DEPARTMENT OF THE INTERIOR

BULLETIN

OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 1

ON HYPERSTHENE-ANDESITE AND ON TRICLINIC PYROXENE IN AUGITIC ROCKS, BY WHITMAN CROSS; WITH A GEOLOGICAL SKETCH OF BUFFALO PEAKS, COLORADO, BY S. F. EMMONS, GEOLOGIST-IN-CHARGE OF ROCKY MOUNTAIN DIVISION

WASHINGTON
GOVERNMENT PRINTING OFFICE
1883

7.

12469
/161.

ADVERTISEMENT.

The publications of the United States Geological Survey are issued in accordance with the statute, approved March 3, 1879, which declares that—

"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization. And the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

ANNUAL REPORTS.

From the above it will be seen that only the Annual Reports, which form parts of the reports of the Secretary of the Interior and are printed as executive documents, are available for gratuitous distribution. A number of these are furnished the Survey for its exchange list, but the bulk of them are supplied directly, through the document rooms of Congress, to members of the Senate and House. Except, therefore, in those cases in which an extra number is supplied to this office by special resolution, application must be made to members of Congress for the Annual Reports, as for all other executive documents.

Of these annuals there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King, 8°, Washington, 1880, 79 pp., 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell, 8°, Washington, 1882, lv, 588 pp., 61 plates, 1 map.

CONTENTS.

The Third Annual Report is now in press.

MONOGRAPHS.

The Monographs of the Survey are printed for the Survey alone, and can be distributed by it only through a fair exchange for books needed in its library, or through the sale of those copies over and above the number needed for such exchange. They are not for gratuitous distribution.

So far as already determined upon, the list of these monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. In press.
IV. Comstock Mining and Miners, by Eliot Lord. In press.
V. Copper Rocks of Lake Superior and their continuation through Minnesota, by Professor R. D. Irving. In press.
VI. Older Mesozoic Flora of Virginia, by Prof. Wm. M. Fontaine. In press.
Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.
Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.
Coal of the United States, by Prof. R. Pumpelly. In preparation.
Iron in the United States, by Prof. R. Pumpelly. In preparation.
Lesser Metals and General Mining Resources, by Prof. R. Pumpelly. In preparation.
Lake Bonneville, by G. K. Gilbert. In preparation.
Dinocerata. A monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In press.
Sauropoda, by Prof. O. C. Marsh. In preparation.
Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these monographs, No. II is published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, Capt. U. S. A., 1882, 4°, 264 pp., 42 plates, and atlas of 26 double sheets folio. Price $10.12.

Nos. III, IV, V, and VI are in press and will appear in quick succession. The others, to which numbers are not assigned, are in preparation.

BULLETINS.

In its Bulletins the Survey will print such papers relating to the general purpose of its work as do not properly come under the heads of ANNUAL REPORTS or MONOGRAPHS.

The Bulletins will each contain but one paper, and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself at the top, and at the bottom, one which belongs to it in the volume.

Of this series of Bulletins this paper forms No. 1, and is also the first part of Volume I.

Its price is ten cents.

Correspondence relating to the publications of the Survey, and all remittances, should be addressed to the

DIRECTOR OF THE UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C.

WASHINGTON, D. C., *February* 24, 1883.

DEPARTMENT OF THE INTERIOR

BULLETIN

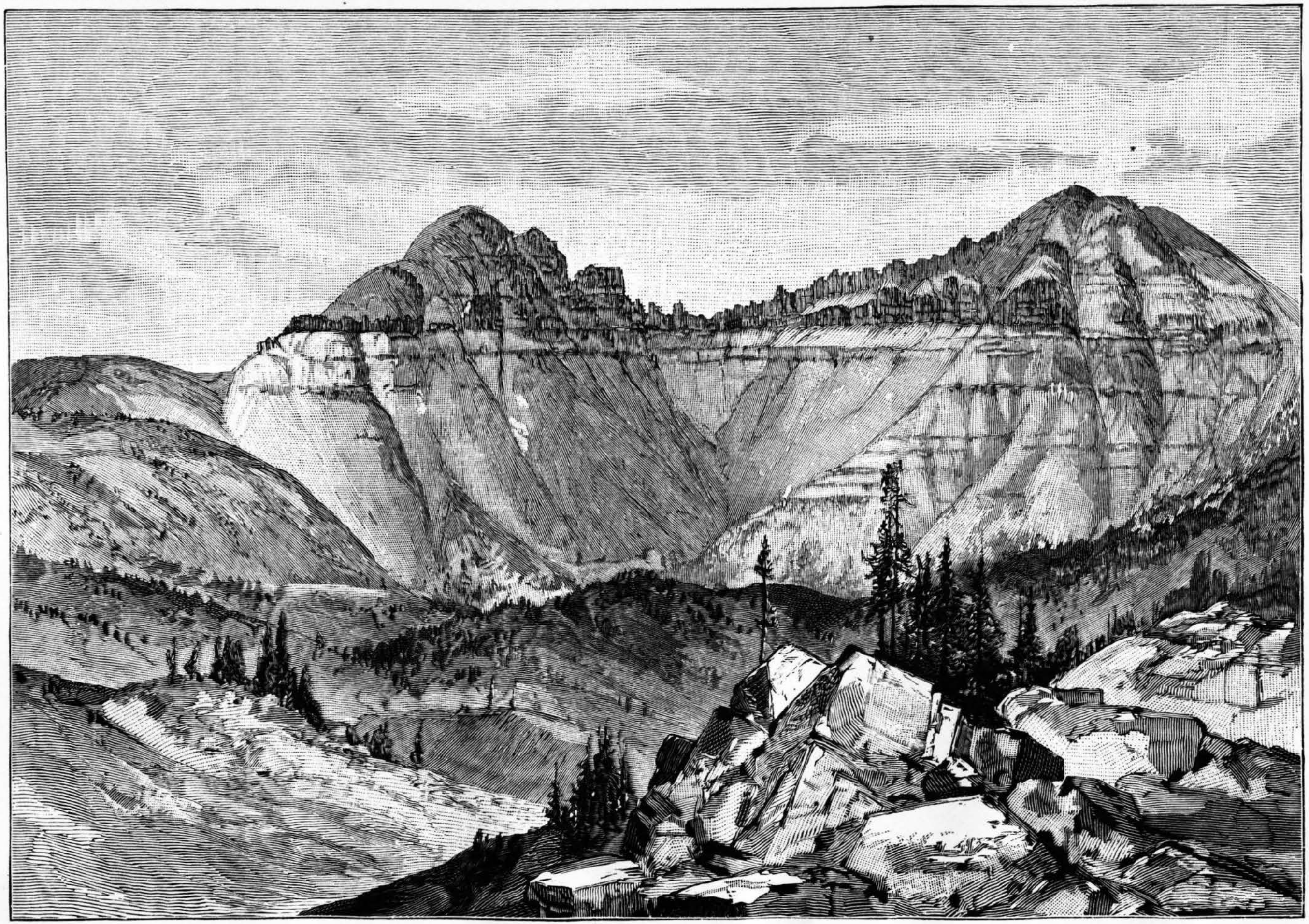
OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 1

WASHINGTON
GOVERNMENT PRINTING OFFICE
1883



BUFFALO PEAKS—FROM THE NORTH.

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL DIRECTOR

ON HYPERSTHENE-ANDESITE

AND ON

TRICLINIC PYROXENE IN AUGITIC ROCKS

BY

WHITMAN CROSS

WITH A

GEOLOGICAL SKETCH OF BUFFALO PEAKS COLORADO

BY

S. F. EMMONS

GEOLOGIST IN CHARGE OF ROCKY MOUNTAIN DIVISION

WASHINGTON

GOVERNMENT PRINTING OFFICE

1883

LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE ROCKY MOUNTAINS,
Denver, Colo., October 1, 1882.

SIR: I have the honor to transmit herewith a paper by Mr. Whitman Cross on Hypersthene-Andesite, with a brief sketch by myself of the geology of Buffalo Peaks.

The material from which it has been prepared was obtained during the geological study of the Leadville region, and would naturally have been included in the monograph on that district but for the following reason: The andesites from Buffalo Peaks, which, at first glance, appeared to be most characteristic augite-andesites, were found by Mr. Cross on careful examination to differ essentially from the normal order as commonly described. In tracing out the relations of these rocks to the closely-allied so-called augite-andesites, Mr. Cross has obtained results which, if substantiated, give to these investigations a much more general than local character, and make them of value to lithologists in general; so that it seems desirable that they should be published by themselves in the form of a special paper.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in Charge.

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

CONTENTS.

ILLUSTRATIONS.

INTRODUCTORY GEOLOGICAL SKETCH OF BUFFALO PEAKS, MOSQUITO RANGE, COLORADO.

BY S. F. EMMONS.

During the summer of 1880, a little over two months' field-work was devoted by the party under my charge to a geological study of a portion of the Mosquito or Park Range, as an essential preparation for the investigation of the remarkable ore deposits of the Leadville region.

The area covered by the geological map prepared at this time, which included a length of about 20 miles along the crest, comprised not only its most elevated portion, but also, with a single exception, the most interesting part of the range from a geological stand-point. This exception was found in the Buffalo Peaks, a double-pointed mountain mass rising about 1,000 or 1,500 feet above the main crest, some 10 miles south of Weston's Pass, at the southern limits of our map. Two days were devoted to a hasty examination of these interesting peaks; but, although as many weeks might have profitably been employed in their study, for the reason that the geological phenomena here exhibited had no apparent connection with the ore deposits at Leadville, it was not considered advisable at the time to devote any more of the brief working season of this elevated region to an extraneous study, however interesting. Inasmuch, however, as the microscopical investigations of the specimens collected at that time, made by Assistant Geologist Mr. Whitman Cross, have led to the discovery of hitherto unrecognized characteristics in an important group of Tertiary volcanic rocks, which is set forth in the following pages, it may not be inappropriate to preface his paper with a brief geological sketch of the structure of these peaks, and of their relation to the rest of the range.

The Mosquito Range north of Weston's Pass is made up of Palæozoic beds about 4,500 feet in thickness, extending from the Cambrian to the Upper Carboniferous, with intercalated sheets or intrusive masses of various quartz porphyries and porphyrites, resting on Archæan granite and gneiss. The elevation of the range, which took place at the close of the Cretaceous period, was accompanied by the compression of these beds into a series of sharp folds, characterized by a steep side to the west, or towards the Archæan island, round which the sediments were originally deposited, and by numerous longitudinal faults, with an upthrow to the east, more or less parallel to the axes of the folds, with which, in general, they are intimately connected.

Towards the south this structure becomes gradually simplified, and the porphyry bodies thin out. At Weston's Pass, already, in place of the complicated system of faults and folds observed in the latitude of Leadville, two great anticlinal and synclinal folds are found, whose axes have the direction of N. 30° W., and whose eastern member has been raised by displacement along a fault plane having about the same direction. One of these folds occupies the main crest of the range, and its corresponding fault runs along the trough of the synclinal on the west, by whose movement the Archæan granite is raised on the crest of the range about 2,000 feet above its corresponding position under the Palæozoic beds which form the surface at the pass itself. The thickness of the interbedded porphyry sheet, which opposite Leadville reaches over 1,000 feet, has here diminished to a little over 20 feet.

The other fold forms a secondary elevation, called Sheep Ridge, on the foot-hills, five miles east of the crest. Here the fault line corresponds very nearly with the axis of the anticlinal fold, which is also that of the ridge, the movement of displacement gradually decreasing in a southerly direction, until the fault ridge becomes simply the elevation of an anticlinal fold. About five miles farther south, at the junction of the Little Platte, which from Weston's Pass flows southeast along the trough of the synclinal, and of Rough-and-Tumbling Creek, which drains the north slope of Buffalo Peaks, not only have the two great faults disappeared, but the two systems of anticlinal folds are merged into a single monoclinal.

Topography is here in singular sympathy with geological structure. Both the main crest and the secondary ridge to the east have the same general direction, with the strike of the geological formations, while the average direction of the topographical crest of the range, as a whole, is more nearly north and south, and its structure consequently that of a series of ridges *en échelon*. Sheep Ridge on the east disappears completely under the plain before the valley of the Little Platte is reached, and is succeeded by an isolated butte called Black Hill, formed by a massive outburst of crystalline rhyolite, breaking through and spreading out over the upturned edges of the Upper Coal Measure formation. The main ridge, which forms the eastern wall of Weston's Pass, descends rapidly to the south, reaching the level of the valley as the Little Platte bends east to flow out into the plains of the South Park, just above its junction with Rough-and-Tumbling Creek. Between these two creeks and near their junction is a series of low ridges formed by strata standing at a great variety of angles and with varying directions of strike, which show the effect of the merging of the double system of folds to the north into the simple monoclinal structure which prevails to the south.

The topographical divide of the range therefore leaves the main crest at Weston's Pass, and crosses to a second ridge, which overlaps it, on the west of the pass. Stretching southeastward in the direction of the strike, it continues with apparent regularity as far as the Trout Creek Pass, about 20 miles distant along the crest of the range. The structure of this portion of the range, as determined in our hasty visit, seems quite simple. On the west, towards the Arkansas Valley, it presents steep precipitous slopes of Archæan granite. The crest of the higher portion of the ridge is covered by a thin shell of easterly-dipping Cambrian quartzite whose average thickness in this region is about 150 to 200 feet. Resting conformably on this is the White or Silurian Limestone, of about equal thickness, succeeded by the Lower Carboniferous or Blue Limestone, also about 200 feet in thickness; then 2,000 to 2,500 feet of silicious beds, which have been designated the Weber grits; and along the extreme eastern flanks of the range the Upper Coal Measure beds, which consist partly of limestone and partly of coarse reddish sandstone. In the plains along the eastern foot of the range are found occasional ridges of the red sandstones and shales of the Trias, from which it is probable that the salt of the salt springs east of Buffalo Peaks has been derived.

Midway in this monoclinal ridge, and resting on the upturned edges of the strata, are the horizontal beds of andesitic lavas which form the Buffalo Peaks. Their western base rests on granite, immediately under the quartzite, while their eastern flows, whose limits were not ascertained, probably extend well out over the Upper Coal Measure formation. The direction of strike of the sedimentary beds, on the north side at least, seems to have been but little affected by this extrusion of volcanic material; but in immediate contact with the lava, as will be shown later, they have been considerably metamorphosed.

The Buffalo Peaks form an extremely picturesque mountain mass, whose highest point rises to an elevation of 13,541 feet above sea level, or about 4,000 feet above the adjacent valleys. It consists of a narrow curving ridge forming about one-third of a circle, its concave side toward the north, with a culminating point at either extremity of the arc, the connecting saddle being about 500 feet below their summits. From the northeast base of the eastern peak spreads a broad, flat, massive shoulder, whose area is considerably greater than that of the main peaks. Between the two peaks lies a semi-circular amphitheatre about 2,000 feet deep, in which the appropriately named Rough-and-Tumbling Creek takes its rise, and flows first northward, then eastward to its junction with the Little Platte. The upper 500 feet of the two main peaks is formed of hornblende-andesite of decidedly trachytic habit. Its matrix is of a brownish-gray color, with small crystals of white feldspar and frequent needles of black hornblende. In it columnar structure is very well developed, especially on the connecting ridge between the two peaks, where the columns are often only a few inches in diameter. At this point, rounded fragments of Archæan rocks included in the andesite are of frequent occurrence. There is also a very considerable development of hyalite on the weathered surface of the rocks, and fulgurite is found at the summit of the higher or western peak, lining small holes made by the electric fluid.

The base of the hornblende-andesite is extremely well defined, as shown in the frontispiece, by a horizontal line at about the level of the saddle connecting the two main peaks. Below this, as well as could be seen on the walls of the amphitheatre where they were sufficiently steep not to be obscured by *débris*, the mass of the mountain seems to be made up of tufas and of half-glassy modifications, which are also horizontally bedded, conformable with the base line of the hornblende-andesite. A section was made down the steep spur extending from the north base of the eastern peak into the amphitheatre, giving a freely estimated thickness of 1,000 to 1,500 feet of these tufaceous varieties.

SECTION.

1. 200–500 feet.—Hornblende-andesite.
2. 50 feet.—Semi-vitreous tufa of bright red color, with streaks of black and reddish glass running through it, and containing crystals of basic minerals and of feldspar, with innumerable small inclosed fragments of lavas and other rocks not always determinable.
3. 100 feet.—Beds of similar material, rather black in color. Among inclosed fragments rounded masses of granite, up to 6 feet in diameter, are frequent. Through the mass are thin seams or beds of black glass of a perlitic structure, like an obsidian, with plentiful small fragments of feldspar scattered through the mass.
4. 100 feet.—White and lilac colored porous tufa, with fragments of light-colored trachytic rock, rich in smoky quartz (dacite or rhyolite?).
5. 200 feet.—Tufaceous breccia, with boulders of black, vitreous-looking hypersthene-andesite.
6. 5 feet.—Bed of *dacite (rhyolite?)*.*
7. 50 feet.—Light-colored tufa with fragments of dacite (rhyolite?).
8. 500–700 feet.—Space somewhat covered, mostly of tufa, inclosing fragments of a great variety of rocks.

The next outcrop below the base of the spur was found to be limestone and shales, probably belonging to the Weber grits formation, dipping to the northeast at an angle of about 45°, and having the regular strike of the sedimentary rocks of the region. Within these tufa beds, and weathered out on their surface, were found an immense number of

*The rock described here as dacite (rhyolite?) is one which, from the specimens at hand, it has been impossible to assign definitely to either of these two classes. Macroscopically it resembles the rhyolites, having large smoky quartz and glassy-looking feldspars in a lilac-colored matrix, and possessing a very decided trachytic habit. Microscopical examination fails to determine definitely whether the one specimen in the collection contains more orthoclase or plagioclase feldspar. A partial chemical analysis is equally unsatisfactory, giving silica, 66.500; potash, 2.567; soda, 3.868. It is identical with a rock found breaking through the granite, near the town of Granite, in the Arkansas Valley, west of the Buffalo Peaks. A further field examination will be required to satisfactorily determine the character and relations of this rock.

more or less rounded fragments of included rocks, consisting mainly of granite and various lavas; the latter of which, as far as examined by Mr. Cross, have proved to be of the same character as the northeastern shoulder, *i. e.*, hypersthene-andesite.

The rock of the eastern shoulder, as far as examined, is a dark, nearly black, compact, semi-vitreous rock of conchoidal fracture, which in the field was determined at once as an augite-andesite. The average level of this eastern spur is some 700 or 800 feet lower than that of the summit of the peaks. As far as our observation extended, this rock was not found in mass in direct connection with the hornblende-andesite.

At the northeast base of the eastern peak, about midway between well-defined outcrops of the two rocks, a German miner had sunk a shaft on the flat surface of the ridge, in an iron-stained, clayey material, undoubtedly the result of decomposition of the lava, in which he found very large, irregular masses of milk-white, common opal. Some of these masses reached several feet in diameter, and when broken open it was generally found that their centre consisted of opaque, flint-like chalcedony; showing that in this case the opal had probably resulted from the hydration of chalcedony concretions within the mass of the rock. It was also observed that while the internal kernel of flint readily gave sparks when struck with steel, the exterior opaline portion was not of sufficient hardness to do this. A chemical examination was made of the flint-like kernel and of the white opaline alteration product, with the following result:

	Flint.	Opal.
Specific gravity	2.570	2.023
Hardness	6.	5.5
Loss by ignition (water)	1.843	2.584
Insoluble (in caustic potash) silica	32.430	0.710
Soluble silica	65.727	96.706
	100.000	100.000

From which it would seem that the change to the opaline form is not simply the result of hydration, since the increase in water in the latter case is only 0.741, or a little over a third more than in the original form of the secretion, but that this must have been accompanied by some molecular change, by which the percentage of soluble silica has become nearly one-half greater.

The outcrops of the upturned sedimentary beds could be traced up to the very entrance of the amphitheatre; the Weber shales, as already mentioned, had been already observed at the base of the eastern peak; the Lower Quartzites resting on the granite form the main crest of the range immediately north of the western peak, while at the northeast base of this peak, at the entrance to the amphitheatre, there was a cropping of white and blue silicified limestone, showing in a very interesting manner a relic of the solfataric action which probably succeeded the eruption of the lavas. Here the bedding is distinctly seen; the color of the limestone, its granular structure and characteristic veining are still preserved; but the whole mass is completely transformed into silica, and the surfaces frequently coated with a thin white opaline deposit. Chemical tests of three specimens brought from these outcrops, one white or drab, the other two blue limestone, showed the following contents in silica:

	Per cent.
White limestone	97.1
Bluish limestone	97.7
Darker limestone	78.9

with an apparently more than normal proportion of manganese, especially in the darker colored specimen.

The southern slopes of the peak were not examined, but from the summit outcrops of the upturned sedimentary beds could be seen continuing on southward beyond the base of the peak, apparently in a direct line with those observed on the north. The very centre of the amphitheatre was also not visited, as the soft slopes resulting from the decomposition of the tufa beds promised but few outcrops.

Two important questions present themselves in the consideration of the structure of this interesting mass; neither of which, unfortunately, can be considered as definitely decided by the hasty observations made during this visit:

First. Are the peaks the relics of an old volcanic crater?

Second. Was the hornblende- or the hypersthene-andesite the earlier flow?

To the first question the circular form of the main ridge, and its bedded structure, seem at first glance to give a decidedly favorable answer. More mature consideration shows that the present form was mainly due to glacial and post-glacial erosion, whose work in this region has been on such a stupendous scale that evidently the present form of the peaks affords little guide as to the original condition of the mass. Had the present semi-circular ridge once formed part of the crater, we should expect to find some relic of the rest of the circle resting on the ridges to the north; but with the exception of the northeast shoulder, which consists of a distinct rock, and which is evidently also the result of a distinct flow, no lavas were found north of the entrance to the amphitheatre.

As regards the relative ages of the two varieties of andesite, it is to be observed, first, that the hornblende-andesite is the higher of the bedded series; and, second, that from the tufaceous beds no fragments of the hornblende-andesite were obtained; while those of hypersthene-andesite were of very frequent occurrence. On the other hand, the flat eastern shoulder, which is probably formed of hypersthene-andesite, resembles in its form the lateral flows which come from the side of already built-up volcanoes; and as a general rule the more basic augite-andesites have been found to be younger than the hornblendic varieties. In the case of lavas, superposition is by no means necessarily a proof of later origin, inasmuch as the later flows often force themselves under those already existing. Still, in the present case, it must be acknowledged that the evidence, as far as obtained, is in favor of the earlier origin of the hypersthene-andesite.

A third point of interest for future investigation is the determination of the true character and relations of the dacite (rhyolite ?) rocks.

The fact that in the present stage of microscopical lithology the old test of the absence of striation lines visible under the microscope is no longer sufficiently conclusive to determine a feldspar as orthoclastic, renders of doubtful value the earlier classification of many rocks as trachytic or andesitic. Many facts already observed by us suggest a doubt whether von Richthofen's classification of volcanic rocks will be found to hold good everywhere in Colorado, and even that many modifications of the relations of the older eruptive rocks, as well as of those of Tertiary age, may be found necessary. The field of work is great, and will involve long and laborious studies before definitive results can be obtained. In the western portion of the Cordilleran system Tertiary volcanic rocks and recent lavas are in vast preponderance, and the older eruptives have been found thus far in but few points. In Colorado, however, while the development of Tertiary eruptive rocks is considerable, it seems probable that a very large proportion of the eruptive rocks will prove to belong to those generally classed as older, from their lithological characteristics alone; of these, however, the most widely developed class may doubtless prove to be Post-Cretaceous, and of those which belong lithologically to the class of Tertiary eruptives or volcanics, there are many whose period of eruption can be but little later than this period.

ON HYPERSTHENE-ANDESITE AND ON TRICLINIC PYROXENE IN AUGITIC ROCKS.

By Whitman Cross.

CHAPTER I.

HYPERSTHENE-ANDESITE FROM BUFFALO PEAKS, COLORADO.

The microscopical and chemical investigation of certain andesites from the Buffalo Peaks in the Mosquito Range, Colorado, having proved conclusively that a rhombic pyroxene is, after plagioclase, the most essential constituent, the writer was led to examine carefully all similar rocks at his command. As the results attained are wide-reaching, and affect many well-known European rocks, the observations made on the Buffalo Peaks rock will be given in detail in Chapter I; the results of the comparative study are embodied in Chapter II.

The "Introductory Geological Sketch" by Mr. S. F. Emmons renders any further description of the Buffalo Peaks unnecessary; all reference to topographical or structural detail will be found sufficiently explained in that sketch.

DESCRIPTION OF ROCK.

Those rocks which are to be specially considered in the following pages occur principally as included fragments in the tufa beds, and were found in place only on the shoulder of the main peak which projects to the northeast.

This latter rock is compact, dark or almost black in color, showing minute glassy feldspars, which, by reason of their transparency, seem dark also. A careful examination shows a number of small, dark-green grains and prisms, which are undoubtedly pyroxene, and glistening ore particles. In the fresh state the base in which these minerals lie has a vitreous lustre.

The fragments found in the tufa vary in outward appearance. Part of them are as dark and compact as the one just described, while others are lighter colored, with more distinct crystals of feldspar and a somewhat porous groundmass. In the darker ones, the feldspars are in part of a clear yellowish tinge, producing a very deceptive resemblance to the partially decomposed olivine of basaltic rocks.

When examined under the microscope in ordinary light, these rocks seem to be typical augite-andesites of very simple composition; clear plagioclase crystals, pyroxene in small crystals and irregular grains, with magnetite and apatite, are the only mineral constituents to be recognized. These larger individuals lie in a groundmass composed of thin plates of plagioclase, light-green microlites of pyroxene, and minute octahedrons of magnetite, with a glass basis between them, which is usually clear, though sometimes devitrified by light-brownish globulites. In the rock occurring in place, the microlites are unusually large, while in the others they sink to extraordinarily minute needles.

PECULIARITIES OF THE PYROXENE.—Examined in polarized light, none of the elements, except the pyroxene, show noteworthy peculiarities. A study of the pyroxenic constituent forces one to the conclusion that *a rhombic mineral, probably hypersthene, is largely predominant, while a great number, if not all of the remaining individuals, must be considered as triclinic in crystallization.*

This conclusion is based on the following microscopical and chemical investigations:

In the first place, on testing under the microscope, in polarized light, all the prismatic sections and small prisms whose vertical axis seemed to lie in the plane of the thin section, with regard to their optical orientation, it was found that at least one-half, and generally a much larger proportion, possessed an axis of elasticity parallel to the vertical crystallographic axis. Now, the only section of a monoclinic mineral, in the prismatic zone, which could act in this manner, is plainly that parallel to the orthopinacoid. And any one who has tested the prismatic sections of augite or hornblende, in slides of massive rocks, knows how rarely a section can be found so nearly parallel to the orthopinacoid that no deviation of the direction of total extinction from the vertical crystallographic axis can be detected. The justifiable conclusion is therefore reached, that nearly all of the sections in question belong to a rhombic mineral.

In the next place, the sections apparently cut perpendicularly to the vertical axis present another remarkable deviation from the rule. While such sections should give no data for the separation of rhombic from monoclinic pyroxene, since in both the directions of extinction coincide with the diagonals of the prism, it is here found that in only a portion of the sections does this relation actually exist, and, further, the numerical ratio between those cross-sections with normal and those with abnormal optical relations is, in any given slide, nearly equal to the ratio between those prismatic sections showing the rhombic and those with deviating optical orientation. It is at once suggested that the cross-sections showing normal optical action belong to the same mineral which, in longitudinal sections, appears as rhombic, while the prismatic sections, which are seemingly normal augite, belong to the apparently triclinic mineral.

The rhombic mineral as shown by the chemical investigations (p. 29) must be considered as hypersthene. Its pleochroism, though distinct, is by no means strong. A section nearly or quite at right angles to the prism has a light greenish-yellow color, and the changes on revolving it through 90° are too slight to be expressed. In prismatic sections the hypersthene is pale-green in color when its vertical axis is perpendicular to the principal section of the nicol, and greenish-yellow when these directions are parallel. In the latter position there is sometimes a tinge of brown. The other pyroxene is not pleochroic to any noticeable degree. It is always of a pale-green color.

The cross-sections of hypersthene are very well defined. They show the characteristic eight-sided figures of pyroxene, with a distinct prismatic cleavage, and, quite subordinate in some of the sections, a cleavage parallel to the pinacoids. In most of the sections showing a rhombic character, the pinacoidal faces are predominant, the prism simply truncating the angles of the rectangle formed by the former faces.

The hypersthene does not show the prismatic cleavage in longitudinal sections so plainly as the triclinic mineral. The lines are finer, and cross-fissures are common. The terminations, too, are often quite regular, being doubtless caused by domes. (See Fig. 9, Plate II.) It is in the small crystals especially that the regular form of a rhombic mineral is most plain. In the dark and compact rocks there is less difference between these two minerals than in the lighter and porous ones. In the latter one finds some crystals of hypersthene, which are fibrous, with an incipient decomposition proceeding from the cross-fissures along the vertical cleavage planes. (See Fig. 8, Plate II.)

TRICLINIC PYROXENE.—Those cross-sections, showing an anomalous position of the axes of elasticity, are in many ways remarkable. The outlines are similar to those of monoclinic augite, being eight-sided figures, with a distinct cleavage parallel to what may be taken as the prism. The deviation of the angle of extinction from the normal one for monoclinic minerals is *not* constant. Very many of the crystals are apparent twins, and the twinning plane bisects the prism angle in all observed cases.

For convenience, it will be assumed that this plane is the macropinacoid, in accordance with the common law of augite. The divergence of the direction of total extinction from this assumed macrodiagonal is in most cases 20° to 25°, but cases are not rare of its exceeding this average up to 38° 30′ as observed maximum. It is more often above 25° than below 20°. It is not uncommon to find several angles of extinction indifferent portions of the same cross-section. This will be best understood by a reference to the figures of Plate II.

Plate II.—Fig. 1 represents a section with partially regular outline, and a cleavage most pronounced in two directions, cutting each other at an angle of nearly 90°. In ordinary light it seems like a simple section of pale augite. In polarized light it appears at first to be a trilling whose composition face is $\infty \bar{P} \infty$. On determining the direction of total extinction, the (in figure) upper and lower portions are found to agree with an angle of 27° 30′ from the assumed macrodiagonal. The central portion, however, has an angle of extinction of 10° 30′, cutting the macrodiagonal in corresponding direction with the preceding. Its relations to the other portions are, therefore, not those of a plate in true twinning position. Moreover, within the central portion, is a small irregular patch, with cleavage parallel to that of the rest, having a third angle of extinction, viz, 6° 30′, and also in the same general direction.

The phenomenon is hence to be regarded as an intergrowth of substances with common crystallographic, but differing optical orientation. The central portion shows brilliant colors of polarization in certain positions, while the other parts vary only in degrees of light and shade.

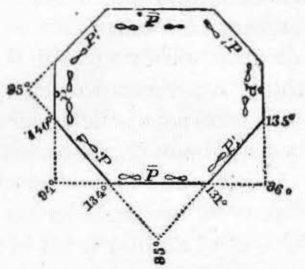
In Fig. 2, the extinction of several parts is, as indicated, with angles of 19° 30′ and 37°. In this case, however, the parts are related as in a trilling crystal, the direction of extinction of the central portion cutting the macrodiagonal in the manner necessary had there been a revolution of 180° about the normal to the macropinacoid. The parts with extinction of 19° 30′ polarize somewhat more intensely than the others.

Fig. 3 shows a crystal 0.16^{mm} in diameter, with twin structure, the angles of extinction being respectively 24° and 29° for the two halves. The former gives more brilliant colors in polarized light.

Many small sections are very similar to Fig. 4, with about the same angle of extinction. Fig. 6 represents an apparent intergrowth of rhombic and triclinic pyroxene. The rhombic character is not demonstrable of course, but it seems most probable, as the intergrowth of hypersthene and other pyroxene in prismatic sections is often visible. (See Fig. 5.) The hypersthene polarizes brightly, while the other mineral neither gives distinct colors nor becomes very dark in any position between crossed nicols, so that its nature cannot be determined.

Although measurements of crystal angles made on chance sections in a slide of a fine-grained rock cannot, from the nature of the case, be accurate, an attempt was made to determine approximately the chief angles of the prismatic zone of this questionable mineral. As far as could be judged the section of Fig. 1 was cut very nearly at right angles to the vertical axis, and its bounding planes were sharply defined. The angle *b* of upper right-hand quadrant was first determined. The mean of several measurements, taken in different ways, was almost exactly 140°. To obtain the angle *a*, a measurement from $\infty \breve{P} \infty$ to the plane of intergrowth was made, as $\infty \bar{P} \infty$ was not well defined; 134° was the result within a few minutes. The angle of the two pinacoids was next measured at 94°, which would be necessary for the two preceding determinations. The angle *a* was determined as a mean of several trials at 134° 47′, the prism angle between faces on right-hand of section = 95° (nearly).

A section of the prism of this mineral, at right-angles to the vertical axis, would therefore have the accompanying form:



The figures of the plate will be seen to have a very similar form. If the sections Figs. 2 and 3 were of normal twins, according to a pinacoid face, there should be a re-entering angle visible, in case the above measurements are correct. On some of the sections seen, this seemed to be actually the case, but they were too small and indistinct to admit of measurement.

In some of the cross-sections the cleavage is apparently better developed parallel to one of the prismatic directions than to the other; for example, see Fig. 1; but this difference is very slight, and no weight can be laid on it.

TRICLINIC PYROXENE IN OTHER ROCKS.

The writer has noticed, and briefly described, an apparent triclinic pyroxene in certain crystalline schists in Brittany.[1] The phenomenon was there less distinct than in the present case, and it was then thought probable that it was an anomalous optical action of the monoclinic augite, the cause of which was unknown. No twin structure or intergrowth was there noticed, and the divergence of the direction of extinction from the normal one was even more variable than in the case in hand. The material, too, was less favorable for accurate observation, yet the two instances are so similar that in all probability they are due to the same cause.

A third occurrence of this same phenomenon has been observed by the writer in a feldspar basalt from Grand River, above the Hot Springs, Middle Park, Colorado. Mr. S. F. Emmons, in passing through the Park, collected specimens of several basalts, and one of them shows, under the microscope, a pyroxene seeming in ordinary light typical of the normal augite of such rocks. It is not pleochroic to any describable degree. Its cross-sections are eight-sided figures, with a strongly marked cleavage. Fig. 7, Plate II, represents a cross-section of a twin

[1] W. Cross: "Studien über bretonische Gesteine." Min. und pet. Mittheilungen. G. Tschermak, (Neue Folge), III, p. 396.

crystal observed in this basalt. The angles of extinction for the two halves, 19° and 22° from twinning plane, are perhaps within the limits of possible error of observation in a section whose exact position cannot be determined. All other cross-sections show similar relations, but the angle of extinction varies from 18° to 33° from a diagonal of the prism. In longitudinal sections the action is normal.

The finding of pyroxene with such abnormal optical properties in three distinct rocks, from such widely separated localities, led naturally to the examination of the pyroxene in the common augite rocks, such as diabase, basalt, &c. The result of such examination is to show that even in well-known rocks a portion of the pyroxene does not exhibit in polarized light the properties required of a monoclinic mineral. In many cases, sections of the supposed augite, which, from all available data, seemed to be cut very nearly at right angles to the vertical axis of the crystal, were found to act abnormally between crossed nicols. A number of instances are given below, mainly from well-known European localities, where this abnormal action was noticed. In each of these rocks, at least one section of pyroxene was found, which, without examination in polarized light, would be considered, as determined by the following tests, to be a typical cross-section of augite. In the first place, if, in a given rock, the pyroxene was found to possess a prismatic development, an eight-sided figure with the proper angles was required. Parallel to two of these outlines there must be a very distinct cleavage, the angles formed by cleavage planes being measurable at very near 87° and 93°. By means of the micrometer screw, it could be shown in each case that the cleavage plane lay nearly or quite parallel to the axis of the microscope.

In each of the rocks mentioned below, a section of apparent augite, determined, as above, to be nearly or quite perpendicular to the vertical crystallographic axis, was found to extinguish light between crossed nicols at a very decided angle from the diagonals of the prism. In all cases cited, the section was clear, fresh, and free from all visible disturbing elements. In a few cases, where the maximum of darkness was not very distinct, the interference cross of the calcite plate and the most sensitive colors produced by the quartz plate were used in the determination.

The instances referred to are as follows:

1. *Diabase.*—Ilkendorf, near Nossen, Saxony.
2. *Diabase.*—Near Elbingerode, Hartz Mountains, Germany.
3. *Diabase.*—Burg in Nassau, Germany.
4. *Olivine-diabase.*—Björfvas, Dalarne, Sweden.
5. *Melaphyre.*—St. Wendel on the Nahe, Germany.
6. *Hornblende-andesite.*—Bolvershahn, Siebengebirge, Germany.
7. *Hornblende-andesite.*—Jakuben, near Tetschen, Bohemia.
8. "*Augite-andesite.*"—Mount Cotopaxi, Ecuador, South America.

9. "*Dolerite.*"—Löwenburg, Siebengebirge, Germany.
10. "*Dolerite.*"—The Meissner, Hessen, Germany.
11. *Feldspar-basalt.*—Bildstein, Vogelsberg, Germany.
12. *Feldspar-basalt.*—Holmestrand, Sweden.
13. *Nephelinite.*—Meiches, Vogelsberg, Germany.
14. *Feldspar-basalt lava.*—Mount Ætna, eruption of 1537.
15. *Nepheline-basalt.*—Robschitz, near Bilin, Bohemia.
16. *Nepheline-basalt.*—Herchenberg, Laacher See, Germany.
17. *Leucite-basalt.*—The Abtei, Laacher See, Germany.
18. *Leucite-basalt.*—Veitskopf, Laacher See, Germany.
19. *Leucite-basalt.*—Niedermendig, Laacher See, Germany.
20. *Haüyne-basalt.*—Cranzahl, Saxony.
21. *Leucite lava.*—Mount Vesuvius, old eruption.

In very many other cases the same behavior was noticed, but less decidedly. Especially in comparison with the hornblende of diorite, porphyrite, &c., is the abnormal behavior of pyroxene noticeable.

So far as is known to the writer, this abnormal action of supposed augite has never been dwelt upon, if indeed it has been noticed at all. None of the available material contains the questionable mineral, in size or perfection, suitable for isolation and crystallographic investigation; hence the correctness of the view here advanced, that it is triclinic, cannot be proven. The only other explanation possible is that of an "optical anomaly."

If this mineral be triclinic in crystallization, it is manifestly different from either Babingtonite or Szabóite, the only known triclinic pyroxenes, and forms a new species, whose chemical composition does not, in all probability, vary greatly from that of common augite. The variations in optical behavior suggest an analogy with the triclinic feldspars.

Whether the observed behavior be finally explained in accordance with the hypothesis here advocated or not, an interesting and important subject for further investigation is certainly indicated.

CHEMICAL COMPOSITION OF THE ROCK.

The rock selected for chemical analysis is that occurring in place on the northeast shoulder of the main Buffalo Peak. (Coll. No. 144.) For a description of its structure and constituents see page 19. The rock was very fresh, and the minerals recognized in it are plagioclase, two pyroxenes, magnetite, and a little apatite. Between these is a brownish glassy base.

The specific gravity was taken at a temperature of 16° C. The analysis was made by Mr. W. F. Hillebrand, chemist to the Rocky Mountain Division of the Survey.

Specific gravity	2.742	
SiO_2		56.190
Al_2O_3		16.117
Fe_2O_3		4.919
FeO		4.433
MnO		trace
CaO		6.996
BaO		trace
SrO		trace
MgO		4.601
Na_2O		2.961
K_2O		2.368
H_2O		1.028
P_2O_5		0.266
Cl		0.022
		99.901

There is but little in the analysis which requires special explanation. The percentage of K_2O is considerably larger than would be expected, as none of the larger crystals of feldspar can be considered as sanidine. The amount of P_2O_5 found, with the Cl, indicates that minute needles of apatite must be quite abundant in the groundmass, though but few can be recognized as such. BaO and SrO are seldom given in analyses of andesites—probably, in many cases, because they were not sought for.

ISOLATION AND ANALYSIS OF HYPERSTHENE.

In order to establish the identity of the pyroxene, which seemed from its optical behavior to be rhombic, an attempt was made to isolate the same for analysis. It is scarcely necessary to mention in this connection that the desire to compare the Buffalo Peaks rock with the hypersthene-bearing andesite of the volcano of Santorin in the Grecian archipelago led to the chemical investigations which follow; and it may be safely assumed that the chief results of the investigations of Fouqué on the Santorin lavas are known even to those to whom the final volume, with its wealth of minute observations and splendid illustrations, is not accessible.[2]

INVESTIGATIONS OF FOUQUÉ ON THE LAVAS OF SANTORIN.—Fouqué found that the lava of the eruption of 1866, which at first glance seemed a typical augite-andesite, contained in reality two pyroxenes, which he isolated and determined as normal augite and *hypersthene*. He also found hypersthene in older rocks of this same volcanic group. It is the first

[2] F. Fouqué, "Santorin, et ses éruptions", Paris, 1879.

instance where the presence of a rhombic pyroxene in "augite-andesite" has been chemically and optically proved beyond dispute.

As the so-called Thoulet solution of the iodide of mercury in the iodide of potassium was not available at the time the investigations were in progress, recourse was had to the method employed by Fouqué (*l. c.*, p. 190) in separating the iron-bearing minerals of the Santorin lavas from the other constituents.

METHOD USED IN ISOLATION OF HYPERSTHENE.—A specimen of the rock was crushed until all passed through a sieve containing sixty meshes to the inch. Only that portion of the powder was used which was retained by a sieve having eighty meshes to the inch, as uniformity in size of the grains acted upon by the acid is desirable, and the finer powder is objectionable on several accounts (see Fouqué, *l. c.*). The grains thus obtained were placed in a platinum dish, and treated with strong fluorhydric acid, which attacks first the feldspars and other substances free from or poor in iron. According to Fouqué, concentrated acid is best, in which case, in pouring the powder, little at a time, into the acid, there is a more or less violent ebullition without the application of external heat. On the ceasing of this ebullition it may be presumed that a large part, if not all, of the easily attacked minerals is dissolved. The action is stopped by dilution with water. If matter still remains which it is desired to remove, the water is poured off and the powder treated again with acid. In the present case the acid was not concentrated, and hence considerable heating was necessary. In all cases the powder should be rapidly stirred with a platinum spatule. On discontinuing the action of the acid, there is always more or less gelatinous silica deposited upon the remaining grains. This is removed by repeated washings and rubbing of the powder under water with the finger. The magnetite is then separated with a small magnet.

A specimen of the Buffalo Peaks rock (Coll. No. 144) of which the complete analysis was made, treated as above at different times, yielded a powder in which there were only a few white grains remaining. The acid did not seem to attack them very readily, and before they entirely disappeared a considerable portion of the pyroxene was also dissolved. The residue was finally obtained quite pure, and yielded upon analysis the results under I and II below. Fouqué found (*l. c.*, p. 195) that if the mixture of augite and hypersthene derived from the Santorin lava were further treated with fluorhydric acid, the augite was much more easily attacked, as it contained less iron, and that he could in this way finally obtain hypersthene with but little admixture of augite. In the present case the microscope showed a large amount of augite with the rhombic mineral, in the rock section, but the analysis shows the substance analyzed to have been nearly pure hypersthene; hence, it is presumable that the quantity of pyroxene which was dissolved in removing the white grains above referred to must have been chiefly augite. Microscopic examination of material left in Analysis I (which has been made since this was written), after the feldspar had disappeared, showed a decided admixture of augite with hypersthene; the augite was, however, removed by further treatment with acid.

Another specimen from the Buffalo Peaks, from a boulder in the tufa beds (Coll. No. 150), was treated in the same manner. This rock was chosen because the microscope showed a large amount of very pure rhombic pyroxene and but little augite. The powder obtained was examined with the microscope and found to be almost absolutely free from impurities. Its analysis is given under III.

MICROSCOPIC INVESTIGATION OF ISOLATED MATERIAL—The microscopic study of the isolated crystals and fragments shows clearly the rhombic nature of the mineral in question. The crystals obtained are often 0.3^{mm} in length, and 0.15^{mm} in thickness. In all those suspected of being rhombic, the pleochroism is much stronger than has been described for the sections observed in the slide. (See p. 21.) The changes in color are from a dark reddish-brown to a very distinct green, instead of from greenish-yellow to pale green. Every such prism extinguishes light, parallel to the vertical axis. The grains of augite are more of a bottle-green color, and only very faintly pleochroic. In the material obtained from specimen (Coll. No. 150) affording III, probably not more than one per cent. of the grains are augite. Many prisms are quite perfect, and it would not be at all difficult to isolate a large number of little crystals of almost the exact appearance of those reproduced by Fouqué in Plate LX, Fig. 2, of his previously cited work. The crystals in the Buffalo Peaks rock are usually stouter than most of those pictured by Fouqué, but are quite as regular in form. Fig. 9 of Plate II shows a crystal from the thin section of the rock which furnished the material for Analysis III.

ANALYTICAL TABLE.—For comparison, the composition obtained by Fouqué for the hypersthene of the Santorin lava of 1866 is given under IV; under V the analysis of the "augite" from the "augit-andesit" of the highest peak of the "Sierra de Mariveles" in the island of Luzon, given by Oebbeke;[3] and under VI, the analysis by Damour of the well-known hypersthene from St. Paul's Island, on the coast of Labrador, as given by Dana.[4]

The isolation of the hypersthene, and Analyses III and III, were carried out by Mr Hillebrand.

[3] K. Oebbeke, Neues Jahrbuch, etc., I Beilage Band., p. 451 (1881).

[4] J. D. Dana. A System of Mineralogy, fifth edition, p. 210.

ANALYSES.

	I.—Buffalo Peaks.	II.—Buffalo Peaks.	III.—Buffalo Peaks.	IV.—Santorin.	V.—Luzon.	VI.—Saint Paul's.
Sp. Gr.	....	....	3.307	3.477	....	....
SiO_2	51.703	51.157	50.043	50.12	51.50	51.36
Al_2O_3	1.720	2.154	2.906	2.12	3.80	0.37
Fe_2O_3	0.304	....	....	1.C0	2.80	....
FeO	17.995	18.360	17.812	23.59	10.66	21.27
MnO	0.363	0.363	0.120	....	0.75	1.32
CaO	2.873	3.812	6.696	10.49	10.45	3.09
MgO	25.091	24.251	21.744	11.05	19.69	21.31
Na_2O	....	....	0.274	0.67	....	....
	100.049	100.097	99.595	99.64	99.65	98.72

The specific gravity of III was taken at 23° C.

DISCUSSION OF ANALYSIS.—In I and II the alkalies were not tested for, and in II and III all the iron is given as FeO, because the special determination of the protoxide was not successful. The amount of Fe_2O_3 present, is in all probability about the same as in I. The amount of iron derived from grains of magnetite included in the pyroxenes of II and III is small. The crystals are unusually free from inclusions of all kinds. The M_nO of II is taken from I, and is undoubtedly very nearly correct, the portions analyzed being derived from the same rock. In III is included a small amount of feldspar attached to hypersthene grains, and which could not be dissolved without losing too much of the latter mineral.

On comparing II and III with the other analyses of the table, it is clear that they are much nearer to typical hypersthene (VI) in composition than the rhombic mineral of the Santorin lava, whose identity with hypersthene has been recently admitted, even by Rosenbusch,[5] who had at first expressed doubts upon the subject.[6] The varying quantities of CaO in I, II, III, and IV may indicate that the simple silicate, $CaSiO_3$, enters more largely into the composition of rhombic pyroxene, as occurring in rocks, than has heretofore been supposed.

The only instance since the work of Fouqué, known to the writer, where the pleochroic pyroxene of an "augite-andesite" has been isolated and examined with regard to its crystal system, is in the case of the rock from the Sierra de Mariveles, which was investigated by Oebbeke (*l. c.*), and which gave Schwager the composition V of the table. Oebbeke finally pronounces the mineral to be augite and not hypersthene. In this case, as in those mentioned later (p. 34), the grounds given for the determination are by no means satisfactory. The only *evidence* given by Oebbeke in favor of the monoclinic system is the following:

[5] Review of Fouqué's work on Santorin, in Neues Jahrbuch, etc., 1880, II, p. 310.
[6] Rosenbusch, Massige Gesteine, p. 418.

He examined a few of the isolated pleochroic prisms by attaching them singly to a piece of wax in such a manner that he could test the direction of extinction parallel to each face of the prismatic zone, and in each crystal examined he found oblique extinction in some position. The writer found, on examining the material which furnished Analysis III, that many pleochroic prisms did not give definitely an extinction parallel to the vertical axis when lying loosely on an object glass in air; but that the same grains mounted in balsam were much more clear and distinct in their optical behavior, and always in favor of the rhombic system. In the case of such tiny grains, especially when obtained by the crushing of rock to powder, the examination of optical properties in the air is very unsatisfactory. The reflection of light from uneven surfaces, the disturbing influence of fissures, of included substances, &c., all tend to make the optical examination of minute particles in air unreliable. If mounted in balsam, the liability to error is much less.

The substance which yielded the composition V was isolated by means of the Thoulet solution, and would represent a mixture of rhombic and monoclinic pyroxenes, were both present in the rock. The figures of V are certainly abnormal for any augite known to occur as a rock constituent, but are easily explained on the supposition of a mixture of augite with a bronzite or hypersthene.

CHAPTER II.

RHOMBIC PYROXENE IN OTHER ANDESITES.

The resemblance of the Buffalo Peaks rock to that variety of augite-andesite which has always been regarded as most typical, naturally demanded that all available examples of the latter should be examined in regard to the character of the pyroxenic constituent. The particular variety referred to is that characterized by a glassy base, often brownish in color, in which lie a multitude of minute microlites of plagioclase and pyroxene, with magnetite grains. The same minerals occur in porphyritic individuals, though by no means so prominently as in other varieties of andesite. Hornblende and biotite are often entirely wanting and are rarely abundant. Olivine appears occasionally. This variety is especially abundant in Hungary, Transylvania, and Servia.

As many of the rocks examined come from well-known European localities, the observations in each particular case will be concisely given. Unfortunately, only their sections, without hand specimens, were available.[7]

In each section the attempt was made to observe and record the direction of total extinction in every prismatic section of pyroxene of sufficient size to allow exact determination.

TABULATED RESULT OF OBSERVATIONS ON AUGITE-ANDESITES.—The ratio of prismatic sections with rhombic, to those with monoclinic optical orientation, was found to be in the rock from:

(1) Bohunitz, near Schemnitz, in Hungary	as 8: 2
(2) Podhrad, near Schemnitz, in Hungary	as 15: 5
(3) Bagonya, near Schemnitz, in Hungary	as 13: 6
(4) "Gönczer Thal," near Schemnitz, in Hungary	as 21: 1
(5) Ober Fernezely, northeast from Nagy-Banya, Hungary	as 15: 2
(6) Roszaj-Ingnies, northeast from Nagy-Banya, Hungary	as 8: 5
[8](7) Southeast of Rank, Abanjer Comitat, Hungary	as 47:11
[8](8) Magos Ter, Abanjer Comitat, Hungary	as 43:17
[8](9) Between Tuhrina and Czervenicza, Saroser Comitat, Hungary	as 24: 6

[7] For Nos. 1, 2, 3, 4, 5, 6, and 13, the writer is indebted to Prof. F. Zirkel, of Leipzig. Nos. 10, 11, and 12 are contained in the "Sammlung No. 6, von typischen vulkanischen Gesteinen aus Ungarn und Serbien," prepared and sold by R. Fuess, in Berlin. The material is said to have been selected and described by Prof. J. Szabó, in Budapest.

[8] Nos. 7, 8, and 9 are rocks sent by the "K. K. geologischen Reichsanstalt" of Austria to the United States Geological Survey of the Fortieth Parallel, and were kindly

(10) Tokajer Berg, Northeastern Hungary..........	None distinctly monoclinic could be found.
(11) Lorinczi, Mátra Gebirge, Central Hungary......	
(12) Borač, Southern Servia..........................	
(13) Mount Cotopaxi, Ecuador, South America.............	as 10 : 5

DISCUSSION OF TABLE.—In Nos. 4, 5, and 6, only the larger sections were counted. There are many of about 0.4^{mm} to 0.5^{mm} in length, all of which extinguish light parallel to the vertical axis.

The few sections in which the optical behavior was not distinct were neglected.

The microlites of pyroxene, in cases where they could be tested, seemed for the most part to be monoclinic, but the determination was seldom satisfactory.

It appears, therefore, that in all those cases mentioned above, a rhombic pyroxene is much more abundant in porphyritic individuals than augite. For it cannot be supposed that such constant results could be obtained through mere chance. It is true that sections of augite parallel to the orthopinacoid are not to be distinguished optically from rhombic pyroxene, but it is not possible to explain the above figures in that way.

The same difference in appearance between the two pyroxenes is to be noticed in the above rocks which was described in the case of the Buffalo Peaks andesite. The rhombic mineral is pleochroic in the same manner (p. 21), while the monoclinic is not noticeably so. There is also a difference in development. The rhombic pyroxene, which, through analogy with the cases described, will be hereafter designated as hypersthene, is better developed than the augite. Its crystals show terminations as if from domes quite frequently, and its cross-sections are sharper, being chiefly bounded by pinacoidal outlines. The augite grains are much more irregular as a rule, and contain glass and magnetite inclusions in greater abundance than the hypersthene crystals. An apparent intergrowth of the two was not unfrequently noticed, as in the rocks from Bohunitz and Roszaj-Ingnies.

AUGITE-ANDESITES OF THE 40TH PARALLEL.—Through the courtesy of Mr. Arnold Hague the slides of the andesitic rocks collected during the geological exploration of the Fortieth Parallel, and which have been described by Prof. F. Zirkel,[9] were placed at the disposal of the writer. The results obtained from the examination of these slides agree fully with what has been stated concerning the European rocks. In all but two of those rocks described by Professor Zirkel as "augite-andesites" a very large part of the pyroxene seems identical

loaned to the writer by Mr. Arnold Hague, United States Geologist, the custodian of the collections belonging to the Fortieth Parallel Survey. The rocks bear respectively the numbers 24, 25, and 19 of the Austrian Survey, and are labeled "Grauer Trachyt, Richthof." They are all typical rocks, in fresh condition, of the class under discussion.

[9] F. Zirkel, Microscopical Petrography. Washington, 1876, p. 221.

with that which is regarded as probable hypersthene in the above rocks. The two exceptions (Mic. Nos. 514 and 515) are basaltic in habitus and carry olivine.

PREVIOUS OBSERVATIONS OF RHOMBIC PYROXENE IN AUGITE-ANDESITES.

HISTORICAL.—The number of instances known to the writer where the presence of rhombic pyroxene in "augite-andesites" has been at all emphasized is extremely small. J. Niedzwiedski[10] described in 1872 a rock from St. Egidi, in Steiermark, as "Hypersthen-Andesit." In 1877 this rock is mentioned by Rosenbusch[11] as the single rock known which can bear that name. In 1880 E. Hussak[12] pronounced it an ordinary augite-andesite, and, so far as the writer is aware, his verdict has not been questioned. Reference will again be made to this case later.

The occurrence of rhombic pyroxene even as an accessory constituent of augite-andesites has been but rarely announced.

R. von Drasche[13] has mentioned bastite as occurring in augite-andesite from Videna, in Steiermark.

Rosenbusch[14] at the time of issuing his often cited work (1877), while not denying that a rhombic pyroxene may occur in augite-andesites, is still inclined to consider those pleochroic prismatic sections of pyroxene in which light is extinguished parallel to the vertical axis, as chance sections of augite parallel to the ortho-pinacoid. It is in great measure owing to this judgment, no doubt, and to the undoubted presence of pleochroic augite in recent rocks, that many observers have seemed to dismiss all thoughts of rhombic pyroxene if in the same slide with pleochroic sections, such as have been described, normal augite with its oblique extinction could be found. Thus, E. Hussak (*l. c.*) disposes of the hypersthene andesite of Niedzwiedski with the simple assertion that the pyroxene is monoclinic, because he has found apparent prismatic sections in which extinction took place at more than 30° from the vertical axis. Inasmuch as he had previously confirmed the statements of von Drasche[15], it seems highly probable that augite is not specially abundant in this andesite.

[10] J. Niedzwiedski, Tschermak's Min. und pet., Mittheilungen, IV, 1872, p. 253.

[11] H. Rosenbusch, Massige Gesteine, p. 480.

[12] E. Hussak, Neues Jahrbuch für Mineralogie, etc., 1880, I. p. 289.

[13] R. von Drasche, Tschermak's Min. und pet. Mitth., 1873, V. p. 1.

[14] H. Rosenbusch, Massige Gesteine, p. 411.

[15] E. Hussak, Verhandl. d. k. k. Geol., Reichsanstalt, Vienna, 1878, p. 338.

Hussak[16] has also published the results of microscopic investigations on the eruptive rocks of the region about Schemnitz, in Hungary. While the rocks of this district have been frequently studied by eminent investigators, such as Zirkel, vom Rath, and Doelter, the publication of Hussak is here considered as the most recent known to the writer. Augite-andesite, of the type especially under consideration, is very abundant near Schemnitz. Hussak mentions a large number of occurrences, among them those of Bohunitz and Podhrad, and the great similarity of most of them is evident. The pyroxenic constituent is always called augite, although some of it extinguishes light parallel to the vertical axis. Decomposition products resembling bastite were also noticed. The pleochroism is quite strong and the pinacoids are markedly predominant. The angle of extinction in two cases is given as 47° and 48°.

The general description given by Hussak corresponds closely to that required by the two slides in possession of the writer, from Podhrad and Bohunitz, except that no allowance is made for two species of pyroxene.

The short description accompanying the slides of the Fuess collection (see p. 31) mentions no other pyroxene than augite, even in those cases where every prismatic section seems to be rhombic.

The determination of hypersthene in the lavas of Santorin, and the statements of Oebbeke concerning the pyroxene in the "augite-andesites" of the Philippine Islands, have already been cited. (p. 29.)

In all other descriptions of or references to augite-andesite of the chief type which have come under the observation of the writer, it is impossible to obtain satisfactory data concerning the pyroxene. In nearly all of them, however, the pleochroism and predominance of the pinacoids are dwelt upon, which, in the light of the present investigation, justifies the suspicion that rhombic pyroxene is not wanting. Two instances will be given where the existing descriptions of "augite-andesites" suggest the identity of the supposed "augite" with the rhombic pyroxene of the rocks here described.

Rosenbusch[17] mentions that the augite of the "augite-andesites" from Chimborazo and Tunguragua, in the Andes of South America, is strongly pleochroic. Artopé[18] has given analyses of several augite-andesites from the Andes, among them being two from Tunguragua. One of these shows nearly 6 per cent. MgO, while in two other cases nearly 4 per cent. MgO is given. The augite-andesite from Cotopaxi, examined by the writer, showed 10 apparently rhombic pyroxenes to 5 monoclinic.

Again, Cohen[19] describes the porphyritic augite crystals of two Ha-

---

[16] E. Hussak, Sitzungsbericht d. k. Akad. d. Wiss., Vienna, July, 1880, p. 164.

[17] Rosenbusch, Massige Gesteine, p. 420.

[18] Artopé, "Über augithaltige Trachyte der Anden," 1872. Göttingen.

[19] E. Cohen, "Über Laven von Hawaii," etc., Neues Jahrbuch, etc., 1880, II, pp. 38 and 54.

waiian andesites as "*kräftig pleochroitisch*" in the same manner shown in the Buffalo Peaks hypersthene, while the microlites in the groundmass do not seem to be so. Also, the augite of an "*Augitandesitbimstein*" found between New Britain and New Ireland, in the South Pacific Ocean, is strongly pleochroic in the same manner.

RHOMBIC PYROXENE IN DIABASIC ROCKS.

The possibility that a rhombic pyroxene may occur in some augite-andesites has been admitted by Rosenbusch,[20] who, while denying that the pleochroic pyroxene, so common in augite-andesites, is rhombic, expresses a belief that the final discovery of a rhombic pyroxene in a subgroup of the augite-andesites is even highly probable. This probability arises out of analogy with the diabase-porphyrites of the left bank of the Lower Rhine, which contain enstatite. It is interesting and significant that this analogy is borne out in Colorado.

ENSTATITE-BEARING DIABASE FROM COLORADO.—At Morrison, near Denver, there is in the Archæan gneiss a narrow dike of a dark aphanitic rock. Under the microscope this rock is seen to consist chiefly of narrow prisms of plagioclase and a colorless pyroxene. The angular spaces between these are filled in part with a colorless anisotropic mineral, which may be orthoclase, and with a dark groundmass. The ore is apparently magnetite, and is almost exclusively confined to the groundmass, where it occurs in regular aggregations, and seldom in single grains. These aggregations seem often like devitrification products, and a glass base is in places to be identified. The pyroxene occurs chiefly in prisms of about 1^{mm} in length by 0.2^{mm} in thickness. All such individuals are colorless, have numerous cross-fissures, and extinguish light when the vertical axis is parallel to the principal section of one of the crossed nicols. The cross-sections show a dominant development of the pinacoids. The cleavage is most pronounced parallel to the prism, but there are many irregular fissures, and some parallel to the pinacoids.

The absolute identity of this mineral with enstatite has not been proven, but there seems to be no good reason for doubting it. The remaining pyroxene is in smaller prisms and has a very slight pinkish color. Nearly all of these prisms have an angle of extinction exceeding 30°, and they belong undoubtedly to augite.

The age of this rock cannot be determined, but it has throughout the habitus of a Pre-Tertiary eruptive.

RHOMBIC PYROXENE IN HORNBLENDE-ANDESITE.

The presence of a rhombic pyroxene in the hornblende-biotite-andesites has been seldom announced.

[20] Rosenbusch, Massige Gesteine, p. 411.

Rosenbusch[20] found it in one dacite; Lagorio[21] found pyroxene in certain andesites of the Caucasus which acted optically like a rhombic mineral, yet he does not pronounce it such.

In the hornblende-andesite from Buffalo Peaks, pyroxene, wholly analogous to that of the hypersthene-andesite, is quite abundant. In the tufas of the same locality hypersthene is often associated with hornblende and biotite.

A slide in the possession of the writer, from Moisar (Mocsar?), in Hungary, shows hornblende, biotite, and apparent hypersthene. The groundmass of this rock is much less prominent than in the typical "augite-andesites," yet seems to be essentially of the same character, and the occurrence may represent a transition form.

The Fuess collection (see note, p. 29) contains two beautiful hyaline andesites from Gorni Milanovatz, and Slatni, in Central Servia, in which the pyroxene seems to be rhombic, with scarcely an exception. Hornblende and biotite are abundant in the same. On the other hand, the pyroxene in the andesite from Jakuben, near Tetschen, in northern Bohemia, though strongly pleochroic, is still unmistakeably augite. The pleochroism of this augite is, however, very different from that which is characteristic of andesitic hypersthene. Augite, sometimes faintly pleochroic, can often be found in andesites and trachytes of the Siebengebirge, the Auvergne, and other districts, but in these cases sections with rhombic optical action are very rare and cannot be considered as indicating a rhombic mineral.

CLASSIFICATION OF ANDESITIC ROCKS.

NEED OF A RECLASSIFICATION.—The group of the andesites, including all Tertiary eruptive rocks with plagioclase and one or more of the minerals hornblende, biotite, or pyroxene as essential constituents, is more in need of a natural subdivision than any other in the category of modern petrography. This statement will hardly be disputed.

The division into hornblende and augite-andesites has often been assailed, with justice, on the ground that very many rocks contain hornblende and augite in about equal quantity, making the transition stage of as frequent occurrence as either of the extremes. On the other hand, the division of the augite-andesites has been justly defended, by pointing to the "original," or the typical rock, in which hornblende and biotite seldom play any other than a very subordinate part, and which has been

[20] Rosenbusch, Massige Gesteine, p. 300.

[21] A. Lagorio, "Die Andesite des Kaukasus," Dorpat, 1878, p. 18.

found in widely separated parts of the world, with a truly remarkable persistence of characteristics.

A glance at the rocks which, according to the prevailing principles of classification, must be called augite-andesites, shows three subdivisions. At one extreme are those rocks upon whose characteristics the objections to the prevalent classification are grounded. These occurrences, united with the great majority of hornblende-biotite-andesites are usually characterized by a trachytic habitus. In these, feldspar is by far the dominant element, and often sanidin forms an important part of it. The structure of the groundmass is prevailingly much more crystalline than in the so-called augite-andesites proper, and plagioclase is especially abundant in it. Quartz or tridymite is often present.

At the other extreme are the rocks, comparatively few in number, which, though possessing the basaltic habitus, are still strictly andesites through the absence or rarity of olivine. As examples of this class may be cited numerous rocks of the Auvergne described by von Lasaulx,[22] and the rock from the Löwenburg in the Siebengebirge, commonly called "dolerite," but classified by Rosenbusch[23] with the augite-andesites. Between these are the normal "augite-andesites."

Chemically considered, the andesites with trachytic habitus are somewhat different from the normal augite-andesite. The percentage of silica is noticeably higher. Thus Lagorio[24] states concerning the andesites of the Caucasus that they vary in amount of silica from 61.33 to 77.40 per cent. Doelter[25] gives the variation in quartz-bearing andesites of Transylvania and Hungary as from 57 to 69 per cent. The typical augite-andesites seldom contain more than 60 per cent. silica, and the average runs quite constantly between 56 and 58 per cent.[26]

The separation of the normal augite-andesites from those with trachytic habitus has often been justified by their geognostic relations. Near Schemnitz, in Hungary, where both types are abundantly represented, the augite-andesites proper were long ago distinguished as "*trachytes semivitreux*" by Bendant. Von Andrian states as a result of the geological survey of the region in 1865, speaking of the "*jüngere andesite*," that "*Übergänge in den (amphibol-) andesit lassen sich auch da, wo beide neben einander vorkommen, nicht nachweisen.*" (Cited as above by Hussak (*l. c.*).) In many other places the normal augite-andesite has been distinguished from the "trachytic" variety, as younger.

[22] A. v. Lasaulx, Neues Jahrbuck für Min., etc., 1870, p. 693, and 1871, p. 673.

[23] Rosenbusch, Massige Gesteine, p. 416.

[24] A. Lagorio, "Die Andesite des Kaukasus," Dorpat, 1878, p. 13.

[25] C. Doelter, Tschermak's Min. und pet. Mitth, V. 1873, p. 51.

[26] F. Zirkel, Mic. Pet. of 40th Par., p. 222; also the well-known tables compiled by J. Roth.

RESULTS.

1. An apparently typical augite-andesite from the Buffalo Peaks is found to contain *hypersthene* as its chief pyroxenic constituent.

2. The remaining pyroxene of this rock must, from its optical behavior, be considered either as *triclinic* in crystallization, or as augite with anomalous action through some unexplained cause. The occurrence of apparent twins and of intergrowth with hypersthene render the *former* explanation most plausible. Pyroxene with similar behavior was found in many well-known augitic rocks.

3. In all so-called "augite-andesites" of the truly typical character which are accessible to the writer, twenty-eight in number, the greater part of the pyroxene corresponds optically and structurally to the hypersthene of the Buffalo Peaks rock.

4. There is nothing in the current description of the "augite-andesites" referred to, which can be regarded as *positive* evidence that hypersthene is not abundant in them.

5. In all so-called "hornblende-andesites" with a structure similar to that of the typical "augite-andesites" which were examined, some fifteen in number, the same apparent hypersthene is more or less abundant.

6. The pyroxene of those andesites with "trachytic habitus" seems to be normal augite.

7. The conclusion is that the chief subdivision of the augite-andesites may much more properly be called *hypersthene-andesite*. To this latter group are to be added certain rocks containing hypersthene, which have been classed with the hornblende-andesites. A separation of the remaining andesites into augite and hornblende-biotite bearing groups does not appear justifiable.

It does not seem probable that future investigations will show the occurrence of hypersthene to be so closely connected with a certain structural form as is indicated by the preceding observations. If, however, it should prove to be the case, the group of the hypersthene-andesites will be one of the best defined in petrography.

It is hoped that the correctness or falsity of the above conclusion will be speedily settled by other determinations of the nature of the pyroxene in the so-called augite-andesites.

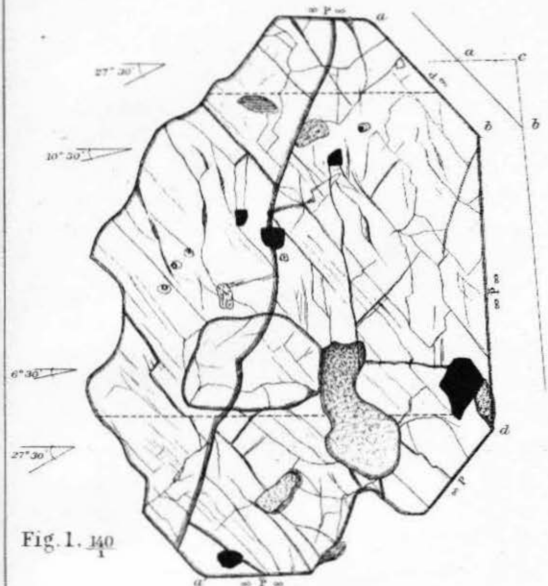


Fig. 1. $\frac{140}{1}$

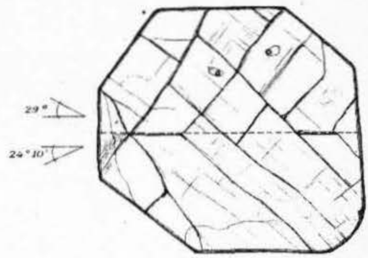


Fig. 3. $\frac{195}{1}$

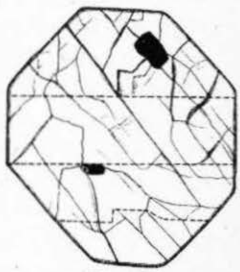


Fig. 6. $\frac{43}{1}$

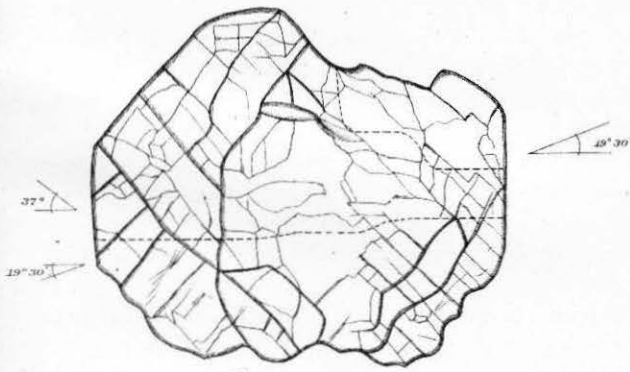


Fig. 2. $\frac{140}{1}$

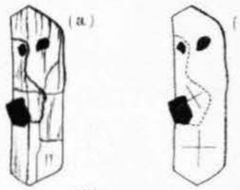


Fig. 5. $\frac{140}{1}$

Fig. 4. $\frac{140}{1}$

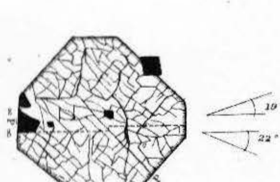


Fig. 7. $\frac{42}{1}$

Fig. 8. $\frac{43}{1}$

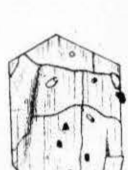


Fig. 9. $\frac{43}{1}$

Julius Bien & Co. lith. N.Y.

INDEX.

○

NOTICE.

The bulletins of the United States Geological Survey will be numbered in a continuous series and will be bound in volumes of convenient size.

This bulletin will be included in Volume I.