Art. XXXVII.—*The Igneous Geology of Carrizo Mountain, Arizona;** by Wilson B. Emery.

During the Summer and Fall of 1913, while employed as a field assistant by the United States Geological Survey, the writer had the opportunity of carrying on, under the direction of Professor Herbert E. Gregory, the first detailed geologic investigation ever made of Carrizo Mountain, Arizona. Reconnaissance studies had been previously made by W. H. Holmes in 1875† and in 1909 by Professor Gregory in connection with his work on the Navajo Reservation.‡ During his brief sojourn in the area Professor Gregory noted the main features of the geology and it was because he thought them of sufficient importance to repay detailed examination that the work during the season of 1913 was undertaken by the writer. The results of these studies, in so far as they concern the igneous geology, are here briefly presented.§

Location.

Carrizo Mountain is located on the Navajo Indian Reservation in the extreme northeastern corner of Arizona. The area of which it is the central feature, and which is discussed in this paper, lies for the most part within Arizona (see map, fig. 1), but embraces also a strip of country about three miles wide across the border in New Mexico. Rising as it does 2000 to 3000 feet above the surrounding plain (fig. 2), "an igneous island in a sedimentary sea," Carrizo Mountain forms a prominent landmark visible for miles in every direction, except to the south where the view is interrupted by the Boundary Mountains.

General Features of the Igneous Geology.

The evidences of igneous activity are now preserved in the Carrizo district in the form of various intrusive bodies, sheets, sills, dikes, and the main large intrusion, a laccolith. It is inferred, however, from the presence of a series of six volcanic plugs just southeast of the mountain that igneous activity was not confined to intrusion but manifested itself as well in extru-

* Published by permission of the Director of the U. S. Geol. Survey.

† Holmes, W. H., U. S. Geol. and Geog. Survey Terr., embracing Colorado and parts of Adjacent Territory, 1877, pp. 274–276.

‡ Prof. Paper, U. S. Geol. Survey, in preparation.

§ The results of the entire investigation, embodied in a report, constitute the thesis submitted as partial fulfilment of the requirements for the degree of Doctor of Philosophy at Yale University.

Fig. 1.

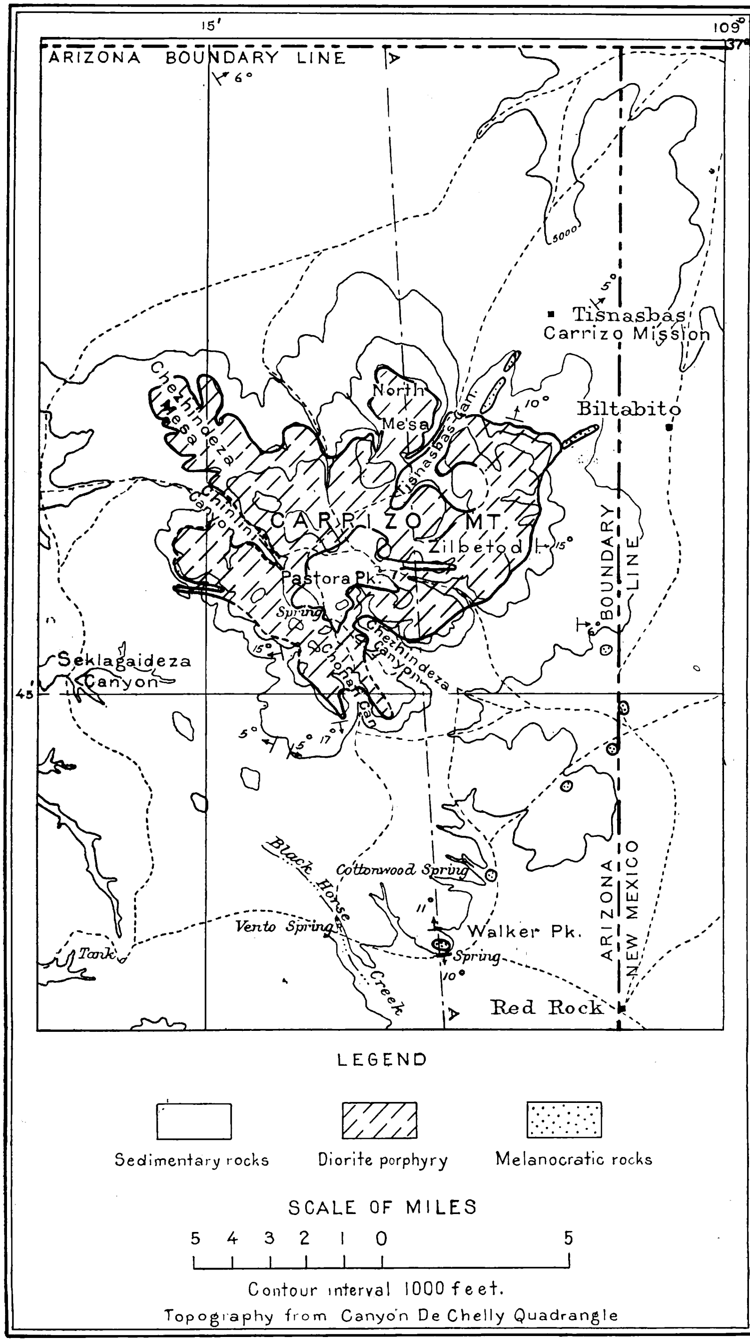

Fig. 1. Geologic map of the Carrizo area.

sion, though all evidence of possible outflows has been completely removed by erosion. The relation of the igneous rock and the surrounding sedimentary beds which range from Triassic to Upper Cretaceous in age is shown on the accompanying map (fig. 1).

Major intrusion.—The major intrusion which has produced the marked upturning of the surrounding sedimentary beds is only poorly exposed. There are a number of large outcrops but they are isolated and not traceable, the one into the other, because of the covering of sediments. Consequently the nature of the intrusion is with difficulty ascertained. Indeed, from the appearance of the outcrops, which are in many places very steep-walled, it would seem that there was not one large intrusion but several smaller ones which had united to produce a single result,—domal uplift. There is no reason to doubt that whether of one large intrusion or several smaller ones, the outcrops represent a single period of igneous activity, and that the magma came from one common reservoir.

Sills and sheets.—On the north of the mountain and dipping from it at an angle of about 15° is an intrusion of sill-like form entirely confined within the base of the Upper Jurassic (?) sediments. This sill, which has been called the Tisnasbas sill, from the canyon of that name where it is best exposed, is somewhat thicker at its innermost margin, where it is seen in connection with

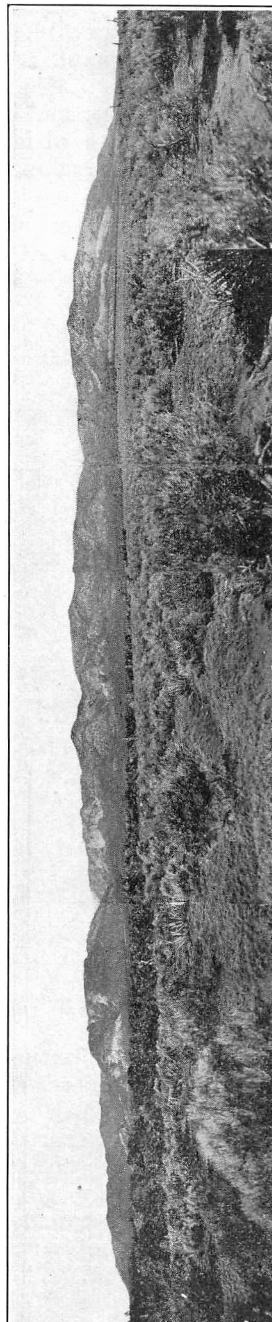

FIG. 2. View of east side of Carrizo Mountain.

its source of supply, than at its outer edge, so that it might be considered a flat laccolith. However, as it is only 300 feet thick at its deepest point, it has been deemed best to call it a sill.

West of North Mesa and between it and Chezhindeza Mesa, there is exposed a mass of igneous material having exactly the same relations to the enclosing beds as the Tisnasbas sill. It is

FIG. 3.

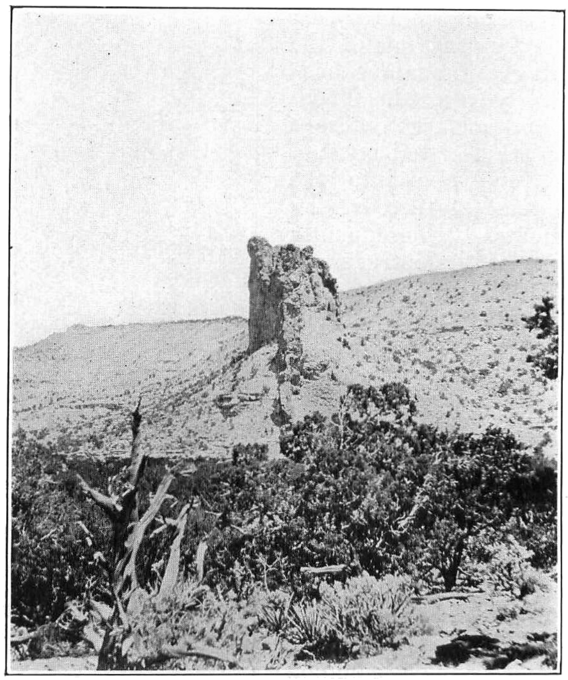

FIG. 3. Holmes Dike.

possible that this is an entirely separate intrusion, but because of the very similar character it is thought to be a portion of the Tisnasbas sill, though the connection is not visible due to the overlying mass of North Mesa.

Intrusive sheets cap both North and Chezhindeza mesas and overlie unconformably sediments of Upper Jurassic (?) age. The sheets evidently are offshoots from the main intrusion and between them and the Tisnasbas sill and its extension the sediments are pinched out. This was noted by Holmes, who says:

"It does not appear to me that the beds of sandstone that occur between the inner mass and the flexed sheets are of uniform thickness. Between the capping of the North Mesa and the inner mass the sandstones are nearly pinched out. They are so obscured by debris that I could not determine their exact relation."*

Dikes.—The few dikes seen in the Carrizo area, with the exception of that forming Zilbetod peak, are arranged about

FIG. 4.

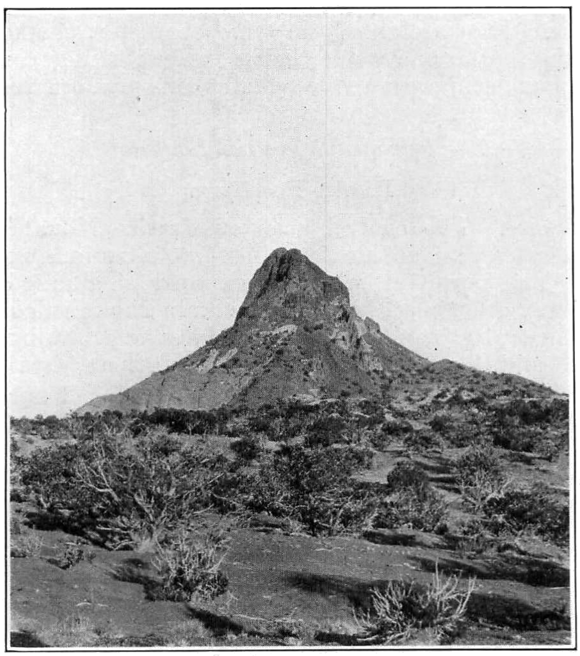

FIG. 4. Walker Peak, a volcanic neck.

the periphery of the intrusions. Of these, Holmes dike, near the mouth of Tisnasbas Canyon, is among the most prominent. It rises about 200 feet above the creek bed and when seen end on, as in fig. 3, where its continuation northward is not evident, has the appearance of a volcanic plug. Another large dike trends outward from the mountain in the direction of Biltabito store. Other smaller dikes are present both east and west of the mountain and each volcanic plug has an encircling

* Holmes, W. H., op. cit., p. 275.

group of radiating dikes. In these dikes the rock is soft yet more resistant to erosion than the enclosing sedimentary beds, so that in every case the dike stands up as a wall of greater or less height.

Volcanic plugs.—A series of six volcanic plugs is exposed southeast of Carrizo Mountain. When these are joined together they are seen to be arranged on a very flat reversed curve about 20 miles long. Such linear arrangement suggests the presence of a fault as a line of weakness favorable for intrusion, but no movement of that character was recognized. These plugs are rather prominent features of the landscape, standing out dark against the red or light-colored sandstones at their base. They are all of the same character, Walker Peak (fig. 4), the southernmost one, being typical, rising conical at the base but terminated above by cliffs 100 or more feet high.

The Petrography of the Intrusions.

Diorite Porphyry.

Occurrence.—The central mass of Carrizo Mountain is of diorite porphyry, as are also the sheet-like intrusions associated with it. The porphyry, which is exposed in all the canyons and in many other places on the mountain summits, covers an area of over 100 square miles. Holmes, in speaking of the intrusions and the mountain resulting from them, says

"It is a typical example of the eruptive groups of this part of the Colorado plateau . . . . . It has a nucleus of its own, and so far as the surface is concerned is independent of all other eruptive masses. . . . . . The trachytes [diorite porphyry of this report] are now found chiefly in contact with the Lower Cretaceous [now referred to the Jurassic] and Jura-Trias rocks, for the reason that the Middle Cretaceous shales, in which a large part of the trachyte was originally deposited, have been completely carried away, leaving only small fragments imbedded in the faces and upper surfaces of the trachyte."*

Macroscopic description.—In the hand specimen the diorite porphyry shows an abundance of plagioclase phenocrysts and less numerous prisms of hornblende set in a white to grayish, aphanitic groundmass. Quartz phenocrysts are not uncommon. With regard to the megascopic character of the rock Holmes says:

"A specimen of trachyte from West Mesa is found to resemble closely in appearance and composition the trachyte of the other groups of the southwest. It has a bluish white paste, which con-

*Holmes, W. H., U. S. Geol. and Geog. Survey Terr., embracing parts of Colorado and adjacent territory, 1875, p. 274.

tains the following minerals porphyritically embedded : fine crystals of translucent oligoclase, minute crystals of sanidite, frequently associated with the oligoclase, small crystals of biotite (rare), and a few small enclosures of quartz."*

Cross later studied the very specimens collected by Holmes, of which he says :

"Three specimens from the Carrizo Mountains, collected by Holmes, have been examined by the writer. They are all hornblende-porphyrites, almost identical in character with those of the El Late group. There are abundant phenocrysts of black hornblende and plagioclase, 1 to 5 millimeters in length, in an even-grained groundmass, chiefly made up of quartz and orthoclase. Biotite is rare or wanting. Quartz phenocrysts were not seen."†

Both Holmes and Cross have brought out the similarity of the rocks constituting the numerous laccolithic intrusions of

FIG. 5.

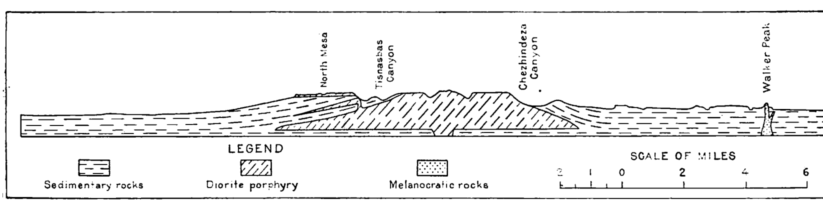

FIG. 5. Structure section across geologic map on line AA.

the Southwest. The writer wishes to further emphasize this similarity. So closely does the description of the rock of the Henry Mountains, given by Cross, correspond to the diorite porphyry of Carrizo Mountain, that his description might be employed here with only minor changes.

Microscopic description.—In thin section the rock is seen to consist of phenocrysts of plagioclase and hornblende set in a groundmass of quartz and orthoclase. Phenocrysts of quartz were observed in a number of slides, biotite in one. Iron ore is present in two generations in some places; in all slides it is seen in the groundmass. Apatite is a constant accessory and titanite is not uncommonly present. A few small crystals of zircon were noticed.

Hornblende is of the common, green, strongly pleochroic type. In some places, however, it is rather light in color.

* Holmes, op. cit., p. 275.

† Cross, Whitman, The Laccolithic Mountain Groups of Colorado, Utah, and Arizona, 14th Ann. Rept., U. S. Geol. Survey, Part II, 1895, pp. 210–211.

The extinction angles are slight, 8° from the cleavage lines, on the face 010. Twinning parallel to 100 is common. Zonal development is shown in a number of crystals and in some, resorption. Euhedral outlines are well displayed. In some places, the outline is completely preserved by the alteration products; in other places the outline is merely indicated by the few remaining shreds of the unaltered mineral. Alteration to chlorite and calcite, less commonly to epidote, takes place.

The plagioclase shows both Carlsbad and albite twinning and was determined to be an andesine with a composition of about $Ab_{45}An_{55}$. Some crystals have a broad tabular outline, others a lathlike development. The feldspar alters most abundantly to kaolin, in less degree to calcite. Quartz when present as a phenocryst is smaller than either the hornblende or the plagioclase. It is of the ordinary type.

Iron ore, as mentioned, is present in places in two generations. As phenocrysts it is observed in places to have a square outline indicating that it is magnetite; elsewhere it is without definite outline and is doubtless, in part, ilmenite. In not a few places it was seen entirely enclosed by the hornblende, indicating its earlier crystallization. It is abundantly concentrated about the borders of the hornblende both within and just without the crystal. As a second generation mineral it is scattered in small grains through the groundmass.

Apatite is present in all sections studied, in some in such large crystals and so abundantly as to almost merit being called a phenocryst. It is of the ordinary type, in long prisms. Titanite is of much less importance as an accessory than apatite, and zircon is of less importance than titanite. Both titanite and zircon are of the usual type.

In the groundmass orthoclase is somewhat more abundant than quartz. Both are developed in very small crystals. In some places, however, the feldspar has a tendency to lathlike development and there it is probably in part plagioclase.

The texture of the rock as a whole is porphyritic. The texture of the groundmass varies from microgranular, where quartz and feldspar are present in about equal amounts, to nearly trachytic, where feldspar is in excess of quartz. In some slides there was observed a tendency toward a micropoikilitic development, and in one section a microspherulitic texture was noted.

Hornblendic inclusions in the porphyry.—There are inclusions of a hornblendic character present in the diorite porphyry. These are ordinarily one or two inches in diameter, but were observed to six inches in length. They are of hornblendic nature so strongly, in places, as to suggest derivation from a hornblende schist, and are in general of very angular outline.

One inclusion, however, in the hand specimen, was seen to fade gradually into the enclosing porphyry. Study of a thin section, containing a portion of both the including and the included rock, revealed the fact that in each there were phenocrysts of similar common green hornblende set in a similar groundmass. The inclusion possessed the characters of the main mass, developed on a smaller scale. This has led the writer to conclude that the inclusions represent portions of the magma, previously solidified, which by later movement came into place in Carrizo Mountain. An occurrence, very similar to this, of hornblende inclusions in diorite porphyry, has been described by Iddings from Electric Peak in Yellowstone National Park.*

Classification.—Holmes was the first to study the rock of the intrusions of Carrizo Mountain. Like his coworkers in the Southwest at that time, he speaks of this rock in the text of his report as a "trachyte."† However in the legend of the geologic map accompanying the reports of the work done by the Hayden Survey in Colorado this same rock is listed as "porphyritic trachyte (hornblendic)."‡ Cross has later had occasion to study the very specimens collected by Holmes from Carrizo Mountain, together with the rocks of other laccolithic intrusions of the Southwest, brought in by the Hayden geologists. He has found that new names must be applied to these rocks, and in speaking of this he says

"In describing these rocks, . . . it will be necessary to use a nomenclature almost entirely different from that adopted by Gilbert, Dutton, Holmes and Peale. That this is true is not a reflection upon these able geologists, for the modern science of petrography was unknown in this country at the time their work in these regions was done. Few of the specimens collected by them had been examined microscopically or chemically when the published reports were written and it is usually stated in those reports that the names used are adopted provisionally."§

Accordingly, in place of Holmes' name, "trachyte," Cross applied the term hornblende porphyrite to the rock of Carrizo Mountain. Since his writing, however, the name porphyrite has itself been abandoned by American petrographers, and this type of rock is now known as diorite porphyry. It should be noted, however, that while the rock is classed as a diorite porphyry, there is in places considerable quartz present.

Place in the Quantitative Classification.—A chemical analysis of a rock which, from his description, is thought to be the

* Iddings, J. P., The Eruptive Rocks of Electric Peak, 12th Ann. Rept., U. S. Geol. Survey, Part I, 1890–91, p. 597.

† Holmes, W. H., op. cit.

‡ Geol. and Geog. Atlas of Colorado and portions of adjacent territory, Hayden, 1877, Sheet XV.

§ Cross, Whitman, The Laccolithic Mountain Groups of Colorado, Utah, and Arizona. 14th Ann. Rept., U. S. Geol. Survey, Part II, 1895, p. 175.

typical diorite porphyry of Carrizo Mountain is given by Cross* and is quoted in the accompanying table. From this analysis the norm and mode have been reckoned, and the rock determined to be a yellowstonose (symbol I, 4, 3, 4) lying almost on the borderline between yellowstonose and tonalose.

Hornblende-porphyrite. Sierra Carrizo.†
(Analysis, W. F. Hillebrand.)

SiO_2	63·18
TiO_2	·66
Al_2O_3	16·47
Fe_2O_3	2·36
FeO	2·28
MnO	·15
CaO	4·77
SrO	·09
BaO	·15
MgO	1·33
K_2O	2·93
Na_2O	4·40
Li_2O	trace
H_2O 110° +	·27
H_2O 110° −	·60
P_2O_5	·28
CO_2	----
Total	99·86

Calculation of the Norm of Yellowstonose.

	Analysis	Molecular Ratio	Or	Ab	An	Di	Hg	Mt	Il	Ap	Q
SiO_2	63·18	1·053	186	426	120	44	21				256
TiO_2	·66	·009							9		
Al_2O_3	16·47	·162	31	71	60						
Fe_2O_3	2·36	·015						15			
FeO	2·28	·032				5	5	15	9		
MnO	·15	·002									
CaO	4·77	·086			60	22				6	
SrO	·09	·001									
BaO	·15	·001									
MgO	1·33	·033				17	16				
K_2O	2·93	·031	31								
Na_2O	4·40	·071		71							
Li_2O	tr.										
H_2O +	·27										
H_2O −	·60										
P_2O_5	·28	·002									
Total	99·86	----	31	71	60	22	21	15	9	2	

* Cross, Whitman, The Laccolithic Mountain Groups of Colorado, Utah, and Arizona, U. S. Geol. Survey, 14th Annual Report, Part II, 1892–1893, p. 227.

† Cross, Whitman, op. cit., p. 227, analysis III, by W. F. Hillebrand.

Q	15·36	Q	15·36	Sal. 86·48
Or	17·24			
Ab	37·20	F	71·12	
An	16·68			
Di	4·91			
Hy	2·26	P	7·17	Fem. 12·64
Mt	3·48			
Il	1·37	M	4·85	
Ap	·62	A	·62	
Rest	·87			
Total	99·99			

Class I

$$\frac{\text{Sal}}{\text{Fem}} = \frac{86{\cdot}48}{12{\cdot}64} > \frac{7}{1}$$

Persalane

Order 4

$$\frac{\text{F}}{\text{Q}} = \frac{71{\cdot}12}{15{\cdot}36} < \frac{5}{3} > \frac{7}{1}$$

Britannare

Rang 3

$$\frac{K_2O + Na_2O'}{CaO'} = \frac{102}{88} < \frac{3}{5} > \frac{5}{3}$$

Coloradase

Subrang 4

$$\frac{K_2O'}{Na_2O} = \frac{31}{71} < \frac{3}{5} < \frac{1}{7}$$

Yellowstonose

Symbols I, 4, 3, 4.

Melanocratic types.

Two types of melanocratic rocks are present in the dikes and plugs associated with the main intrusions of Carrizo Mountain. In the absence of a chemical analysis it is not thought best to discuss their petrographic character at this time. It may be said, however, that they have been provisionally classified as shonkinite and Carrizo minette, since their mineral character is such as to indicate their relationship to the types shonkinite and minette. Though readily distinguishable under the microscope, these rocks cannot be separated megascopically and so for field purposes may be simply classified as "mica trap."

Leucocratic type.

Dacite.

Occurrence.—Dacite was noted in only two places in this region. A dike of it is exposed in Seklagaideza Canyon where the trail to the head of that canyon ascends the east wall, and again on the lower trail from this canyon to Red Rock store. Another and smaller dike, thought to be of the same character, is imperfectly exposed on the east of Carrizo Mountain at the mouth of Chezhindeza Canyon.

Macroscopic description.—In the hand specimen numerous phenocrysts of a rather pinkish feldspar, quartz, and hornblende are seen set in a light grayish aphanitic groundmass. An occasional phenocryst of iron ore is present.

Microscopic description.—Under the microscope the phenocrysts megascopically observed are seen set in a minutely granular groundmass of quartz and feldspar.

Hornblende is idiomorphically developed in long, slender prisms. It is of a somewhat lighter green color than common green hornblende and in places has a distinctly brownish tinge. In it the iron ore is abundantly concentrated. The hornblende is largely altered to chlorite.

Feldspar occurs in two generations. As phenocryst it is present in a few large crystals which show both Carlsbad and albite twinning and have been determined to be andesine with a chemical composition of about $Ab_{65}An_{35}$. The feldspar of the groundmass shows albite twinning in places and for many crystals the index of refraction is higher than that of Canada balsam, indicating its plagioclase character. As the feldspar is developed in long, tabular crystals, many of the pieces seen in thin section have a square outline, and as extinction takes place parallel or very nearly parallel to the side this feldspar is thought to be an acid andesine.

Quartz is present in two, and very probably in three generations. It occurs as phenocrysts, in the groundmass, and very likely combined with feldspar in the interstitial glass. As phenocryst the quartz is seen in large rounded forms which exhibit a nearly square cross-fracturing. About these masses the groundmass is much finer grained than elsewhere in the slide and it is supposed that the quartz, partially crystallized before, has been resorbed, thus giving rise to the rounded and embayed outline and a zone of more siliceous character surrounding it.

In the groundmass the quartz is seen to have square outlines and to extinguish diagonally with respect to the side of the square. Quartz of this character, in minute dihexahedrons, has been described by Küch as being very characteristic of certain dacites of the Andes,* and it is interesting to record that in Carrizo Mountain there is found another example of this somewhat rare mode of occurrence of this mineral.

The texture of this dacite is porphyritic. The groundmass is of microgranular character with a small amount of glass, which very probably consists of uncrystallized quartz and feldspar, filling up the minute interspaces.

* Küch, Richard, Geologische Studien in der Republic Colombia, I, Petrographie, 1, Die vulcanischen Gesteine, 1892–93, pp. 68–69.

Name.—The mineral character of this rock is so clearly that of a dacite, that, even without chemical analysis, it has been classed as such.

Manner of Intrusion.

Daly has recently classified all intrusive igneous masses under two main heads, (1) injected and (2) subjacent bodies, according as they come into place either by the injection and consequent uplift of the enclosing strata or by the replacement of these beds. Under the first division are placed sills and laccoliths; under the second, stocks and batholiths.

The uniform character of the diorite porphyry of Carrizo Mountain demonstrates that if, as is possible, the various outcrops of that rock are not portions of one large intrusion, they at least represent upwellings of magma from a single common reservoir. Nowhere were there observed stoped blocks nor was any evidence of assimilation noted, facts which, taken together with the upturning of the beds at the base of the mountain, suggest that intrusion was by injection rather than by a replacement of surrounding beds,—that the intrusion is of the injected rather than of the subjacent type.

It is evident from a study of the writings of Holmes and Peale that they both considered the Carrizo intrusion as belonging to the class of intrusion to which the name laccolith was later applied by Gilbert. Indeed on the geologic sections accompanying the maps of the Hayden Survey, Carrizo Mountain is portrayed in laccolithic form.* No sedimentary floor is as yet exposed by erosion and that this intrusion is symmetrical and of typically laccolithic shape cannot be assumed. Aside from the irregularity produced by Tisnasbas sill and the sheets capping North and Chezhindeza mesas, it seems clear that the intrusion is asymmetrical and has in places broken up through the overlying beds. The porphyry may be seen cutting across the Triassic rocks and the Wingate sandstone (Jurassic) in Tisnasbas canyon to supply the material for the Tisnasbas sill. It also appears that the igneous mass east of Biltabito Canyon has cut across the Triassic rocks and the Wingate sandstone, and there are probably other transgressions not yet exposed by erosion. Indeed it seems possible that the intrusion consists of several sills with their connecting pipes which have united in producing the effects of laccolithic uplift. Until such facts can be definitely proven, however, it is at least convenient to speak of the intrusion as a laccolith, which form of intrusion to all outward appearances it most closely resembles. (See fig. 5.)

* Hayden, F. V., U. S. Geol. and Geog. Survey Terr., Atlas of Colorado and portions of adjacent territory, 1877, Sheet XVII, Section 11.

Depth of Cover.

The lowest formation observed in contact with the porphyry of Carrizo Mountain is of Triassic age; the highest is the McElmo formation (Jurassic?) within which the Tisnasbas sill is intruded. It is evident from a study of the surrounding region that the Cretaceous sediments were once continuous over the area, but that they were present at the time of intrusion remains to be demonstrated. Indeed the determination of the depth of cover depends upon the age of the sandstone and conglomerate which cap the mountain summit and outcrop for a short distance on the mountain flank south of Chezhindeza Canyon. This sandstone, which is similar both to the Dakota and to certain Tertiary sandstones and whose age cannot be determined because of absence of fossil evidence, rests in angular conformity and apparently without erosional unconformity upon the Triassic rocks. Whether Cretaceous or Tertiary, an erosion cycle is necessary to bring the Triassic into juxtaposition with formations so much higher than it. It is known that in northern Arizona there were such erosion cycles in both pre-Dakota and pre-Tertiary time, so that erosion is of no avail in the age determination of this intrusion. At present it can only be said that if the beds are Tertiary, intrusion took place below a cover of 2000 feet; if the beds are Dakota, beneath a cover of about 5000 feet.

Age of Intrusion.

The age of the various laccolithic intrusions of the Southwest has been considered by all students of that region as Tertiary, but so far as the writer has been able to ascertain, little definite evidence of this has been adduced. Were it possible to determine the age of the sandstone capping Carrizo Mountain, the date of intrusion there might be very definitely ascertained. Even in the absence of such proof it is still possible to place the age of the intrusion with much assurance as Tertiary, though not more definitely than that. It is known that there are certain structures of pre-Tertiary age in the area, and that these structures have been magnified by intrusion. Since, then, intrusion is younger than these features, which were probably developed at the end of the Cretaceous, it must have occurred in Tertiary time.

The relative ages of the different intrusions, the main mass, the sills, sheets, volcanic plugs, and dikes cannot be determined as they were not observed cutting each other.

Contact Metamorphism.

Tisnasbas sill.—There are only a few contacts of the diorite porphyry and the enclosing sedimentary rocks visible in the Carrizo area. The lower contact of the Tisnasbas sill with the underlying Jurassic (?) sediments is, however, excellently exposed and may be considered typical. Study of a series of thin sections from specimens collected at various distances from this contact revealed a slight increase in the amount of iron oxide in the cement of the sandstone directly at the contact. If, however, one did not know that such an amount of iron oxide was unusual in this sandstone he would not recognize the sandstone as metamorphosed in the least, and, indeed, the amount of metamorphism has been so small that at a distance of three feet from the contact the bed is absolutely normal.

On the mountain summit metamorphism was somewhat more potent inasmuch as the original sandstone has been changed to a resistant quartzite, and this to an unknown though probably not great distance from the contact.

Sandstone columns at Holmes Dike contact.—Where melanocratic types of rock have penetrated the sedimentary beds, metamorphism, though not of great importance, is more pronounced than that produced by the porphyry. In the majority of cases a baking of the enclosing sediments has accompanied the intrusion of basic types of rock in this region, but Holmes Dike (fig. 3) has produced certain quartzite columns similar in appearance to those commonly observed in igneous outflows. Study of a thin section of one of these quartzite columns demonstrated the absence of any admixture of igneous material, that the columns consist only of Jurassic sediments altered to quartzite. The columns are of various diameters to one and one-half inches and in length range to three feet, the maximum distance of metamorphic action. Similar, though less perfect, columns were observed by the writer 35 miles west of Carrizo Mountain along the contact of a dike associated with Boundary Butte, Utah; more perfect columns have been noted by Professor Gregory at the northern end of Lukachuka Mountain, Arizona.*

Cause of the absence of intense contact metamorphism.

It is evident from the above discussion that there has been no great amount of contact metamorphism in the Carrizo area, since such effects are commonly not noticeable at a distance of more than three feet from the contact. This phenomenon has previously been recognized by Cross as characteristic of laccolithic intrusions in the southwest and has been attributed by him to the lack of the so-called mineralizing agents, fluorine, chlorine, and superheated steam in the magma.† The absence of intense metamorphism in Carrizo Mountain is believed to be due to this cause.

* Prof. Paper U. S. Geol. Survey, in preparation.

† Cross, Whitman, Spencer, A. C., Purington, C. W., La Plate folio (No. 60), Geol. Atlas, U. S., U. S. Geol. Survey, 1899, p. 11.