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On March 2, 1895, the following provision was included in an act of Congress·

"*Provided*, That hereafter the report of the mineral resources of the United States shall be issned as a part of the report of the Director of the Geological Snrvey.'

In compliance with this legislation, the report Mineral Resources of the United States for the Calendar Year 1894 forms Parts III and IV of the Sixteenth Annual Report of the Survey.

The money received from the sale of these publications is deposited in the Treasury, and the Secretary of the Treasury dec ..es to receive bank checks, drafts, or postage stamps; all remittances, therefore, must be by POSTAL NOTE OR MONEY ORDER, made payable to the Director of the U. S. Geological Survey, or in CURRENCY, for the exact amount. Correspondence relating to the publications of the Survey should be addressed

TO THE DIRECTOR OF THE
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

WASHINGTON, D. C., *June, 1896.*

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE ANCIENT VOLCANIC ROCKS OF SOUTH MOUNTAIN, PENNSYLVANIA

BY

FLORENCE BASCOM

WASHINGTON
GOVERNMENT PRINTING OFFICE
1896

CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Baltimore, Md., March 17, 1894.

Sir: I have the honor of transmitting herewith, for publication as a bulletin of the Survey, a paper by Miss Florence Bascom on the Ancient Volcanic Rocks of South Mountain, Pennsylvania.

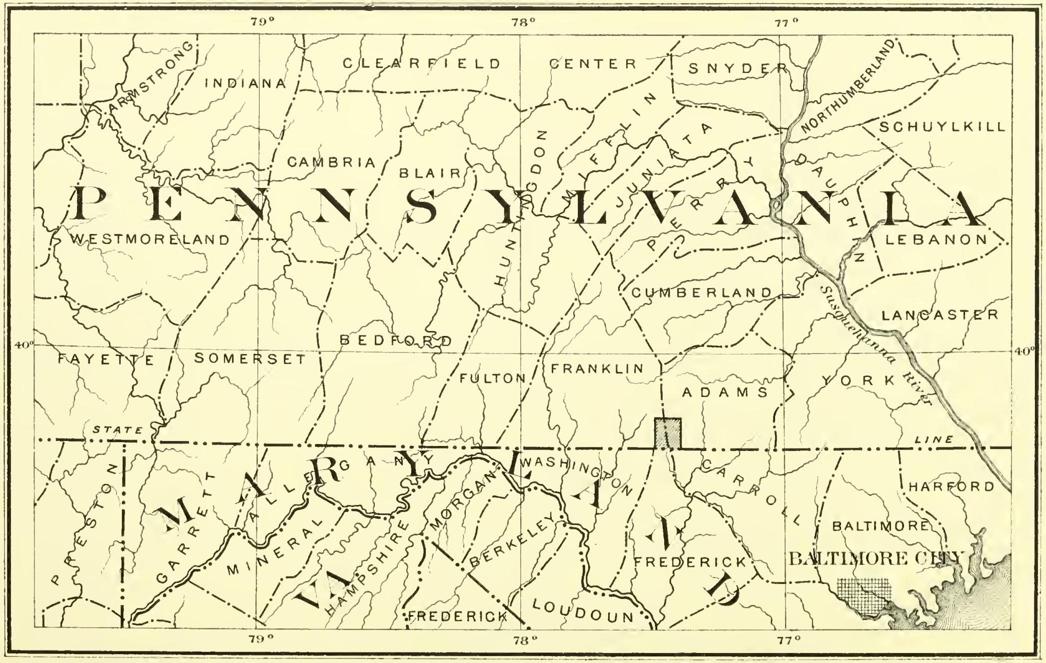
This work was done in the field during the summer of 1892 and in my laboratory during the winter of 1892–93. That part of it relating to the acid eruptive rocks was accepted in June, 1893, as a thesis for the degree of doctor of philosophy at the Johns Hopkins University.

Since that time the paper has been amplified and improved, and I believe that the detailed investigations which it describes will prove to be of permanent value in elucidating the character and history of ancient volcanic rocks, not merely in South Mountain, but in many other regions of the Eastern United States.

Very respectfully,

George H. Williams,
Geologist.

Hon. J. W. Powell,
Director United States Geological Survey.



MAP SHOWING LOCATION OF MONTEREY DISTRICT.

THE ANCIENT VOLCANIC ROCKS OF SOUTH MOUNTAIN, PENNSYLVANIA.

By Florence Bascom.

INTRODUCTION.

The mountain range known in Vermont as the Green Mountains, in Massachusetts as the Taconic Mountains, and in New York and New Jersey as the Highlands, is the South Mountain in Pennsylvania and Maryland, the Blue Ridge in Virginia, and the Smoky Mountains in North Carolina. The South Mountain in Pennsylvania lies just east of the middle of the State, and stretches from Maryland north and east in a sickle-shaped curve toward the Susquehanna. While in the New England States the mountains of this range rise to heights from 3,000 to 4,000 feet above sea level, and in its southern extension from 4,000 to 7,000 feet, in Pennsylvania its summits rarely exceed 1,500 feet.

South Mountain is 50 miles in length, and 10 miles wide at its broadest point. It covers from 150 to 175 square miles, and abundantly exposes distinct and interesting rock types. These rocks, prevailing throughout the entire South Mountain range, have long been known to geologists, although their true character was not recognized until recently.

In December, 1892, as the result of field work on the part of Dr. G. H. Williams in the northern and of the writer in the southern portion of South Mountain, there appeared a preliminary description[1] of two of the rock types, in which their identification as ancient volcanics was announced. In this bulletin it is proposed to substantiate that identification with more detailed proof. It is further proposed to show that these ancient igneous rocks were, at the time of their consolidation, identical in character with their recent volcanic analogues, and that their present differences are due to subsequent changes, chief among which has been devitrification. It is also proposed to recognize these facts in the nomenclature.

The petrographical features of the third and only remaining rock type of the South Mountain will also be described in some detail.

A brief report upon the previous geological work accomplished in the South Mountain, and some account of the structural features of the mountain and the age of its rocks, will precede the petrographical discussion.

[1] The volcanic rocks of the South Mountain in Pennsylvania and Maryland: Am. Jour. Sci., 3d series, Vol. XLIV, Dec., 1892, pp. 482-496, Pl. I. Reprinted in the Scientific American for Jan. 14, 1893.

CHAPTER I.

AN ACCOUNT OF GEOLOGICAL SURVEYS IN THE SOUTH MOUNTAIN BELOW THE SUSQUEHANNA.

HISTORICAL REVIEW.

The first topographical description of South Mountain appeared as early as 1755.[1] It was made by Lewis Evans, of Philadelphia, who describes the South Mountain with a fair degree of accuracy, as "not in ridges like the Endless Mountains, but in small, broken, steep, stony hills; nor does it run with so much regularity." He continues: "In some places it gradually degenerates to nothing, not to appear again for some miles, and in others it spreads several miles in breadth."

In a publication[2] which appeared in Germany in 1787 several pages are devoted to a general description of South Mountain. Two of the type rocks (the sandstone and the porphyry) were noted and aptly described, as the following quotation shows:

One finds here and there gray *laminated sandstones with quartz veins;* fragments of coarse ferruginous quartz. At one spot on the road [from Sharpsburg to Fredericktown] I found blocks of *gray-reddish porphyry* with little transparent quartz grains intermixed, and milk-white opaque feldspars. * * * The South Mountain in its entire extent contains rich crevices, gangues, and nests of ore, especially of iron and copper. * * * I have still to add, from the observations made upon this journey, that the eastern slope is gentler and more gradual than the western.

The most important publications on the South Mountain have appeared under the auspices of the various surveys of Pennsylvania and Maryland. The First Geological Survey of Pennsylvania was organized in 1836 under the distinguished geologist, Henry D. Rogers. The difficulties encountered, however, were so great that it was not until 1858 that the two quarto volumes of the survey were issued. Professor Rogers deals somewhat cursorily with the South Mountain region. He says:[3]

In its geological constitution, this tract is without much variety, for it contains *scarcely any rocks* except those of the Primal series. It is doubtful if the true gneissic rocks anywhere reach the surface within its borders, and only in one or two localities have even the lowest members of the Auroral limestones been met with covering the upper Primal slates. Even of intrusive igneous rocks, it embraces a *singularly small amount,* those met with being chiefly greenstones and trap rocks.

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[1]Analysis of a Map of the British Colonies in America, 1755.

[2]Schöpf's Beyträge zur mineralogischen Kenntniss des östlichen Theils von Nordamerika und seine Gebürge, chapter 30, pp. 96-101, Erlangen, 1787. A translation of this work has been made by Prof. John M. Clark, of the New York State Museum of Natural History, to whose kindness the writer its indebted for a copy of the unpublished manuscript of the pages relating to South Mountain.

[3] Geology of Pennsylvania, Vol. I, Part II, pp. 203-209, 1858.

The geological structure or mode of stratification of this belt is equally simple. The whole tract consists of two or three groups of high, narrow, nearly parallel anticlinal ridges, expanding and subdividing toward the southwest. These are composed of the Primal white sandstone. Between them are high parallel valleys and plateaus of the *Primal upper slates*, which, from being softer and more fissile, have been worn and trenched by the plowing force of waters to somewhat lower levels than the more resisting, ter cemented sandstones. The crests of the ridges are therefore stony and rugged, their flanks usually smoother, being formed chiefly of the *slate*.[1]

That Professor Rogers did not include in the "singularly small amount" of igneous rocks the rocks forming the valleys, the mountain flanks, and even the summits of the mountains, is further indicated by the following:

Another section across the mountain more to the southwest extends from south to north along the Baltimore and Carlyle turnpike. The first important stratum of the hills is the usual gray *siliceous altered rock*, so common along their southern side.

North of this, about 3 miles from Petersburg, occurs the *dark green slate*, with its epidote and white intrusive quartz. Succeeding this is an extremely *compact siliceous altered slate*, and beyond this a *reddish gray rock*, of the same series, containing specks of reddish feldspar and small veins of epidote, and near this the *fissile talcose rock*, several times mentioned before. * * * The *summit* of the ridge exhibits a dark blue and greenish blue indurated rock, weathering a dark brown, and evidently very ferruginous. It appears to be a band of the Primal slate in a *highly metamorphic* condition, approaching jasper. * * * These lower Primal slates are highly indurated, and even decidedly crystalline, containing in some of their layers *segregated specks*, and *even half-formed geodes* of epidote and other minerals.

On page 206 of the same report Professor Rogers has figured a section across South Mountain, along the Gettysburg Railroad, from Fairfield to Monterey Springs. This section shows stratified rocks lying in a series of anticlinal flexures, which accord rather with Professor Rogers's conception of "rock waves" than with his observed dips. These dips are, with a single exception, to the southeast. Accompanying the section is the following description, which bears directly upon the portion of South Mountain that is particularly discussed in this bulletin:

Passing now to the eastward of the Green Ridge axis we cross a high slope of slate, apparently the upper Primal, in a synclinal fold, and then traverse a succession of outcrops of the Primal white sandstones and slates to the eastern base of the high land called Jack's Mountain, at the foot of which the older rocks disappear under the Mesozoic red sandstone of the plain of Adams County.

The exposures in the sandstone near the tunnel opposite Jack's Mountain indicate a probable thickness of 1,000 feet. Near the tunnel at the northwest side of the mountain there is a hard epidotic rock, and not far from it a *highly altered greenish slate*, a rock found in several other localities farther west and containing layers of *gray slate, spotted with epidote*. Farther west occurs epidote with asbestus. Near Minie Branch search was made many years ago for copper ore, but nothing was found to justify the expectation of finding a productive vein of that mineral. A small quantity of copper ore was once obtained and a furnace built for smelting it in a small ridge north of Jack's Mountain, but the exploration was abandoned. The metal occurs in the form of a green and blue carbonate, with a little native copper. Evidently the ore is not abundant.

[1] The italics in this and the following quotations are the writer's.

Many of the characteristic features of the South Mountain rocks were aptly described by Professor Rogers, yet, plainly, their nature was not fully understood nor their importance appreciated at the close of the First Geological Survey of Pennsylvania. In 1860 the Primal series of Pennsylvania, as it occurs in Maryland, was thus characterized by Tyson:[1]

1. A hard sandstone, made up of grains of quartz, with occasionally grains of feldspar and kaolin.

2. A slate, varying in color from gray to brownish and greenish. It is ranked as an argillite, but portions of it assume a marked talcose appearance, especially in the Catoctin Mountain, and in parts of Middletown Valley, where it has been much disturbed and altered by proximity to intrusive rocks. These last consist of amphibolites (trap), porphyries, amygdaloid, serpentine, and epidote. This last-named rock is extensively developed, both in large masses and intercalated between the slates.

The Second Geological Survey of Pennsylvania was organized in 1874 under Prof. J. P. Lesley, who had been an assistant to Professor Rogers in the earlier survey.

With improved facilities for scientific work, and with more accurate methods of mapping, a new survey of South Mountain was undertaken by Dr. Persifor Frazer, with A. E. Lehman as topographical assistant. Five sections (Nos. 7, 8, 9, 10, 11), more or less incomplete, were made through the mountain, and as the result of his investigations Dr. Frazer says:[2]

It is apparent that the great South Mountain is composed essentially of two groups of rocks, the *lower* (and along this line, the northwestern) consisting of various modifications of the quartz conglomerate above spoken of, and in which quartz occurs in various forms.

The *upper* and southeasterly group is felsitic in character, but contains, also, large beds of hydromica and chlorite schists intersected by veins of milk quartz, while the orthofelsite presents every variety of appearance, from a sandy and earthy slate, in which the crystals of orthoclase are very much decomposed, indeed, are sometimes almost clay, through the jasper-like variety to the massive and coarsely porphyritic structure in which it is suited to be used as an ornamental building stone.

In the same year (1877) Dr. Frazer published a further account[3] of the nature and origin of these "orthofelsites." This account was in substance twice repeated by him, in 1879[4] and in 1880:[5]

The rocks of this region [South Mountain] may be divided into two great series—a western (*underlying*), of which the characteristic strata are composed of quartzite and of arenaceous schist containing quartz pebbles (Mountain Creek rock), and the eastern (*overlying*) of hydromica and chlorite schists, and orthofelsite, both porphyritic and unporphyritic. Both these series show indications of having been penetrated by dikes of plutonic character within this area.

The porphyry, which carries the copper in this region, *shows no character of igneous action, but occurs in coarse and thin beds*, more or less disintegrated, and in certain

[1] Report on the Geology of Maryland, Jan., 1860, pp. 34, 35.

[2] Report of Progress in the Counties of York, Adams, Cumberland, and Franklin, 1877, CC, pp. 285-295.

[3] The copper ores of Pennsylvania: Polytechnic Review, Nos. 16 and 17, Vol. III, April, 1877.

[4] Trans. Am. Inst. Min. Eng., Vol. VII, 1879, p. 338.

[5] Second Geol. Survey, Pa., CCC, Appendix, 1880, pp. 312-313.

PANORAMIC VIEW OF THE MOUNTAINS OF THE MONTEREY DISTRICT.

localities reduced almost to the state of kaolin. Nothing which might correspond to the term sandstone was observed, though all the above sediments were free of grit and sandy particles. * * * It seems fair to conclude that the region of the copper-bearing rocks belongs to the Huronian cycle.

With these views Dr. T. Sterry Hunt expressed entire concurrence.[1] Dr. Hunt had previously made some study of the South Mountain rocks, and published, at various times, his observations concerning them. In 1876 he said: [2]

In the southern part of Pennsylvania, to the west of Gettysburg, this mountainous belt, rising between the Mesozoic on the east and the great limestone valley on the west, presents an immense development of a peculiar type of crystalline rocks which I detected there last year, and which has a considerable geological importance. It is a *bedded* petrosilex, grayish, reddish, or purplish in color, sometimes granular but more often jasper-like in texture, and frequently porphyritic from the presence of small crystals of orthoclase-feldspar or of glassy quartz. There is found here a great breadth of this rock distinctly bedded, presenting different varieties, and alternating with dioritic, or diabasic, epidotic, and chloritic rocks, with argillites, in which are sometimes included thin beds of the petrosilex, the strata generally dipping at high angles to the east.

These rocks Dr. Hunt provisionally referred to a position near the base of the Huronian division, adding:

This petrosilex is identical in its lithological character with the hälleflinta, or stratified flint rock of the Swedish geologists, which is by them assigned a similar position, i. e., above the most ancient gneisses.

In 1878 Dr. Hunt expressed essentially the same views,[3] and in 1879[4] he opposed the correlation of the South Mountain rocks with the copper-bearing rocks of Lake Superior (Keweenawan series), although at an earlier date he notes a resemblance. He says: [5]

I may also note that I have observed bedded petrosilex rocks like those just noticed [South Mountain porphyries] to the north of Lake Superior, both in an island south of St. Ignace and on the adjacent mainland. The conglomerates or breccias, which, in the rocks of the Keweenawan series on the south shore of the lake, include the native copper of the Calumet and Hecla and the Boston and Albany mines, are also made up of the ruins of a precisely similar petrosilex porphyry.

In October, 1879, Mr. J. F. Blandy made a brief reconnoissance of the lower portion of the South Mountain with not unfruitful results. He makes a suggestive correlation of the copper-bearing rocks of southern Pennsylvania with the Lake Superior copper formation,[6] thus recognizing the volcanic nature of the greenstones, at least, which he called "amygdaloidal trap." The acid rocks still remain "slates."

In the final report of the Pennsylvania survey,[7] Professor Lesley

[1] Trans. Am. Inst. Min. Eng., Vol. VII, 1879, p. 339.
[2] Proc. Am. Ass. Adv. Sci., 1876, pp. 211-212.
[3] Second Geol. Surv. Pa., Vol. E, p. 193.
[4] Trans. Am. Inst. Min. Eng., Vol. VII, p. 331.
[5] Proc. Am. Ass. Adv. Sci., 1876, p. 211.
[6] Trans. Am. Inst. Min. Eng., Vol. VII, pp. 331-333.
[7] Final Report of the Pa. Geol. Surv., Lesley, Summary, Vol. I, 1892.

gives in substance the views of Dr. Frazer, which have already been quoted. He refers to Dr. Frazer's "section 8" as representative of the South Mountain rocks and structure. In this section, as in the others in which the orthofelsite appears, notably section 9, the bedded orthofelsite is represented as overlying the quartzose conglomerate. Professor Frazer concludes his summary with the statement that "it is hard to avoid the inference that our South Mountain rocks represent the Huronian section of Murray and Logan."

The geological map of Adams, Cumberland, and Franklin counties made by this final Pennsylvania survey refers all the rocks of the South Mountain region by the use of a single color to the "Azoic system."

The Second Geological Survey of Pennsylvania, while recognizing the extent and crystalline character of the South Mountain rocks and emphasizing the absence of the Primal of Rogers, still failed to solve the problems of the structure of the region and the age and origin of its rocks.

Professor Lesley has been very ready to acknowledge the incompleteness of the survey in the South Mountain, and since Mr. Walcott's determination of the age of its sedimentary rocks has appeared, he has expressed himself as desiring a new investigation of that region. While he claims that the survey of Pennsylvania "has been so minute and complete that comparatively little remains to be desired in the future," he adds: "The geology of the South Mountain is therefore [because of the new aspect given to it by the investigation of Mr. Walcott] in a very unsatisfactory condition and requires, in fact, a special and protracted investigation in the field. It is the most unsatisfactory part of the work of the Geological Survey of the State."[1]

Subsequent workers in the South Mountain are indebted to the Survey for the superior topographical maps of the mountain made on a scale of 1 inch to 1,600 feet (about 3 inches to the mile) by A. E. Lehman. These maps are invaluable to the field geologist and render possible accurate areal mapping. Owing to a confusion of cleavage planes and bedding the dips recorded on these maps are not reliable.

While the geological explorations of the South Mountain have been careful and minute and conducted by able geologists, the petrography of its rocks has never been thoroughly investigated. The microscope has not been used to assist in determining the nature and origin of the rocks, and to correct impressions colored by preconceived ideas or by an experience more or less limited to sedimentary structures. Under microscopic scrutiny and the comparative study of recent lavas, an increasing number of the so-called sedimentary rocks are proving to be igneous in origin. That such has proved to be the case in the South Mountain, while not surprising, is a fact of considerable significance, both because of characteristics which the rocks themselves possess and

[1] Report of the Board of Comm., pp. 5-6, 1893.

because they form an important part of a belt of similar rocks extending northward and southward along the Atlantic Coast.

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CHAPTER II.

GEOLOGICAL RELATIONSHIP OF THE ROCKS OF THE MONTEREY DISTRICT.

GENERAL DESCRIPTION OF THE AREA STUDIED.

This bulletin will treat chiefly of the geology of that portion of South Mountain which lies in Franklin and Adams counties and is embraced between the lower Cambrian quartzites of the Green Ridge on the west and the Triassic red sandstones of the plains on the east. The southern limit is the State line, while a parallel line passing through the Russel copper mine, some 6 miles to the north, furnishes a northern boundary.[1] (See Pl. I.) Well-wooded mountains (Green Ridge, Monterey Peak, Pine Mountain, Jacks Mountain, Raven Rock Mountain, Haycock Mountain, etc.), varying in altitude from 1,500 or 1,850 feet, with a general trend from northeast to southwest, inclosing high plateau-like valleys and sloping toward the eastern plains, constitute a region of exceptional natural beauty and geological interest. (See Pl. II.)

Though but a limited portion of an extended South Mountain area, this district is in many respects quite typical and furnishes ample material for some general conclusions in regard to the geology of the entire area. Although, because of the short time at the disposal of the writer, detailed field work was limited to the Monterey district, the petrographical study included material collected throughout the South Mountain.

EXTENT AND CHARACTER OF THE THREE ROCK TYPES.

Three distinct rock types are readily recognized. (Pl. III.)

1. A siliceous sedimentary rock, represented by a quartzose conglomerate, a sandstone, and a quartzite. This is rarely accompanied by an interbedded argillaceous slate.

2. An acid volcanic rock, which shows all phases of crystallization, from a spherulitic rhyolite to a true quartz-porphyry, is amygdaloidal or compact, is accompanied by pyroclastics and breccias, and is sometimes sheared into a perfectly fissile slate or sericite-schist.

3. A basic, holocrystalline, volcanic rock, which is usually amygdaloidal, massive, or more frequently schistose, and is also accompanied by pyroclastics and breccias and sheared to a slate.

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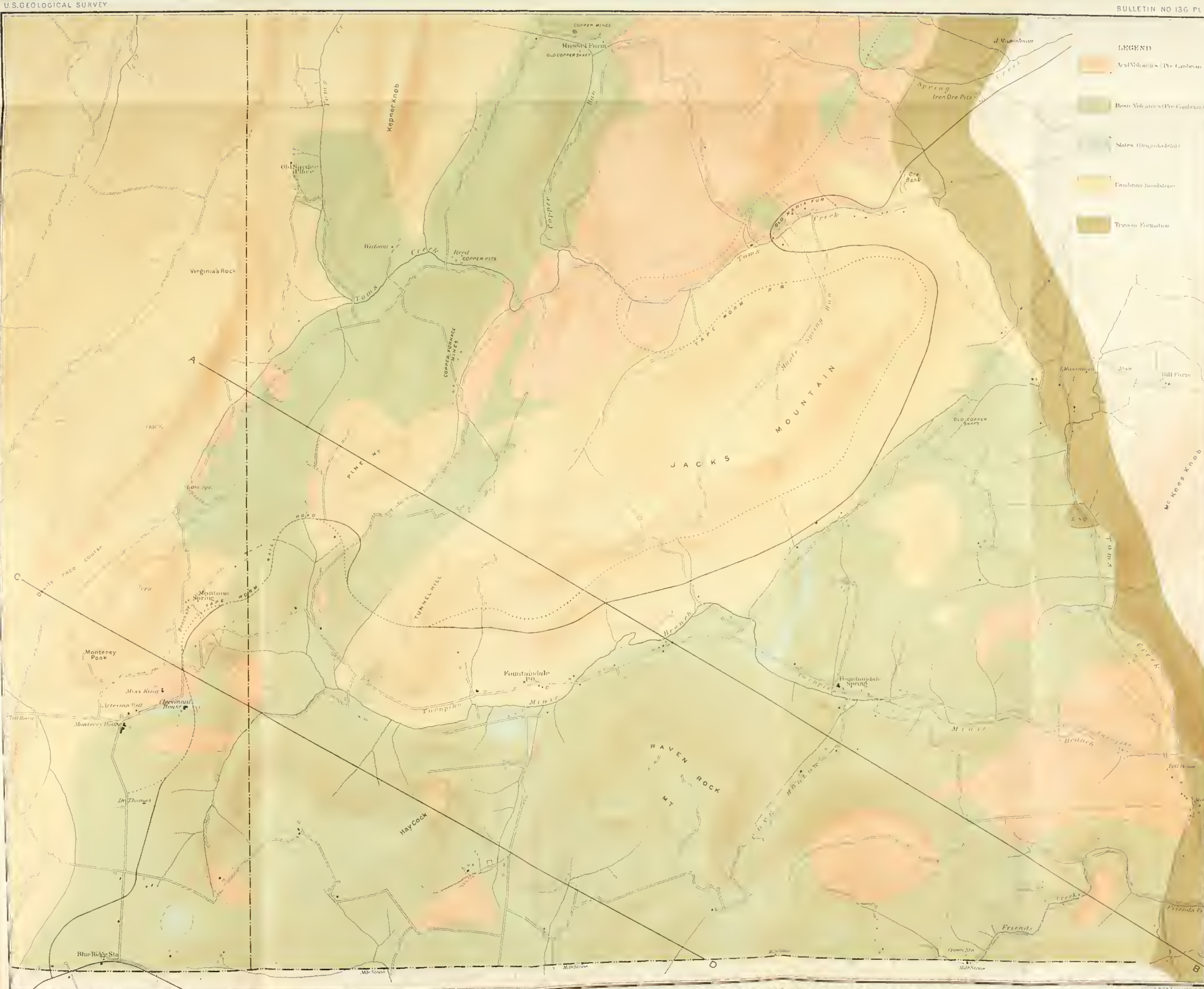
[1] As a matter of convenience this area will be called the Monterey district.



GEOLOGIC AND TOPOGRAPHIC MAP OF THE MONTEREY DISTRICT.

Scale

The slates of the region thus prove to be both sedimentary and igneous. The former are argillaceous. The latter are either acid or basic, and are far more abundant than the former.

SEDIMENTARY ROCKS.

Areal distribution.—The first-mentioned of the rock types occupies the high altitudes only, Green Ridge, Monterey Peak, Pine Mountain, and Jacks Mountain being largely formed of it, while it caps Haycock Mountain and the foothill to the east of Jacks Mountain.

Structural features.—The strike of the sediments is uniformly northwest and southeast, with a mean dip of about 45 degrees southeast. There are some exceptions to this southeasterly dip, notably at Monterey Peak, where the dip is northwest, forming, with the Green Ridge sandstone, a gentle syncline. (See Pl. V.)

In the Jacks Mountain quartzite the bedding is exceedingly obscure and the cleavage very marked. There is an opportunity for error in determining the dip by the confusion of the two.

At the northeast end of the tunnel which is cut through a spur of Jacks Mountain, on the Gettysburg Railroad, stratification is distinctly visible, and shows that minor crumpling of the sediments as well as folding on a large scale resulted from their uplift. The rock is here folded in a series of small anticlines and synclines. (See Pl. IV.)

Thickness.—Professor Rogers estimated the thickness of the sandstone at 1,000 feet. Professor Lesley, on the other hand, considers it "immensely thick," and states that Frazer's "section 11" shows 32,000 feet of quartzite and 64,000 feet of schistose conglomerate.[1]

Walcott[2] and Keith,[3] in their examination of a section of the same quartzite, sandstone, and conglomerate, displayed to the west of the Monterey district, agree essentially with Professor Rogers's estimate (1,000–1,200 feet). The writer did not find sufficient data within the Monterey district for a reasonably correct estimate of the thickness of the quartzite. There are undoubtedly a very great number of minor crumplings and foldings resulting in compressed synclines, anticlines, and thrust planes in Jacks Mountain. Since there are no means of determining the number of these folds, no estimate can be made of the thickness of the formation. If the minor folds are ignored, the dip and horizontal extent of the sediments indicate a thickness which is enormous, an indication unsustained by sections only 2 miles to the west. Probably the estimate made by Mr. Walcott (1,200 feet) in that more favorable locality will be approximately correct for the Jacks Mountain quartzite.

Age and superposition.—These siliceous clastics are the "Primal white

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[1] Summary, Final Report Geol. Pa., Vol. I, 1892, pp. 145–146.

[2] Walcott, Notes on the Cambrian rocks of Pennsylvania and Maryland from the Susquehanna to the Potomac: Am. Jour. Sci., Vol. XLIV, Dec., 1892, p. 481.

[3] Keith, The geologic structure of the Blue Ridge in Maryland and Virginia: Am. Geologist, Dec., 1892, Vol. X, No. 6, p. 365.

sandstone" of Rogers, and are represented by him as interbedded with slates and occurring in a series of narrow anticlines. They form the "Mountain Creek rock" of Frazer and Lesley, mapped by them as Azoic and represented both in sections and text as underlying the "chlorite schists" and "bedded orthofelsites." Messrs. Geiger and Keith,[1] in their earlier investigation of the southward extension of this sandstone in the Blue Ridge, placed it above the limestone of the Cumberland Valley, and, upon structural grounds, determined its age as Upper Silurian (Medina). The true age of these sediments has recently been determined beyond question, through the discovery of fossils, by Mr. Walcott.[2] No fossils were found in the quartzose conglomerates and quartzites of the Monterey district (No. 2 of Mr. Walcott's section), but the interbedded argillaceous shales, of which mention has been made, are found to the west of the Monterey district passing beneath quartzite and other shales in which were discovered the remains of *Scolithus linearis*, *Olenellus*, and *Camerella minor*. These discoveries undoubtedly refer the conformably underlying Monterey quartzite to a Lower Cambrian age.

In a recent section made in the light of Mr. Walcott's discoveries and of his own subsequent discovery of fossils in the Blue Ridge, Mr. Keith[3] gives the Monterey sediments a similar position (No. 4), describing them as a "massive white sandstone with bluish black bands, feldspathic, and in places conglomeratic." Mr. Walcott calls them "a coarse-grained quartzite, sometimes conglomeratic."

The sections (Pl. V) through the Monterey district show the relative distribution and position of the three type rocks. It will be observed that the sandstone lies in a gentle syncline, or almost flat, and wholly above the eruptives. These observations made by the writer in the Monterey district and elsewhere in the South Mountain, accord with the observations of Mr. Keith[4] in Maryland. Owing to the entire absence of exposure, save at the tunnel, the minor folding, which is undoubtedly present at many other points, is not indicated in the sections.

Mr. Keith[5] finds that in Maryland, as a result of faulting, the igneous rocks occasionally overlie the sandstone. This is nowhere the case in the Monterey district. The facts that no inclusions of sandstone were found in the volcanic breccia, and that fragments of the acid eruptive occur in the quartzose conglomerate, suggest the superficial character of the latter.

Further indications of the same nature will be discussed in considering the comparative age of the sedimentary and igneous rocks.

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[1] H. R. Geiger and Arthur Keith, The structure of the Blue Ridge near Harpers Ferry: Bull. Geol. Soc. Am., Vol. II, p. 163, pls. 4 and 5.

[2] C. D. Walcott, Notes on Cambrian rocks of Pennsylvania and Maryland: Am. Jour. Sci., Vol. XLIV, 1892, p. 481.

[3] A. Keith, Geologic structure of Blue Ridge in Maryland and Virginia: Am. Geologist, Vol. X, 1892, p. 365.

[4] Geiger and Keith, loc. cit., p. 155, pls. 4 and 5.

[5] Loc. cit., p. 365.

CRUMPLING OF SANDSTONE AT THE EAST END OF TUNNEL THROUGH JACKS MOUNTAIN, ON THE GETTYSBURG RAILROAD.

Economic value.—The susceptibility of these porphyries to a fine polish and their suitability for ornamental purposes have been remarked by many of those who have studied them.

The earliest mention of this sort was made in 1822 by Dr. Hayden,[1] who notes "handsome porphyry, Nicholson's Gap, Blue Ridge, Pennsylvania, crystals red and distinct."

Speaking of Catoctin Mountain, the southern extremity of South Mountain in Maryland, Tyson says:[2]

> Its porphyries and amygdaloids are deserving of the attention that I propose hereafter to bestow upon them. Some of them will receive a beautiful polish, but their hardness renders the process expensive. This can, however, be overcome by appropriate machinery.

Dr. Frazer[3] has, as already quoted, described the porphyries as "suitable for an ornamental building stone."

Dr. Hunt[4] has also called attention to the fact that "these peculiar rocks, which make such a conspicuous figure in the South Mountain of Pennsylvania south of the Susquehanna, are of interest economically from the fact that they are in other regions the repositories of rich iron ores, and also because they afford ornamental porphyries of rare beauty, similar to those wrought in Elfdalen, in Sweden."

The Tenth Census[5] reports that "it [the South Mountain porphyry] is well adapted to ornamental work, as it is rich in color, durable, and susceptible of a good polish, and in many cases could be obtained in abundant quantities. It has not yet been quarried for purposes of construction."

BASIC ERUPTIVES.

Areal distribution.—The basic eruptives occupy, in this district, an area fully twice as large as that covered by the acid eruptives constituting the major part of the valleys, foothills, and mountain flanks.

Character.—The rocks are massive, schistose, or slaty. They are usually conspicuously amygdaloidal, and associated with these amygdaloids are banded fine-grained schists, which have been considered altered accumulations of volcanic ash. In a section exposed on the Gettysburg Railroad there are alternating bands, from 2 to 3 feet wide, of a compact, fine-grained, epidotic rock which may also represent a basic volcanic ash. Bombs were found embedded in this epidotic rock. As with the acid rocks, there are accompanying basic breccias, though the latter are not abundant. The cementing material in every case was epidotic. An agglomerate formed of rounded fragments from an inch to 6 inches in diameter was also found. There was no opportunity for estimating the thickness of the accumulated basic flows. Wells have been bored in the basic rock to the depths of 55, 85, and 110 feet.

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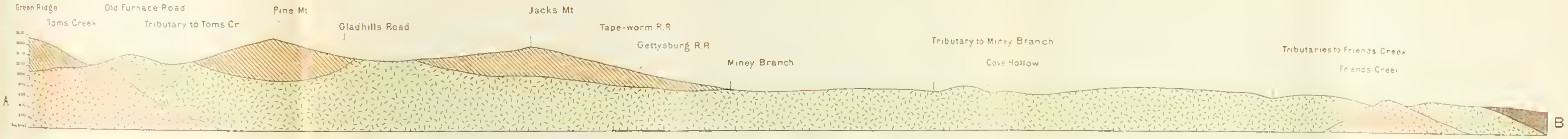
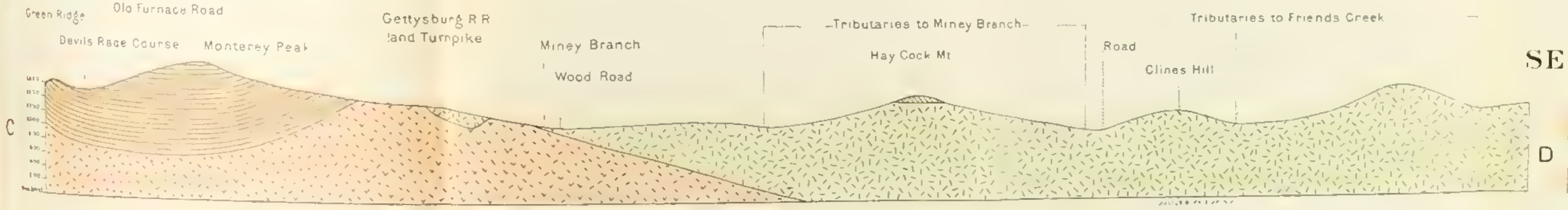
[1] H. H. Hayden, Mineralogical notes: Am. Jour. Sci. and Arts, Vol. V. 1822, p. 255.
[2] Tyson, First Annual Report, 1860, Appendix, p. 3.
[3] Frazer, Vol. CC, p. 285.
[4] Hunt, Proc. Am. Ass. Adv. Sci., 1876, p. 212.
[5] Tenth Census Report on the Building Stones of the United States, p. 168.





SECTIONS THROUGH THE MONTEREY DISTRICT.

Cambrian Sandstone.

Triassic Formation

Volcanics (Pre-Cambrian)

Basic Volcanics (Pre-Cambrian)

The basic rock, by reason of its softer character, is more subject to alteration under dynamic action than are the hard acid rocks. The effect of this is seen in the almost universal schistosity of the basic rock. This metamorphism is accompanied by a correspondingly greater chemical alteration than is shown by the acid rocks. The alteration consists largely in the abundant development of epidote and chlorite, which gives to the rock its uniform green color and its popular name of "greenstone."

Previous descriptions.—Dr. Hayden[1] notes the remarkable development of epidote as follows:

> Most beautiful epidote, with green and other shades of copper scattered in quartz. The blue is prevalent. Abundant in Blue Ridge. * * *
>
> Quartz and epidote, with green carbonate and red oxid of copper and native copper. Blue Ridge; abundant.

The greenstones are locally known as the "copper rock," because of the copper ore which they carry. They are Rogers's "lower Primal slates," which "are highly indurated, and even decidedly crystalline, containing in some of their layers segregated specks, and even half-formed geodes [amygdules] of epidote and other minerals." "A highly altered, greenish slate." "Dark-green slate, with its epidote and white, intrusive quartz." Tyson describes them as "slates." Dr. Frazer calls them "chlorite schists," and Dr. Hunt terms them epidotic or chloritic rocks. Blandy approaches most nearly the present idea of their nature in describing them as "amygdaloidal trap."

ORE DEPOSITS OF THE MONTEREY DISTRICT.

The workable deposits of ore in the South Mountain fall into two classes: The limonite ores, which are deposited in Paleozoic sedimentary rocks, and the copper ores, which are associated with pre-Paleozoic igneous rocks.

Profitable limonite iron mines are being worked at various localities in the South Mountain, in the Cambrian sandstone, and along the contacts between it and the Silurian limestone. They are fully discussed in the Final Report of the Second Geological Survey of Pennsylvania, Vol. I.

One such ore bank occurs within the Monterey district, on its northeastern boundary, at the contact between Triassic limestone and the Cambrian sandstone, near Old Maria furnace. This bank is exhausted and has not been worked for many years.

An interesting occurrence of copper ore and native copper[2] is to be found within the South Mountain chain, in a belt extending from a point some 6 miles north of the State line, in a southwesterly direction,

[1] Loc. cit., 1822, p. 255.

[2] Frazer, Copper ores of Pennsylvania: Polytechnic Review, Vol. III, 1887, No. 16, p. 159; An hypothesis of the structure of the copper belt of the South Mountain, pp. 82–85. Henderson, The copper deposits of the South Mountain: Trans. Am. Inst. Min., Eng., Vol XII, pp. 85–90.

to and beyond the State line into Maryland. This belt lies along the contact between the acid and basic eruptives.[1]

The principal localities where shafts have been sunk within this belt are the Snively copper mines, the Russel farm (the Bechtel shaft), the Reed copper pits, the Bigham copper mine, and the Headlight mine. (See map, Pl. III.) To the east of this belt, on the road between Fairfield and Fountaindale, a fifth old copper shaft is located.

The Snively copper mine, which is a mile north of the Monterey district, was not visited by the writer.

Frazer reports that the copper is associated with quartz, epidotic rock, and azurite.[2]

At the Russel copper mine, which is located on the Russel farm, at the fork of Copper Run, native copper occurs in quartz veins, associated with calcite, in a very siliceous epidotic rock, an epidosite. The material thrown out at the lower shaft was amygdaloidal greenstone; at the upper or Bechtel shaft, an acid slate, which indicates that the copper belt is along the contact between the two igneous rocks.

The Reed copper pits lie on the north side of Toms Creek, at the forking of the highroad near Spring Run. It has not been worked for forty years, and there is nothing visible to indicate the character of the copper occurrence. The dump pile shows scoriaceous greenstones with malachite stains. Dr. Snively reports that native copper occurs here in quartz veins.

The excavation for copper ore on the Bigham property, which lies just northwest of the forking of Gladhills road, furnishes interesting material for the petrographer. It is here that acid amygdaloids have been exposed in great perfection. They are abundantly stained with malachite, azurite, or cuprite. Metallic copper occurs in quartz veins traversing the amygdaloids, and in submacroscopic quantities in the amygdules. In the latter case the copper is frequently surrounded by zones of the oxide and the carbonate. An analysis of these rocks gives 4 per cent of copper. The Headlight mine is tunneled beneath the turnpike half a mile (eastward) below the Clermont House. Here the dump pile shows only greenstones, more or less stained with copper carbonates. This is also the case at the old copper shaft on the Fairfield road. Asbestos in quartz is quite generally found at these copper mines.

Throughout this belt the copper is evidently of secondary origin, occurring in seams and amygdules, where it has been deposited from solution. This occurrence of metallic copper in the igneous rocks of South Mountain is interesting because of its similarity to the Lake Superior copper-ore deposits. Its associations are quite analogous. In the Lake Superior region it occurs in veins, quartzose and epidotic, in the open-textured amygdaloids (basic), and in interbedded con-

[1] Frazer says: "The ore belt lies in the orthofelsite which forms this portion of the chain."

[2] P. Frazer, Copper ores of Pennsylvania: Polytechnic Review, Vol. III, 1877, No. 16, p. 170; also Appendix, Vol. CCC, Second Geol. Surv. Pa., p. 310.

glomerates. In the South Mountain, in the absence of contemporaneous interbedded clastics, the occurrence is limited to the igneous rocks.

The replacement of the feldspar by chlorite and epidote, and their replacement in turn by copper, characterizes the amygdaloids of the South Mountain also.

The explanation of the precipitation of the copper is doubtless the same in both regions.[1]

A correlation of the South Mountain formations and the Keweenawan copper-bearing rocks was suggested by Mr. Blandy in the article before quoted. There is great petrographical similarity between the porphyrites and felsites and diabase porphyrites of the Keweenawan series and their equivalents in the South Mountain, but it seems to the writer unwise to parallelize on petrographical evidence the South Mountain igneous rocks and the Keweenawan of Lake Superior. All correlation upon such grounds, when applied to rocks widely separated, is well known to be untrustworthy. There has not as yet been found sufficient evidence to show to what horizon in the Algonkian series the igneous rocks of South Mountain should be referred.

COMPARATIVE AGE OF SEDIMENTARY AND IGNEOUS ROCKS.

CONTACTS DESCRIBED.

That the Cambrian rocks do not underlie the "slates" and "orthofelsites," as stated in the reports of the Pennsylvania surveys, is quite plain, but whether the sediments are entirely subsequent to the igneous rocks or are in part, at least, contemporaneous, it is not so easy to decide.

Contacts between the sedimentary and igneous rocks are finely exposed at two localities. About halfway through the tunnel on the Gettysburg Railroad the basic igneous rocks and the Cambrian rocks are in contact. Both formations dip gently to the southeast (±20°). The sandstone has become an indurated quartzite. Close to the greenstone it has acquired a green color, due to the abundant development of chlorite. It has also become very schistose, and in fact might readily be confused with the greenstone itself. Granulation, undulatory extinction, and the obliteration of all direct evidence of clastic origin, as revealed by the microscope, indicate the action of dynamic force on the quartzite. The greenstone is slaty and too decayed at the contact for microscopic study.

Southwest of Old Maria Furnace, in an abandoned cut on the Tapeworm Railroad, a great surface of red felsite[2] is partially exposed and partially overlain by the clastic formation. (Pl. VI.) Here again there is a gentle dip of both rocks to the southeast (±45°). The sand-

[1] Pumpelly, Geology of Michigan, Vol. I, Part III, p. 43.

[2] Felsite is used here as a field term for a compact, stony, nonporphyritic or inconspicuously porphyritic volcanic rock. See pp. 37–38.

stone has become a vitreous quartzite. The hard felsite does not show alteration. That the igneous and sedimentary rocks have been subjected to the same forces of folding is shown by the uniformity of their cleavage dips at both these localities.

This conformity of structure planes, the absence of contact metamorphism, and the evidences of dynamic action indicate planes of thrust rather than planes of original deposition or of subsequent igneous intrusion.

CONCLUSIONS.

These two contacts do not decisively prove the younger age of the overlying sediments, although they very strongly indicate it. If the sandstone has been thrust over the lava from *beneath*, it would be necessary to suppose an enormous amount of erosion to account for the entire absence of volcanic material above the sandstone. On the other hand, it is very easy to suppose that overlying sediments, on being subjected to pressure, were thrust up over the igneous rocks from the east. This explanation of the facts coincides with other evidence relative to the comparative age of the sedimentary and volcanic rocks.

(1) Nowhere in the South Mountain has there been found a dike of the volcanic material in the sedimentary rock. Were the lavas more recent than the sediments, the former could hardly fail of filling cracks in the latter.

(2) No sedimentary beds have been found intercalated with the lava flows.

(3) There is no evidence of the alteration of the sedimentary rock by igneous contact.

(4) The igneous rocks, in their fluxion and amygdaloidal structures, and in their accompanying pyroclastics and ash deposits, bear every evidence of being *subaerial* lava flows.

(5) The presence of igneous fragments in the basal conglomerate of the sedimentary formation shows that erosion of the igneous rocks was taking place while the sediments were accumulating along their edges.

While it is true that some erosion of the eruptives must have taken place before and during the deposition of the Cambrian sediments, there is no evidence of extended erosion; indeed, the character of surface flows, which the lavas retain so conspicuously, would incline one to suppose that no great load of material has been removed. Mr. Keith's conception that the granite which in Maryland is intruded into the "diabase" (greenstone) is younger than the volcanics necessitates an immense original thickness of the diabase flows and an extended subsequent erosion to expose the plutonic eruptive. In this respect his argument for the comparative age of the deep-seated and surface igneous rocks seems at fault[1]. Such unlimited erosion is unsupported by field observations in the South Mountain.

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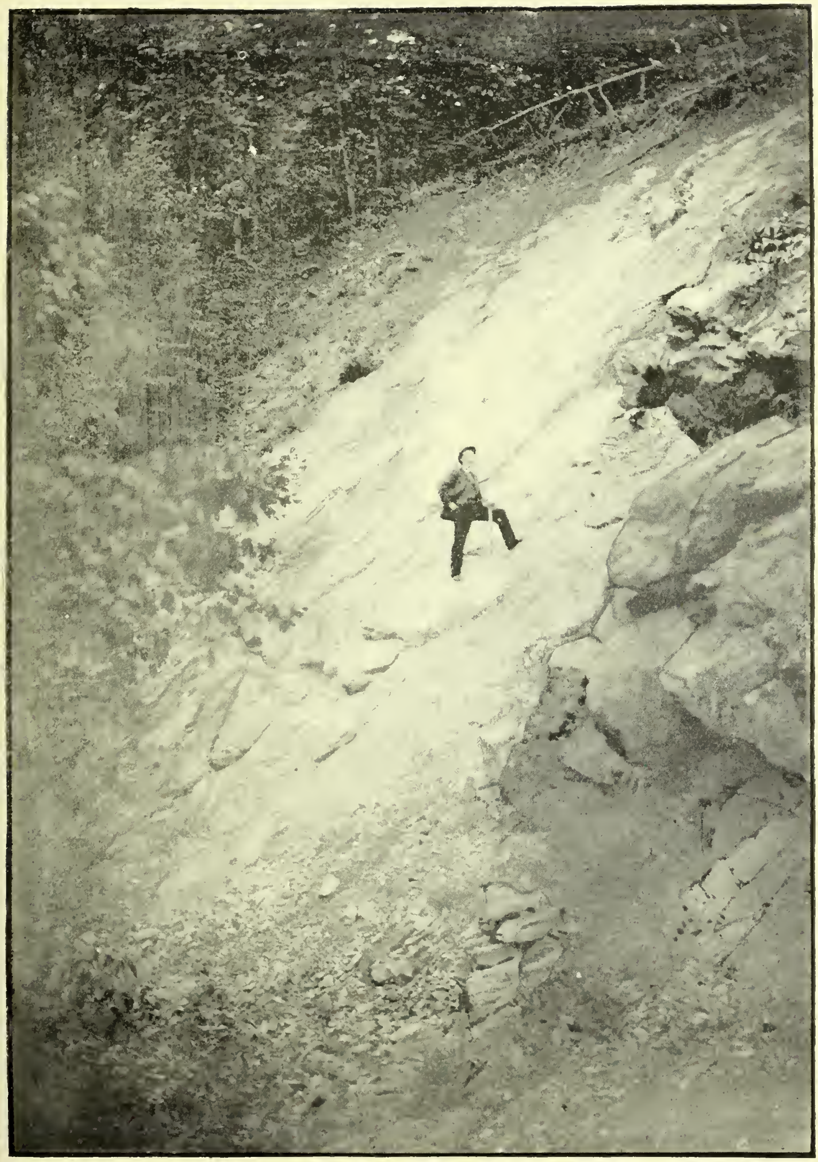
[1] Geologic structure of Blue Ridge in Maryland and Virginia: Am. Geologist, Vol. X, 1892, p. 368.



Felsite. Sandstone.

JUNCTION OF FELSITE AND SANDSTONE ON THE OLD TAPEWORM RAILROAD.

COMPARATIVE AGE OF ACID AND BASIC ERUPTIVES.

FIELD RELATIONS.

The relative age of the acid and basic volcanics is an interesting question, a question to which it is not possible with our present knowledge to give an entirely satisfactory answer.

On the one hand we find the acid rocks occupying, as a rule, the lower altitudes, and even overlain by the basic rock. Occurrences of the latter nature are located as follows:

(1) At the junction of Gladhill's road and the Fountaindale turnpike, in the northeast angle of the roads, a slight excavation exposes an outcrop of gray, slaty felsite overlain by greenstone.

(2) Not far from the source of Minie Branch there is exposed by the cutting of the stream a gray felsite, overlain by greenstone.

(3) On the road from Fountaindale to Fairfield, southeast of Jacks Mountain, a much-altered felsite is overlain by greenstone.

(4) Lastly, on the Fountaindale turnpike, about half a mile above the Emmetsburg tollgate, the same superposition is exposed by the roadside.

The only published statement of opinion as to the relative age of the volcanics has been made by Mr. Keith.[1] From his observations of the relative positions of the acid and basic rocks in Maryland, Mr. Keith expresses himself as confident that the "quartz-porphyry underlies the diabase."

On the other hand, over against this somewhat meager proof must be considered a few facts of another sort. Professor Williams reports that a position of the acid and basic rocks the reverse of that which has been described in the Monterey district occurs north of that district. Throughout the northern portion of the range the acid eruptives, which abound almost to the exclusion of the basic eruptives, form the mountains, while the latter occupy the valleys.

We must, moreover, bear in mind that the principles of stratigraphy employed in determining the age of sedimentary rocks may prove very misleading if applied to igneous rocks. The younger lava may be found overlain by the materials of an earlier eruption where the former, in coming to the surface, breaks through the older formation. The latest eruption may fill the depressions.

Where two different lavas occur on the same level, as is the case south of the Clermont House, the lava (in this case the acid lava) occurring as a narrow strip inclosed by the other might be an intrusive eruptive, and thus younger than the inclosing basic lava.

PROBABLE EXPLANATION.

With these principles in mind, with conflicting field evidence, and in the absence of genuine dikes of either acid or basic character, the data for the determination of the comparative age of the acid and basic

[1] Loc. cit., p. 367.

volcanics are not sufficient. In all probability there were several sources of lava flow.

The southern vents furnished the great areas of basic lava (greenstones) in Maryland and southern Pennsylvania, while the northern vents poured out the enormous acid flows.

In the Monterey district the two lavas are mingled, and apparently the basic flow was preceded by the acid flow.

Thus the facts observed by Professor Williams in the north, Mr. Keith in the south, and the writer in the Monterey district, may be brought into accord.

SUMMARY.

Three types of rocks are present in the South Mountain: (1) Siliceous sedimentary rocks of Lower Cambrian age, overlying with structural conformity and stratigraphical unconformity igneous rocks. These igneous rocks are surface flows of (2) an acid and (3) a basic constitution. They are probably pre-Cambrian, and lithologically resemble the Keweenawan copper-bearing rocks of Lake Superior.

There is not sufficient evidence to decide their comparative age, though in the Monterey district field observations, on the whole, indicate that the acid rocks are the older.

The subaerial flows were subjected to a limited erosion before the sediments were deposited and while they were being deposited, so that the region must have possessed some elevation at that time.

The intense dynamic action shown by the igneous rocks occurred after the deposition of the sediments. Since the sediments were laid down the whole region has been subjected to lateral pressure (at the time of the Appalachian uplift), whereby the igneous rocks were cleaved and sheared and the sedimentary formation was thrust up over them from the east—where it has been largely eroded, occurring now only sporadically—and the whole region was elevated. That erosion has removed a great thickness of material since this elevation is indicated by the cleavage dips of the igneous rocks.

CHAPTER III.

PETROGRAPHICAL DESCRIPTION OF THE CAMBRIAN ROCKS.

MACROSCOPICAL DESCRIPTION.

The sedimentary formation exhibits two marked phases, the conglomeratic and the quartzose. Its lowest member is conglomeratic.

These conglomerates are frequently slaty, through the development of more or less sericite. They contain quartz pebbles from an inch to an inch and a half in length, and sometimes show included fragments of quartz-porphyry and of a green slate.

From a conglomeratic character the sediments pass through a coarse sandstone into a compact quartzite exhibiting under the microscope the characteristics of a recrystallized clastic.

The quartzose sandstone is exposed in great masses on the flanks and summit of Monterey Peak, on Haycock Summit, at the Gladhills Switch on the Gettysburg Railroad and at many points along the railroad as it skirts the east side of Jacks Mountain, and in massive pinnacles along the crest of that mountain. That the sandstone has been greatly fissured and broken is indicated by the conspicuous and frequent quartz veining, but metamorphism, save in a few cases, has been limited to the formation of a vitreous quartzite by the deposition of a siliceous cement. The original stratification planes are usually preserved, and cross bedding is frequently conspicuous. A secondary cleavage is also very marked, so much so as, in the absence of well-defined stratification planes, to be mistaken for the bedding.

MICROSCOPICAL DESCRIPTION.

QUARTZITE.

Four specimens of typical quartzite were studied in the thin section. They were obtained from widely separated localities, and range in color from gray to a light green. Two of them illustrate the enlargement of quartz fragments and the genesis of a quartzite as perfectly as do any of the Lake Superior sandstones.[1] (Pl. XV, *a*.)

[1]Quartz enlargements were first described by Törnebohm, subsequently by Sorby, Young, Irving and Van Hise, Bonney, Phillips, and Iddings:

A. E. Törnebohm, Ein Beitrag zur Frage der Quartzbildung: Geol. Foren. Stockh. 1876, Vol. III, p. 35. Ref. Neues Jahrbuch für Mineral., 1877, p. 210.

H. Clifton Sorby: Anniversary Address, Quart. Jour. Geol. Soc. London, Vol. XXXVI, 1880, p. 62.

A. A. Young: Am. Jour. Sci., Vol. XXII, July, 1881.

R. D. Irving: Am. Jour. Sci., Vol. XXV, June, 1883.

R. D. Irving and C. R. Van Hise: Bull. U. S. Geol. Survey No. 8, 1884.

T. G. Bonney and J. A. Phillips: Quart. Jour. Geol. Soc. London, Vol. XXXIX, 1883, p. 19.

R. D. Irving and C. R. Van Hise: The Penokee iron-bearing series of Michigan and Wisconsin: Tenth Ann. Rept. U. S. Geol. Survey (1888–89), p. 375, Pl. XXVII, fig. 2.

J. P. Iddings: Mon. U. S. Geol. Survey, Vol. XX, 1892, pp. 346–347.

The original grains are conspicuously outlined by a rim of iron oxide and surrounded by interlocking areas which are optically continuous with the inclosed grain. Rarely the grain itself is composed of two differently oriented areas, in which case the enlargement is also composed of two different areas oriented with the two portions of the grain.

These same specimens show feldspar grains, usually with the "gridiron" structure of microcline. Occasionally a hornblende fragment is also present. The rock is evidently derived from granitic débris and might more accurately be called arkose. The fresh character of the fragments is in general noteworthy and suggests a source not far distant.

The best examples of the vitreous quartzite, the extreme phase of metamorphism in the sediments, are to be found in the tunnel at and in the neighborhood of the contact with the greenstone, and on the unfinished Tapeworm Railroad southwest of the Old Maria Furnace at the similar contact of the sandstone and felsite. At both of these localities the rock shows macroscopically and microscopically the effect of dynamic action. Of two specimens from the first locality, which has already been described in sufficient detail on page 27, one is a pure quartzite with prominent cleavage, on the surface of which iron rust is deposited. The thin section shows a quartzite from which every vestige of the original waterworn grains has been obliterated. The rock consists of interlocking areas of quartz and some interstitial material. This is a fine aggregate of quartz grains, and may be a remnant of the granulation which must have occurred as a result of the movement of the grains against one another.

A similar phenomenon in the sandstone of Sugar Loaf Mountain has been figured by Dr. Keyes.[1]

Another specimen from the same locality, but nearer the greenstone, shows a rock which, because of the shearing and chloritization that it has undergone, very closely resembles a chlorite schist. Its clastic character, however, becomes quite evident under microscopic examination. This shows it to be a siliceous rock, greatly sheared and altered in character by the formation of sericite and chlorite. It is the only section of quartzite in which chlorite has been observed. Its close proximity to the greenstone, in which that mineral is so abundantly developed, suggests a probable source of the magnesia, iron, and alumina. Tourmaline, zircon, magnetite, and feldspar are also present in this rock.

The quartzite at the felsite contact is similar, both in the hand specimen and in the thin section, to the first of the two specimens just described. No trace of the original grain remains. Undulatory extinction is pronounced and recrystallization complete. Specimens obtained close to the acid igneous rock differ only in the presence of a large amount of

[1] C. R. Keyes, A geological section across the Piedmont Plateau in Maryland: Bull. Geol. Soc. America, Vol. II, 1891, p. 321.

red iron oxide. The quartz crystals are frequently cracked, testifying to more intense dynamic action. The extreme induration at both these contacts is confined to a selvage of the sandstone.

SLATES.

In a cut on the Gettysburg Railroad, southwest of the Old Maria Furnace, the sedimentary rock is locally of a different character from that which has been described. It resembles the second specimen described from the contact in the tunnel more closely than any other of the clastics. Shearing has been accompanied by the development of sericite and chlorite, producing a soft, green, slaty rock. The chloritic areas have usually clearly defined boundaries, and possibly represent former hornblende grains. Zircon is present. The major part of the rock consists of quartz grains, with undulatory extinction.

Another local alteration of the clastic rock is to be found on the hilltops southeast of Jacks Mountain. Here it appears as a yellowish schistose rock. The thin section is characterized by the development of a large amount of sericite and granular epidote. The sericitic scales show a parallel arrangement, which is the product of shearing. The color of the rock is due largely to an iron hydroxide.

Among the sedimentary rocks within the Monterey district there rarely occurs, associated with the sandstone, an argillaceous slate. This is exposed just north of Jacks Mountain Station. It is the only representative in the Monterey district of the interbedded slates occurring west of that district. It is silky, pearl-gray, crinkled, and cleaves readily into slabs.

The thin section shows that the rock has been somewhat recrystallized, though its clastic origin is still apparent in the angular shape of its quartz fragments. Quartz and sericite are the principal constituents of the rock. The other constituents are magnetite, hematite, and a gray cloudy aggregate which, under the highest power, obscurely suggests leucoxene and granular epidote.

CHEMICAL ANALYSIS.

The analysis of the quartzite given below shows proportions which would be possible only in a derivative rock where the exact chemical composition is a matter of accident and subject to no fixed laws.

The silica percentage is disproportionately high for any but a clastic rock. The alkalies indicate the presence of a considerable amount of either orthoclase feldspar or sericite, probably the latter. The alumina and lime percentages denote the presence of epidote.

Analysis of quartzite.[1]

	Per cent.		Per cent.
SiO_2 (quartz)	84.130	CaO..............	.040
SiO_2 (Combined) .	7.870	K_2O..............	1.160
TiO_2..............	.145	Na_2O..............	.160
P_2O_5..............	.205	Ignition	.960
Al_2O_3..............	4.210		
Fe_2O_3..............	1.800	Total	100.680

SUMMARY.

The Cambrian sediments of the Monterey district may be classified as conglomerate, sandstone, quartzite, and slate.

The first two of these phases represent original sedimentary deposits, of which the latter has been locally metamorphosed by induration into a quartzite. The slates are in some cases from deposits of a more finely divided material, and in other cases they are the product of shearing.

There has been a limited and local introduction of new material, which shows itself in the production of chlorite and epidote. In every case the clastic character of the rock remains indubitable.

[1] Specimen No. 1157, 1½ miles S. of W. of the burned sawmill on the Conococheague. This analysis was made by Dr. F. A. Genth, formerly of Pennsylvania University, for the Second Geological Survey of Pennsylvania, Vol. CCC, Second Geol. Surv. Pa.

CHAPTER IV.

PETROGRAPHICAL DESCRIPTION OF THE ACID ERUPTIVES.

NOMENCLATURE.

The question of the nomenclature of the acid volcanics has proved to be one of considerable interest and importance. In the discussion of suitable terms for the description of these rocks, it will be necessary to anticipate, in some degree, the results of their microscopic study. A variety of names have been applied by petrographers to the acid type of the older volcanic rocks. Under the general group of quartz-porphyries, Rosenbusch classifies them as *microgranites*, with a micro-granitic groundmass; *granophyres*, with a micropegmatic groundmass; *felsophyres*, with a microfelsitic base; and *vitrophyres* (including pitch-stones and pitchstone-porphyries), with a vitreous base. Fouqué and Lévy employ *microgranitite*, *micropegmatite*, and *porphyre petrosiliceux* as corresponding terms. British petrographers have described these acid rocks under the terms *hornstones*, *claystones* and *claystone-porphyries*, *felsites*, *quartz-felsites*, and *felsite-poryhyries*, agreeing in this respect with the older German usage, when they have not followed Rosenbusch. In America both German and English usages have been followed, with more or less confusing results. In the nomenclature of the South Mountain rocks an effort has been made to avoid such confusion and to use such a term or terms as shall accurately characterize them and all similar rocks.

Among the acid eruptives of South Mountain are typical representations of Rosenbusch's quartz-porphyries. Closely associated with them and impossible of separation by any sharp line of demarcation are acid rocks with every structural characteristic of modern lavas.

Although possessing some characteristics in common with the *felsophyres*, these ancient prototypes of the rhyolite can not be included under that term, since they have a holocrystalline groundmass. Insomuch as many of the English *felsites* have been shown by Rutley, Allport, Cole, and Bonney to be devitrified obsidians and pitchstones, and thus, like the American rocks, representatives of the glassy lavas of pre-Tertiary times, these South Mountain lavas might, with some propriety, be termed felsites. Strict consistency would then compel the replacement of the term quartz-porphyry by the more limited and less well-established term quartz-felsite, which was felt to be a disadvantage. Moreover, the distinction between the rhyolitic lavas of

South Mountain and the typical quartz-pophyries is not one of the absence or presence of phenocrysts. Thus the term felsite would be forced to cover not only nonporphyritic acid rocks, but also conspicuously porphyritic rocks. Finally, felsite, though useful as a field name, may well be objected to as an inaccurate petrographical term.

A brief history of the word felsite and its synonyms in different countries (petrosilex, eurite, and hälleflinta,) will serve to illustrate the unfitness of it and these allied terms for exact petrographical usage.

"Felsit" was introduced into German petrographical nomenclature by Gerhard[1] in 1814, who applied the term to a matrix which he claimed was common to all feldspar, claystone, and hornstone porphyries. This matrix was a compact homogeneous aggregate of feldspar and quartz, supposed by Gerhard to be compact feldspar.

In 1858 Naumann[2] adopted Gerhard's word for the feldspar-quartz groundmass, and called all porphyries with such a base felsite-porphyries. This term has since been applied by Tschermak to porphyries without quartz phenocrysts (orthofelsites, orthophyres).

The more accurate German usage of the present day discards felsite save as a macroscopic term for an unresolvable porphyry base,[3] while "felsitfels" is used if, in the absence of phenocrysts, the rock is composed of this base only.[4]

This same quartz-feldspar mosaic, confused with compact feldspar, was distinguished as petrosilex by Wallerius[5] as early as 1747, and subsequently by Dolomieu. This term was also early used by Brongniart. In 1819 the same groundmass was called eurite by Daubisson[6] because of its fusibility. Michel-Lévy[7] uses the term petrosilex, but with a more limited meaning. He defines it as essentially synonymous with Rosenbusch's microfelsite, making "porphyre petrosiliceux" equivalent to felsophyre. Petrosilex is, however, generally used by Lévy and other French petrographers in a more or less loose and vague way, to cover a crystalline or cryptocrystalline quartz-feldspar aggregate or a partially amorphous siliceous feldspathic magma.

In Sweden, the fine-grained, apparently homogeneous acid rocks consisting essentially of quartz and feldspar and rarely porphyritic, are called hälleflinta.[8] They may be of aqueous or of igneous origin.

The early meaning of *felsite* in England was quite similar to that given it on the Continent. According to Pinkerton[9] the term was

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[1] Beiträge zur Geschichte des Weissteins des Felsit und anderer verwandten Arten: Abhandl. K. Akad. Wiss. zu Berlin, 1814, 1815, pp. 18-26.

[2] Lehrbuch der Geognosie, 2d ed., Vol. I, 1858, p. 597.

[3] Rosenbusch, Mikro. Phys., etc., 2d ed., Vol. II, p. 373.

[4] Rosenbusch, loc. cit., p. 354.

[5] Systematica Mineralogicum, 1847, French translation, 2 vols., Paris, 1853.

[6] Traité de géognosie, 1st ed., Vol. I, 1819, p. 112.

[7] Structures et classification des roches éruptives, p. 17.

[8] Justus Roth, Allgemeine und chemische Geologie, Vol. II, p. 494. F. Zirkel, Lehrbuch der Petrographie, Vol. I, p. 564.

[9] T. Pinkerton, Petralogy, A Treatise on Rocks, Vol. I, 1811, p. 161.

introduced in 1794 by Kirwan [1] for compact feldspar. Current usage as defined by Teall [2] applies the term to "compact stony rocks, the mineral composition of which can not be ascertained by examination with the naked eye or with the lens. * * * These rocks are anhydrous (or nearly so), and except in this respect agree in composition with the acid glassy lavas."

Dana [3] (as an exponent of American usage) defines "felsyte," a rock, as "compact orthoclase with often some quartz intimately mixed, fine granular to flint-like in fracture, * * * both metamorphic and eruptive." The mineral he defines as follows: "Felsite is compact, uncleavable orthoclase, having the texture of jasper or flint, which it much resembles. It often contains some disseminated silica. It is distinguished from flint or jasper by its fusibility. * * * It is the base of much red porphyry." This is substantially the "felsitfels" and "felsit" of Rosenbusch.

In short, "felsite" has been used to describe an acid base, unresolvable by the naked eye, and once supposed to be a single mineral. With the introduction of the microscope this macro-"felsitic" base was resolved into the microgranitic, micropegmatitic, and microfelsitic groundmass, the point of ignorance having been shifted from the felsitic base, macroscopically unresolvable, to the microfelsitic base, which is microscopically unresolvable.[4]

On the Continent "felsite" has practically been replaced by these terms. British and American petrographers retain it as a useful field name for rocks formed of this macroscopically unresolvable base without phenocrysts or with inconspicuous phenocrysts. In this sense the word will be used, when used at all, in this paper.

It is very generally recognized that structural features are not conditioned by the geological age of rocks, but are a function of the conditions of consolidation. That these conditions, while very varied and complex in any geological period, have not essentially altered since Paleozoic times, has been shown to be the case by some of the most able observers.[5]

With this recognition has come the growing conviction among petrographers that mere age should be eliminated as a factor in geological nomenclature. While this is true, it is felt on the other hand that the rock name should show some recognition of the alteration

[1] Richard Kirwan, Elements of Mineralogy.

[2] J. J. Harris Teall, British Petrography, p. 291.

[3] J. D. Dana, Manual of Mineralogy and Lithology, 3d ed., 1883, pp. 280, 442. Manual of Geology, 3d ed., 1879, pp. 73, 77.

[4] Rosenbusch does not assent to this interpretation of microfelsite, but regards it as a definite chemical compound allied to feldspar, just as felsite was once regarded.

[5] Teall, Address of the Pres. of the Geol. Soc. of the British Ass. Adv. Sci., 1893.

Judd, On the gabbros, dolerites, and basalts of Tertiary age in Scotland and Ireland: Quart. Jour. Geol. Soc., London, Vol. XLII, 1886, pp. 49–97.

Allport, Tertiary and Paleozoic trap rocks: Geol. Mag., London, 1873, p. 196. British Carboniferous Dolerites: Quart. Jour. Geol. Soc., London, Vol. XXX, 1874, pp. 529–567.

Iddings and Hague, On the development of crystalization in the igneous rocks of Washoe, Nev., with notes on the geology of the district: Bull. U. S. Geol. Survey No. 17, 1885 which the rock has undergone subsequent to its solidification. If at the time of its solidification the rock presented the features of a rhyolite, as is believed to have been the case with much of the South Mountain acid lava, but since that time has become holocrystalline, both these facts—its original character and its present character—should be recognized in the name. It is believed that this result may be secured by the retention of such well-established names as rhyolite, obsidian, trachyte, etc., preceded by a prefix which shall have such a signification as will indicate the altered character of the rock. The prepositions *meta*, *epi*, and *apo* all indicate, as prefixes, some sort of an alteration. Their exact force has been thus defined by Professor Gildersleeve. *Meta* indicates change of any sort, the nature of the change not specified. This accords with the use of the prefix by Dana in such terms as "metadiorite" and "metadiabase." These terms have been recently revived to designate "rocks now similar in mineralogical composition and structure to certain igneous rocks, but derived by metamorphism from something else."[1]

Epi signifies the production of one mineral out of and upon another. This prefix has not been much used. We find it in such terms as epidiorite, epigenetic hornblende, and epistilbite. *Apo* may properly be used to indicate the derivation of one rock from another by some specific alteration.

If, therefore, we decide to employ this prefix to indicate the specific alteration known as devitrification (Entglasung) we may obtain, by compounding it with the names of the corresponding glassy rocks, a set of useful and thoroughly descriptive terms like aporhyolite, apoperlite, apobsidian, etc., as to the exact meaning of which there can be no doubt.

In accordance with this usage, it is proposed in this paper to call all the acid volcanic rocks the structures of which prove them to have once been glassy, *aporhyolites*, while such as were originally holocrystalline, or whose original character is in doubt, will be termed quartz-porphyries.

The writer feels that the introduction of a new name into petrographical literature is to be deplored unless it can be shown that the name is formulated in accordance with certain well-defined principles. A good rock name should express composition, original structure, and as far as possible the process of alteration, if alteration has occurred. It is thought that aporhyolite and the suggested series of similarly formed terms meet these requirements. They are therefore adopted as preferable to any in present use.[2]

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[1] Whitman Cross, "On a series of peculiar schists near Salida, Colo.:" Proc. Colo. Sci. Soc., Jan., 1893, p. 6.

[2] Since the above was written the term eorhyolite has been proposed by Dr. Nordenskjöld to cover ancient acid volcanics identical with those of the South Mountain. In a review of Dr. Nordenskjöld's able paper, "Ueber archæische Ergussgesteine aus Småland" (Bull. Geol. Instit. Upsala No. 2, vol. 1, 1893), the writer has discussed the disadvantages that attend the use of any term or series of terms which carry with them the idea of age. The reader is referred to this review, which appeared in the American Geologist for March, 1896, pp. 179-184, for a fuller statement of the writer's idea of the relation existing between devitrification and age of volcanics.

It is a question whether it is always possible to distinguish between a primary and a secondary crystalline groundmass, and no attempt has been made to draw a sharp line between the quartz-porphyries and the aporhyolites. In the absence of some of the more marked structures of a glass the presence of a secondary crystalline structure has not been considered sufficient evidence for the completely secondary character of the crystallization. It is very probable that while a large portion of the lava flow consolidated as a glass, much of the lava solidified at a sufficient depth to have secured a holocrystalline groundmass.

QUARTZ-PORPHYRIES.

DISTRIBUTION.

A deep-red porphyry outcrops along the turnpike leading from the west to Monterey Station, and covers a small area north of the highroad.[1] One mile north of this, in the neighborhood of "Gum Spring," there are several limited areas of blue, purple, and brick-red porphyries. About 4 miles northeast, on the "Old Furnace Road," by the unfinished viaduct, is a large area of dark-blue porphyry, passing toward the southwest by insensible gradations into typical aporhyolites.

These are the more important areas of porphyries. There are other porphyries so closely associated with the devitrified glassy lava that they will not be separately located.

MACROSCOPICAL DESCRIPTION.

The beauty and variety of color of these porphyries have already been noted. The phenocrysts are not large (5 to 11 ^{mm} long), but are conspicuous against the dark or brilliantly colored matrix. The orthoclase phenocrysts are opaque white, pink, or brick-red. They usually possess a well-defined crystalline outline and show twinning in the hand specimen. The quartzes are colorless or a rich wine-red. The fracture is conchoidal and there is a less-marked tendency to cleavage than in the aporhyolites.

The porphyries show a reddish-brown color on the weathered surface, and on decomposing form a red earth. The presence of manganese is abundantly exhibited in dendritic markings on the cleavage surfaces. This is especially true in the case of the slates developed from the porphyries. (Pl. XIV.)

MICROSCOPICAL DESCRIPTION.

PHENOCRYSTS.

Feldspar.—The porphyritical feldspars are more abundant than the quartz phenocrysts, and are remarkably fresh and unaltered. That they belong to the group of alkali feldspars, and that both monoclinic and triclinic varieties are undoubtedly present, are indicated by chemical analysis (given on page 61), by their specific gravity, and by their

[1] See the geological map of the Monterey district accompanying this bulletin, Pl. III.

optical properties. Feldspar crystals were separated from specimens of the porphyry taken from different localities and their specific gravity was determined. The range was from 2.6 to 2.62. On account of the presence in the heavier feldspars of minute inclusions of piedmontite, the lowest specific gravity was considered to represent the purest feldspar.

Twinning is very common, according to either the Carlsbad or Manebacher (pericline) laws. Pl. XV, *b*, shows a Manebacher penetration twin of feldspar. The section is nearly parallel to the clinopinacoid, as the following observations indicate: The axis of least elasticity makes an angle with the twinning line (rhombic section) of about 15 degrees on one side and 21 degrees on the other; the obtuse positive bisectrix emerges. There is a slight trace of a basal cleavage and a microperthitic intergrowth parallel to *ć*. The position of the plane of the optic axes, the distribution of the axes of elasticity, and the specific gravity all indicate that the crystal is the triclinic soda feldspar anorthoclase.

The resemblance to this of the other feldspar phenocrysts makes it probable that this is the prevailing feldspar. Other sections show the albitic intergrowth (microperthite) developed in a pronounced manner (Pl. XVI, *a*). Every gradation of this structure is present, from the microperthitic to the cryptoperthitic. Sometimes the perthitic growth does not persist throughout the crystal, but is present in an incipient stage along its edge.

The feldspars are often cracked and drawn apart in the direction of the schistosity of the rock, and the cracks cemented with sericite scales whose parallel arrangement conditions the schistosity (Pl. XVI, *b*). This is most striking in porphyry obtained 40 feet below the surface, which shows an abrupt passage into a sericite-schist. The phenocrysts are crushed and pulled apart. This action had been accompanied by an abundant development of sericite. Some of the phenocrysts possess in the hand specimen a red color, which is due to a fine admixture of red iron oxide. These phenocrysts frequently prove, from a test of their optical properties, to be orthoclase.

The alteration of the feldspars to epidote may indicate the presence of lime in the feldspar. Undoubtedly, however, much of the lime is of secondary origin. This alteration of feldspar to epidote seems to be a direct one. There is no intermediate kaolin stage, such as observed by Rutley.[1] Accompanying the epidote is granular quartz. These two alteration products usually occupy the center of the crystal and are surrounded by a rim of unaltered feldspar.

Brilliantly colored piedmontite frequently fills cavities in the feldspar crystals. This mineral is often surrounded by a rim of epidote.

Quartz.—The bipyramidal or rounded quartz phenocrysts are remarkable only for their undulatory extinction and the cracks by which strain

[1] Rutley, On some perlitic felsites and on the possible origin of some epidosites: Quart. Jour. Geol. Soc. London, Vol. XLIV, 1888, pp. 741-742.

has been relieved. They are fresh and show characteristic embayments and inclusions. Like the orthoclase, they are sometimes reddened by inclusions of hematite, or are more rarely given a rich wine-red color by inclusions of piedmontite.

GROUNDMASS.

The holocrystalline groundmass of the porphyries consists essentially of quartz and feldspar. These minerals form either a finely micro-granitic mosaic or a structure which becomes of considerable interest in connection with the question of the original character of the crystallization.

In the first case there is no reason per se for supposing the crystallization to be other than primary. It is only as the crystallization is associated with secondary structures, or structures testifying to a primitive glassy condition, that the presumption favors its secondary character. When the crystallization is micrograinitic and presumably primary, the rock is a genuine quartz-porphyry.

The structure alluded to, which occasionally replaces the quartz-feldspar mosaic in the porphyries, is the micropoikilitic,[1] where all the quartz of the groundmass has crystallized in irregular areas inclosing the feldspar as lath-shaped microliths. These feldspar microliths are oriented quite independently of one another. This structure characterizes the aporhyolites, and the question of its primary or secondary character will be fully discussed in connection with these rocks.

The alteration of the groundmass to sericite and the formation of a sericite schist will be discussed in connection with the acid slates.

ACCESSORY CONSTITUENTS.

Piedmontite (manganese epidote) is the most remarkable of the accessory constituents. It is not only disseminated in microscopic quantities through the deep-red porphyry, but it also occurs in macroscopic masses, as a radiating aggregate, filling veins and cavities in the red felsite or replacing spherulitic crystallization.

Two localities in the Monterey district furnish a great abundance of the piedmontite: the southwest flank of Pine Mountain, 1 mile northeast of Monterey station, and the hillside south of the Clermont House, between the turnpike and Minie Branch. Microscopic sections of the aggregate show brilliantly colored needles of piedmontite intergrown with clear quartz. (Pl. XXV, *b*.) This intergrowth with quartz is also marked in the hand specimen. The radiating needles have the appearance of being broken, stretched apart, and the spaces filled with secondary quartz. The only other locality where piedmontite was found in macroscopic quantities is in the Buchanan Valley, 2 miles north of

[1] G. H. Williams, On the use of the terms poikilitic and micropoikilitic in petrography: Jour. of Geol., Vol. I (No. 2, Feb.-March, 1893), pp. 176–179.

the Chambersburg turnpike, and one-eighth mile west of Musser's store. Piedmontite occurs here in cavities associated with scheelite.[1]

Epidote is also abundantly present in the porphyries, passing by gradations of rose-colored epidote to the deep carmine of the piedmontite. Both of these silicates are undoubtedly secondary products.

Innumerable black globulites of manganese oxide and black and red iron oxide crowd the groundmass. In their arrangement they show fluxion structure, or form meshes inclosing the quartz areas which constitute a part of the micropoikilitic structure. This arrangement is sometimes so marked as to be conspicuous in the hand specimen, giving the rock a mottled appearance. Crystals of zircon are not infrequently present.

A study of the quartz-porphyries of the South Mountain shows us that they are present there in characteristic development, and offer no marked variations from the normal type described from other localities. For this reason a brief space only has been devoted to them.

APORHYOLITES.

DISTRIBUTION.

There remains to be described a large and important portion of the acid rocks of the Monterey district. These will be termed aporhyolites, for reasons already suggested and to be more fully discussed in the sequel.

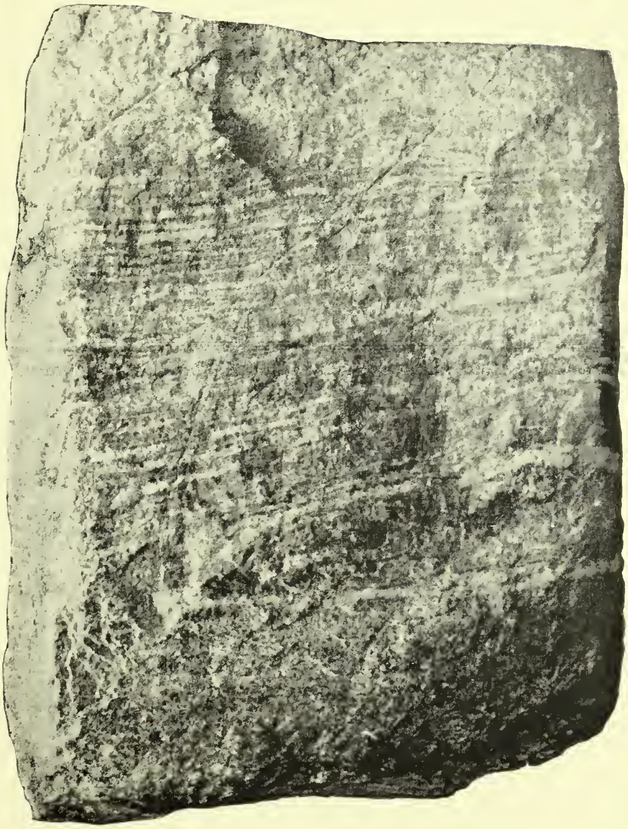
The localities colored red upon the geological map of the Monterey district (Pl. III) are aporhyolitic areas associated, in the cases already mentioned, with quartz-porphyries. The largest area begins just south of the Bigham copper mine, and, widening toward the north, extends far beyond the Monterey district. This area furnishes most of the spherulitic structures. A small detached area south of the Clermont House furnishes slaty and spherulitic aporhyolites. These aporhyolites and those of the four detached areas near the Maryland State line, separated from each other by a distance of a mile to a mile and a half, show some marked points of resemblance, to which attention will be called later.

The areas covering the foothills southeast of Jacks Mountain show an altered aporhyolite. There are several small areas of red aporhyolite on the Gladhill road leading to the Bigham property. At the forking of this road with the Fountaindale turnpike occurs the aporhyolite slate mentioned on page 29.

MACROSCOPICAL DESCRIPTION.

The aporhyolites have about the same range in color as the porphyries, varying from light bluish-gray, or buff, to many shades of red and purple. While usually compact and always fine-grained, they are

[1] G. H. Williams Piedmontite and scheelite from the ancient rhyolite of South Mountain, Pennsylvania. Am. Jour. Sci., Vol. XLVI, 3d series, July, 1893, pp. 50-57.



FLOW STRUCTURE IN APORHYOLITE, MONTEREY DISTRICT.

Four-fifths natural size. The specimen is deep red, with lines of flow in pink.

also sometimes very vesicular. In the latter case the amygdules of dark-green epidote and clear quartz, elongated by fluxion and conspicuous against a pale-pink background, render the rock strikingly handsome. Phenocrysts are usually present, but generally inconspicuous.

Delicate lines of flow structure, which are brought out in great detail by weathering or are painted in rich colors on the material washed by the mountain brooks, are another marked feature of the aporhyolites. These flow lines are frequently very sinuous, showing contortion and crumpling of the lava. (Pls. VII and VIII.) The flowage is often emphasized by the mingling of two contrasting magmas, forming taxites of either a eutaxitic or an ataxitic character. A fuller description of these taxites is given on page 57.

Another characteristic which these aporhyolites possess in common with their modern analogues is the spherulitic structure. Spherulites are rarely, if ever, altogether absent, and in some localities they are crowded so close together as to constitute the major part of the rock mass. They range in size from microscopic dimensions to those of a butternut. Where there is no regularity of arrangement and they are brought out in relief by weathering, the rock has a superficial resemblance to a conglomerate composed of rounded pebbles of remarkably uniform size (BB shot) and shape. (Pl. IX.) The rich grays and blues and purples of the spherulites and matrix render this a conspicuous rock. Other specimens from the same locality (the south flank of the mountain northeast of the junction of Copper Run and Toms Creek) show spherulites elongated by flow. They are thus drawn out into solid cylinders with a diameter of 1^{mm} and a length of some 2^{cm}.

Specimens of aporhyolites composed of spherulites about the size and shape of almonds (18^{mm} by 9^{mm}) were also found. The rock had been greatly sheared and the spherulites flattened.

Spherulites become a still more striking feature of the aporhyolites when arranged in layers which traverse the face of the rock in long, parallel, dotted bands. This arrangement has been described by Iddings in the obsidian of the Yellowstone National Park.[1]

While sometimes these bands are 4^{mm} wide, at a nearly uniform distance apart, and of an indefinite length, in other cases they are very narrow, dwindling into mere lines and dying out, to be succeeded by other lenticular bands. (Pl. X.) The planes of these spherulites have become planes of weakness and solution. The rock cleaves readily parallel to them and shows a coating of secondary silica on the cleavage surfaces. This deposition of silica causes these planes to become the hardest part of the rock, and hence they often stand out as parallel ridges on the weathered surfaces.

At the locality mentioned on pages 41–42, piedmontite, in radiating needles, associated rarely with scheelite, has, together with quartz, been

[1] Obsidian Cliff: Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 276, Pl. XVIII.

deposited along these planes of former spherulitic crystallization. The silica occupies the center of the deposit and gives rise to ridged surfaces. These layers of spherulites do not always lie in a single plane. Cross sections of the layers show irregular and minute sinuosities, which were doubtless caused by movement in the lava during consolidation.

The bands consist always, when not composed of piedmontite, of a central dark line (impurities) with a lighter band (opaque quartz) on either side. These in turn are bordered by dark lines (iron oxide) (Pl. X). This parallel banding, conspicuous even at a considerable distance, though recognizable as a true igneous structure by one familiar with the acid lavas of the Yellowstone National Park or of the Lipari Islands, counterfeits a sedimentary structure so closely that it is not surprising that the rocks should be described as "bedded orthofelsites."

Still other specimens show spherulites with a tendency to an arrangement in rows and chains which are in turn collected in bands some 2 inches in width traversing the rock and alternating with bands approximately free from spherulites. This arrangement differs from the layer spherulites in the fact that the outline of individual spherulites is quite distinct and the grouping irregular.

Some fine examples of the lithophysal structure were found in the Raccoon Creek region (Pl. XI). Nothing that could be definitely recognized as lithophysæ was observed in the Monterey district.

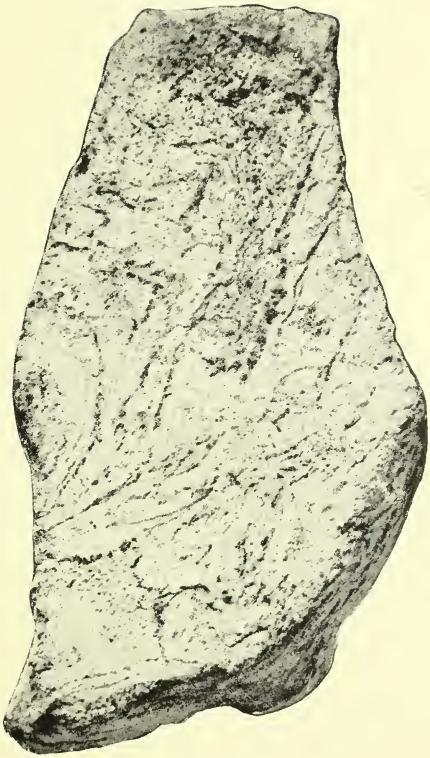
In the areas southeast of Jacks Mountain the aporhyolites have been more or less silicified or epidotized, or both, and are sometimes very difficult to distinguish, in the hand specimen, from the neighboring sandstone. A good example of this rock is seen in the exposures on the turnpike about one-fourth of a mile above the Emmitsburg tollgate, where silicification has produced a close resemblance to a quartzite. The fresh surface is white. Feldspar phenocrysts are sparsely distributed and scarcely discernable. Quartz blebs are more numerous. Pyrite is finely disseminated, and the exposed surfaces of the rock are tinged with yellow and red iron oxide. The rock cleaves in two directions oblique to each other. In this respect it resembles many of the felsites.

The microscopic evidence of igneous character is supported by the field evidence, which shows a continuity between this altered rock and that which would be at once recognized as a felsite.

MICROSCOPICAL DESCRIPTION.

PHENOCRYSTS.

Feldspar and quartz.—The feldspar phenocrysts are very like the feldspars of the quartz-porphyries, and little needs to be added to the description of them already given. They are fresh, contain inclusions of a once glassy magma, show perthitic intergrowth, and are twinned in accordance with the Carlsbad (albite) and Manebacher (pericline) laws.



FLOW STRUCTURE IN APORHYOLITE, RACCOON CREEK. NATURAL SIZE.

The specimen is light pink showing on a smooth, weathered surface delicate and sinuous lines of an original flow structure, in shades of red and purple.

In the former case the twinning is sometimes repeated, and furnishes another indication of the triclinic character of the feldspar.

The feldspars are frequently bent or broken, causing the twinning striations to show curvature and faulting. Occasionally a phenocryst has been completely broken, the fragments pulled apart, and the space filled with a quartz-albite mosaic of much coarser grain than the groundmass, and evidently of subsequent formation. (Pl. XVII, *a*.) A complete replacement of the feldspar crystal by a quartz mosaic sometimes occurs.[1]

The quartz phenocrysts have rounded outlines and characteristic embayments and inclusions; undulatory extinction is almost universal; frequently the quartzes are cracked, and sometimes completely granulated. Both the porphyritical constituents of the aporhyolites give rise, in connection with curving flow lines, to the "augen" structure which has often been described.[2]

These flow lines leave clear, triangular spaces on one side of the phenocrysts, such as Futterer describes.[3]

Other porphyritic constituents.—The only ferromagnesian silicate unmistakably present in the aporhyolites is biotite. This was found in sections representing three different areas of acid volcanics which lie along the southern limit of the Monterey district. The first area is a small one at the head of Minie Branch. The second area is larger and caps the mountain southeast of Raven Rock Mountain. The third area is directly to the east of this, on Friends Creek. The lavas of these three localities show a marked similarity, both in the hand specimens and in the thin sections. They are compact, dirty-gray rocks, weathering a yellowish-gray. Feldspar phenocrysts are somewhat sparsely and inconspicuously present. On a fresh surface biotite can be detected with the naked eye. Magnetite is present, and in one of two specimens from the mountain locality pyrite is abundant in minute crystals.

All of the thin sections of these rocks are distinguished by finely striated feldspars. The carlsbad and pericline twinning are sometimes both present in a single crystal. Quartz phenocrysts are not numerous.

The presence of titanic iron oxide in abundance is attested by the formation of leucoxene. The groundmass is holocrystalline and finely microgranitic, with a tendency toward the micropoikilitic structure. This tendency is fully developed in one of the sections. The hand specimen, from which this section was cut, shows a rock more completely silicified than the other specimens indicate, and also contains pyrite, which is indicative of secondary crystallization.

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[1] Similar replacements have been described by Dr. Milch, Beiträge zur Kenntnis des Verrucano, 1892, p. 126.

[2] J. Lehmann, Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, Bonn, 1884. G. H. Williams, Bull U. S. Geol. Survey No. 62, pp. 85, 118, 207, Pl. XV, fig. 1.

[3] Karl Futterer, Der "Ganggranit" von Grossachsen und der Quartz-porphyr von Thal im Thüringer Wald, Inaug. disser., 1890, p. 32.

There is some epidotization of the groundmass, resulting in the production of finely granular epidote concentrated at certain centers of development.

The mica by which these lavas are characterized has a fibrous character, and is the andesitic type described by Rosenbusch.[1] It is in idiomorphic clusters of reddish-yellow fibers. The absorption is characteristically strong and the pleochroism marked. Parallel to the cleavage the fibers show a deep reddish-brown color, and at right angles a light yellowish-red or straw-yellow color. The marked resemblance of the lava from these localities suggests a continuity in the lava flow—a continuity probably maintained underneath the greenstone.

If this is the case these areas are exposed by erosion of the overlying basic lava, if it ever completely overlay the aporhyolite. That the continuity was maintained above the greenstone is a scarcely tenable hypothesis, because of the extended erosion which such a superposition would necessitate.

If any other ferromagnesian constituents were present in the aporhyolites—and there are indications that there were—they have been totally decomposed and removed.

Harker[2] found it to be true of the pre-Cambrian acid volcanics of Wales, that clusters of biotite flakes were preserved in a comparatively fresh condition, while only slight trace of augite or hornblende remained.

In the South Mountain aporhyolites these minerals must have been rare originally, and are now completely replaced by epidote. Occasionally the outline of a perfect crystal section parallel to 010 is preserved, while the substance of the crystal is entirely replaced by epidote individuals. In the absence of basal sections there is no clue to the specific character of the original crystal.

GROUNDMASS.

The groundmass is always a quartz-feldspar aggregate, of varying structure and grain (about $\frac{1}{85}$ of a millimeter in diameter), more often finely than coarsely microgranitic. The structures of the groundmass are of the highest interest and importance in their disclosure of the original character of the rocks which possess them.

The fluidal, micropoikilitic, spherulitic, axiolitic, lithophysal, rhyolitic, micropegmatitic, perlitic, taxitic, amygdaloidal, and trichitic structures are characteristically developed and merit detailed description.

Fluidal structure.—The fluidal structure, which is so familiar to all students of rhyolitic lavas, is a conspicuous feature of the aporhyolites, both macroscopically, as has been described, and microscopically. Globulites of magnetite and hematite and indefinable opaque crystallites follow sinuous lines of flow, twisting around the phenocrysts and

[1] Rosenbusch, Massige Gesteine, 2d ed., Vol. II, p. 658.

[2] Bala Volcanic Series of Rocks, p. 18.

SPHERULITIC APORHYOLITE, MONTEREY DISTRICT.

Seven-tenths natural size.

imparting to them the appearance of eyes, previously mentioned. Pl. XVIII, *a*, is the reproduction of a photomicrograph of a section showing this structure.

Micropoikilitic structure.—The micropoikilitic structure has been defined in connection with the quartz-porphyries, where it was not infrequently a significant feature of the groundmass. It is still more characteristic of the aporhyolites, and is occasionally present in the basic eruptives.

These irregular quartz patches, inclosing microlites of lath-shaped feldspars or other minerals of independent orientation, give a pronounced mottled or "patchy" appearance to the groundmass, an appearance which has been noted in volcanics of all ages. It has been observed and variously described, usually without being named, in quartz-porphyries, felsites, porphyrites, rhyolites, and peridotites, by numerous writers—Irving,[1] Williams,[2] Haworth,[3] Cross,[4] Iddings,[5] Diller,[6] Lindgren,[7] Teall,[8] Harker,[9] Brögger,[10] and Nordenskjöld.[11] Felsite from the Archean rocks of Georgia shows the same structure.[12] This structure is likewise present in the felsites from the neighborhood of Boston,[13] as is the case also with the quartz-porphyries and felsites of Marblehead Neck, Massachusetts.

An acid lava of the Keweenawan series from Minnesota, recently examined by the writer, shows with a high power and polarized light the micropoikilitic structure in perfection.[14]

While the term micropoikilitic is not restricted to a quartz-feldspar

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[1] R. D. Irving, Copper bearing rocks of Lake Superior: Mon. U. S. Geol. Survey, Vol. V, 1883, pp. 99-100, Pl. XIII, figs. 13 and 14.

[2] G H. Williams, Neues Jahrbuch für Min. u Pet., Supp. Vol. II, 1882, p. 607, Pl. XII, fig. 3. The peridotites of the Cortlandt series: Am. Jour. Sci., Vol. XXX, p. 30; Vol. XXXIII, p. 139.

[3] E. Haworth, A contribution to the Archæan geology of Missouri: Am. Geologist, 1888, Vol. I, p. 368, Pl. I, figs. 1 and 2; also, Crystalline rocks of Missouri: Ann. Rept. Mo. Geol. Survey, Vol. VIII, 1894, p. 195, Pl. XXII.

[4] Whitman Cross, On some eruptive rocks from Custer County, Colo.: Proc. Colo. Sci. Soc., Vol. II, 1888, pp. 232, 242. On a series of peculiar schists near Salida, Colo.: Proc. Colo. Sci. Soc., Jan., 1893, p. 8.

[5] J. P. Iddings, The eruptive rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park: Twelfth Ann. Rept. U. S. Geol. Survey, pp. 589, 646.

[6] J. S. Diller, Mica-peridotite from Kentucky: Am. Jour. Sci., 3d series, Vol. XLIV, Oct., 1892, p. 287.

[7] Waldemar Lindgren, On sodalite syenite and other rocks from Montana: Am. Jour. Sci., 3d series, Vol. XLV, Apr, 1893, p. 287.

[8] J. J. Harris Teall, British Petrography, 1888, p. 337.

[9] Alfred Harker, Bala Volcanic Series of Rocks, pp. 23, 53, 54.

[10] W. C. Brögger, Der Mineralien der Syenitpegmatitgänge der südnorwegischen Augit und Nephelinsyenit: Groth's Zeitschrift für Krystallographie, Vol. XVI, p. 46.

[11] Otto Nordenskjöld, Zur Kenntniss der sogen. Hälleflinta des nordöstlichen Smålands: Bull. Geol. Inst. Upsala, Vol. I, No. 1, 1893.

[12] A section of this felsite was loaned by Prof. L. V. Pirsson. It is of especial interest in its great similarity to the South Mountain felsite, thereby showing the southward persistence of this rock type.

[13] J. S. Diller, Felsites and assoc. rocks north of Boston: Proc. Boston Soc. Nat. Hist., Vol. XX Jan. 21, 1880, pp. 355-368; also Bull. Mus. Comp. Zool. Harvard Coll., whole series, Vol. VII; geol., series, Vol. I. Thin sections of these felsites were kindly loaned by Mr. Diller to the Johns Hopkins laboratory. They have many microscopic features in common with the South Mountain rocks, and like them were first supposed to be of sedimentary origin.

[14] The writer's attention was called to the presence of this structure in the Minnesota acid volcanics by Dr. U. S. Grant, of the Minnesota State Geological Survey.

intergrowth, in most of the occurrences described these have been the component minerals. In the South Mountain rocks the feldspathic material is usually so abundant as not to admit of the determination of the mineral character of the host. In such cases a clue to the nature of the cementing material is found in its optical continuity with the porphyritic quartz. These phenocrysts are severally included within a single micropoikilitic area, with which they are always similarly oriented (Pl. XVII, *b*). The cementing material acts as a sort of secondary enlargement of the quartz phenocrysts. The feldspar phenocrysts, on the other hand, have no effect upon the orientation of the cement.

In the basic rocks, which are coarser-grained, the character of the host can be directly tested and proved to be quartz. The mottled appearance, previously alluded to, is usually emphasized by the arrangement of globulites, longulites, and trichites of iron oxide. This is such as both to accord with the flow structure and to outline the quartz areas, which in these cases have a somewhat oval shape.

When shearing has led to the production of sericite, this mineral is formed around the micropoikilitic areas, rarely traversing a single area, when it seems to be cementing material filling a crack (Pl. XVII, *b*). These areas are persistent, and slowly disappear in the development of a slate.

While in some cases this structure is undoubtedly of primary character, as Professor Iddings considers it to be in many porphyrites, in a large class of rocks its secondary origin seems equally certain. Irving, who gives one of the best as well as the earliest (1881) descriptions of this structure, considered it of a secondary character. His statements as to its nature and origin are so applicable to the South Mountain aporhyolites that they are quoted here in full:[1]

Although wholly absent from some sections, a very highly characteristic feature of the sections of many of these rocks, and more particularly of the felsites without porphyritic quartz, is a network quartz which can only be regarded as of secondary origin. I find no mention of such a feature in any of the descriptions of the felsites of other regions which I have examined. Only occasionally * * * is this network quartz coarse enough to be readily seen with a low power in the ordinary light. Usually both a high power and the use of the polarized light are required for its detection, when it appears in its most characteristic development as a delicate aborescent tracery or frost-work saturating the ground mass in all directions.

In the polarized light all of the quartz network within each of these numberless irregularly round areas, whose existence would not be suspected in the ordinary light, is found to be similarly oriented.

From these more pronounced developments the secondary quartz is found through many degrees of lessening amount and less plainly marked character until it disappears altogether. It is plainly of the same nature as the secondary quartz of the already described orthoclase-gabbro, diabase-porphyrite, and quartzless porphyry, and of the augite-syenite described below. It never, however, reaches in the rocks now under description the coarseness nor presents the graphic forms with which it appears in the augite-syenites, its characteristic development here being the deli-

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[1] Loc. cit., pp. 99-100.

APORHYOLITE WITH SPHERULITES IN LAYERS.

From Jim Saunder's farm, Bigham Copper mine district. Five-sevenths natural size The details of the spherulitic chains are lost in the photograph.

cate arborescent clusters above mentioned. Whether this secondary quartz may ever be rather a result of devitrification than a truly secondary or alteration product, I have no means of deciding, though it is certainly the latter often, and I should suppose always. It surely can have no connection with the original solidification of the rock.

Observations made on the South Mountain aporhyolites lead to essentially the same conclusions as those reached by Irving. As the nature of the structure is of both interest and importance in its bearing upon the question of the primary or secondary character of the groundmass, attention will be called to some of the observations which prove suggestive.

It has been stated that a few sections of the basic lavas of South Mountain exhibited this structure. In these sections the nature of the structure could be more readily detected. (Pl. XIX, *a* and *b*.)

The outline of the lath-shaped feldspars, forming an original ophitic structure, is completely preserved, though none of the original constituents of the rock remain, unless some of the titaniferous iron oxide is original.

At present the rock consists entirely of quartz, epidote, magnetite (or ilmenite), and leucoxene. It is amygdaloidal, and the vesicles are filled with secondary quartz. Quartz is also a cement for the minerals of the groundmass, and forms irregular interlocking areas, which are quite similar to the micropoikilitic areas of the finer-grained acid rocks, and produce in polarized light the familiar patchy effect. Fine cracks traversing the sections are still preserved in outline by the ferrite, but are prior to the quartz areas, which have obliterated all trace of cementing material. The epidote, which replaces crystals of some former ferro-magnesian constituent, is often pierced by these cracks, which become invisible in the quartz areas save for the outlining ferrite. There can be no question as to the secondary character of the micropoikilitic structure in these cases.

Some structures described by Zirkel[1] in the rhyolites of the Washoe district are suggestive in this connection. He notes (slide 350, fig. 1, Pl. VI) perlitic parting in certain rhyolites (southeast from Wadsworth), where the cracks, semicircular and oval, traverse a glassy groundmass and are bordered by a narrow zone of microfelsite, "giving [to the section] the appearance of a network." The same general effect is produced in other rhyolites of the district (secs. 351, 352, figs. 2, 3, Pl. VI) by faint granular lines "which, by their fluidal running, form a net with a multitude of meshes of oval shape." These lines seemed to be the vestiges of perlitic cracks, though they could not be certainly determined as such. A widespread and characteristic type of rhyolite (secs. 333, 407, fig. 1, Pl. VIII) shows the same network of dark granular lines, but in this case the meshes are filled with a spherulitic crystallization.

There are, then, two types of crystallization which may occupy the

[1] Geol. Expl., 40th parallel, Vol. VI, Microscopic Petrography.

oval spaces, the spherulitic and the microfelsitic. The former does so to the exclusion of a glassy groundmass, and must have been formed prior to the consolidation of the rock. The latter shares the space with the glass into which it gradually passes and of which it may be a molecular alteration. Turning to the South Mountain aporhyolites (particularly the spherutaxites), we find a similarity in the development of faint granular lines forming irregular oval meshes and giving to the section the network appearance figured by Zirkel. These lines may be traces of a former perlitic parting or of a microfluidal structure. The meshes are now filled either by the quartz areas which condition the micropoikilitic structure or by the vestiges of a spherulitic crystallization.

The latter represents a primary structure, as in the rhyolites; the former may represent the molecular rearrangement of a spherulitic crystallization or of a glassy groundmass. In the last case it is the direct result of devitrification and infiltration, processes more readily initiated along the borders of the perlitic cracks, as in the rhyolites of the Washoe district.

A comparative study of some sections[1] of the rhyolites of the Rosita Hills, Colorado, and of Obsidian Cliff, Yellowstone National Park, side by side with the aporhyolites under discussion, also suggests the secondary character of the micropoikilitic structure with reference to the spherulitic crystallization. In the trichitic spherulites of the modern rhyolites there is an appearance analogous to the micropoikilitic mottling, caused by the breaking up of the radiating spherulitic fibers into irregular areas which extinguish differently. An altogether similar phenomenon occurs in some of the spherulites of the ancient rhyolites. It is indicative of an intermediate stage between the spherulitic and a completely micropoikilitic crystallization. This change from the spherulitic to the micropoikilitic structure is carried still further in some sections, notably in the case of a specimen crowded with minute red spherulites. Each spherulite extinguishes as an individual filled with inclusions of feldspar and iron oxide (hematite). The host can be determined by optical tests to be quartz. The shape of the spherical bodies in the hand specimen and in thin section, their tendency to form bands and chains, and their uniform color put their original spherulitic character and the secondary nature of the micropoikilitic structure beyond doubt. It is not supposed that a prior spherulitic crystallization always existed where now the aporhyolites show a micropoilitic structure, but these evidences of the derivation of the structure from spherulites establish a presumption for its secondary origin in other aporhyolites, where it may be the direct result of devitrification or may be due to the subsequent alteration, by infiltration, of a granular crystallization.

On the whole, the plainly secondary character of the micropoikilitic

[1] Sections of material from these localities were kindly loaned the writer by Dr. Cross and Professor Iddings.

structure in the basic volcanic, the evidence in the aporhyolites of its being subsequent to fluidal lines or to perlitic parting, the indications that in many cases it is subsequent to a spherulitic crystallization, all denote a secondary origin for this structure in the South Mountain rocks.

Spherulitic structure.—There are two sorts of spherulitic crystallization in the aporhyolites. They differ in no essential respect, but are unlike in appearance. The most numerous spherulites are also the simplest and smallest. They are colorless, microscopic spheres, scarcely or not at all perceptible in ordinary light, but between crossed nicols showing a distinct dark cross. Spherulites in every respect similar have been described and figured by Professor Iddings from the rhyolites of the Yellowstone National Park.[1] Similar spherulites also occur in the rhyolites of Hungary and in the felsites of the Boston Basin. These radial growths are grouped in bunches and along lines, and are composed of positive fibers. Further optical determination of the fibers could not be made. Their positive character indicates either a prismatic section of quartz elongated in the direction of the vertical axis or a clinopinocoidal (010) section of orthoclase elongated in the same direction. In the latter case the extinction would be slightly inclined. This is impossible, however, of determination.

While it is not impossible that some of these spherulites are secondary, in some cases there is evidence of their primary character. One such case of spherulites whose formation was coincident with the consolidation of the rock occurs in an aporhyolite from a cut made by the Gettysburg Railroad north of Toms Creek trestle. Minute colorless spherulites are embedded in a base which suggests in every way its former glassy condition. In ordinary light there is no evidence of crystallization except the porphyritical.

The groundmass is traversed by irregular, angular cracks, evidently the result of crushing. These cracks, which are cemented by epidote, pass through the spherulitic aggregates (seen with crossed nicols), sometimes cutting directly across a spherulite, portions of which appear on either side of the crack. Between crossed nicols the field breaks up into a mosaic of quartz and feldspar. The granular crystallization disregards the cracks, filling the spaces left by the cementing epidote. It seems fair to conclude from these observations that the spherulitic crystallization is prior to the cracking, that the granular crystallization is subsequent, and that the cracking occurred in an already solidified glass.

The secondary character of the granular crystallization admitted, it is easy to suppose that it is due to devitrification continued through lapse of time. The spherulites, on the other hand, being prior to the crystallization of the groundmass, and prior to the cracking, are doubtless primary and contemporaneous with the consolidation of the glass.

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[1] Obsidian Cliff: Seventh Ann. Rept. U. S. Geol. Survey, Pl. XVII, p. 276.

The other class of spherulites correspond to those figured by Professor Iddings.[1] They are much larger than those that have just been described. The smallest is easily discernible by the naked eye, while the largest is 12½ cm. in diameter. They are spherical, hemispherical, cylindrical, fan-shaped, oval, or irregular in form. While they all possess a clear-cut, conspicuous outline in ordinary light, in many sections they completely disappear between crossed nicols. The fresh spherulites (Pl. XXII, *b*), which still show in polarized light a radiating structure, are usually colored red by a finely disseminated iron oxide. The globulites of hematite are distributed homogeneously throughout the spherulite, or they are grouped in radial and concentric lines. These lines are most dense near the margin of the spherulite, and may be separated from the central portion by a narrow clear zone, or it is the outer rim of the spherulite which is clear. In the central portion of the spherulite the coloring matter shows a tendency to collect in bunches that correspond with areas which extinguish as individuals. Between crossed nicols the field is broken up into the minute areas which were referred to on page 50 as forming a structure approaching the micropoikilitic. Feldspar phenocrysts usually occupy the center of the radiating crystallization, and two or more spherulitic centers may be included within a single outer zone. In specimens from Raccoon Creek[2] these radial growths were remarkably well preserved and occur in a groundmass which retains the characteristics of a glass in great perfection (Pl. XX, *a*; Pl. XXI, *a*). It bears a close resemblance to the groundmass of some of the Colorado rhyolites, and in ordinary light would certainly be mistaken for the base of a fresh glassy lava. Delicate perlitic parting, which because of its delicacy is easily obliterated, is here preserved in wonderful detail. It is evidently subsequent to the radial crystallization to which it accommodates itself. The presence of innumerable globulites accentuates the perlitic and rhyolitic structures. With crossed nicols the groundmass at once betrays its holocrystalline character (Pl. XX, *b*). All glassy structures disappear, to be replaced by granular quartz and feldspar, a crystallization which closes the perlitic parting and thereby completely obliterates it.

The porphyritic feldspars still show inclusions of a glassy base. It is impossible by any description to produce that definiteness of conviction as to the original glassy nature of the groundmass which the character of the sections justifies. To one who has studied these sections in both ordinary and polarized light there can be no question as to the secondary character of the holocrystalline groundmass. One can not escape the conviction that the rock originally consolidated as a spherulitic perlite and has become holocrystalline by a process of devitrification.

The sequence of events, as revealed by microscopic study, is as follows: There was first the intratelluric development of the porphyritic

[1] Op. cit., p. 277, Pl. XVII.

[2] In Franklin County, Pa., east of Rocky Ridge and south of Graeffenburg.

crystals, followed by the emergence of the magma, the development of globulites and fluxion structure, the commencement of radial crystallization, and finally the consolidation of the magma as a glass and the development of perlitic parting. Subsequent to all this, and extending over a much longer period of time, the process of devitrification took place.

Associated with a holocrystalline groundmass, which bears less marked evidence of an original glassy character, are the more altered spherulites. Their circular outline in the thin section and their spherical shape in the hand specimen testify to their former presence.

In both hand specimen and thin section a threefold zonal arrangement is often clearly defined by the distribution of red or black iron oxide. With crossed nicols these boundaries become inconspicuous, and the field of the microscope shows only a uniform quartz-feldspar mosaic, or the former radial growth is indicated by zones of a finer-grained crystallization than the groundmass (Pl. XXIII, *a*), or a micropoikilitic structure is present within the spherulitic boundaries when absent in the groundmass. Occasionally, vestiges of a radiate structure still remain.

In the specimen already referred to on page 50 and figured in Pl. XXII, *a*, the spherulites are colored red by a uniform dissemination of hematite particles, and are not more than one-half mm. in diameter. They traverse the rock in rows and chains, which are in turn grouped in bands about 2 inches wide. The rock has been sheared, a ready cleavage has been produced, and sericite has developed around each spherulite. As has already been mentioned, the spherulitic individuals have become micropoikilitic individuals. Another specimen shows spherulites which have been rendered almond-shaped through shearing or, less probably, by the fluidal movement of the magma during this consolidation. That the former was probably the case is indicated by the gradual passage of the rock into a slate and the development of biotite.

Spherulites which, like these, have been replaced by a fine-grained mosaic of quartz and feldspar have been described by Klockmann.[1]

Chain spherulites.—The arrangement of spherulites in layers and along planes so that a cross-section shows a chain of spherulites has been described on page 43 and figured on Pl. XVIII, *b*, as it appears in the hand specimen. In ordinary light the microscope discloses somewhat sinuous or straight dark bands, with scalloped borders sharply outlined, inclosing an irregular clear chain which also has scalloped edges.

Frequently there are detached clear spots with circular outline. These bands sometimes spread out so as to include phenocrysts and sometimes curve around them. (Pl. XVIII, *b*.) A comparative study of these spherulitic chains and the chains of fresh spherulite of the Yel-

[1] Die Porphyre; Der geologische Aufbau des sogen. Magdeburger Uferrandes mit besonderer Berücksichtigung der auftretenden Eruptivgesteine: Jahrbuch K. preuss. geol. Landesanstalt, Vol. XI, 1890, p. 179.

lowstone obsidians discloses a striking similarity in ordinary light—the same irregularly scalloped outline, the same central chain of clear spherules. With crossed nicols the close similarity vanishes, for in the ancient rocks the radial growth has utterly disappeared. The central clear chain consists now of a fine quartz mosaic. The dark borders, except for the crowded magnetite globulites, can not be distinguished from the holocrystalline quartz-feldspar groundmass. This clear central zone where the spherulites converged evidently furnished the plane of weakness and easy solution, along which silica was infiltrated and parallel to which the rock cleaves.

The impurities which have entered the rock along this cleavage plane give rise to the central dark line mentioned in the macroscopic description, while the silica forms the opaque white band on either side. The central zone is sometimes more than a millimeter wide. Where a feldspar crystal lies across this plane of weakness with its longest axis at right angles to the latter, the strain has proved too great for the crystal, which has been broken apart and the break cemented by infiltrated silica (Pl. XXIII, *b*).

The chain spherulite structure is of more common occurrence in the aporhyolites of the Monterey district than any other form of spherulitic growth. The acid rocks east of the Bigham copper mine show them in great perfection. Rutley[1] has figured some similar chain spherulites in the felsitic lavas of England and Wales. In felsite of the Keweenaw series from the Minnesota shore of Lake Superior the writer has recently observed fine bands of silica so similar to the altered chain spherulites as to suggest a like explanation for them.

Axiolitic structure.—Closely related genetically to the chain spherulites, but unlike them in being radial linearly rather than centrally, is the axiolitic growth.[2]

Axiolites are not particularly characteristic of the South Mountain aporphyolites. Curving, linearly radiating growths do occur, however, in specimens from more than one locality. Pl. XXI, *b*, shows this structure.

Rhyolitic structure.—The rocks in which the axiolites were observed are holocrystalline, yet they exhibit most strikingly the characteristics of a glass. Flow and vesicular structures, stringers and shreds, and curved patches of a brownish-red color, forming what has been called the rhyolitic structure, abound. (Pl. XXIV, *a* and *b;* Pl. XXV, *a.*) This latter structure has been figured and described by Rutley,[3] Nordenskjöld,[4] and de la Vallée-Poussin,[5] and on a macroscopic scale by

[1] Felsitic lavas of England and Wales: Mem. Geol. Survey, Gt. Brit., 1885, Pl. VII, figs. 11 and 12.

[2] Zirkel, Microscopic Petrography: Geol. Expl. 40th parallel, p. 167.

[3] Rutley, On the microscopic structure of devitrified rocks from Beddgelert and Snowden: Quart. Jour. Geol. Soc. London, Vol. XXXVII, p. 406, figs. 1 and 2.

[4] Nordenskjöld, Zur Kenntniss des sogen. Hälleflinta des nordöstlichen Smålands: Bull. Geol. Inst. Upsala, No. 1, Vol. I, p. 5, 1893.

[5] De la Vallée-Poussin, Les anciennes rhyolites, dites eurites, de Grand-Manil: Bull. Acad. Roy. Belgique, 3d series, Vol. X, 1885, p. 271.

LITHOPHYSÆ, RACCOON CREEK.

The rock is a pale pink, while the originally hollow spaces between the concentric layers of the lithophysæ are filled with a deeper pink siliceous deposit.

Irving.[1] A perlite from Deer Creek Meadows, 25 miles south of Lassen Peak, displays a similar rhyolitic structure. This structure is essentially a phase of the fluidal structure.[2]

Lithophysal structure.—Very often the macroscopic features of the aporhyolites disclose their original character more convincingly than do the microscopic. Lithophysæ are best revealed in the hand specimen, where they are brought out in delicate relief by weathering. In such specimens from the Raccoon Creek locality, the rose-pink petals of the lithophysæ in a pale-pink base produce quite as beautiful examples of this glassy structure as any obsidian or rhyolite offers. (Pl. XI.) No undoubted lithophysæ were found within the Monterey district. The microscope discloses some vesicular structures which bear slight trace of a lithophysal character, but the alteration has been too great to allow of their identification as hollow spherulites.

Micropegmatitic structure.—The micropegmatitic structure shows itself in microscopic pegmatoid groups of phenocrysts, such as have been frequently described in porphyries and rhyolites.[3] It does not play an important part in the aporhyolites.

Perlitic structure.—That this structure is present in the South Mountain rocks, and in great perfection, has already been noted. (Pl. XX, *a*, Pl. XXI, *a*.) While its presence is a most reliable proof of the former character of the rock, its absence furnishes no evidence against the previous glassy condition of the rock, both because many recent rhyolites showed no trace of that structure and because it is most readily effaced by devitrification.

Amygdaloidal structure.—At Raccoon Creek, at the Bigham copper mine and its near vicinity, are light-colored (pink and yellow), extremely vesicular aporhyolites. The vesicles are oval or elongated by flow movement. (Pl. XXVI, *a* and *b*.) They are uniformly filled with epidote or quartz, with both, or with either to the exclusion of the other. When both are present the quartz forms a rim around the epidote. The epidote has often a radial arrangement, while crystal boundaries are absent. Its color varies from a deep yellowish green to light yellow, and pleochroism is marked. In some of the larger amygdules the radiating needles of epidote have been broken and pulled apart at right angles to their longer axis and the spaces filled with silica. Piedmontite and quartz show the same relation, as described on page 41. The groundwork of these amygdaloids is the usual holocrystalline quartz-feldspar aggregate. Incipient alteration to granular epidote is more frequent in these open-textured amygdaloids than in the compact aporhyolites. These

[1] Irving, Copper-bearing rocks, etc.: Mon. U. S. Geol. Survey, Vol. V, pp. 312–313, fig. 22.

[2] This is the "Aschenstructur" of Mügge (Untersuchungen über die "Lenneporphyre" in Westfalen und den angrenzenden Gebieten: Neues Jahrb. für Min., Geol. u. Pal., B. B. VIII, 1893, pp. 648, 649, 713), who considers it due to the original fragmental character of the lava. Whether it is always to be so interpreted is a question for further investigation.

[3] Iddings, op. cit., p. 275, Pl. XV, fig. 5.

rocks are pierced with coarse quartz veins which bear native copper. Copper in microscopic quantities and copper oxide also occur in the amygdules. Hand specimens are frequently coated with the copper carbonates, malachite and azurite. There were picked up on the roadside some specimens of amygdaloidal aporhyolites that are quite diverse from the amygdaloids of the Bigham copper mine which have just been described. They are similar to specimens found north of the Monterey district at Raccoon Creek. The amygdules, which are black against a yellowish-white background, are finely attenuated and elongated in long parallel hair lines, lending to the rock the appearance of an eutaxite. The black color is due to magnetite, which either is finely disseminated in quartz (the other infiltrated mineral), or is present in masses, or simply forms a heavy rim around the amygdules.

Some of the amygdaloids from Raccoon Creek merit a detailed description. In these rocks the vesicles are usually bordered by a broad rim like the groundmass, in its present crystallization, but separated from it by a narrow, clear zone of quartz, and characterized by a greater abundance of magnetite (or ilmenite). On the inner edge of this border are spherulitic growths, while the rest of the vesicle is filled with quartz (Pl. XXVII, *b*) or with quartz and an opaque black oxide (Pl. XXVII, *a*). In the latter case the black oxide occupies the center of the vesicle, leaving a clear zone of silica around the spherulites. Crossed nicols show that the spherulites are optically continuous with the quartz, and that the radial appearance which has been retained is due to the arrangement of the impurities. The appearance of these vesicles is very suggestive of those figured by Professor Cole.[1] Professor Cole explains this type of spherulite by a dual mode of growth—a radial growth outward from the groundmass, as well as inward, originating in the glass and converging toward a spherulitic center! He does not give the mineral character of the spherulite. Whatever may be the facts with reference to the Rocche Rosse obsidian, it is not necessary to postulate an abnormal method of crystallization to explain the phenomena observed in the South Mountain aporhyolites.

The spherulites projecting into the vesicle, with their bases sunk into its walls, were recognized by Professor Iddings, who kindly examined the section, as tridymite spherulites, such as form on the walls of vesicular cavities in all kinds of modern lavas. Tangential sections of such spherulites are represented by granular aggregations. The form of the tridymite has been preserved by impurities, while its molecular arrangement has been altered to that of quartz. The presence of a border between the groundmass and the cavity suggests that crystallization, starting from the walls of the cavity, took place within the magma, initated, perhaps, by the gaseous content of the vesicle.

[1]Grenville A. J. Cole and Gerard W. Butler, On the lithophyses in the obsidian of the Rocche Rosse, Lipari: Quart. Jour. Geol. Soc. London, Vol. XLVIII, 1892, p. 438.

Somewhat similar radial growths within vesicles in ancient rhyolites have been described and figured by de la Vallée-Poussin.[1]

Taxitic structure.—Another structure which the South Mountain rocks possess in common with rhyolites is what has been called the taxitic.[2] This consists in the intimate mingling of two portions of the magma which from some cause (liquation) are slightly differentiated. The iron constituent, which evidently separated out in the original glass, has been still further crowded into bands and curved lines by the secondary crystallization. The result is the production, in some cases, of an irregular mottling, when the rock is called an *ataxite;* and in other cases of a more or less complex network of interlacing bands following lines of flow and forming a *eutaxite.* This mottling and banding is made the more striking by a marked contrast in color. The body of the rock is light-gray or pink, and the lines are dark blue-gray or red, according to the varying degrees of oxidation of the iron. Where the dark lines outline oval and spherical spaces and contain porphyritical crystals in or near their centers, the crystallization is regarded as having once been spherulitic and the rock is termed a *spherutaxite.* These have been described on page 50.

The eutaxites are frequently so sheared as to give a hair-like tenuity to the bands in cross section, while the microscopic slide shows the effect of pressure on the rock in the parallel arrangement of the globulites of black oxide. The universal presence of globulites, trichites, and microlites of black and red iron oxide in flow bands, or indifferently distributed, or in concentric zones around spherulites and vesicles, is worthy of mention as a further point of resemblance to the modern rhyolite. Such a *trichitic structure* in similar rocks has been described by various petrographers.[3]

SUMMARY OF PROOF OF DEVITRIFICATION.

It is not easy to present the evidence for the secondary nature of the holocrystalline groundmass so that it shall have the weight which properly belongs to it. Very much depends upon effects which it is impossible to convey by description, but which carry conviction to the student of these rocks. The contrasting appearance of many of the sections in ordinary and polarized light can not be adequately reproduced. The disappearance under crossed nicols of rhyolitic, perlitic,

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[1]Les anciennes rhyolites, dites eurites, de Grand-Manil: Bull. Acad. roy. Belgique, 3d series, Vol. X, 1885, p. 292.

[2]Fritsch and Reiss, Teneriffe, 1868, p. 414.

Rosenbusch, Mic. Phys. der Massigen Gesteine, 2d ed., p. 625.

F. Loewinson-Lessing, Zur Bildungsweise und Classification der klastischen Gesteine, 1888, pp. 228–235. Note sur les taxites et sur les roches clastique vulcanique: Bull. Soc. Belg. géol., etc., Vol. V., 1891 Loewinson-Lessing's division of the taxites into ataxites, eutaxites, and spherutaxites has been followed in this bulletin.

[3]R. D. Irving, Copper bearing Rocks, etc.: Mon. U. S. Geol. Survey, Vol. V, p. 312.

S. Allport, On certain ancient devitrified pitchstones and perlites from the Lower Silurian district of Shropshire. Quart. Jour. Geol. Soc. London, Vol. XXXIII, p. 449.

Nordenskjöld, op. cit.

spherulitic, and fluxion structures, so clearly indicated in ordinary light, in a homogeneous holocrystalline mosaic is one of the strongest evidences for the secondary character of the crystallization.

There are also instances where the nature of the crystallization is distinctly proved. On page 51 it was shown to be subsequent to the cracking which must have occurred in a solid rock. Pages 52–53 describe the replacement of the radiating crystallization of the spherulites and chain spherulites by a granular crystallization which is homogeneous with a granular groundmass. Finally, on pages 49–50, the secondary character of the micropoikilitic crystallization has been indicated. One or another of these indications of secondary crystallization is almost invariably present in the rocks which have been included under the name aporhyolite.

The exceptional occurrences, where these structures are absent, show genetic relationship in the field to typical aporhyolites. The determination of the character of the groundmass in the cases described thus practically determines it for all the aporhyolites.

The secondary character of the holocrystalline groundmass once admitted, and the indications of an original glassy base recognized as such, one is forced to conclude that the former was developed from the latter by a process of devitrification.

That the processes of crystallization do not necessarily cease with the solidification of a magma is well known, for experiment has proved that crystallizing forces are active in a glass as well as in a molten magma.[1] This action is exceedingly sluggish, and requires, unless accelerated by heat and moisture, an immense amount of time. Devitrification has been considered the result of dynamic action only;[2] but while dynamic action undoubtedly accelerates the process, if it does not initiate it, devitrification may also take place independently of dynamic action, as was the case in the famous example of the old cathedral window glass[3] and the ancient devitrified glass from Nineveh investigated by Sir David Brewster.[4] The nature of the process is in no way different from the process of crystallization in a fluid magma save in the rapidity of the action, and is of both a physical and a chemical character.

The devitrification which has occurred in the South Mountain aporhyolites is not attributed to dynamic action, of which there are many evidences of another nature in the South Mountain, but to statical metamorphism. The former would, by shearing, obliterate the original structures of a glassy rock and produce a slate, while the latter might be an important initiatory and accelerating factor in the process of devitrification of the glassy rocks.

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[1] Daubrée, Géologie expérimentale, 1879, p. 158.

[2] De la Vallée Poussin, Les eurites quartzeuses (rhyolites anciennes) de Nivelles et des environs: Bull. Acad. roy. sci. lett. et des beaux arts de Belgique, 57 année, 3d series, Vol. XIII, No. 5, 1887, pp. 521–522. T. G. Bornemann, Der Quartzporphyr von Heiligenstein und seine Fluidalstructur: Zeitschr. Deutsch. geol. Gesell., Vol. XXXIX, 1887, p. 793.

[3] British Ass. Rept., 1840.

[4] Trans. Royal Soc. Edinburgh, Vols. XXXII, XXXIII.

Opinions of petrographers.—Paleozoic and pre-Paleozoic acid volcanics have long been studied on the European continent. Although their variation from the modern type of acid volcanics, rather than their resemblance to that type, has, for the most part, been emphasized by German and French petrographers, there have not been wanting able advocates of devitrification and of an original glassy base for the ancient lavas.

R. Ludwig[1] (1861) and Vogelsang[2] (1867) inclined to the opinion that the groundmass of certain quartz-porphyries is the result of the devitrification of a glassy lava.

The late Dr. K. S. Lossen[3] (1869), on comparing the spherulitic porphyries of the Harz Mountains with the obsidians of Lipari, Mexico, and Java, found the resemblance sufficiently striking to lead him to declare that the porphyry groundmass was originally crystallized as glass, and became cryptocrystalline through molecular rearrangement. Later, Kalkowsky[4] (1874) suggested that devitrification through the chemical activity of water was the process by which the microfelsitic base of certain pitchstones and felsites was developed; and still later, H. Otto Lang[5] (1877) described a macroscopically unindividualized base which is similar macroscopically to the devitrified base described by Kalkowsky. Sauer[6] (1889) considered the Dobritz porphyries as the final alteration product of a pitchstone. More recently Klockmann[7] (1890) has described the replacement of the spherulitic crystallization in quartz porphyries, through secondary processes, by a fine-grained aggregate of quartz and feldspar.

Osann[8] (1891) described incipient devitrification in perlite and other glassy rocks from Cabo de Gata. Finally, Link (1892) considered that the fine-grained groundmass of some American rocks closely related to mica-syenite-porphyries was once glassy, or at least partially glassy, and C. Vogel[9] (1892) reached the same conclusion as to the Umstädt porphyries in Hessen. Many no less capable observers still hold to an original difference between ancient and recent acid volcanics, and the possibility of devitrification and an original similarity is yet an open question in Germany.

In France, La Croix[10] describes andesites from Martinique in which the glass has altered into quartz spherulites and a granular quartz aggregate.

It is interesting to note that many of the hälleflinta of Sweden,

[1] Erl. zur geol. Karte Hessens, Bl. Dieburg, 1861, p. 56.

[2] Phil. de géologie, pp. 144, 153, 194.

[3] Beiträge zur Petrographie der plutonischen Gesteine: Abhandl. der Berliner Acad., 1869, p. 85.

[4] Tschermaks mineral. Mittheil, pp. 31, 58.

[5] Grundriss der Gesteinskunde, p. 43.

[6] Erl. zur geol. Specialkarte Sachsens, Bl. Meissen, pp. 81–91.

[7] Die Porphyre; Der geol. Aufbau sogen. Magdeburger Uferrandes mit besonderer Berücksichtigung der auftretenden Eruptivgesteine: Jahrbuch K., preuss. geol. Landesanstalt, Vol. XI.

[8] Zeitschr. Deutsch. geol. Gesell., Berlin, pp. 691, 716.

[9] Abhandl. geol. Landesanstalt von Hessen, Vol. II, p. 38.

[10] Comptes-rendus, CXI, p. 71.

which, like the South Mountain volcanics, were once described as sedimentary, are proving to be acid volcanics, preserving the features of their modern equivalents. Quite recently glassy and rhyolitic structures in these rocks have been observed and described by Otto Nordenskjöld.[1]

In Belgium, de la Vallée-Poussin seems to be the only writer who has brought out the resemblance between the eurites of that country and modern rhyolites. He describes at some length structures similar to those possessed by the aporhyolites of South Mountain. A vacillating state of mind as to the matter of nomenclature is indicated in the titles of his successive papers.[2]

In England the rhyolitic character of ancient acid volcanics has been recognized and emphasized, and the idea of devitrification is widely accepted. Allport, Cole, Bonney, Rutley, Judd, and Harker have accomplished most valuable work along this line.

Dr. Wadsworth[3] was the first American petrographer to advocate the abandonment of age as a factor in rock classification, while at the same time he recognized devitrification as the process which was forming felsites out of rhyolites. What he says is of interest in its anticipation of ideas now more generally accepted:

> This devitrification gives rise in the older and more altered rhyolites to the feldspar, quartz, and microfelsitic (so called) base that has so puzzled lithologists in the study of the felsites. The rhyolites of all volcanic rocks preeminently show lamination produced by flowing, a fact which is doubtless due to their being so siliceous. This structure and their devitrification enable us to trace a direct connection between the rhyolites and felsites, which are simply the older and more altered rhyolites. * * * One of the best illustrations of this is to be found on Marblehead Neck, Massachusetts, where at least two distinct flows of felsite occur, one cutting the other. They show the fluidal structure so characteristic of rhyolites—a character that has been mistaken for lines of sedimentation by geologists, while the inclosed crystals of orthoclase have been taken for pebbles. * * * While to the naked eye and under the microscope this rock shows the fluidal structure of a rhyolite, in polarized light it is seen that the base has been completely devitrified, a process that is carried to a great extent in many known modern rhyolites.

No other American petrographer has so distinctly advocated the identity of felsites and ancient rhyolites, in spite of the fact that many of our felsites illustrate it as unmistakably as do the English felsites.

Dr. Irving,[4] in his description of the Beaver Bay group of the Keweenaw series, repeatedly calls attention to the resemblance between the ancient felsites and quartz-porphyries and the modern rhyolites, though he does not express an opinion as to their equivalence.

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[1] Op. cit. Also Ueber archæische Ergussgesteine aus Småland: Bull. Geol. Inst Upsala, No. 2, Vol I, 1893, pp. 1-127.

[2] Les anciennes rhyolites, dites eurites, du Grand-Manil: Bull. Acad. roy. Belgique, 3d series, Vol. X, 1885, pp. 253-315. Les eurites quartzeuses (rhyolites anciennes) de Nivelles et des environs: Bull. Acad. roy. des sci. et des beaux-arts de Belgique, 57 année, 3d series, Vol. XIII, No. 5, 1887.

[3] M. E. Wadsworth, Notes on the mineralogy and petrography of Boston and vicinity: Proc Boston Soc. Nat. Hist., Vol. XIX (May, 1877), p. 236. On the classification of rocks: Bull. Mass. Comp. Zool. Harvard Coll., Vol. V, No. 13, June, 1879, p. 277.

[4] Op. cit., pp. 312, 313, note 5, p. 436.

Messrs. Hague and Iddings[1] make the statement "that the degree of crystallization developed in igneous rocks is mainly dependent upon the conditions of heat and pressure under which the mass has cooled, and is independent of geological time."

On the question of devitrification the writer finds no more direct expression of opinion, but the fact of devitrification is recognized by Iddings, Williams, Cross, and Diller. In none of the felsites elsewhere described have the varied structures of the modern rhyolites been more perfectly and conspicuously preserved than in the aporhyolites of the South Mountain.

CHEMICAL COMPOSITION OF THE ACID ERUPTIVES.

The chemical study of the South Mountain rocks has been rendered easy by a number of analyses of these rocks made by the late Dr. Genth, under the auspices of the Second Geological Survey of Pennsylvania. Analyses of the sedimentary, acid, and basic igneous rocks of South Mountain are distributed through pages 252 to 282 of Report CCC.

The analyses of the acid volcanics have here been brought together and tabulated.

Table of analyses.

	I.	II.	III.	IV.	V.	VI.
SiO_2	79.970	79.920	76.76	76.62	75.570	75.31
P_2O_5		.190	.11		.190	.05
Al_2O_3	13.860	12.400	12.64	12.26	11.940	12.96
Fe_2O_3		2.950	2.63	2.08	3.830	3.05
FeO	2.700			4.03		
TiO_2			.68			.41
MgO	1.230			.26		
CaO	.220	Trace.	.11	.34		
K_2O		6.490	6.15	2.57	5.250	3.15
Na_2O		2.320			3.010	5.11
H_2O			1.53			
Ignition		.440		.40	.270	.61
Total	95.038	100.71	100.77	99.09	100.06	100.65

I. Fissile green schist. Between Pine Grove Furnace and Laurel forge.[2]

II. "Orthofelsite." "One-fourth of a mile north of Lerew's store."[3]

III. "Orthofelsite." "Cut on turnpike 5 miles northwest of Petersburg, Cumberland County."[3]

IV. "Laminated felsite." "East of Bigham Copper Mine."[4]

V. "Laminated orthofelsite." "One-fourth of a mile southeast of Caledonia Furnace."[3]

VI. "Finely laminated orthofelsite." "One-fourth of a mile west of Cole's sawmill, on the Shippenburg road."[3]

Their general uniformity and their close agreement with the analyses of typical rhyolitic lavas is the most striking feature of these analy-

[1] On the development of crystallization in the igneous rocks of Washoe, Nev., with notes on the geology of the district: Bull. U. S. Geol. Survey No. 17, 1885, p. 40.

[2] Analysis made by A. S. McCreath for commercial purposes; alkalies undetermined.

[3] Analyses made by Dr. Genth and Henry Trimble, Second Geol. Surv. Pa., Vol. CCC, pp. 263–269.

[4] Analysis made by C. Hanford Henderson, of Philadelphia, The copper deposits of the South Mountain: Trans. Am. Inst. Min. Eng., Vol. XII, 1884, p. 90.

ses, and is a convincing proof of the igneous origin of the rocks which they represent. In the absence of samples of the rocks analyzed or of exact descriptions of their character, special points can be brought out only inferentially.

The high percentage of the alkalies and the slight trace of lime plainly denote the character of the feldspathic constituents. This indication of their chemical character coincides with the optical and physical properties enumerated on page 40. The rock from which Analysis IV was made is reported to be from the same locality from which many of the aporhyolites were obtained, the optical character of whose feldspars were tested.

Microscopic study of these rocks leads us to expect a percentage of titanium oxide. In two instances the analyses show it. It is not unlikely that in the other cases the titanium oxide was not determined. The absence of manganese oxide from these analyses is surprising, as the Monterey porphyries and aporhyolites show a high percentage of it. The lime and magnesia present are doubtless due to the presence of epidote in the rock. The silica, alumina, and iron percentages are exactly normal and call for no remark.

Analysis I, of a fissile schist, illustrates the slight change of chemical constitution which accompanies dynamic action in the acid rocks.

Among the analyses made by Dr. Genth for the Second Geological Survey of Pennsylvania are the following, which, because of their anomalous character, have not been tabulated with the others:

	I.	II.
SiO_2	53.86	52.82
P_2O_5	....	.21
Al_2O_3	22.18	20.73
Fe_2O_3	7.11	....
FeO	1.46	10.72
TiO_2	....	1.92
MnO	....	.52
MgO	2.79	2.03
CaO	1.99	.23
K_2O	4.56	6.68
Na_2O	4.12	....
Ignition	2.55	4.28
Total	100.42	99.62

I. "Slaty rock." "Nine miles southwest of Dillersburg."

II. "Purplish slaty orthofelsite." "One and one-half miles southeast of Mount Alto."

These rocks plainly do not represent the normal type of the South Mountain acid rock. In the absence of specimens or means of determining the character of the rocks from which these analyses were made, it is impossible to explain altogether satisfactorily the abnormally low percentage of silica and the high percentages of alumina and iron.

If these slates were once normal aporhyolites, the shearing which produced the subsequent slaty character must have been accompanied by an abundant development of sericite from the feldspar. If the silica

FLOW BRECCIA.

From crest of hill east of the Clermont House. One-half natural size. The details of the brecciated structure are greatly obscured in the photograph. Some of the fragments are spherulitic; many of them fit together, forming what was once a large fragment. The colors are shades of pink, red, and purple.

thus set free was carried off by percolating water, a low silica percentage and a correspondingly high alumina percentage would result, while the alkalies would remain about the same. The increase in iron may be due to infiltration.

ACID VOLCANIC BRECCIA.

DISTRIBUTION.

The presence of acid pyroclastics in the Monterey district has already been mentioned. Although a conspicuous feature of a portion of South Mountain, notably of the Buchanan Valley north of the Chambersburg turnpike, where they cover about 2 square miles, they play an insignificant rôle among the rocks of the Monterey district. Their character, however, is unmistakable. They may be classified as tuffs, flow breccia, and true breccia or tuffaceous breccia.

TUFF.

This is a dark-purple banded rock, the clastic character of which is hardly evident in the hand specimen. Microscopic examination discloses its tuffaceous nature. Minute angular fragments, not exceeding a millimeter in length, are thickly distributed through a crystalline groundmass.

The fragments are usually spherulitic, with the replacement of the spherulitic crystallization, as in the massive aporhyolites described on page 52, by a fine mosaic, so that in ordinary light the spherulites are traceable only from their outline. In the same way, under crossed nicols a uniform granular crystallization obscures the fragmental character of the rock—a character which, in ordinary light, is sharply brought out by an outlining pigment of red iron oxide. Fragments of quartz and feldspar are among the inclusions. The groundmass, which is of the same chemical and mineralogical constitution as the included fragments, doubtless represents an ash recrystallized.

FLOW BRECCIAS.

These occur at widely separated localities—northwest of Old Maria furnace, near the source of Toms Creek, on the Gladhills road, and on the brow of the hill east of the Clermont House. These breccias are composed of fragments of considerable size, which plainly were caught in a viscous acid magma, as is evidenced by their linear arrangement in flow lines and by the way in which different fragments fit together, forming what was once a larger fragment. On the weathered surface of the rock its brecciated character is rendered very manifest in the varying tints of pink, red, purple, and blue (Pl. XII). The fragments range in size from the submacroscopic to those that are 2½ inches in diameter. Their spherulitic character is discernible by the naked eye. Under the microscope, in ordinary light, the fragments frequently show either perlitic parting, a spherulitic character, or a regular arrangement of the coloring matter parallel to the boundaries of the fragments, due to water deposition. Crossed nicols again show uniform crystallization or a micropoikilitic structure. In one specimen of breccia this was not the case, however. A coarsely crystalline siliceous cement is quite distinct in grain from the uniformly finely crystalline fragments. This may be a lava flow crushed and recemented.

TUFFACEOUS BRECCIA.

In some instances the groundmass doubtless represents an altered ash, when the rock becomes a true breccia. A breccía of this sort from the Monterey district has epidote largely developed in the matrix. The granulated quartzes and the perthitic feldspars of the included fragments show in a marked way the effect of dynamic action.

At Raccoon Creek a fine specimen of breccia was found (Pl. XIII), and in the Buchanan Valley breccia is extensively exposed. Some of the fragments contain chain spherulites. At Coles Corner (Buchanan Valley), some 6 miles northeast of Graeffenburg, the breccia is sheared, and with the development of sericite the rock has become more or less slaty, while still conspicuously retaining its brecciated character.

The presence of these tuffs, flow breccias, and breccias proper, which are the natural accompaniments of surface lava flows, is inexplicable under any other hypothesis of the origin of the acid rocks.

METAMORPHOSED ACID ERUPTIVES: SERICITE-SCHISTS AND SLATES.

The alteration of the feldspathic constituent of quartz-porphyries to sericite or some other micaceous mineral, under the action of dynamic forces, has been frequently described.[1]

The production, in this way, from massive acid eruptives, of schists and slates resembling true porphyroids,[2] is finely illustrated in the South Mountain. In a single exposure (west end of Long Mountain, west of Gettysburg) felsites with distinct phenocrysts grade insensibly into a crinkled sericite slate. The shear zone is of limited width (10 feet), and bounded on each side by massive felsites. The phenocrysts are only slowly obliterated and can be distinguished until the last stage in the alteration has been reached.

Thin sections of five successive stages were studied. They show a development of sericite first around the feldspar phenocrysts and in a plane of dislocation. It is only sparingly developed in the ground-

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[1] J. Lehmann, Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, Bonn, 1884, Cap. IX, Druckschieferung und Glimmerbildung, p. 136.

A. von Groddeck, Zur Kenntniss einiger Sericitgesteine, welche neben und in Erzlangerstätten auftreten: Neues Jahrbuch für Mineral., etc. Supp. Vol. IV, 1886, p. 428.

G. H. Williams, Bull. U. S. Geol. Survey No. 62, pp. 61, 121, 212.

Bonney, On some nodular felsites in the Bala group of North Wales: Quart. Jour. Geol. Soc. London, Vol. XXXVIII, p. 289.

Callaway, On the genesis of the crystalline schists of the Malvern Hills: Quart. Jour. Geol. Soc. London, Vol. XLIII, pp. 530, 531.

P. L. Milch, Beiträge zur Kenntnis des Verrucano, 1892, pp. 128, 129.

[2] Rosenbusch, Pet. Massigen Gesteine, Vol. II, 2d ed., p. 411.

ACID BRECCIA, RACCOON CREEK.

Natural size. The photograph does not bring out clearly the brecciated character of the work, which is very pronounced in the specimen. The matrix is apparently an ash containing angular fragments of a larger size (average diameter 1 cm.). The colors are blue, gray, and buff.

mass. In the next stage the groundmass shows a decided tendency to a parallel arrangement, and sericite is more abundantly developed. Eventually the phenocrysts are obliterated and there is much sericite in the groundmass. It is not, however, developed to the exclusion of the feldspar, while the quartz remains unaltered.

In general, the development of sericite stands in direct relation to the shearing, and increases up to an almost complete, if not quite complete, replacement of the feldspathic constituents of the groundmass. Silica remains as a constituent of the groundmass.

Material obtained from an artesian well at a point 40 feet below the surface furnished a similar shear zone, which displayed an even more abrupt transition from a porphyry to a sericite-schist. A single microscopic section included both porphyry and schist in typical development. The former showed an early stage of the alteration which was complete in the latter, where only sericite and a very schistose siliceous microgranitic groundmass remained. In this case, and in the extreme stage of the transition previously described, it would be impossible, with the microscope alone, to decide whether the schists were of clastic or nonclastic origin. This is one of the instances where field evidence is quite essential to the authoritative determination of the origin of the rock.

At the Bechtel shaft there has been thrown out a mottled red and white schist which has been produced by the shearing of a massive felsite. Here the phenocrysts have been replaced by a quartz mosaic and some sericite, which is also largely developed in the groundmass. The red mottling is due to a more or less parallel arrangement of red iron oxide globulites.

A light green sericite-schist found on the railroad near Blue Ridge Summit station, and closely resembling some schists in situ exposed on the Gettysburg Railroad below the Clermont House, shows under the microscope phenocrysts of feldspar containing inclusions of a former glassy magma, still well preserved and showing twinning striations. These phenocrysts occur in a groundmass of quartz, a little feldspar presumably, much sericite, epidote, ilmenite, or magnetite, and leucoxene.

The color of the schist is due largely to the epidote.

At the exposure just now mentioned on the Gettysburg Railroad, east of the Clermont House, there occurs a handsome, light, silvery-green, crinkled sericite-schist. Several rods to the north of this exposure the railroad cuts through quartz-porphyry, but the contact between the porphyry and the schist is not exposed. The schist is similar to those already described, whose gradual passage into a massive porphyry could be followed in the field, and shows traces of phenocrysts under the microscope, and in the hand specimen on the surface at right angles to the cleavage. The cleavage surfaces often display exquisitely delicate and manifold dendritic tracery. (Pl. XIV.)

On the highroad from Fountaindale to Fairfield, not far from the "Old Copper Shaft," occurs a dark purple-gray spotted slate. The light-green spots are sometimes irregular, but more frequently possess crystalline outlines and prove under the microscope to be a sericitic alteration of feldspar phenocrysts. Much of the feldspathic material still remains. The groundmass consists largely of iron oxide, which by its prevalence obscures the other constituents—leucoxene and quartz.

Microscopic evidence is sufficient in this instance to determine the origin of the rock. It is plainly a sheared eruptive, and probably a porphyritic aporhyolite, although the irregular outline of some of the sericitic areas suggests a brecciated aporhyolite.

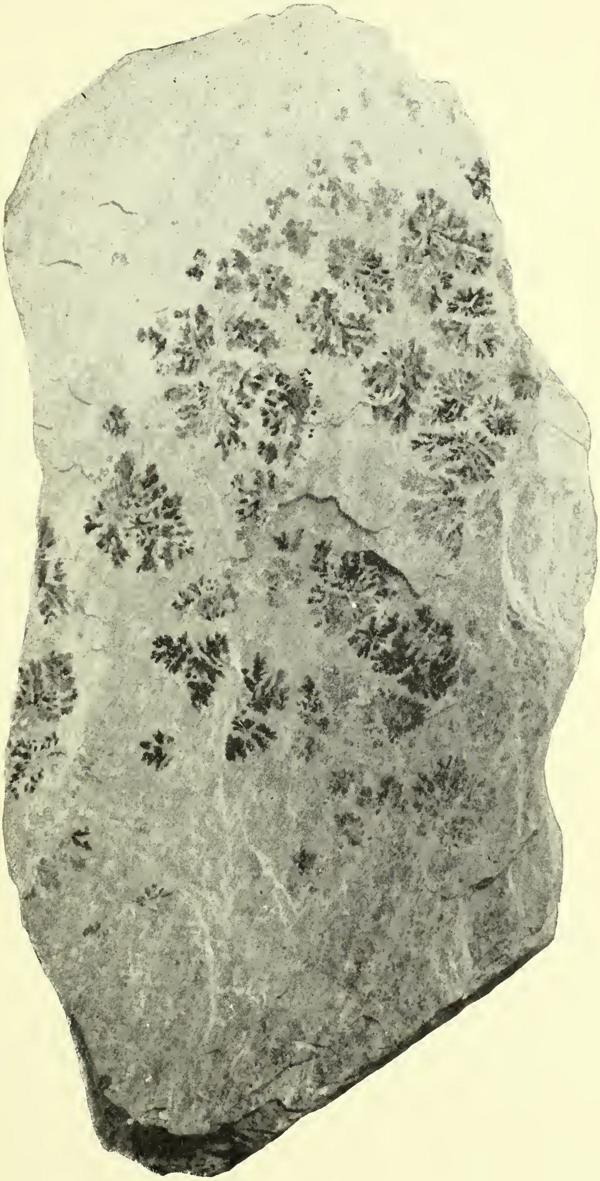
The occurrence of these slates is an interesting feature of the geology of the South Mountain. In the hand specimen they might readily be confused with a porphyroid, that is, a metamorphosed clastic rock, and have been so confused by geologists. They did not escape the attention of Professor Rogers, who alludes to them as "the fissile talcose rock" near the "reddish gray rock, containing specks of reddish feldspar," and includes them among the primal slates whose highly altered condition he repeatedly contrasts with the other slightly altered sediments (sandstone). If these slates were of clastic origin, a high degree of metamorphism was necessary to produce their present crystalline condition, and Professor Rogers was quite right in drawing a contrast between their extreme metamorphism and the comparatively unaltered condition of all the other sediments. The very fact that their development from a sediment calls for such a high degree of metamorphism confined to limited and isolated zones, and for which no adequate cause can be assigned, renders such an origin as improbable as it is unnecessary. Such a "selective metamorphism" is not demanded by the facts.

As a matter of fact, these slates are scarcely more altered than the sandstone. Dynamic action in the latter has developed a quartzite. Dynamic action in the less resistant porphyry and aporhyolite has produced a sericite slate. That the chemical character of the acid rock remains essentially unaltered is evinced by analysis I, given on page 61. This shows exactly the composition of a rhyolite, and is totally unlike that of the sediments of the region. The sedimentary argillaceous slates of South Mountain are very little altered, and exhibit no tendency toward the development of porphyroids.

All evidences—field relationship, successive stages shown in the hand specimen and under the microscope, chemical character, inherent improbability of clastic origin—combine to reveal the igneous character of these acid slates.

SUMMARY.

The acid igneous rocks of the South Mountain have proved to be quartz-porphyries, devitrified rhyolites (aporhyolites) with accompanying pyroclastics, and sericite-schists.



SERICITE SCHIST.

From exposure on the Gettysburg Railroad just below (east of) the Clermont House. One-half natural size. It shows the dendritic markings which are frequently to be seen upon the cleavage surfaces of the acid slate.

The first are typical holocrystalline porphyries, characterized by a soda-feldspar and by the presence in many cases of accessory piedmontite. The second group are the prototypes of the modern rhyolites, differing from them only in the loss of a vitreous base through devitrification. They are without phenocrysts, with inconspicuous phenocrysts, and with abundant and conspicuous phenocrysts. Like the porphyries, they are characterized by a soda-feldspar—that is, they are of the pantellerite type. The evidence for devitrification lies in the abundant presence of structures peculiar to glassy lavas, in the present holocrystalline character of the rocks, and in the empirical knowledge that glass may become crystalline through lapse of time.

The sericite schists are a metamorphic product of the first two classes by means of dynamic action.

The alteration which the original types have undergone subsequent to consolidation is, in the case of the aporhyolites, devitrification (statical metamorphism); in the case of the schists, sericitization (dynamical metamorphism); and in the case of all three groups, including the quartz-porphyries, an epidotization (weathering).

CHAPTER V.

PETROGRAPHICAL DESCRIPTION OF THE BASIC ERUPTIVES.

NOMENCLATURE.

Many of the petrographical data upon which uniformitarian arguments have been based have been drawn from the comparative study of basic eruptives, and there is a marked disposition to disregard age in the nomenclature of these rocks. Among German petrographers, Reyer,[1] Tietze,[2] Reiser,[3] Reusch (H. H.),[4] and Suess[5] have supported the view that age is not a just ground of distinction between eruptive rocks, and Rosenbusch[6] predicts that in no very distant future the separation of effusive rocks into an older and a younger series "will prove untenable." English and American petrographers are practically disregarding age in their nomenclature of the basic igneous rocks. Among the former, Judd,[7] Teall,[8] Allport,[9] Bonney,[10] Phillips,[11] and Hobson[12] are notable. Among American petrographers, the Danas[13] and Iddings[14] have disregarded age in their usage of basic rock names.

In plagioclase-augite rocks, the distinction between the gabbro and the diabase groups has been finally recognized as structural and not mineralogical, and the distinction between the diabase and the

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[1] E. Reyer, Beiträge zur Fisik der Erup., 1877, pp. 142–171; ref. Hussak: Neues Jahrbuch für Mineral., etc., 1892, Vol. II, p. 147. Beiträge zur Fisik der Erup. und der Eruptivgesteine 1887, p. 135.

[2] E. Tietze, Das Altersprincip bei der Nomenclatur der Eruptivgesteine: Verhandl. k. k. geol. Reichsanstalt, Wien, 1888, p. 166; ref. F. Becke: Neues Jahrbuch für Mineral., Vol. II, 1884, p. 303.

[3] Karl A. Reiser, Ueber die Eruptivgesteine des Algaü: Tschermaks mineral. Mittheil., Vol. X, 1889, pp. 500–550.

[4] H. H. Reusch, Ueber Vulkanismus, Berlin, 1883.

[5] Suess, Das Antlitz der Erde, Vol. I, pp. 204–206, 1883.

[6] H. Rosenbusch, Ueber die chemische Beziehungen der Eruptivgesteine: Tschermaks mineral. Mittheil., Vol. XI, 1890, p. 146.

[7] Judd, On the gabbros, dolerites, and basalts of Tertiary age in Scotland and Ireland: Quart. Jour. Geol. Soc. London, Vol. XLII, 1886, pp. 49–97. The secondary rocks of Scotland: Quart. Jour. Geol. Soc. London, Vol. XXX, 1874, pp. 220–303.

[8] Teall, Address of the president Geol. Sec. (*e*) of the British Assn. Adv. Sci., 1893.

[9] Allport, On the basaltic rocks of the Midland coal fields: Geol. Mag., Vol. VII, No. 70, 1870, pp. 159–162 Tertiary and Palæozoic trap rocks: Geol. Mag. Vol. X, 1873, p. 196.

[10] Bonney, Quart. Jour. Geol. Soc. London, Vol. XXX, p. 529.

[11] Phillips, On the so-called greenstones of central and eastern Cornwall: Quart. Jour. Geol. Soc., London, Vol. XXXIV, p. 471.

[12] Hobson, On the basalts and andesites of Devonshire: Quart. Jour. Geol. Soc., London, Vol. XLVIII, 1892, pp. 496–507.

[13] J. D. Dana, On some points in lithology: Am. Jour. Sci., 3d series, Vol. XXXVIII, 1878, pp. 336, 438. E. S. Dana, Trap rocks of the Connecticut Valley: Proc. Am. Assn. Adv. Sci., 1884.

[14] Iddings, The columnar structure in the igneous rock on Orange Mountain, New Jersey: Am. Jour. Sci., 3d series, Vol. XXXI, May, 1886, p. 331.

basalt (dolerite) as one of the degree and granosity of the crystallization. It is easy to see that these features are determined by the geological conditions of consolidation. It follows from this that the essential characteristics of the rock groups are independent of age.

A history of the classification of the gabbro and its allied groups and an exact statement of the final definition of these groups have been concisely given by Dr. Bayley.[1] He suggests that the group of melaphyres and augite-porphyrites will eventually be dispensed with, when the olivine diabases and the diabase "will take the position thus left vacant, and the plagioclase-augite rocks will be found to occupy these places with respect to each other; the gabbros, the position of a deep-seated rock; the diabases, that of the corresponding holocrystalline effusive; and the basalt, that of the hypocrystalline equivalent." With this understanding of the use of the terms diabase and basalt, the South Mountain basic rocks fall into the diabase group.

They are holocrystalline, effusive, plagioclase-augite rocks, with or without olivine. They thus possess the characteristics of the augite-porphyrites and melaphyres (diabase group). They are so fine-grained as to appear homogeneous in the hand specimen, yet show no evidence in the thin section of an originally hypocrystalline character. There is no proof for or against devitrification. In the absence of such proof their present holocrystalline character will be recognized in their nomenclature as primary.

MELAPHYRES AND AUGITE-PORPHYRITES.

DISTRIBUTION.

The quartz-porphyries and aporhyolites in the Monterey district are limited to numerous small detached areas. The melaphyres and augite-porphyrites, on the other hand, occupy a large, irregular area, covering the valleys, the foothills, and the mountain flanks. Besides this area, which constitutes about one-half of the entire district, there are two small areas north of the old Maria Furnace, which are surrounded by the acid rocks, thus reversing the usual relation of the basic and acid eruptives. Along the State line and to the south of that line the diabases are massive or schistose, and inconspicuously amygdaloidal. In the Monterey district the amygdaloidal character of the diabases is their most marked feature. In the exposures on the Gettysburg Railroad narrow zones of inconspicuously amygdaloidal or nonamygdaloidal melaphyres grade above and below into conspicuously scoriaceous rocks.

Basic igneous slates occur at the west end of the Gettysburg tunnel, where they grade into massive diabases. They also occur on Colonel Benchoff's place, at a locality just north of Gum Spring, on a line northeast of the Blue Ridge Summit station, and form a knoll south of the Fountaindale post-office. (See map, Pl. I.)

[1] The basic massive rocks of the Lake Superior region: Jour. of Geology, July-August, 1893, Vol. I, No. 5, pp. 433-456.

There are a few other localities where slates occur. Where the slates were not studied in thin section their igneous origin has not been considered as proved.

Ash beds, diabases crushed and recemented with epidote and quartz, are exposed along the Gettysburg Railroad in the cuts west of the tunnel.

A tuffaceous breccia, composed of fragments so rounded as to appear waterworn, was found at the head of Mime Branch. At the Russel copper mine and a few other localities epidosites are abundant. At the former place they are evidently vein material, and carry the native copper. In other localities they undoubtedly represent the last stages of decomposition and alteration of the massive or more often of the tuffaceous diabases.

MACROSCOPICAL DESCRIPTION.

The augite-porphyrites and melaphyres vary in color from a slate-blue or purple to all shades and tones of green. Where epidote is the predominating alteration mineral the prevailing color is light yellowish-green; with chlorite or actinolite as the alteration products the color is a dark green.

The most persistent and striking feature of the augite-porphyrites and melaphyres is their amygdaloidal character, to which allusion has already been made.

Bowlders on the roadside and in the fields show a curiously rough and pitted surface, due to epidote or quartz amygdules brought out in relief by weathering. Sometimes the bowlders closely resemble conglomerates composed of green or white oval pebbles; or the quartz amygdules, when perfectly spherical, mimic the spherulites of the acid rocks.

The diabases (augite-porphyrites and melaphyres) are rarely massive, usually schistose, sometimes slaty, and almost universally amygdaloidal.

As the amygdules quickly respond to pressure, they furnish a delicate test of the degree of schistosity present in the rock. Macroscopically the schistosity is otherwise more or less obliterated by subsequent epidotization or chloritization.

Genuinely massive diabases are exceptional in occurrence and limited in extent. Occasionally a mass of rock has moved as a whole, under pressure, and thus close to schistose or even slaty diabase the rock may retain its massive character. In these cases, since there has been no shearing, the vesicles are often perfect spheres, showing no elongation from magmatic movement. This is notably the case just north of Gum Spring, on the Old Furnace Road. Quartz amygdules show conspicuously as round white spots on the fresh surface of the rock, which is a dark blue-gray, or are brought out in relief on the weathered surface, giving the rock the appearance of being riddled with shot. In other localities there is a greater diversity both in the shape and in the composition of the amygdules.

There is frequently a zonal arrangement of three minerals—epidote, chlorite, and quartz—the light-green epidote being developed on the edge of the vesicle and surrounding the chlorite and quartz, which are successively developed in the interior. Where the vesicles are large, epidote sometimes occurs in beautiful radiating crystals, not completely filling the vesicle, and occasionally associated with crystallized malachite.

It is doubtless to these amygdules that Professor Rogers refers when he describes the "decidedly crystalline" primal slates as containing "segregated specks and even half-formed geodes of epidote and other minerals," or "as gray slate spotted with epidote." Wherever there has been sufficient shearing to form a slate a micaceous mineral is formed in the vesicles. This micaceous mineral is either sericite, when the slate is conspicuously ornamented with greenish-white oval spots, or it is chlorite, when the slate is marked with brilliant dark-green oval spots.

The nonamygdaloidal diabase is always more or less schistose and frequently slaty. At the second railroad cut beyond Gladhill's switch it has a banded appearance, due to an alternation in color, purplish green, dark and light green rapidly succeeding one another. The rock is fine-grained. The form of the banding and the structure of the rocks as disclosed by the microscope suggest that the bands represent ash beds.

At the west end of the tunnel there is a curious differentiation of the diabase in color and sensitivity to pressure. This differentiation is limited to an irregular band which suggests in many ways an intrusive dike. The apparent dike traverses the nonamygdaloidal diabase in a direction oblique to the schistosity of the latter. At one end it diverges and sends out a branch which pursues a course vertically downward and disappears beneath the surface.

Fragments of the schistose diabase are included within the dike. Its upper surface is somewhat amygdaloidal, the interior compact, and the lower surface bordered by a band of light-yellow epidote. This band is more irregular in outline than the upper surface.

The dike is intersected by two systems of fine parallel, or approximately parallel, quartz veins. Parallel to one of these systems is an easy cleavage.

The diabase just above and below the dike is finely schistose. This schistosity is parallel to the course of the dike, and is particularly remarkable above the dike, where it follows every curve of the latter. The color of the dike is purplish, and contrasts with the surrounding dark-green diabase.

The obliquity of this seeming dike to the general schistosity of the diabase, its inclusions of fragments of the surrounding schist, its divergent branches, and the foliation of the diabase parallel to the band are all more readily explained on the supposition that we are dealing with a genuine igneous dike than in any other way. The structure of the rock under the microscope and its analysis (see Analysis III, p. 78) show that there is no essential difference in these characters between the band and the schistose diabase which it traverses. Its chemical composition differs only in the high percentage of iron which it carries. It is possible that for some cause there has been a local concentration of iron (to which the color is due) within the limits of this band, which renders it harder than the surrounding diabase and enables it to resist pressure more successfully. Hence, while not yielding itself to the pressure which produced the schistosity of the diabase, it has also been the means of producing a foliation in the diabase parallel to itself. The only other tenable hypothesis is that it represents a later intrusive lava flow of the same general composition as that of the rock into which it was intruded. The manner in which it grades into a finely vesicular rock on its upper surface, and the inclusions of fragments of a green diabase, would be explained by this hypothesis. Its resistance to pressure would be due to the same cause in either case.

In only a few instances do the diabases show a porphyritical structure apparent to the naked eye. The diabases have not infreqently suffered crushing, and are recemented with quartz, epidote, and hematite, the former minerals predominating. Veins of asbestos with quartz occur in the more epidotic diabase.

MICROSCOPICAL DESCRIPTION.

Original structures.—There is a marked uniformity of structure and of mineral constituents in the South Mountain diabases.

Unlike the aporhyolites, the porphyrites and melaphyres do not show the effects of magmatic movement. Their structure is universally the ophitic, which is produced only in a magma in a state of equilibrium. The vesicles also, as has already been noted, do not betray any fluidal movement. (Pl. XXVIII, *a*.)

Crystallization is fine-grained (see p. 69), corresponding to what has been called the "microophitic." That originally this microophitic structure was associated with and passed insensibly into the hyalopilitic is not impossible, although subsequent processes of alteration, chief among which is silicification, have destroyed all trace of an unindividualized base.

Shearing has obscured and sometimes obliterated the delicate ophitic structure through processes detailed later. Where dynamic action found relief in the crushing of the rock rather than in the production of a schist, the ophitic structure remains perfectly preserved in the rock fragments. The porphyritic structure is inconspicuous. Among the nonolivinitic porphyrites intratelluric crystallization is nearly absent. Feldspar and augite phenocrysts are rare. This characteristic, together with the widespread development of the amygdaloidal structure, allies these rocks to Rosenburch's *spilite* type.

The olivinitic porphyrites, or true *melaphyres*, contain olivine as a constituent of the groundmass as well as in the very plentiful porphyritical crystals.

The distribution of the melaphyres is quite similar to that of the spilites. The history of the two types since consolidation has been the same, and they will be discussed together.

The vesicular structure is a conspicuous feature of the melaphyres and spilites. They range from rocks almost as vesicular as a sponge to a compact rock containing only a few scattered vesicles. These vesicles are filled with material furnished by percolating waters, and a solid amygdaloid is formed.

The mineral nature of the amygdules will be described under the secondary constituents. The vesicles vary in size from microscopic dimensions to 5 centimeters in length and 3 in breadth. They are very significant, both of the amount of shearing and of alteration present in the rocks which they characterize, and they have undoubtedly been a factor in determining the character of both processes (pp. 74–75).

Secondary structures.—The micropoikilitic structure, as has been noted on page 49, is occasionally present. It is found in those melaphyres and spilites which have been thoroughly silicified by infiltration. The secondary nature of the structure is very plain. The original structure (the ophitic) is so well preserved, in spite of the replacement of the mineral constituents, that in ordinary light the altered character of the rock is scarcely apparent (Pl. XIX, *a* and *b*). Polarized light at once betrays the extent of the alteration.

Where the schistose character of the rock is pronounced in the hand specimen, it is also a marked feature of the thin section. The constituents, which in these cases are for the most part secondary, are arranged with their longest axes at right angles to the pressure.

There has been so complete a recrystallization of the rock as to obscure its original character. It has been repeatedly pointed out that under conditions of pressure igneous rocks acquire a degree of schistosity which renders it almost impossible to determine their true character and to distinguish authoritatively between foliated traps and metamorphosed slates (clastics). In the schists under discussion their relation to undoubted porphyrites leaves no room for doubt as to their origin, nor is their alteration so extended as has been described in other localities. The structure of the South Mountain porphyrites is usually far less altered than is the case with the greenstone schists of the Menominee and Marquette regions.

Original constituents.—It is to be expected that these ancient rocks, comparatively soft and extremely vesicular, exposed as they have been to pressure, percolating waters, and weathering, should exhibit alteration. It is surprising that the alteration has not been so complete as to obscure altogether the original structures and constituents. The original constituents of the rock—plagioclase feldspar, augite, olivine, titaniferous magnetite—are either present in a comparatively fresh condition or are represented by characteristic alteration products, which are often paramorphs of the original mineral. The former is only rarely the case, while the latter is the rule.

The feldspar occurs both as porphyritic crystals and as a constituent of the groundmass. The crystals of the first generation are from 0.6 to 0.8 millimeters in length to 0.2 millimeters in breadth. Those of the second generation are lath-shaped, 0.4 millimeters in length to 0.4 millimeters in breadth, and condition the microophitic structure. They are both striated, and show undulatory extinction when any of the original substance remains. Usually the feldspars are altered to epidote and quartz, or they have been completely replaced by quartz, while their crystal outline is preserved by the iron constituent.

It is doubtful whether augite is present otherwise than as a constituent of the groundmass where it is allotriomorphic. It is universally replaced by the more stable amphibole minerals or by epidote or chlorite, and some porphyritic crystals of the latter minerals may represent augite phenocrysts. The chief alteration product of augite in the schistose porphyrites is actinolite. This mineral is not limited in its development to the augite outlines, and it thus obscures the ophitic structure. Olivine crystals of two generations are readily recognized by means of their characteristic form, their irregular fracturing, and sometimes by their alteration products. Usually the olivine is altered to epidote. In a few cases (Pl. XXVIII, *b*) the crystals are still sufficiently unaltered to respond to the optical tests for olivine.

There is a large amount of an opaque black oxide in the porphyrites. Where this was tested the powder was found to be magnetic. This fact, the crystal form of some of the oxide, and the analyses of these rocks point to the conclusion that much of it is magnetite, though undoubtedly very titaniferous. Occasional rhombohedral forms and cleavages indicate that ilmenite is also present. Both these minerals have given rise to an abundant development of leucoxene (Pl. XXVIII, *b*).

In order of abundance the original constituents rank as follows: feldspar, augite, magnetite and ilmenite, olivine.

Secondary constituents.—The processes of alteration have been greatly assisted by the open-textured, vesicular nature of the rocks, and the mineral character of the amygdules is indicative of the character of the alteration of the rock mass. The vesicles are almost universally filled with one or two or all of three minerals: epidote, quartz, and chlorite. Whatever is the amygdaloidal filling is also the prevailing alteration mineral. If quartz fills the amygdules the rock mass is more or less completely silicified. The ophitic structure, while preserved in outline, is replaced by the micropoikilitic. Quartz, titaniferous magnetite, leucoxene, and some epidote constitute the rock, which is distinguished in the hand specimen by its blue-gray color and white amygdules.

One of the most common amygdaloidal fillings is epidote with a little quartz. In this case epidote is the predominating alteration product These rocks are recognized in the hand specimen by a light-green color and green amygdules. Feldspar, augite, and olivine have all been replaced by epidote. The material for this mineral has undoubtedly been furnished by the interaction of feldspar and augite, and also has been brought to the rock by percolating water from overlying rocks. In the extreme phase of this alteration these rocks are true epidosites.

In the presence of a larger amount of iron, actinolite is abundantly developed. There is also much free iron oxide, and the rock becomes dark green in color. Where there has been shearing movement, as in the case of the acid rocks, a micaceous mineral is developed. In the aporhyolites the mineral is sericite; in the porphyrites it is chlorite. In the incipient stages of the schistose structure chlorite occupies the center of the amygdules, with quartz and epidote filling the rest of the space. When the rock is so schistose as to be fairly called a slate the amygdules are represented by brilliant dark-green spots and consist of chlorite only.

Chlorite in turn becomes the prevaling alteration product. Often none of the original constituents remain. Actinolite, chlorite, epidote, and secondary silica are the invariable constituents of the "spotted greenstone schists." The actinolite and chlorite both blur the outlines of the original constituents and obliterate the original structure. These rocks are a medium green in color.

The important secondary constituents of the porphyrites are quartz, epidote, actinolite, chlorite, and leucoxene. The prevalence of one or the other of these alteration products can be determined in the hand specimen by means of the color of the rock and the character of the amygdules. With reference to the character of the alteration which they have undergone, the melaphyres and spilites thus fall into the following groups:

1. A blue-gray rock with quartz amygdules which do not show shearing. Under the microscope it shows an ophitic structure well preserved, and a silicified groundmass. Localities: Near Gum Spring, on the Old Furnace road, on Minie Branch, and along the Gettysburg Railroad.

2. A light yellowish-green rock with epidote-quartz amygdules, and epidote as a prevailing constituent. The original structure is obscured. Localities: South of the Clermont House on the Gettysburg Railroad and at the Russel copper mine.

3. A medium-green spotted schist. Chlorite is the prevailing mineral. The original structure is more or less completely obscured. Localities: Along the State line at the west end of the tunnel and at many other places. This is a prevailing type of the porphyrite.

4. A dark-green rock, more or less schistose. Epidote, quartz, and chlorite form the amygdules. Actinolite is abundant as an alteration

product. Feldspar is often fresh and unaltered and the structure preserved.

In the first three types actinolite may also be present, but not so abundantly as in the last. The first type passes into the second by increase in epidote, and the second type grades readily into the third by increase in chlorite. As this increase accompanies the development of schistosity, most of the schists belong in the third group.

Types 3 and 4 are not sharply separated. Chlorite and actinolite are present in both. In the former chlorite predominates, and in the latter actinolite.

Olivine may be present in any of the four groups. The crystal outlines are best preserved in the first group; hence the ophitic structure is here best preserved; and it is most obscured in group 3, where original crystal outlines are lost.

Group 1 contains the rocks which have been the least sheared, a fact which is perhaps accounted for by the silicified character of the rock.

The peculiar dike-like band which traverses the basic eruptives at the west end of the tunnel is not unlike type 1 in color and compactness of texture. The color is several shades darker, and the specific gravity of the rock is greater. Under the microscope a further remsemblance is seen. The compact rock mass consists largely of titaniferous magnetite (arranged in layers, or outlining obscurely an ophitic structure), chlorite, epidote, and quartz.

The amygdaloidal selvage of the band shows the same constituents in an inverse proportion, and the ophitic structure is strongly marked. This was true in all the numerous thin sections made of the band. In the vesicular portion of the band the ophitic structure is well preserved, and even olivine crystals with unaltered outline are present. The amygdules are filled with quartz, granular and crystalline epidote, and chlorite. It is probable that the yielding of the vesicles, which would offer the least resistance to pressure, saved the rock. The tendency to a parallel arrangement of the feldspars on either side of the amygdules accords with this supposition. The passage of this band, which is sometimes only from an inch to two inches wide, into a green chlorite-schist or slate is very abrupt. The difference seems to be due to the presence in the band of a large amount of iron. Its chemical analysis, given on page 78, coincides with this view.

Epidote and quartz are by far the most abundant and widely distributed of the secondary minerals. This is true not only of the basic eruptives, but also of the acid eruptives when they are the prevalent alteration products and amygdaloidal filling, and where piedmontite, a member of the epidote group, occurs in macroscopic quantities. There seem to have been conditions favoring an extensive epidotization and silicification. Undoubtedly there has been within the rocks themselves a mutual reaction between the decomposition products of feldspar and augite resulting in the production of epidote. The fact that rarely some fresh feldspar still remains, while the augite is always decomposed, indicates that the decomposition products of augite have acted upon fresh feldspar, thus also developing epidote. But the feldspars and augite of the porphyrites under discussion will not account for all the epidote and quartz present in them, composing, as they do, the amygdules, and in many cases the entire rock. The dip of the foliation planes of the basic eruptives indicates a thickness formerly much greater. A large amount of erosion of the igneous rocks has occurred since they were elevated to their present position. The water which percolated through this great thickness of igneous material brought with it the lime and alumina.

It is plain that these processes of epidotization and silicification took place not only while the porphyrites were being elevated, but have continued since the cessation of all dynamic action. The filling of vents and cracks by these materials, the fresh, unschistose character of the epidote and quartz in vesicles which themselves show the effect of squeezing, the presence of granular epidote in the schists and slates, all lead to this conclusion. While this is true, there are, on the other hand, amygdules of epidote where the fan-shaped radiating crystals of epidote have been broken and pulled apart in consonance with the alteration in the shape of the vesicle, and the spaces thus formed filled with silica.

The nonvesicular character of the acid eruptives has saved them from so extended an epidotization as characterizes the basic eruptives. In the case of the amygdaloidal aporhyolites of the Bigham copper mine, the same conditions which obtained with the porphyrites have operated to effect with them an extended development of epidote. While there is so complete an alteration in mineral constituents, there is surprisingly little change in structure.

In this respect the South Mountain basic eruptives are a contrast to similar greenstones of the Menominee and Marquette regions. A comparative study of the greenstones of the two regions shows that the Lake Superior rocks, while more altered in structure, possess feldspars less altered than do the South Mountain greenstones. Calcite is much more abundant in the former rocks, and epidote in the latter, as a secondary product.

Accessory minerals.—Copper occurs in microscopic quantities in the amygdules of the basic eruptives, just as it did in the amygdaloidal aporhyolites. This is true only of the amygdaloids from the various copper-mine localities described on pages 25–27. At these localities the carbonates of copper, malachite and azurite, occur as thin stains. The former sometimes forms crystals of considerable size in the vesicular cavities (one-fourth inch). A silvery-green asbestos occurs in some abundance in quartz veins penetrating the basic eruptives. It is plainly a secondary product. A finely divided red hematite is sometimes quite conspicuous in the amygdules as a cementing material for the crushed porphyrites. It also occurs in crystalline form, and at a single locality (south of the Fountaindale turnpike, on the north flank of Haycock Mountain) micaceous hematite occurs in veins. Calcite is rare. It is occasionally present in the amygdules or as vein material; and in the case of a single specimen, broken from a roadside bowlder, it almost completely replaces the substance of the rock.

The range of minerals, original, secondary, and accessory, found in the South Mountain rocks is a very limited one.

DISCUSSION OF CHEMICAL ANALYSES.

The analyses tabulated below, with the exception of No. IV, are collected from analyses scattered through the publications of the Second Geological Survey of Pennsylvania. For Analysis IV the writer is indebted to the courtesy of Professor Daniells, of Wisconsin University:

Table of analyses.

	I.	II.	III.	IV.	V.
SiO_2	48.93	48.02	41.280	37.225	37.03
P_2O_5	....	1.45	....	....	0.51
Al_2O_3	15.42	17.84	18.480	} 44.82	} 24.13
Fe_2O_3	14.71	11.61	9.440		....
FeO	....	.98	8.200		19.03
TiO_2	....	....	....	....	4.05
CaO	18.16	18.25	7 040	15.79	0.21
MgO	2.78	....	7.486	1.14	1.44
K_2O	....	....	2.208	....	8.93
Na_2O	....	....	3.523	([1])	Trace.
Ignition	....	1.50	2.740	....	3.54
Total	100.54	99.65	100.397	98.975	99.67

[1] Not determined.

I. "Orthofelsite, containing epidote, 11¾ miles west of Gettysburg."[1]
II. "Epidotic rock, 2½ miles from Mount Alto furnace."[1]
III. "Chloritic schist from Bechtel shaft."[2]
IV. Differentiated band at the west end of the tunnel.[3]
V. "Variegated chlorite-schist with chlorite (?), one-half mile northeast of Pine Grove."[1]

The characterization of these rocks by the Second Geological Survey is somewhat vague, and in the discussion of the analyses the writer is again hampered by the lack of hand specimens of the rock analyzed.

The percentages are about those of the normal augite-porphyrites and melaphyres as given in Roth's tables. They scarcely show as much variation as the altered augite-plagioclase rocks of his tables.

Although the analyses show some phosphorous pentoxide, no apatite was noted in the microscopic study. The iron percentage is high in all of the analyses, though not abnormally so—not higher than the microscopic study would lead us to expect.

[1] Second Geological Survey of Pennsylvania, Vol. CCC, pp. 255-275. Analyses made by the late Dr. F. A. Genth.

[2] Frazer: Hypothesis of the structure of the copper belt of the South Mountain, p. 82: Trans. Am. Inst. Min. Eng., Vol. XII, pp. 85-90. Analysis made by C. Hanford Henderson.

[3] Analysis made by Prof. W. W. Daniells, of Wisconsin University.

The "epidotic rock" (I and II) shows, as would be expected, an abnormally high lime percentage.

The chief variation from the normal type lies in the addition of lime and iron oxide and the abstraction of the alkalies and magnesia.

BASIC SLATES.

DISTRIBUTION AND DESCRIPTION.

The localities where the basic slates occur in any considerable extent are colored a light yellow-green on the map of the Monterey district. The slight rounded eminence opposite the Fountaindale post-office is composed of a dark-gray crinkled and finely laminated slate. It is darker colored than the clastic slate of the region and is surrounded by the basic eruptives. The thin section shows very distinct traces of an ophitic structure. Iron oxide, chlorite, and sericite are the only constituents that can be determined. About three-fourths of a mile north of Monterey station, on the road leading from the turnpike to the Old Furnace road, there is an exposure of a lighter-colored slate. The same constituents are found in this slate, with a larger proportion of sericite and the addition of leucoxene. The ophitic structure is barely discernible, and it is with considerable hesitancy that the slate is referred to the group of igneous rocks. Half a mile farther northeast, on the Old Furnace road, just beyond Gum Spring, occurs a light-gray spotted slate of undoubted igneous origin. It is not so finely foliated as the slates that have just been described, and much of the original structure remains. The constituents are the same as those of the last-mentioned slate. Leucoxene is more abundant and the ophitic structure is pronounced.

The amygdules, which give the slates a spotted appearance, are composed of quartz, sericite, and some chlorite. These slates are related to the porphyrites of Group I, some typical examples of which occur near by.

At the west end of the Gettysburg tunnel, just above the iron-bearing band previously described, another spotted slate has been developed from the basic igneous rock. In this case the slate is green, and the spots are a brilliant dark shade of the same color. Iron oxide, chlorite, epidote, and some silica are the constituents. The original structure is entirely obliterated. Some of the epidote grains faintly suggest olivinitic forms. Chlorite is the prevailing mineral. The spots, which as in the other slate are sheared amygdules, are formed of chlorite only. This slaty zone is only a few inches wide and passes somewhat abruptly into a slightly schistose porphyrite.

The first tunnel on the old Tapeworm Railroad, which was abandoned before an excavation was made, exposes a green slate which differs from the one just described only in its nonamygdaloidal character and in the greater abundance of epidote. The knoll northeast of Blue Ridge

Summit station, the roadway crossing the Gettysburg Railroad in front of the Clermont House, and the hill to the east of the Fairfield-Fountaindale road and north of the Fountaindale turnpike, are the other localities where slates occur. While their association and their appearance in the hand specimen, which resembles that of the first two slates discussed, indicate an igneous origin, in the absence of thin sections that origin can not be considered beyond question.

BASIC PYROCLASTICS.

DISTRIBUTION AND DESCRIPTION.

The basic breccias of South Mountain may be classified as follows: (1) Crushed porphyrites which have been recemented with epidote and quartz and sometimes brilliantly colored with red hematite; (2) Tuffaceous breccia; (3) Ash.

(1) *Crushed porphyrites.*—The crushed and broken porphyrites, while perhaps not in a strict sense breccias, present a strikingly brecciated appearance. Fragments of all sizes, of a blue or purple-gray rock, are embedded in a bright-green and white or rose-colored matrix. The fragments have undergone either silicification or epidotization without affecting materially their structure (microophitic), which is outlined by iron oxide.

(2) *Tuffaceous breccia.*—Some large bowlders found near the source of Minie Branch furnish the only unmistakable tuffaceous breccia. The fragments show a considerable range in size (see page 24) and are thickly crowded in a basic cement. As there has been no shearing, the structure of the fragments is perfectly preserved. (Pl. XXVIII, *a*.) Epidote, quartz, and iron oxide are their present constituents.

(3) *Ash.*—Above the Headlight copper mine on the Fountaindale turnpike and in the fourth cut beyond Monterey station (northeast), on the Gettysburg Railroad, are intercalated bands of a light-green rock which, for the following reasons, have been considered altered ash: At the west end of this cut a fine-grained homogeneous rock is striped with alternating bands of light green and reddish green. Under the microscope these bands show no trace of any structure save a slight schistosity. They are composed almost wholly of angular grains of epidote, magnetite and leucoxene, actinolite, chlorite, and quartz. The difference in color is due to the presence in the reddish bands of red iron oxide. Toward the eastern end of the same cut the whole face of the rock is banded with light-green epidotic layers from 1 foot to 2 feet wide, running approximately parallel to one another.

A microscopic slide of one of these bands consists wholly of granular epidote and quartz, with a little iron oxide, usually the red oxide.

These rocks overlie and are in close proximity to scoriaceous basic lava. This fact, together with their variation in color and their structureless and fragmental character, is very suggestive of an altered ash. At the first locality mentioned, the Headlight copper mine, the so-called ash occurs as a light-green schist. It is not banded, but presents under the microscope the same structureless character as the rocks above described. It consists of actinolite blades and needles, epidote granules, and some chlorite, magnetite, and leucoxene.

SUMMARY.

The basic igneous rocks display but little variety of structure or mineral constitution. The former is that common to porphyrites and melaphyres—the microophitic—and in spite of great alteration in the mineral constituents of the rocks it still remains a marked structure. Shearing obscures it, but in the extreme form of the sheared porphyrite—the slate—it is still discernible.

The formation of chlorite and actinolite tends to confuse outlines; hence some of the slates in which there is not much of these minerals preserve their original structure better than the chlorite-schists. The original mineral constituents, plagioclase, feldspar, augite, and olivine, have almost completely disappeared. No augite remains; olivine crystals are well preserved in outline, and sometimes a core of the original mineral remains. There is considerable feldspar still unaltered. It is always striated, but the crystals are too small to allow of an accurate determination of their character. That they belong to the basic end of the series is shown by their extended alteration to epidote, and by the chemical analyses of the rocks.

The vesicular character of these rocks has aided in the extended replacement of their original minerals, and the amygdules are an index of the character of that replacement. The presence of vesicles has also, doubtless, been a factor in preserving the internal structure of the rock in spite of dynamic action. Silicification, epidotization, and chloritization are the processes of alteration which have been most active.

The source of material is twofold—from the rocks in which these processes have been described, and from the overlying rocks which have been removed by erosion.

CHAPTER VI.

SUMMARY OF CONCLUSIONS.

EVIDENCE OF THE ERUPTIVE CHARACTER OF THE TWO ROCKS.

The preceding chapters have treated in detail structural and chemical features possessed by the South Mountain rocks and characteristic of igneous rocks *only*. These are regarded as sufficient evidence of the igneous origin of the rocks which they characterize, without further proof on that point. It only remains to show on what grounds a sedimentary origin has been attributed to them, and to sum up the evidence against such an origin.

FIELD EVIDENCE.

Schistosity.—The conformity of the foliation planes of the porphyries, the aporhyolites, and the porphyrites, with the foliation planes of the Cambrian sediments is a prominent and persistent feature, and one which, among others, has undoubtedly led to the ascription of a sedimentary origin to the former rocks. The confusion of foliation planes and bedding planes in the quartzite, owing to the obscurity of the latter, added force to this argument.

This conformable schistosity is not, of course, inconsistent with the igneous origin of the underlying rocks. The schistosity is a secondary feature, produced by forces which affected the igneous and aqueous rocks alike.

The cleavage is quite as plainly secondary in the clastic rocks as in the nonclastic, and sometimes conforms to the bedding and sometimes does not.

Lamination.—An original lamination, conspicuous in the aporhyolites, the nature of which was described on pages 43-44, characterized as bedding by Hunt and others, doubtless furnished another reason for attributing stratification and an aqueous origin to the rocks possessing it. The real nature of the lamination has proved to be such that it becomes an evidence of the igneous character of the rocks in which it occurs.

That the lamination is due to bands of spherulites has been pointed out. True spherulitic crystallization, such as has been described in these aporhyolites, has thus far been known only as the product of crystallization from a molten magma.

The slates.—The slaty character of the rocks has been another reason for assigning a sedimentary origin to them.

The slates, both acid and basic, have been considered clastic slates by Professors Rogers and Lesley, by Frazer, Tyson, Blandy, and Dr.

Hunt, as the quotations from these writers, given in Chapter I, show. While the igneous slates of South Mountain do not resemble any of the Cambrian sediments of that region, their resemblance to porphyroids from regions where there has been extended metamorphism is very great. This resemblance is internal as well as external, and furnishes an instance of the production of essentially similar results by either of two different methods.

The true nature of these slates and the manner of their production are conclusively revealed through field evidence. Where a single exposure shows a shear zone of not more than 20 feet in which every gradation from a porphyry to a fissile slate is displayed, or where a single hand specimen shows such a metamorphism, the evidence of such a genetic relationship is irrefutable.

Absence of gradation between igneous and clastic rocks.—There is, on the other hand, no such gradation between the igneous rocks and undoubted clastics as might be expected if the former were metamorphosed clastics. We have holocrystalline rocks sharply separated from noncrystalline clastics, with an entire absence of intermediate stages.

Professor Rogers was impressed with the high degree of metamorphism which these rocks must have undergone in order to attain their present holocrystalline character. "A gray siliceous altered rock," "a compact siliceous altered slate," are the terms he uses to describe the porphyries and aporhyolites, while he speaks of the porphyrites as "primal slate in a highly metamorphic condition" and "highly altered greenish slate." The sediments and the igneous rocks have been subjected to the same dynamic forces, and, as a matter of fact, we find one no more highly metamorphosed than the other relatively to their respective powers of resisting alteration.

Surface-flow features.—Positive field evidence for the nonsedimentary origin of these rocks is found in the features which they possess in common with surface flows. Their vesicular, scoriaceous, and pumiceous character, the accompanying pyroclastics, their flow structures, even grain, conchoidal fracture, and other characteristics of a glassy lava all testify to an eruptive origin.

PETROGRAPHICAL EVIDENCE.

Structural.—The petrographical evidence of the origin of the porphyries, aporhyolites, and porphyrites is of an even more unmistakable character.

Their porphyritic structure is indicative of their origin. Olivine and feldspar phenocrysts with crystalline outlines, idiomorphic quartz with embayments and edges rounded by magmatic corrosion, are possible only in rocks which have once been molten.

The ophitic structure, preserved in great perfection in the porphyrites, is peculiar to rocks which have consolidated from a molten magma.

Other structures which furnish additional and convincing proof of an igneous origin need only be mentioned. A detailed description of their appearance in the aporhyolites and porphyrites has been given in the previous chapters. Such structures are the spherulitic, axiolitic, lithophysal, perlitic, rhyolitic, fluidal, and amygdaloidal.

Mineralogical.—Metamorphosed sedimentary rocks are always accompanied by certain characteristic minerals. The absence of such minerals in these South Mountain rocks is conspicuous. Epidote and sericite are the only prominent alteration minerals. Of these, the former is the product of weathering rather than a true metamorphic mineral; the latter is more or less limited to shear zones, where its development is directly related to the dynamic force acting upon massive porphyries and aporhyolites. The absence of all evidence of contact action indicates their effusive character.

Chemical.—The close conformity of the composition of these rocks in the one case with that of the rhyolites and in the other with that of the diabases and melaphyres from all parts of the world, as tabulated by Roth, indicates an igneous origin. Their uniform composition is a contrast to the composition of a series of clastic rocks, where the chemical proportions are largely a matter of accident. A similar test has been applied by Rosenbusch[1] to the determination of the origin of Archean gneisses. The association of these types of acid and basic lava accord with the laws of petrographical consanguinity.

ORIGINAL ROCK TYPES.

ACID IGNEOUS ROCKS.

The acid-lava flows in South Mountain are regarded by the writer as quite comparable, at the time of their consolidation, to similar flows in post-Tertiary time, such, for instance, as those which have been recently studied in the Yellowstone National Park. Certain portions of the flow, as in the case of the Obsidian Cliff, were completely vitreous save for spherulitic and lithophysal crystallization. In other localities the lava was lithoidal, and in the central portion of thick flows holocrystalline. In this way three types of acid volcanics would be developed—rhyolites, lithoidal rhyolites, and quartz-porphyries. Every gradation between these types would accompany these.

Thus, while there are certain areas in the South Mountain, notably the Bigham Copper Mine and Raccoon Creek localities, which exhibit typical ancient rhyolites, other regions display genuine quartz-porphyries. While in the latter rocks, which constitute a not inconsiderable portion of the acid flows, the groundmass may have been, and probably was, originally holocrystalline, as in some modern lavas, in the case of the former rocks it is supposed that the groundmass was, at the time of consolidation, wholly or partly glassy.

[1] Zur Auffassung der chemischen Natur des Grundgebirges: Tschermaks mineral. Mittheil., Vol. XII, 1891, pp. 49-61.

Chief among the processes of alteration which have been going on since that time is devitrification. Out of glassy and lithoidal rhyolites devitrification has been developing aporhyolites. This process consists in the replacement of whatever glassy base was present in the original rock by a uniform quartz-feldspar mosaic. Sometimes the alteration is carried still further, and the original spherulitic crystallization is also replaced by this secondary granular crystallization. Rarely, if ever, does the secondary crystallization completely obscure the former character of the rock, while often all of the structures peculiar to a fresh glassy lava are retained.

The other processes of alteration, which all of the original rock types have undergone in some slight degree, and some of them in an extreme degree, are the processes of sericitization and epidotization. The former process has been a chief factor in the development of slates from massive porphyrites and aporhyolites.

These three processes of alteration—devitrification, sericitization, and epidotization—represent statical metamorphism, dynamic metamorphism, and weathering, respectively.

BASIC IGNEOUS ROCKS.

In contrast with the acid rocks, the basic rocks have their original constituents so completely replaced that it is not easy to determine the original type or types. The original constituents were plagioclase, pyroxene, olivine, ilmenite, and magnetite. The original structures were the microophitic, the porphyritic (inconspicuous and mostly confined to the olivine-bearing type), and the amygdaloidal, a universal structure.

In view of these constituents and structures, these rocks have been regarded as members of the diabase or augite-porphyrite group and of the olivine-diabase or melaphyre group. The augite-porphyrites resemble the spilites in their scanty porphyritic crystals, their ever-present inclination to the amygdaloidal structure, and their susceptibility to weathering.

The character of the alteration which has taken place in these melaphyres and spilites varies with the amount of shearing which has occurred. Where shearing has been a factor in the alteration, chlorite, actinolite, and quartz replace the pyroxene and plagioclase.

In the absence of shearing, epidote has resulted from the interaction of plagioclase and pyroxene. Olivine has altered to epidote, serpentine, and iron oxide; ilmenite has altered to leucoxene, and magnetite to hematite, when altered at all. In the absence of shearing the ophitic structure is preserved in outline, although sometimes the micropoikilitic is added to it through the infiltration of silica; with the presence of shearing the development of chlorite and actinolite has obliterated the original structure and produced the schistosity characteristic of chlorite-actinolite rocks.

SIMILAR ROCKS IN OTHER REGIONS.

These South Mountain volcanics form a part of a belt of similar rocks which have been recently recognized along the Eastern Coast of the United States and Canada.

Such volcanics have been described in New Brunswick by the Canadian geologists—Bailey,[1] Matthew,[2] and Ells.[3]

More recently, in the Sudbury district, similar rocks have been observed by Bell.[4] They have been described in Maine by Shaler,[5] and are recognizable in Canada, Maine, and New Hampshire through the writings of Hunt, Jackson, and Hitchcock, although they were otherwise interpreted by these observers.

Spherulitic volcanics have recently been definitely recognized by W. S. Bayley[6] at Vinal Haven, Maine, and have been studied in detail by Mr. G. O. Smith, of Johns Hopkins University.

They have been identified in the Boston Basin by Wadsworth[7] and by Diller,[8] who has studied them in some detail. The thin sections loaned by the latter for comparative study have already been mentioned as showing a marked similarity to the South Mountain acid volcanics.

The continuation of the South Mountain volcanics in Maryland and Virginia has been studied by Keith.[9] Similar volcanics have been found in North Carolina by Professor Williams,[10] in South Carolina by Lieber,[11] and in Georgia by Professor Pirsson.[12]

In Canada, Maine, in the neighborhood of Boston, and in Missouri[13] the felsites were, like the South Mountain rocks, first regarded as sedimentary in origin, and have only recently been identified as volcanic.

With continued petrographic investigation of the pre-Cambrian rocks of North America volcanics may yet be recognized at other points where the rocks have been interpreted as sedimentary.

In the Lake Superior region they have long been known through the writings of Irving and others, and their extent in that region has recently been still further enlarged.[14]

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[1] Bailey, Report on the pre-Silurian rocks of South New Brunswick: Rept. Can. Geol. Survey, 1877-78 D. D.

[2] Bailey, Matthew, and Ells, Report on Southern New Brunswick: Rept. Can. Geol. Survey, 1878-79.

[3] Ells, Volcanic rocks of Northern New Brunswick: Rept. Can. Geol. Survey, 1879-80, D.

[4] Ibid., 1889-90, F, 1891.

[5] Shaler, Cobscook Bay, Maine: Am. Jour. Sci. (3), Vol. XXXII, 1886, p. 40. Mount Desert: Eighth Ann. Rept. U. S. Geol. Survey, 1886-87, pp. 1043, 1054.

[6] Bull. Geol. Soc. Am., vol. 6, 1894, pp. 474-476.

[7] Wadsworth: Bull. Mus. Comp. Zool. Harvard Coll., Vol. V, No. 13, p. 282.

[8] Diller, op. cit.

[9] Keith, op. cit.

[10] For full statement of distribution of volcanic rocks on Atlantic Coast, see paper by Professor Williams in Jour. of Geology, Vol. II, No. 1, pp. 1-31.

[11] Lieber, Report on the survey of North Carolina, 1856, 2d ed., 1858, p. 31.

[12] A section of a Georgian felsite, loaned by Professor Pirsson, has already been alluded to.

[13] Haworth: Am. Geologist, Vol. I, 1888, p. 280; Bull. Missouri Geol. Survey, No. 5.

[14] U. S. Grant, Volcanic rocks in the Keewatin of Minnesota: Science, Vol. XXIII, Jan. 12, 1884, p. 17.

The reported rarity of volcanic action[1] in America in pre-Cambrian times is perhaps more apparent than real, and is due rather to the failure to recognize the results of such action than to the actual absence of volcanic action.

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[1] Dana, J. D., Manual of Geology, 4th ed., 1895, p. 938.

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PLATES.

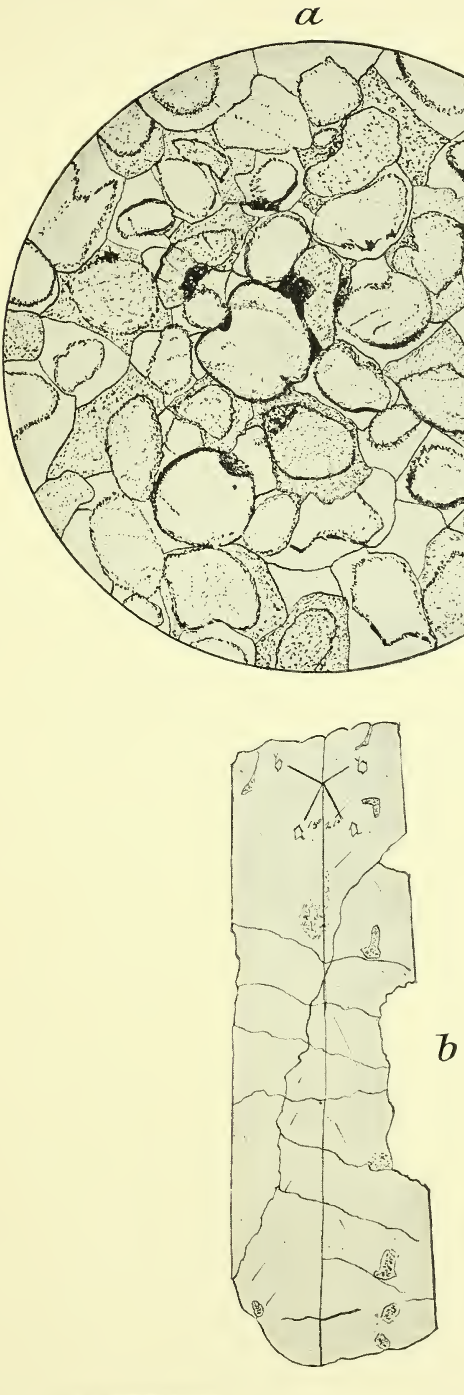
PLATE XV.

PLATE XV.

Fig. *a*.—Quartzite. Specimen I. Slide 1 D. Between Waterloo and the Blue Mountain House. In polarized light, X 32. Illustrates the induration of a sandstone by enlargment of the original grains.

Fig. *b*.—Penetration Manebacher twin of anorthoclase in quartz-porphyry. Specimen 23. Slide 23 D. From well, at depth of 40 feet near Clermont House. In polarized light, X 10 (about).

Piedmontite fills the cavities in the crystal.



THIN SECTIONS.

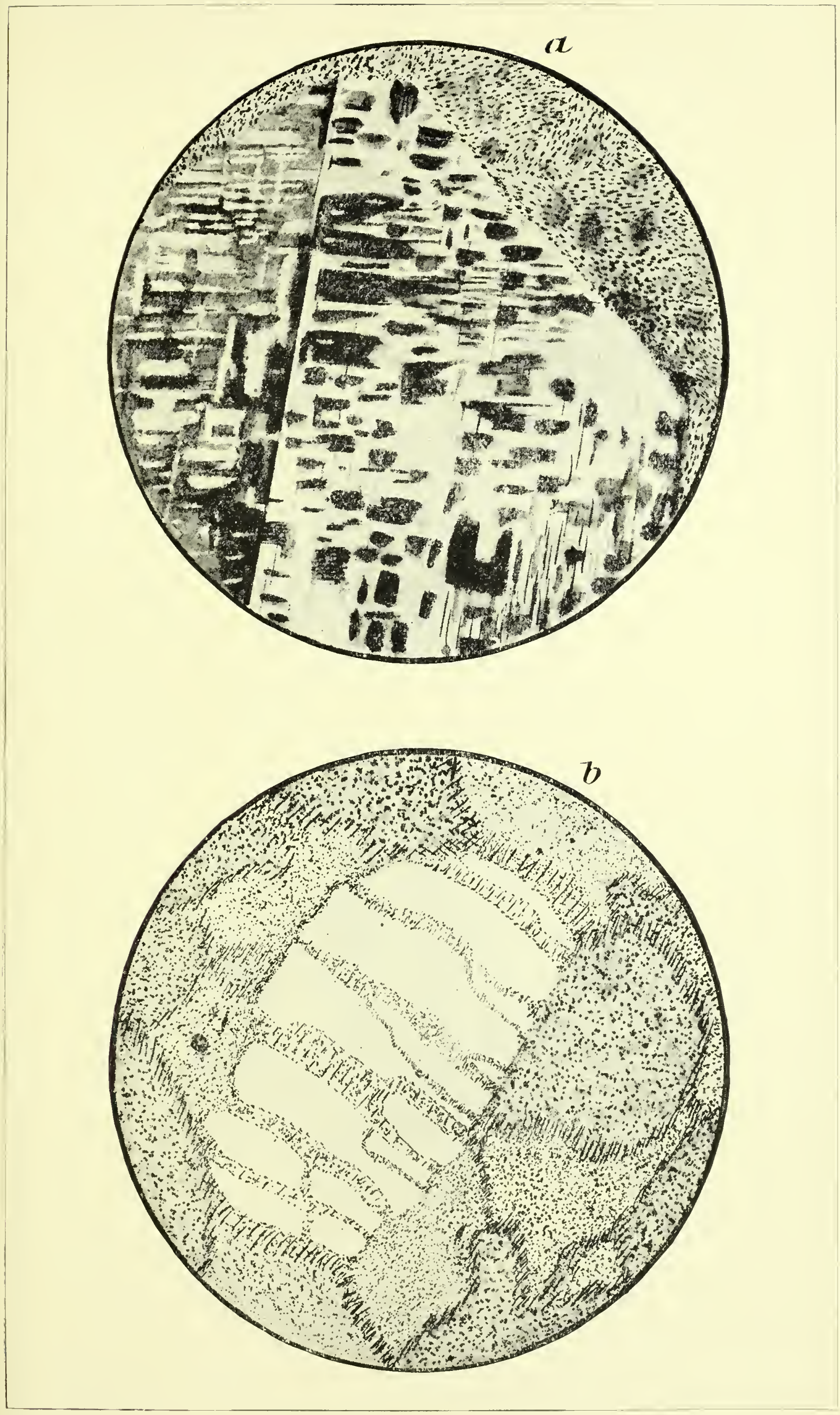
a, Quartzite ; *b*, feldspar crystal.

PLATE XVI.

PLATE XVI.

Fig. *a*.—Microperthic structure in a Carlsbad twin of anorthoclase in quartz-porphyry. Specimen 181. Slide 181 D. Near the old viaduct on the Tapeworm Railroad. In polarized light, X 85.

Fig. *b*.—Broken feldspar crystal in quartz-porphyry. Specimen 166. Slide 166 D. Near Gum Spring on the Old Furnace road. In polarized light, X 28. The phenocryst has been broken and pulled apart and the cracks cemented with sericite scales. The ground mass shows the micropoikilitic structure and the micropoikilitic areas are surrounded with sericite scales.



THIN SECTIONS.

a, Microperthitic structure in feldspar; *b*, stretched feldspar crystal.

PLATE XVII.

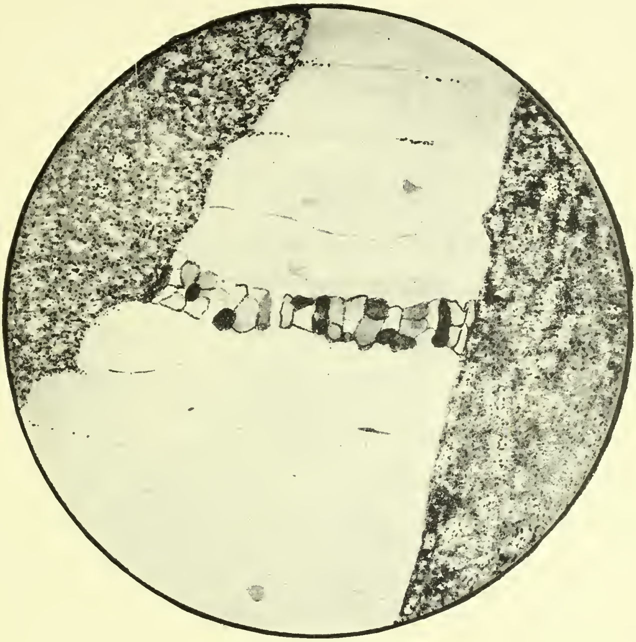
PLATE XVII.

Fig. *a*.—Broken feldspar crystal in quartz-porphyry, Specimen 177, Slide 66. Old Furnace road north of the junction with the Gladhill's road. In polarized light, X 115.

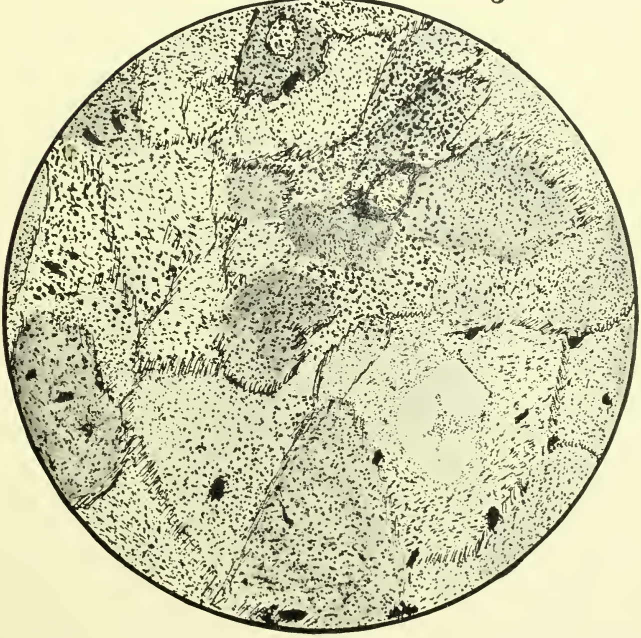
Fig. *b*.—Quartz-porphyry. Specimen 25. Slide 64. Artesian well near Clermont House. In polarized light, X 28.

It is attempted in this figure to show the continuity of orientation of a quartz phenocryst with the micropoikilitic area surrounding it, and to show (in a very crude way) the patchy effect given to the groundmass by the micropoikilitic structure. The quartz areas are bordered by sericite scales.

a



b



THIN SECTIONS.

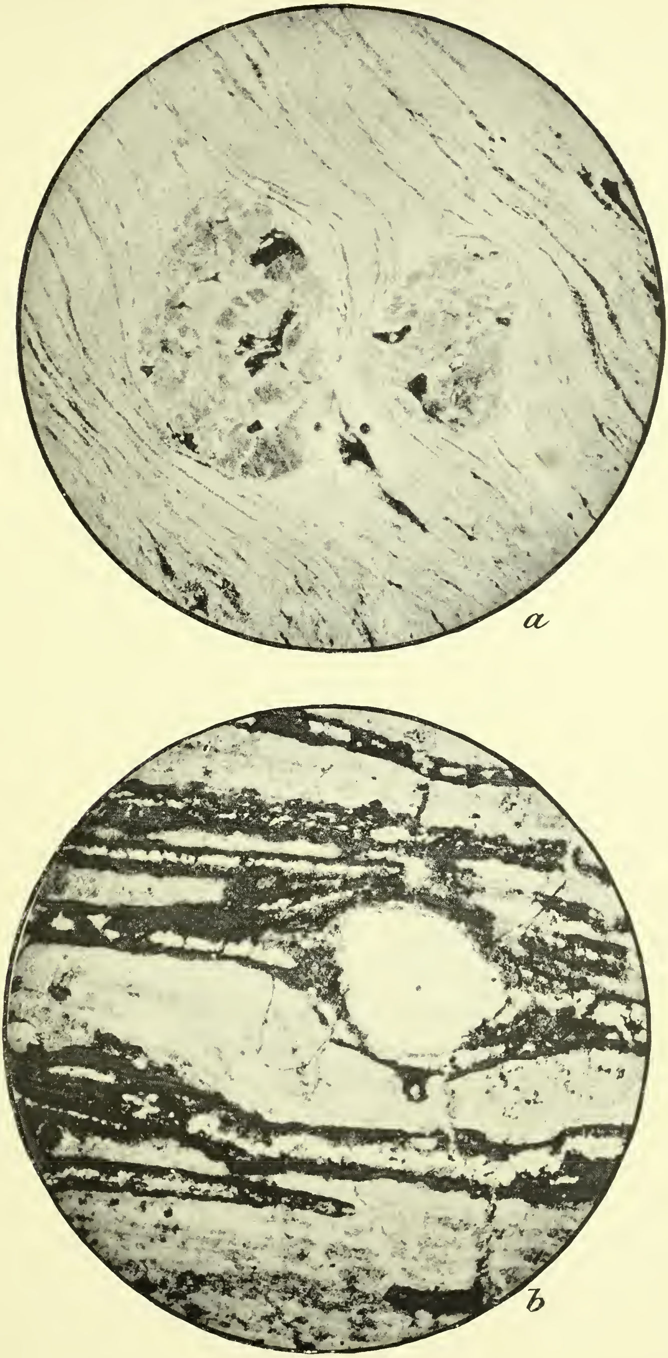
a, Quartz-albite mosaic filling crack in feldspar crystal; *b*, micropoikilitic structure.

PLATE XVIII.

PLATE XVIII.

Fig. *a*.—Flow structure in an aporhyolite. Specimen and slide loaned by Prof. S. L. Powell, of Newbury, S. C. From the South Mountain. In ordinary light, X 24.

Fig. *b*.—Chain spherulites in an aporhyolite. Specimen 34. Slide 34 D. From the neighborhood of the Bigham copper mine. In ordinary light, X 24. Quartz phenocryst (now granulated) inclosed by chain spherulites. Clear spherules in center of dark bands are still preserved.



THIN SECTIONS.

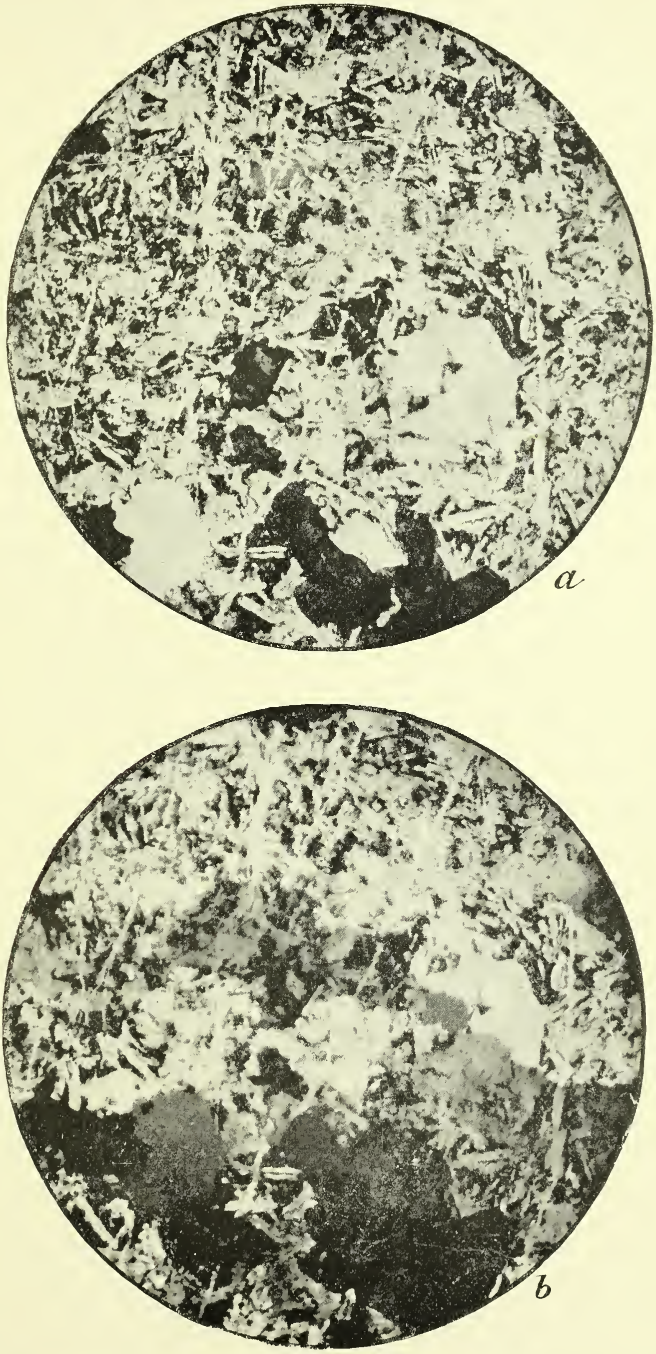
a, Flow structure in an aporhyolite; *b*, chain spherulites in an aporhyolite.

PLATE XIX.

PLATE XIX.

Fig. *a*.—Augite-porphyrite. Specimen 69. Slide 69 D. Gettysburg Railroad, southeast of the Clermont House. In ordinary light, X 24. Ophitic structure outlined by iron oxide. Colorless areas are quartz, and the considerable irregular areas are epidote.

Fig. *b*.—The same. In polarized light, X 24. The quartz breaks up into irregular areas, producing the mottled effect of the micropoikilitic structure.



THIN SECTIONS.

a, *b*. Augite-porphyrite in ordinary and in polarized light.

PLATE XX.

PLATE XX.

Fig. *a*.—Perlitic parting in an aporhyolite. Specimen 279. Slide G. H. W. (unnumbered). Raccoon Creek, Franklin County. In ordinary light, X 88.

Fig. *b*.—The same. In polarized light, X 225. A quartz-feldspar mosaic obscures all trace of glassy structures.

THIN SECTIONS.

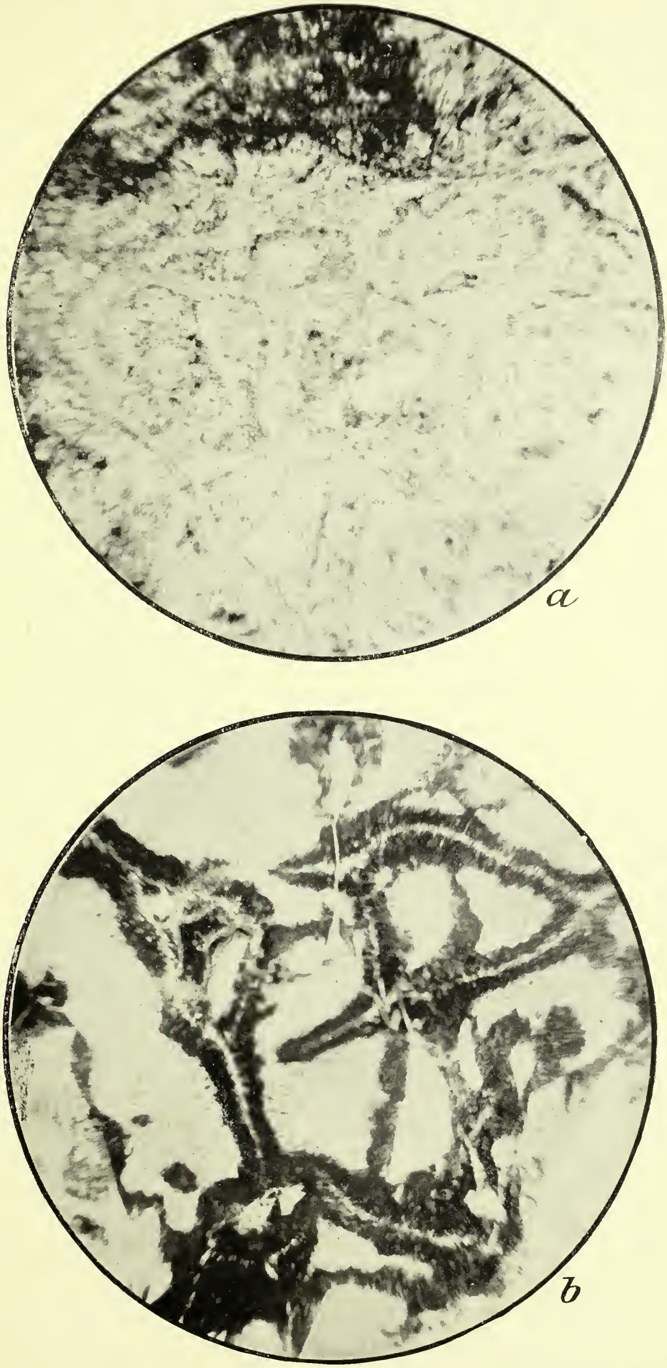
a, *b*, Perlitic parting in an aporhyolite in ordinary and in polarized light

PLATE XXI.

PLATE XXI.

Fig. *a*.—Perlitic parting in an aporhyolite. Specimen G. H. W. Slide G. H. W. (unnumbered). Raccoon Creek, Franklin County. In ordinary light, X 40.

Fig. *b*.—Axiolites in an aporhyolite. Specimen 77. Slide 77. South Mountain. In ordinary light, X 40.



THIN SECTIONS.

a, Perlitic parting in an aporhyolite ; *b*, axiolites in an aporhyolite

PLATE XXII.

PLATE XXII.

Fig. *a*.—Altered spherulite in an aporhyolite. Specimen 280. Slide 280 D. Peach Orchard, southwest flank of Pine Mountain. In ordinary light, X 5. In polarized light the slide shows an even-grained quartz-feldspar mosaic, with the micropoikilitic structure and with no trace of spherulitic crystallization.

Fig. *b*.—An unaltered spherulite in an aporhyolite. Specimen 279. Slide G. H. W. (unnumbered). Raccoon Creek, Franklin County. In ordinary light, X 30. Groundmass devitrified, but spherulitic crystallization still in a large part preserved.

a = ALTERED SPHERULITE IN AN APORHYOLITE.
b = UNALTERED SPHERULITE IN APORHYOLITE.

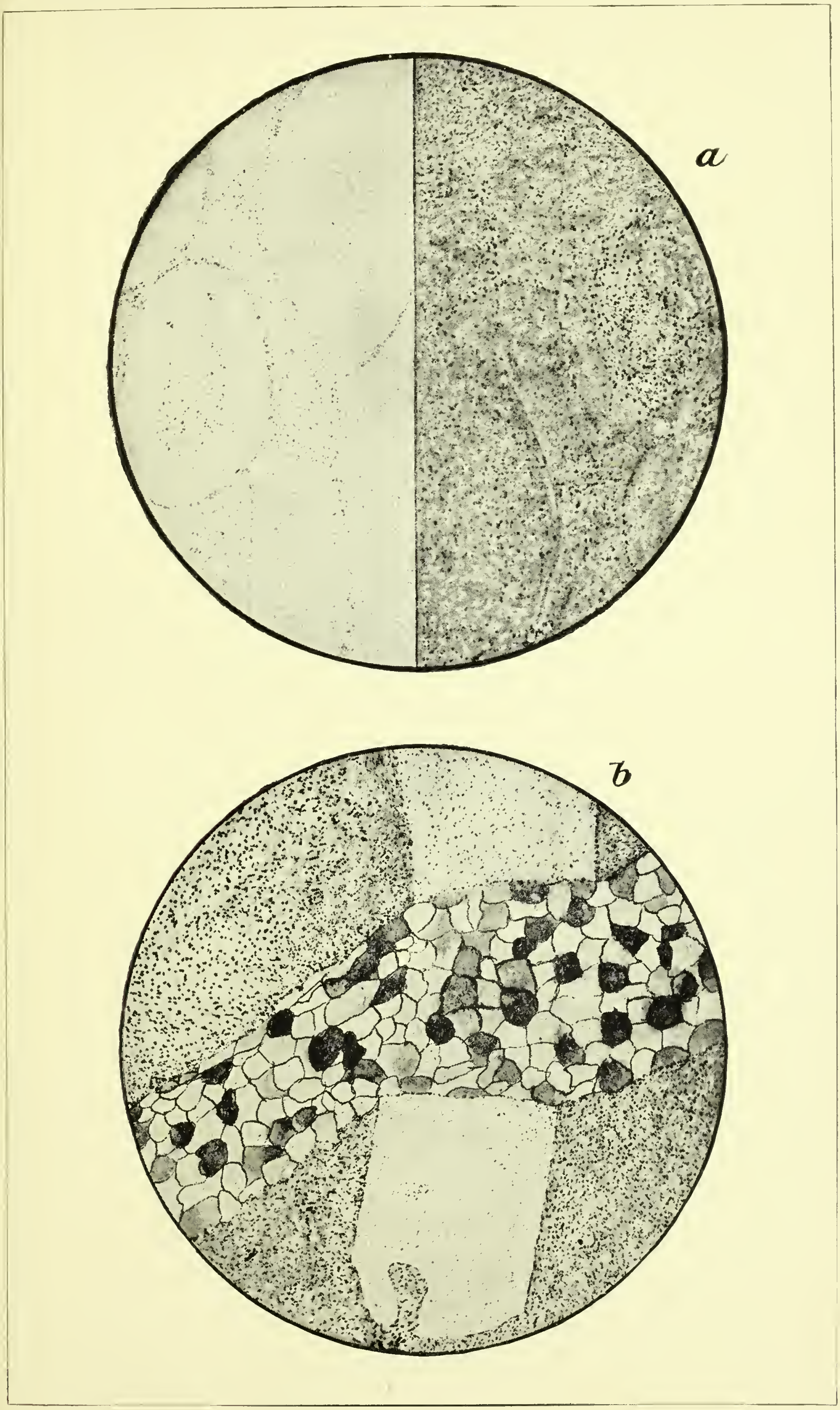
PLATE XXIII.

PLATE XXIII.

Fig. *a*.—Spherulitic aporhyolite. Specimen 226. Slide 226 D. South flank of mountain northeast of the junction of Copper Run and Toms Creek. In polarized light, X 28.

The left-hand side of the figure shows the spherulites in ordinary light; the right-hand shows the same spherulites in polarized light.

Fig. *b*.—Aporhyolite. Specimen 121. Slide 121 D. One-half mile beyond the Bigham copper mine, Old Furnace road. In polarized light, X 80. A crystal of feldspar broken by the cleavage along the plane of former spherulitic crystallization. The figure shows the crystalline silica, which has replaced the spherulitic crystallization and which is much coarser in grain than that of the groundmass.



THIN SECTIONS.

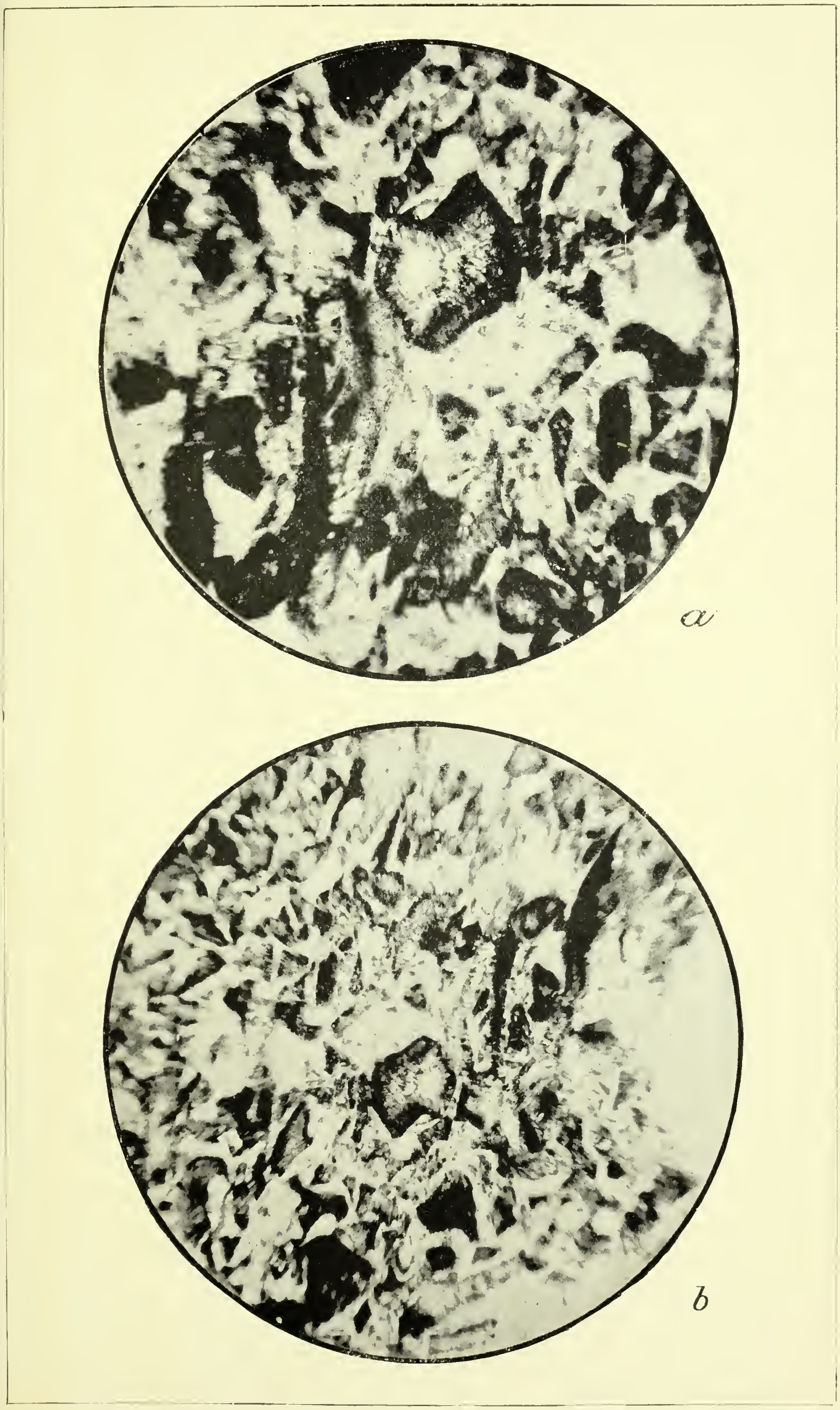
a, Altered spherulites in ordinary and in polarized light; *b*, chain spherulites with phenocryst.

PLATE XXIV.

PLATE XXIV.

Fig. *a*.—Rhyolitic structure in an aporhyolite. Specimen 153. Slide 153. South Mountain. In ordinary light, X 120.

Fig. *b*.—The same. In ordinary light, X 40. The structure is not satisfactorily shown in either figure.



THIN SECTIONS.

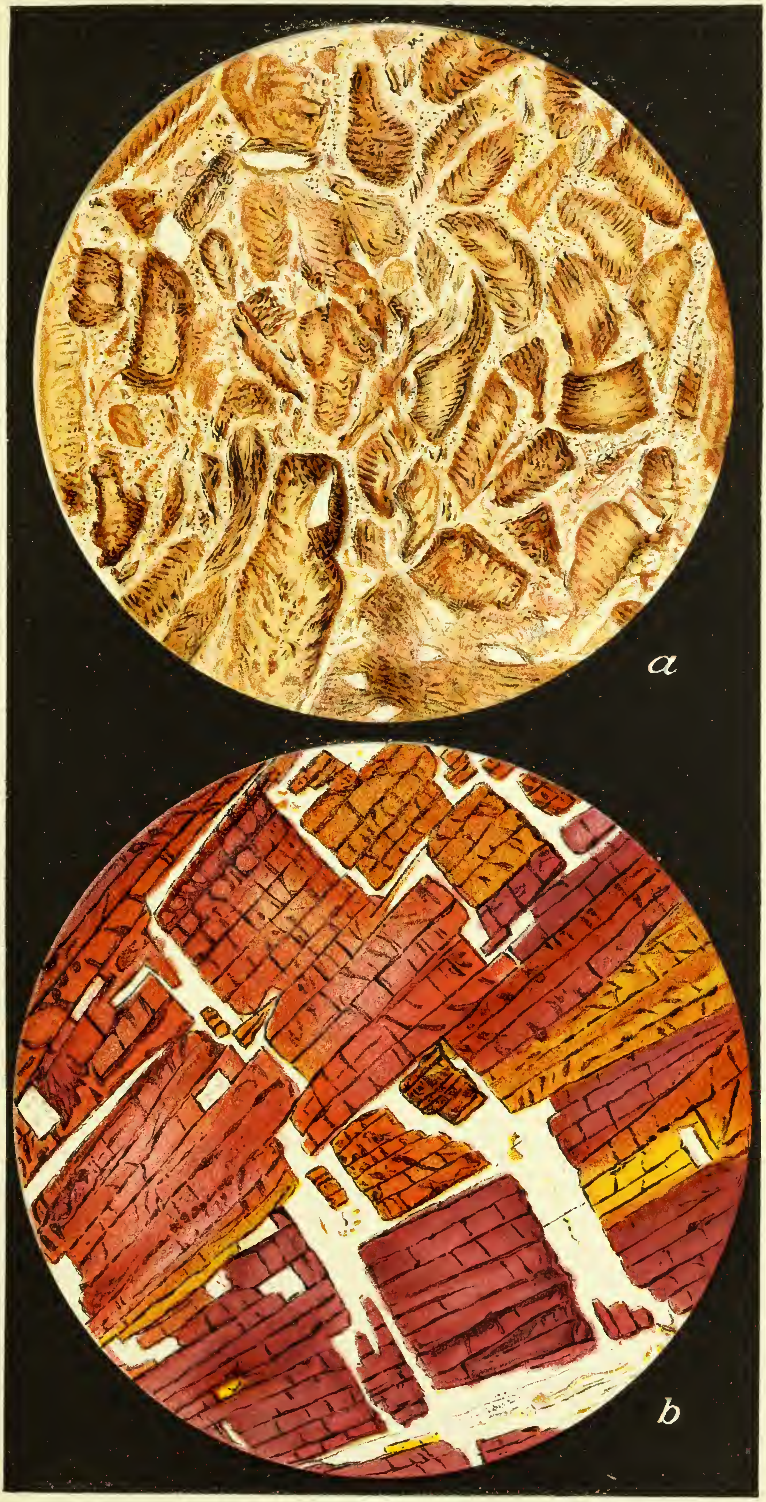
a, *b*, Rhyolitic structures in aporhyolites.

PLATE XXV.

PLATE XXV.

Fig. *a*.—Rhyolitic structure in an aporhyolite. Specimen 153. Slide 153. South Mountain. In ordinary light, X 120. Aschen-structur of Mügge.

Fig. *b*.—Piedmontite in an aporhyolite. Specimen 162. Slide 482. Southeast flank of Pine Mountain. In ordinary light, X 120.



a = RHYOLITE STRUCTURE IN AN APORHYOLITE.
b = PIEDMONTITE.

PLATE XXVI.

PLATE XXVI.

Fig. *a.*—Amygdaloidal aporhyolite. Specimen 48. Slide 48 D. Bigham copper mine. In ordinary light, X 30. Epidote fills the center of the amygdule and quartz surrounds the epidote.

Fig. *b.*—Amygdaloidal aporhyolite. Specimen G. H. W. Slide G. H. W. (unnumbered). Raccoon Creek, Franklin County. In ordinary light, X 30.

a, b = AMYGDALOIDAL APORHYOLITE.

PLATE XXVII.

PLATE XXVII.

Fig. *a*.—Amygdaloidal aporhyolite with tridymite spherulites. Specimen 276. Slide G. H. W. Raccoon Creek, Franklin County. In ordinary light, X 30.

Fig. *b*.—The same. Specimen G. H. W. Slide G. H. W. (unnumbered). Raccoon Creek, Franklin County. In ordinary light, X 30.

a, b = TRIDYMITE SPHERULITES IN AN APORHYOLITE.

PLATE XXVIII.

PLATE XXVIII.

Fig. *a*.—Augite-porphyrite. Specimen 237. Slide 237 D. Head of Minie Branch. In ordinary light, X 120.

Fig. *b*.—Melaphyre. Specimen 87. Slide 87 D. On Gettysburg Railroad, at fourth cut northeast of Monterey Station. In ordinary light, X 120.

a = AUGITE-PORPHYRITE.
b = MELAPHYRE.

INDEX.

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