884	481,004	1,843,865	3.83		$8,000			1,851,865
1885	536,960	1,638,467	3.05		10,000			1,648,467
1886	536,790	1,610,370	3.00					1,610,370
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	b $258,042	6,019,220
1908	1,333,171	5,186,167	3.89	4,793,812	793,304	.165	b 337,346	6,316,817
1909	1,133,713	4,394,597	3.87	5,112,894	876,089	.171	b 170,732	5,441,418
1910	1,260,621	4,844,664	3.84	5,181,498	999,098	.192	b 392,997	6,236,759
1911	1,124,677	4,348,571	3.87	5,744,577	1,027,605	.178	b 351,843	5,728,019
1912	1,197,288	4,636,185	3.87	5,765,273	1,013,220	.166	b 393,913	6,043,318
1913	1,113,944	4,461,062	4.00	6,312,011	1,233,838	.195	b 480,576	6,175,476

a Estimated.
b 1907 includes 5,711,105 school slates, valued at $48,152, and 1,531,330 square feet of blackboard material, valued at $198,995; 1908 includes 5,036,147 school slates, valued at $42,364, and 2,388,886 square feet of blackboard material, valued at $291,500; 1909 includes 3,650,831 school slates, valued at $32,319, and 1,095,540 square feet of blackboard material, valued at $130,195; 1910 includes 5,610,518 school slates, valued at $47,075, and 2,821,689 square feet of blackboard material, valued at $334,070; 1911 includes 4,308,292 school slates, valued at $35,157, and 2,636,650 square feet of blackboard material, valued at $300,034; 1912 includes 4,482,571 school slates, valued at $38,852, and 2,898,742 square feet of blackboard material, valued at $352,109; 1913 includes 6,174,526 school slates, valued at $51,313, and 3,504,162 square feet of blackboard material, valued at $426,703.

As will be seen from the above tables, the values from 1879 to 1889 do not represent the entire value of slate quarried, as no record of slate used for mantles, school slates, pencils, tombstones, etc., was kept. In 1885 there was a large decrease in the average value per square—from $3.83 in 1884 to $3.05 in 1885. From 1885 to 1892 both the price and production increased in value, but owing to the financial troubles of 1893 the output decreased considerably, or from a total of $4,117,125 in 1892 to $2,523,173 in 1893. Since that time the value of the output has steadily increased, being aided largely since 1896 by export trade, until in 1903 the value of the output was $6,256,885, the greatest yet obtained. In 1903, however, while the beginning of the year showed active operations in the slate industry, the later part of the year showed a greatly decreased demand, owing to strikes in the building trades. Several of the chief producing States showed decreased output of roofing slates, with increased price.

In 1908 and 1910 the slate output was practically the same as in 1903, owing to the increased production of mill stock. The output of roofing slate was larger in 1908 than in any other year for which statistics have been collected.

The largest average price per square obtained has been $4, in 1913. The value of slate used in the manufacture of blackboards and school slates has been separated from other mill stock since 1906 and included under "Other uses." This slate is obtained entirely from Pennsylvania, and a separation of these figures into quantity and value is shown in the footnote to the above table and also in the table showing the output of Pennsylvania by counties.

Pennsylvania, producing over 57 per cent of the total value of the slate in the United States, is practically the only State where the industry is not confined to one district, and the following table is given showing the production of this State by counties and by uses for the years 1909–1913:

Production of slate in Pennsylvania, by counties and uses, 1909–1913.

County.	Number of operators.	Roofing slate.			Mill stock.								Other (value).	Total value.
		Squares.	Value.	Price per square.	Manufactured.		Rough.		Blackboards.		School slates.			
					Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.		
1909.														
Carbon	1	12,843	$77,129	$3.69	....	....	....	....	....	....	....	....	....	$77,129
York (Peach Bottom)	3			6.19										
Lehigh	37	185,249	670,443	3.62	147,313	$40,119	575,903	$47,208	289,132	$21,747	1,885,221	$15,170	$5,398	800,085
Northampton	57	428,136	1,534,207	3.58	2,272,592	324,684	393,311	29,453	806,408	108,448	1,765,610	17,149	1,203	2,015,144
	98	626,228	2,281,779	3.64	2,419,905	364,803	969,214	76,661	1,095,540	130,195	3,650,831	32,319	6,601	2,892,358
1910.														
Carbon	1	14,291	75,191	2.25	....	....	....	....	....	....	....	....	....	75,191
York (Peach Bottom)	4			5.60										
Lehigh	43	216,743	697,964	3.22	294,730	73,092	173,052	18,578	1,522,741	172,448	2,627,821	22,429	464	984,975
Northampton	56	546,156	2,036,438	3.73	2,741,663	435,369	267,081	12,533	1,298,948	161,622	2,982,697	24,646	10,032	2,680,640
	104	777,190	2,809,593	3.62	3,036,393	508,461	440,133	31,111	2,821,689	334,070	5,610,518	47,075	10,496	3,740,806
1911.														
Carbon	1	17,354	91,573	3.58	....	....	....	....	....	....	....	....	....	91,573
Lancaster	1			5.00										
York (Peach Bottom)	5			5.55										
Lehigh	34	160,150	566,161	3.53	506,461	60,710	194,941	19,078	1,040,593	107,967	1,832,293	14,971	5,063	773,890
Northampton	57	521,840	1,850,761	3.55	3,188,160	487,015	140,101	8,163	1,596,057	192,067	2,475,999	20,186	7,696	2,565,888
	98	699,344	2,508,435	3.59	3,694,621	547,725	335,042	27,241	2,636,650	300,034	4,308,292	35,157	12,759	3,431,351
1912.														
Lancaster	2	18,135	99,810	5.71	....	....	....	....	....	....	....	....	....	99,810
York (Peach Bottom)	3			5.50										
Lehigh	33	158,603	571,269	3.60	394,419	53,764	197,930	19,619	902,697	101,686	3,109,417	27,650	....	773,988
Northampton	55	540,032	1,857,712	3.44	3,269,099	466,970	239,752	12,576	1,996,045	250,423	1,373,154	11,202	1,566	2,600,449
	93	716,770	2,528,791	3.53	3,663,518	520,734	437,682	32,195	2,898,742	352,109	4,482,571	38,852	1,566	3,474,247
1913.														
Lancaster	2	9,965	57,059	6.00	....	....	....	....	....	....	....	....	....	57,059
York (Peach Bottom)	3			5.71										
Lehigh	31	143,145	513,027	3.58	353,948	63,632	191,902	21,193	1,395,847	147,119	4,126,144	34,329	17	779,317
Northampton	54	525,286	2,035,796	3.88	3,116,338	535,284	548,327	28,107	2,108,315	279,584	2,048,382	16,984	1,450	2,897,205
	90	678,396	2,605,882	3.84	3,470,286	598,916	740,229	49,300	3,504,162	426,703	6,174,526	51,313	1,467	3,733,581

IMPORTS.

The importation of slate into this country has never assumed very great proportions, and the largest quantity was of course imported before the slate quarries of the United States were fairly developed and in running order. The following tables, taken from the reports of the Bureau of Statistics, Department of Commerce and Labor, and Bureau of Foreign and Domestic Commerce, Department of Commerce, show the value of roofing slate and other slate, chiefly slate mantels, chimney pieces, etc. From 1867 to 1875 the total annual value amounted to more than $100,000, the value of the roofing slate averaging two-thirds of the whole. In 1875 there was a decided drop in the value of roofing slate imported, and since that time the imports of roofing slate have amounted to practically nothing. The tariff act of October, 1913, reduced the duty on imported slate by half. Formerly the duty on slates, slate chimney pieces, mantels, slabs for tables, roofing slates, and all other manufactures of slate was 20 per cent ad valorem; the present rate is 10 per cent ad valorem.

The following table shows the value of roofing and other slates imported and entered for consumption in the United States from 1867 to 1913, inclusive:

Value of roofing and other slate imported and entered for consumption in the United States, 1867 to 1913, inclusive.

Year.	Roofing slate.	Other.	Total.	Year.	Roofing slate.	Other.	Total.
1867	$85,204	$37,510	$122,714	1891	$1,148	$12,373	$13,521
1868	118,776	16,045	134,821	1892	1,615	4,952	6,567
1869	85,364	19,602	104,966	1893	1,878	6,671	8,549
1870	107,521	19,879	127,400	1894	2,198	6,342	8,540
1871	117,484	21,381	138,865	1895	4,418	1,212	5,630
1872	107,192	25,925	133,117	1896	224	6,191	6,415
1873	91,503	26,643	118,146	1897	72	4,997	5,069
1874	80,519	27,519	108,038	1898	58	4,866	4,924
1875	16,342	42,022	58,364	1899	0	4,025	4,025
1876	2,051	44,266	46,317	1900	0	6,998	6,998
1877	4	34,479	34,483	1901	3	6,467	6,470
1878	275	39,935	40,210	1902	0	4,817	4,817
1879	620	46,260	46,880	1903	2,221	7,182	9,403
1880	72	51,165	51,237	1904	45	9,391	9,436
1881	2	46,862	46,864	1905	913	8,941	9,854
1882	154	45,774	45,928	1906	228	9,243	9,471
1883	2,813	44,375	47,188	1907	208	5,196	5,404
1884	16,099	34,640	50,739	1908	....	....	7,227
1885	5,196	56,913	62,109	1909	....	....	7,872
1886	4,366	60,512	64,878	1910	....	....	4,127
1887	529	46,188	46,717	1911	....	....	8,367
1888	765	44,069	44,834	1912	....	....	14,768
1889	481	35,828	36,309	1913	....	....	5,479
1890	369	34,602	34,971				

EXPORTS.

Almost from the beginning of the slate-quarrying industry in the United States slate has contributed to the export trade of this country. In 1876, 1877, 1878, and 1880 a large quantity of slate was exported, the greatest part going to Great Britain and the Continent, a remarkable feature being that several cargoes were shipped directly to Welsh ports, the base of the slate supply for Great Britain. From that time until 1896 Great Britain did not take much of the product, which found an outlet in South America, the West Indies, and Australia. In fact, British Australasia has always been one of the largest foreign consumers of American slate. Until 1884 no general record of the export movement was obtainable, but as probably 90 per cent was shipped from the port of New York, the following table is given, showing the shipment of slate from that port from 1876 to 1888. The export of manufactured slate is also shown in this table, and is almost entirely the value of school slates.

Value of exports of roofing and other slate from the port of New York from 1876 to 1888, inclusive.

Year.	Roofing slate.	Other.	Total.	Year.	Roofing slate.	Other.	Total.
1876	$377,233	$87,500	$464,733	1883	$54,063	$40,674	$94,737
1877	646,272	68,437	714,709	1884	90,262	53,021	143,283
1878	308,852	88,215	397,067	1885	115,206	49,965	165,171
1879	166,220	74,251	240,471	1886	79,064	40,804	119,868
1880	220,292	76,709	297,001	1887	62,052	39,560	101,612
1881	138,904	62,109	201,013	1888	116,119	46,142	162,261
1882	153,318	68,150	221,468				

The following table, taken from the report of the Bureau of Foreign and Domestic Commerce, Department of Commerce, shows the value of exports of roofing slate from the United States, by fiscal years from 1884 to 1904 and by calendar years from 1903 to 1913. No separate record has been kept of the manufactured product.

Exports of slate from the United States, by fiscal years 1884–1904, by calendar years 1903–1913.

1884	$79,464	1899	$1,363,617
1885	51,011	1900	950,543
1886	123,565	1901	898,262
1887	61,047	1902	945,352
1888	97,707	1903	[1] 628,612
1889	109,896	1903	[2] 838,683
1890	94,048	1904	[1] 726,715
1891	84,408	1904	[2] 449,743
1892	57,514	1905	408,309
1893	52,012	1906	255,785
1894	37,195	1907	220,995
1895	38,806	1908	197,216
1896	266,385	1909	209,338
1897	780,112	1912	[3] 171,775
1898	1,370,075	1913	226,413

No figures are available for 1910 and 1911, the slate exports not being kept separate from those of other kinds of stone. A large part of the slate exported from the United States goes to Great Britain and Ireland, and in 1912, according to figures published by the Slate Trade Gazette of London, the imports of United States slate amounted to 4,441 tons, valued at £18,133; in 1913 these exports decreased to 2,498 tons, valued at £9,362, or about one-fifth of the slate exported.

[1] Fiscal year. [2] Calendar year. [3] July 1 to Dec. 31 only.

APPENDIX.

BIBLIOGRAPHY OF SLATE.

The following bibliography is divided into three sections. The first includes only works of a general character, the second special scientific papers and memoirs, and the last works of an economic character.

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GLOSSARY OF GEOLOGIC AND SLATE-QUARRY TERMS.

As this bulletin is intended largely for the use of persons unfamiliar with geologic science, a number of the geologic terms used in it, whose meaning is not self-evident, are here explained, and for the benefit of geologists who may have occasion to use the book some of the terms in use among slate quarrymen are also translated into scientific terms.

AGGREGATE POLARIZATION. The optical property possessed by a thin section of slate cut transverse to its cleavage, which causes it, when viewed through a microscope under polarized light, to appear like a crystal of mica cut across its mineral cleavage. The aggregate polarization of a slate is due to the parallelism of the flakes of mica in the slate, and this, when marked, shows it to be a mica slate and not a clay slate. A very brilliant aggregate polarization, coupled with regularity in size of particles, indicates a high grade of fissility.

ANTICLINE. The arch part of a folded bed.

ANTICLINORIUM. A mountain mass arch-shaped in its general internal structure.

AUTHIGENOUS. Minerals originating chemically within a rock are called authigenous.

BACK JOINT. Joint plane more or less parallel to the strike of the cleavage and commonly vertical.

BATE. False cleavage.

BED. A continuous mass of material deposited under water at about one time.

BLIND JOINT. Obscure bedding plane.

BOTTOM JOINT. Joint or bedding plane horizontal or nearly so.

BRECCIA. Rock made up of angular fragments produced by crushing and then recemented by infiltrating mineral matter.

BRECCIATED. Applied to a rock made up of angular fragments but not transported.

CLASTIC. Constituted of rocks or minerals which are fragments derived from other rocks.

CLEAVAGE. Cleavage in a rock is an arrangement of its particles that gives it the property of splitting readily in a certain direction into thin plates. (See on slaty cleavage, p. 33.)

CLEAVE. Slaty cleavage.

CONFORMITY. When one bed overlies another in parallelism without any disturbance of the crust having affected the lower one before the deposition of the upper they are said to be in conformity.

CREEP. Effect of the motion of the continental glacier on the upper edges of a mass of steeply inclined thinly foliated rock, bending the foliation for a few inches or feet from the surface in the direction of the motion of the glacier. Creep may also result from gravity operating on steeply inclined weathered beds.

DIAGONAL JOINTS. Joints diagonal to the strike of the cleavage.

DIP. The degree and the direction of the inclination of a bed, cleavage plane, joint, etc.

DIP JOINT. Vertical joints about parallel to the direction of the cleavage dip.

DIKE. Molten material erupted through a narrow fissure.

END JOINT. Vertical joint about parallel to direction of the cleavage dip.

EROSION. The "wear" of a rock surface by natural mechanical or chemical agencies.

FALSE CLEAVAGE. A secondary slip cleavage superinduced on slaty cleavage. (See p. 37 and Pls. VII, XI, *A*.)

FAULT. A fracture resulting in a dislocation of the bedding or cleavage, one part sliding up or down, or both changing positions along the fracture.

FLINTS. A term applied alike to quartz veins or beds of quartzite.

FORMATION. A larger group of beds possessing some common general characteristics or fossil forms differing from those of the beds above and below.

GRAIN. An obscure vertical cleavage, usually more or less parallel to the end or dip joints.

HARDS. Term applied to beds of quartzite or quartzitic slate.

HCl. Hydrochloric or muriatic acid.

HOGBACKS. Shear zones. (See p. 44 and Pl. VIII.)

HYGROSCOPIC. Term denoting the absorption of moisture by a rock or chemical compound.

ISOCLINAL. Folds with sides nearly parallel are said to be isoclinal.

MATRIX. Term used in microscopic descriptions of slate, etc., to denote the chief substance of the slate itself, apart from the various mineral particles or crystals it may inclose.

METAMORPHISM. The process, partly physical, partly chemical, by which a rock is altered in the molecular structure of its constituent minerals and in their arrangement.

OVERLAP. Where, owing to the depression of a coast and the consequent landward shifting of the shore line, the later marine sediments cover up the extremities of the older ones, they are said to overlap.

PITCH. The inclination of the axis of a fold of rock.

POST. A mass of slate traversed by so many joints as to be useless. The term is also used to denote bands of hard rock.

PSEUDOMORPH. A mineral that has assumed the crystal form of a different mineral as the result of the partial or entire alteration or replacement of the original mineral through chemical processes.

QUARTZITE. A sandstone in which the grains are held together by a siliceous (quartz) cement.

RIBBON. A line of bedding or a thin bed appearing on the cleavage surface, sometimes of a different color; or a small bed of quartzose or calcareous material either crossing or parallel to the cleavage. If such ribbons are separated by beds of slate too thin to be worked, the ribbons and the small beds are together designated as "ribbon."

SCULPING. Fracturing the slate along the grain; that is, across the cleavage in the direction of the dip.

SERICITE. A ribbon-like or fibrous form of muscovite or potash mica.

SHEAR ZONE. Hogback. (See p. 44 and Pl. VIII.)

SLANT. Longitudinal joint more or less parallel to cleavage and commonly slickensided.

SLATY CLEAVAGE. See CLEAVAGE.

SLICKENSIDES. Surface of bed or joint plane along which the rock has slipped, polishing and grooving the surfaces.

SLIP. Joint crossing the cleavage, but of no great continuity. Many slips are fault planes.

SLIP CLEAVAGE. Microscopic folding and fracture, accompanied by slippage; quarrymen's "false cleavage." (See p. 37 and Pls. VII, XI, *A*.)

SPLIT. Slaty cleavage.

STRATUM. A bed.

STRATIFICATION. Bedding, in distinction from cleavage.

STRIKE. Direction at right angles to the inclination of a plane of bedding, cleavage, jointing, etc.

STRIKE JOINT. Joint parallel to the strike of the cleavage.

SULPHUR. Quarrymen's term for iron pyrites.

SYNCLINE. The trough part of a fold of rock.

SYNCLINORIUM. A mountain mass, in general internal structure trough-shaped.

THICK JOINT. Two or more parallel joints between which the slate has been broken up or decomposed.

TILL. A mixture of clay and pebbles deposited by glaciers.

TOP. The weathered surface of a slate mass or the shattered upper part of it.

UNCONFORMITY. If the lower one of two contiguous deposits affords evidence of having been exposed to atmospheric erosion before the deposition of the upper one, there is said to be an unconformity between them.

VEIN. When correctly used, denotes a more or less irregular, in places ramifying mineral mass, commonly of quartz, with calcite, etc., within the slate. Such veins are called veins of segregation, to show that they consist of matter collected from the adjacent rock by solvent waters. But, as generally used by slate quarrymen, "vein" is the equivalent of bed or stratum.

WAVERS. Annelid trails.

WILD ROCK. Any rock not fit for commercial slate.

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