A RECONNAISSANCE OF THE ARCHEAN COMPLEX OF THE GRANITE GORGE, GRAND CANYON, ARIZONA.

By L. F. Noble and J. Fred. Hunter.[1]

INTRODUCTION.

The field work upon which this article is based was done in March and April, 1914. From Garnet Canyon, near the west end of the Granite Gorge, the route followed the Tonto trail along the so-called lower plateau, or Tonto platform, to Red Canyon, at the east end of the Granite Gorge. The distance covered was roughly 100 miles measured along the trail, or about 40 miles measured along the course of Colorado River. Supplies were carried by pack burros, and Mr. John Walthenberg acted as packer and guide. Stops of several days each were made at Garnet Canyon, Copper Canyon, Bass Canyon, Serpentine Canyon, Ruby Canyon, Turquoise Canyon, and Slate Creek, in the Shinumo quadrangle; Boucher Creek, Hermit Creek, Salt Creek, Pipe Creek, Lone Tree Canyon, and Grapevine Creek, in the Bright Angel quadrangle; and Cottonwood Creek, Hance Creek, and Red Canyon, in the Vishnu quadrangle.[2]

From Hermit Creek eastward the Tonto trail is often traveled by tourists and was known to be in fairly good shape. The western part of the trail, however, between Hermit Creek and Bass Canyon, was not known to have been used by any party with pack animals since 1905, when the Shinumo quadrangle was topographically surveyed, but progress over it was made with little difficulty. At only one place was it impossible to pass without unloading the pack animals. This was at the head of the small canyon just east of Serpentine Canyon, in the Shinumo quadrangle, where a flood and landslide had carried away the narrow ledges of Bright Angel shale on which the trail passes around the head of the canyon. Except Bass trail and the trail built by Mr. Bass between Bass Canyon and Copper Canyon, there is now very little west of Hermit Creek that can properly be called a trail. The traveler will find the Geological Survey's topographic maps of the greatest value in making this part of the trip, because, although nearly all traces of a trail have disappeared, the route marked on the maps as the Tonto trail still shows the most feasible way along the Tonto platform.

It was thought that there would be difficulty in finding water in many of the side canyons where it was proposed to camp, because most of them do not contain living streams, and the intermittent underground flow derived from the melting snows on the sheltered slopes high under the south rim rarely lasts long after the opening of spring. While the beds of most canyons proved to be dry for the greater parts of their courses, whether on bedrock or on gravelly waste, water was always found flowing for a few hundred yards where the stream courses cross the upper layers of the cliff-making Tapeats sandstone. Most of the camps were made at this level and proved to be equally convenient for the examination of the Archean rocks below the camps and the Paleozoic rocks above, up to the base of the Redwall limestone. During April the small flow of water was constantly diminishing, and it seemed unlikely that there would be any flow whatever by June. It was evident that in any part of the year except early in spring camps at intervals so short and in places so conveniently situated would be impossible.

The chief object of the excursion was the study and areal mapping of the Algonkian and Paleozoic formations of the southern wall of

[1] Field work by Mr. Noble; microscopic study of rocks by Mr. Hunter.

[2] These three quadrangles have been mapped by the United States Geological Survey.

the Grand Canyon in the Kaibab division. Detailed sections of the Tonto group were made in seven places at intervals of 5 or 6 miles, and particular attention was given to the interesting unconformity at the summit of the Tonto group, where the Devonian is present in some places and lacking in others. Three sections of the Carboniferous formations were made, one in each quadrangle. Parts of the three quadrangles were mapped in detail, including all of the Bright Angel quadrangle south of the Granite Gorge, all of the Shinumo quadrangle south of the Granite Gorge as far west as Garnet Canyon, and all of the Vishnu quadrangle south of the Granite Gorge and west of Red Canyon.

It had not been intended originally to make any examination of the Archean rocks, because an adequate study of their character and structural relations would take at least as much time as the writer had planned to devote to the entire trip. On arrival in the canyon, however, it was found that it would not be difficult to get down to the Archean from camp in each of the larger side canyons and devote a part of the time spent in each camp to the study of these rocks. Geologic literature concerning the Archean complex of the Grand Canyon is very meager, and even the fundamental facts of the lithology and distribution of the rocks are unknown. It was realized that if the Archean could be examined at short intervals through the Granite Gorge it would at least be possible to determine definitely the petrographic character of many of the rocks, and a foundation would be laid for future detailed study. Something might also be learned of their origin and structure. It was therefore decided to make this reconnaissance, and the results are set forth in the present paper. A second paper will be devoted to the detailed discussion of the Paleozoic rocks, and another to a description of the faults in the Grand Canyon on the south side of the river. The location of the known Archean rocks in the Grand Canyon is shown in figure 9.

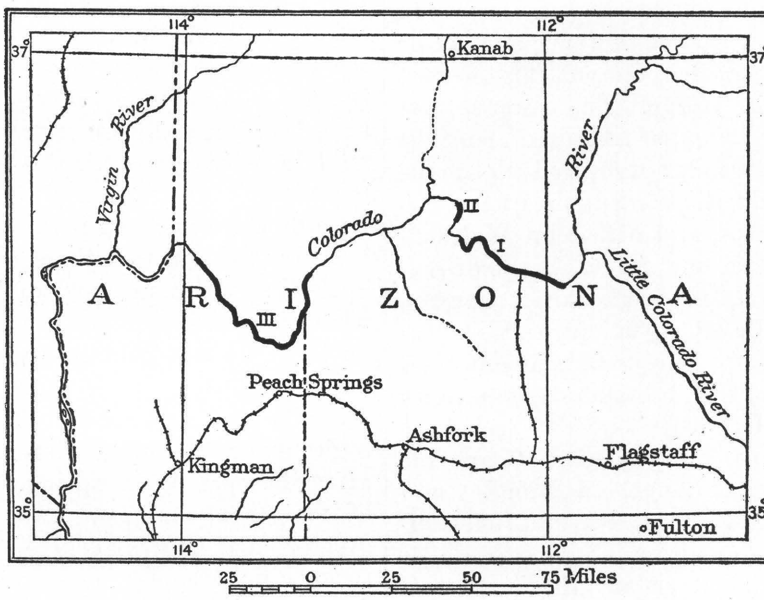

FIGURE 9.—Key map of northwestern Arizona showing location of exposures of Archean rocks in the Grand Canyon. I, Granite Gorge of Kaibab division (described in this paper); II, Lower Granite Gorge; III, Granite Gorge of Shivwits division.

GEOGRAPHY.

Three elements in the topography of the Grand Canyon below the Redwall in the Kaibab division that are important to the geologist who wishes to study the Archean are the Tonto platform, the Tapeats cliff, and the Granite Gorge. All are intimately related to geologic structure.

The Tonto platform, locally misnamed the "lower plateau," is the wide ledge left in the interior of the canyon by the wasting back of the relatively weak Bright Angel shale from the summit of the underlying resistant Tapeats

GRANITE GORGE OF THE GRAND CANYON, ARIZ., LOOKING NORTHWEST.

sandstone.[1] It affords the only possible route of travel through the interior of the canyon on land.

The Tapeats cliff is the outcropping edge of the resistant Tapeats sandstone below the Tonto platform. It is wonderfully persistent, averages 300 feet in height, and is the chief obstacle that bars the way to the Archean rocks.

The Granite Gorge (see Pl. XIX) is the deep, narrow V-shaped canyon which Colorado River has cut in crystalline Archean rocks below the Tapeats sandstone. Descending into it, the traveler leaves the wide outer canyon, whose walls are carved in horizontal Paleozoic strata, and enters what is geologically and scenically another world. At the base of the Tapeats cliff a great unconformity of erosion separates the Paleozoic beds from the two underlying systems of rock—the Archean crystalline rocks and the Algonkian Grand Canyon sediments, which are inset in the Archean in places by block faulting. The change in scenery is no less abrupt than the change in geologic structure. The sides of the Granite Gorge, carved in Archean rocks, descend to the river in steep, bare slopes whose surface is jagged and chaotic in the extreme.

The Granite Gorge is about 40 miles long, measured along the course of Colorado River, and runs from southeast to northwest. The average width between the inclosing cliffs of Tapeats sandstone is perhaps 2,000 feet, and the average depth, measured from the base of the Tapeats cliff to the river, about 800 feet. At irregular intervals of a mile or so tributary gorges are cut back into the Tonto platform. Most of these do not expose the Archean rocks far back from the main gorge of the river, but some of the larger ones expose them for several miles. The upper end of the Granite Gorge begins abruptly in the Vishnu quadrangle near the mouth of Red Canyon, where the river flows southwestward out of great masses of Algonkian strata that dip steeply northeastward upstream. It ends gradually in the Shinumo quadrangle below Garnet Canyon, where the river flows southward across a broad zone in which the Paleozoic strata dip southwestward; as the dip of the strata is greater than the grade of the stream, the river bed is gradually carried out of the Archean rocks into the overlying Tapeats sandstone.

The inaccessibility of the exposures of Archean rocks and the extreme ruggedness of the topography in the Granite Gorge are the chief obstacles to geologic study. The sheer, high cliff of Tapeats sandstone along the rim of the gorge is, in most places, an impassable barrier to descent from the Tonto platform, and there are only three situations in which it has broken down enough to allow the traveler to reach the Archean—(1) at the heads of tributary gorges, where it is cut by stream erosion; (2) in places where a hill or "monadnock" of Archean or Algonkian rock rises through the sandstone and excludes it; (3) where a line of faulting crosses the sandstone and shatters it. The most numerous breaks are those caused by stream erosion at the heads of tributary gorges. Once the Archean rocks are reached progress is exceedingly difficult and slow, except in the beds of the larger tributary canyons, and it is impossible to travel very far along the edge of the river, because the walls rise steeply from the water.

The exposure of Archean rocks in the Granite Gorge is so small a part of the vast areas buried under Paleozoic and later strata north and south of the canyon that the chance of deciphering much of the structure from it would be remote were it not for the fact that the northwest course of Colorado River crosses at right angles the dominant trend of nearly all the structural features in the Archean. Thus the Granite Gorge is a magnificent 800-foot cross section 40 miles in length. The difficulties incidental to the roughness of the topography are largely compensated, for the geologist, by the clearness with which the structure is revealed in the bare slopes.

PLAN OF INVESTIGATION.

The method of study followed was to descend to the Archean rocks in every side canyon where a camp was made and in any other place that could be reached by detour when moving from one camp to another. Twenty localities were visited in traveling the length of the Granite Gorge. The distance between them ranged from three-tenths of a mile to

[1] The Tapeats sandstone is the basal formation of the Tonto group of strata, of Cambrian age, which comprises the Tapeats sandstone, Bright Angel shale, and Muav limestone.

4 miles, but the average interval was about 2 miles. At these localities 67 hand specimens were collected, and thin sections were cut from 48 of them. Eight distinct groups of rocks were crossed in exploring the Granite Gorge, as set forth in the accompanying table. (See also fig. 10.) In this table and the following discussion the localities and groups of rocks are numbered in the order of their occurrence from west to east.

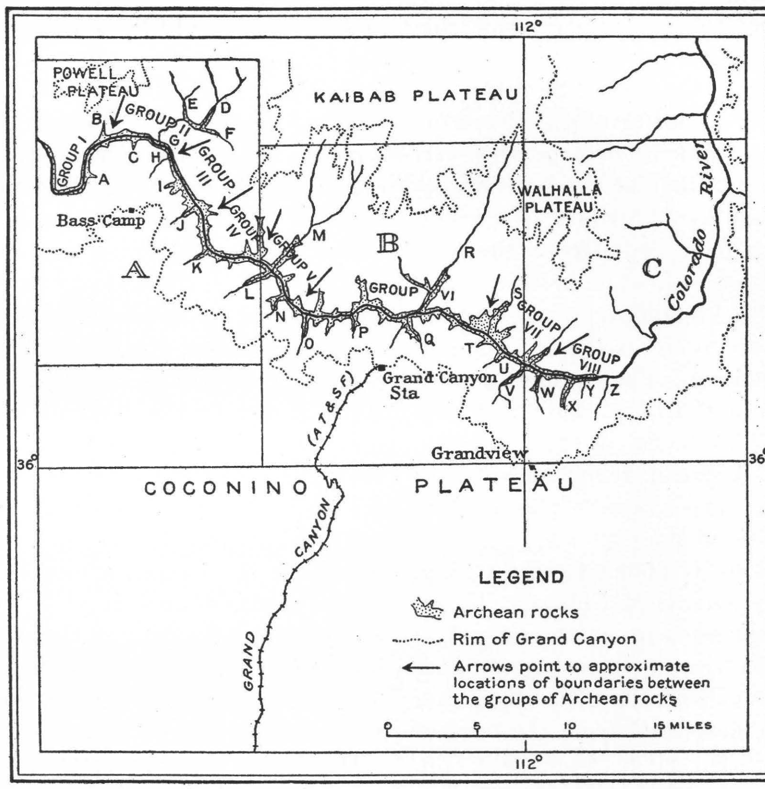

FIGURE 10.—Map of Kaibab division of Grand Canyon, Ariz., showing distribution of Archean rocks and localities where the rocks were examined. Quadrangles mapped by United States Geological Survey are indicated by outline letters as follows: A, Shinumo; B, Bright Angel; C, Vishnu. Localities examined: A, Garnet Canyon; B, Walthenberg Canyon; C, Copper Canyon; D, Shinumo Creek; E, White Creek; F, Flint Creek; G, Cable Crossing; H, Bass Canyon; I, Serpentine Canyon; J, Ruby Canyon; K, Turquoise Canyon; L, Slate Creek; M, Crystal Creek; N, Boucher Creek; O, Hermit Creek; P, Salt Creek; Q, Pipe Creek; R, Bright Angel Creek; S, Clear Creek; T, Lonetree Canyon; U, Boulder Creek; V, Grapevine Creek; W, Cottonwood Creek; X, Hance Creek; Y, Mineral Canyon; Z, Red Canyon.

THE ROCKS.

GROUP I. GNEISSES, AMPHIBOLITES, AND GRANITE.

From the west end of Granite Gorge to the mouth of Walthenberg Canyon, a distance of about 6 miles, the rocks are banded gneisses cut by pink intrusives. The gneisses are of several types and occur in parallel bands which range in width from a few feet to over 300 feet. From Garnet Canyon westward the prevailing strike of the gneissoid banding is N. 60° E. and the dip nearly vertical. In places between Garnet Canyon and Walthenberg Canyon the strike becomes northwesterly. Here and there the gneiss is greatly mashed and contorted. The commonest type of gneiss is hornblende gneiss (metamorphosed quartz diorite, specimen No. 3), and there are some bands of a very dark hornblende schist (amphibolite, No. 4). A quarter of a mile below the mouth of Garnet Canyon there is a 50-foot band of biotite-chlorite gneiss (No. 5) containing numerous garnets about the size of a pea, from which Garnet Canyon was named. Within Garnet Canyon an intrusive body of pink granite (No. 6) is the prevailing rock.

The pink intrusive rocks that are associated with the gneisses are granite, aplite, and pegmatite. The granite is a medium-grained even-textured rock which consists essentially of quartz, microcline, soda plagioclase, muscovite, *Archean rocks examined in Granite Gorge, Grand Canyon, Ariz.*

Quadrangle.	Localities where the Archean rocks were examined and specimens collected (reading from west to east).	Distance between localities (miles).	Nos. of specimens from which thin sections were cut.	Group.	Predominant type of rock.	Approximate length of exposure, measured roughly by the course of the river (miles).[a]
Shinumo.	1. Gorge of Colorado River from mouth of Garnet Canyon to a point 1 mile south	....	3, 4, 5	I	Hornblende gneiss, granite gneiss, and amphibolite (much injected granite and pegmatite).	6
	2. Garnet Canyon (0.2 mile east of mouth)	1.0	6			
	3. Gorge of Colorado River 0.5 mile southwest of mouth of Copper Canyon	2.9	([b])	II	Mica schist (some injected granite and pegmatite).	4.2
	4. Copper Canyon (near mine)	.3	1, 2			
	5. Gorge of Colorado River at Cable Crossing	1.9	8			
	6. Bass Canyon (near mouth)	.4	([c])	III	Massive basic intrusives (some injected pegmatite).	4.5
	7. Serpentine Canyon (head of inner canyon to river)	1.6	9, 10, 11			
	8. Ruby Canyon (0.8 mile southwest of mouth)	1.7	13			
	9. Turquoise Canyon (0.6 mile southwest of mouth)	2.4	15, 16, 17, 18, 20	IV	Metabasite and metadiorite (much injected granite and pegmatite).	2
	10. Slate Creek (1 mile southwest of mouth)	2.9	22, 23, 24, 25, 26, 27	V	Mica schist (little injected granite and pegmatite in eastern part; much in western part).	5.7
Bright Angel.	11. Boucher Creek (0.7 mile southwest of mouth)	1.5	31, 32, 33, 34			
	12. Hermit Creek (head of inner canyon to river)	1.9	35, 38, 39, 40	VI	Granite gneiss and amphibolite (much injected granite and pegmatite).	10.4
	13. Salt Creek (0.7 mile southeast of mouth)	2.7	45, 46			
	14. Pipe Creek (0.8 mile south of mouth)	2.7	49, 50			
	15. Lonetree Canyon (0.5 mile southwest of mouth)	4.0	53, 54	VII	Mica schist (little injected granite and pegmatite in western part; much in eastern part).	3.5
	16. Boulder Creek (0.7 mile southwest of mouth)	1.2	([b])			
	17. Grapevine Creek (1.6 miles southwest of mouth)	1.5	56, 57			
Vishnu.	18. Canyon 0.7 mile southeast of mouth of Cottonwood Creek	2.7	60, 61	VIII	Granite gneiss (much injected granite and pegmatite).	3.7
	19. Hance Creek (1.5 miles southwest of mouth)	1.4	62, 63			
	20. Gorge of Colorado River from mouth of Mineral Canyon to end of Granite Gorge	1.7	64, 65, 66, 67			

[a] Distance in straight line between east and west ends of Granite Gorge, 31 miles; by course of river, 40 miles. [b] No thin sections. [c] See U. S. Geol. Survey Bull. 549, pp. 32–37, 1914.

and biotite, named in the order of decreasing abundance. The aplites and pegmatites consist as a rule of quartz, microcline, and muscovite, but in places the muscovite is absent.

Apparently the pink intrusives comprise from one-fourth to one-third of the rocks of Group I, but the proportion varies considerably from place to place and may be actually much less. Some of them are in sheets parallel with the bands of gneiss. Others, chiefly granites, are in irregular bodies that cut the gneisses. In places the granite in these bodies grades into pegmatite. Still others, chiefly pegmatites, are in dikes that cut both the gneisses and granites.

Petrography of specimens.[1]

No. 3. *Hornblende gneiss* (probably a metamorphosed quartz diorite).—The rock in hand specimen is gray, well banded, and medium grained and contains a considerable amount of quartz in crystals larger than the other mineral constituents. In thin section the gneissoid character is less conspicuous, the rock having a seriate porphyroid fabric in which the individual crystals average about 1 millimeter in the longest direction, although the quartz crystals may be as much as 4 millimeters. Quartz, plagioclase, hornblende, and orthoclase are the essential mineral constituents named in the order of decreasing abundance. The quartz occurs in large irregularly shaped crystals which interlock with and in places include the other constituents. It also contains numerous microscopic inclusions whose character has not been determined. The quartz crystals have no uniformity of orientation, although some of them, particularly those cut at a small angle to the principal optic axis, show undulatory extinction as an evidence of straining. The plagioclase has the composition of andesine (about $Ab_{65}An_{35}$), is usually twinned after the albite law, and is partly altered to sericite. Orthoclase is thought to be present in small amounts but is very much altered. The hornblende crystals are of deep color, showing pleochroism in greens and yellows, and for the most part are arranged with their c′ axes parallel. There is a small amount of leached biotite which is altering to epidote and a reddish mineral thought to be chlorite. The section also contains iron oxides, apatite, zircon, epidote, and titanite in accessory amounts. The rock may have been metamorphosed from a granodiorite or a quartz diorite.

No. 4. *Hornblende schist or amphibolite.*—The specimen is fine grained, black, and schistose. Little else but hornblende can be discerned with the unaided eye. Under the microscope a thin section cut nearly parallel to the schistosity exhibits a seriate fabric in which very few of the individual crystals are as much as 1 millimeter in longer dimension. Mineralogically the rock consists essentially of hornblende, quartz, and feldspar (altering to sericite), named in about the order of decreasing abundance. The feldspar is almost entirely changed to sericite, which is nearly as abundant as the quartz. Epidote and sericite occur in narrow veinlets cutting the other minerals and in small grains associated with hornblende. Titanite is the commonest accessory, but iron oxides, apatite, and zircon, in microscopic size, are also present.

No. 5. *Biotite-chlorite gneiss, or schist.*—This is a dark-green medium-grained micaceous rock, not well lamellated. Its degree of metamorphism is not apparent from the small hand specimen examined. Mineralogically the rock consists essentially of quartz, biotite, chlorite, epidote, sericite, feldspar, and garnet, displaying seriate fabric in thin section in which the grains are as much as 3 millimeters in longer dimension and average about 1 millimeter. The thin section shows little evidence of schistosity or metamorphism of the deeper and regional type. However, the rock has suffered certain profound changes which probably are due more to thermal agencies than to dynamic metamorphism. Thus the feldspars, which apparently were in large part plagioclase, are altered to sericite and chlorite. Some of the chlorite, particularly that which has replaced feldspar, is greenish, but other areas of it are yellow. The yellow variety occurs as pseudomorphs, the original nature of which can not be determined, although the shape of the individuals suggests that they may have resulted from rhombic pyroxene. The epidote occurs in subhedral to euhedral grains and shows noticeable pleochroism in pale yellows to light browns. Fine grains of magnetite and even larger crystals of apatite are abundant. This band may represent a relatively late intrusion into the metamorphic complex.

No. 6. *Granite gneiss.*—Pink medium-grained granite, the small hand specimen of which suggests a more or less gneissoid character. Mineralogically the rock consists chiefly of quartz, microcline, orthoclase, soda plagioclase, muscovite, biotite, and iron oxides, named in order or decreasing abundance. The individual crystals are allotriomorphic, average about 1 millimeter in diameter, and are arranged in a seriate porphyroid fabric as seen in thin section. The rock is relatively fresh, although the feldspars, particularly the orthoclase and soda plagioclase, contain a large amount of finely divided ferritic material, which gives them a dirty reddish-brown appearance in transmitted light. The muscovite is largely secondary, as are also small quantities of sericite, chlorite, epidote, and most of the iron oxides. Apatite occurs as an accessory.

GROUP II. MICA SCHIST.

From the mouth of Walthenberg Canyon to a point about half a mile east of the mouth of Shinumo Creek, a distance of $4\frac{1}{5}$ miles, the rocks are rather fine grained dull reddish or

[1] The thin sections were studied microscopically by J. Fred. Hunter in April, 1915. Only the chips from which the thin sections were cut were available for megascopic study.

pinkish mica schists which are cut in places by dikes of pink pegmatite. One of these dikes in Copper Canyon is over 200 feet wide. In general, however, the amount of intrusive rock is small and the schist is free from it over large areas, particularly in the western part of the exposures.

The schist is rather homogeneous in composition. Specimen No. 1, from Copper Canyon, represents the prevailing type of rock. In places where the schist is not too intensely crumpled and mashed, there are numerous alternating bands a few feet in width in which the rock becomes denser, finer grained, and more quartzose in appearance and changes in color from pinkish to gray. In the field the character of this banding strongly suggests an original sedimentary bedding. Specimen No. 2, from Copper Canyon, is the schist from one of these bands of denser rock.

The areas of schist that exhibit this obscure banding are in the western part of the exposures, extending from Copper Canyon to Walthenberg Canyon. Here the prevailing strike of the banding is northwesterly and the dip from 45° to 75° NE., both corresponding in a general way with the strike and dip of the schistosity. If the banding represents an original sedimentary bedding and if there is no duplication by folding or faulting, the exposed thickness of the series can not be less than 5,000 feet and is probably much greater.

East of Copper Canyon, near the contact of the schist with the quartz diorite of Group III, there is a great deal of local twisting and contortion in the schists and they are injected with pink feldspar and milky quartz in veins and lenses. In this area the strike of the schistosity is approximately N. 20° E. and the dip nearly vertical. The schist contains a great deal of pink feldspar and some black tourmaline and in places is rather coarse in texture. Specimen No. 8 is a piece of this schist obtained near the Cable Crossing.

Petrography of specimens.

No. 1. *Mica schist.*—Gray, with pinkish tones; yellow on weathered surface. Mica and quartz individuals are easily distinguishable with the unaided eye. The rock has doubtless been entirely recrystallized during the process of metamorphism, so that no trace of the original structure remains. In a thin section, cut oblique to the cleavage of the rock, the schistosity is indicated by the parallel arrangement of the micas, which average 0.5 millimeter in length, whereas the other constituents average approximately 0.3 millimeter across and a few individuals are as much as 1 millimeter. The mineral composition of the rock may be represented approximately as follows: Quartz $\gg$ biotite $\gtrless$ muscovite $\gtrless$ feldspar $>$ iron oxides, with accessory apatite, zircon, and garnets. The quartz occurs in subequant anhedral grains and is commonly filled with numerous inclusions of mica, apatite, and minute specks whose character has not been determined. The feldspar is likewise anhedral, is altered to sericite and in some places to kaolin, and generally has a lower index than that of quartz. It probably makes less than 15 per cent of the rock. So far as the mineral content is concerned the schist may have been derived from the metamorphism of a shaly arkosic sandstone or equally well from an igneous rock having the general composition of granite.

No. 2. *Mica schist.*—Gray, more compact, and less micaceous than No. 1, but otherwise differing very little, though it is finer grained and the micas are smaller and less conspicuous, giving it a more quartzose appearance. Its mineral constitution is the same, and apparently it has about the same amount of feldspar, which appears to be orthoclase or soda plagioclase.

These rocks resemble pre-Cambrian rocks from the Black Canyon of Gunnison River, in Colorado.[1] The microscopic study does not give conclusive evidence as to their origin.

No. 8. *Muscovite schist.*—Pinkish gray, with silvery sheen in certain light; very micaceous and fissile. The specimen indicates more or less weathering. In a section cut transverse to the cleavage of the rock the parallel arrangement of the micas, which average 0.6 millimeter in length, brings out the schistosity strikingly. The other constituents are allotriomorphic, are equant to subequant, and average 0.2 millimeter in diameter. The mineral composition of the schist may be represented approximately as follows: Quartz $>$ feldspar $\gtrless$ muscovite $\gtrless$ biotite (ferritized) $>$ iron oxides, with accessory apatite, zircon, and garnets.

The feldspar, being badly stained with iron oxide, which gives it a reddish-brown color, is easily distinguishable from the clear quartz and makes up approximately 20 per cent of the rock. It has a low index and appears to have been in part orthoclase, which was somewhat altered to sericite before it was stained by weathering. The biotite likewise is iron-stained and nearly opaque. This rock differs from Nos. 1 and 2 in texture, but is similar in composition, although the degree of weathering has emphasized the abundance of the feldspars.

In addition to the exposures in the Granite Gorge there is an area of the schists in the Shinumo Amphitheater, on the northeast side

[1] A report on the Archean rocks of the Black Canyon region, by J. F. Hunter, is in preparation.

of the West Kaibab fault, 2 miles northeast of the mouth of Shinumo Creek. It extends about 3 miles southeastward in the inner canyons of White, Shinumo, and Flint creeks and a mile northeastward up the canyon of Shinumo Creek. This area of schists was visited in 1908, in the course of a study of the Algonkian strata of the Shinumo quadrangle, and a few specimens of the chief types of rock were collected from which thin sections were made.[1]

Three types of schist were recognized—(1) quartz-mica schists which, in general aspect, resemble the mica schists of the Granite Gorge, above described, and which may contain feldspar, though the two thin sections studied show little or none; (2) fine-grained quartz-hornblende schist, consisting of about equal proportions of quartz and green hornblende; (3) hornblende schist, consisting almost entirely of green hornblende, which occurs in a narrow outcrop with sharp boundaries and apparently represents a body of metamorphosed igneous rock of a basic type.

No definite hypothesis as to the origin of the quartz-mica and quartz-hornblende schists was entertained, because no detailed study was made of the Archean rocks in the field, but the large amount of quartz in the schists suggested a sedimentary origin.

The contact between the gneisses of Group I and the schists of Group II near Walthenberg Canyon was not examined on the present trip, because there was no break in the Tapeats cliff that would permit descent to the Archean within several miles of the contact. Seen from above it appeared to be a rather sharp line crossing the Granite Gorge from northwest to southeast and was thought to be a fault.

GROUP III. MASSIVE BASIC INTRUSIVE ROCKS.

From a point near the Cable Crossing to a point about 1 mile southeast of the mouth of Ruby Canyon, a distance of 4½ miles, the rocks are all coarse granular massive igneous rocks in which no gneissoid banding or schistosity was observed in the localities visited. For at least a mile up the river above the Cable Crossing the rock is a coarse-grained quartz diorite which is intrusive in the schist of Group II. This quartz diorite was examined in 1908 near the mouth of Bass Canyon and has been described as follows:[2]

> The quartz diorite in the river gorge east of Cable Crossing is a coarse-grained, dense, resistant rock of typical granitic texture, which tends to weather into roughly angular blocks and thus to assume forms that distinguish it in the mass from the Vishnu schist. It is dark gray, looks remarkably fresh, and contains visible particles of white striated feldspar, dark hornblende, and glistening black biotite. The rock is uniform in texture throughout the exposures observed, is apparently without contact modifications, and shows no gneissoid banding.
>
> Under the microscope it is seen to be a coarse-granular rock of granitic texture. Its dominant mineral constituents are plagioclase and common hornblende, the plagioclase ranging from oligoclase to labradorite. Microcline, orthoclase, and quartz are present in about equal proportions, but their total amount does not equal that of the plagioclase. Brown biotite appears in somewhat less quantity than the hornblende, and titanite and magnetite are accessories. Occasionally the quartz is poikilitic in the orthoclase. The feldspathic and ferromagnesian minerals occur in about equal proportion. The microscope reveals no cataclastic structure nor other evidence of dynamic action, and the minerals are fresh and unaltered.

In 1908 the rocks of the Granite Gorge were not examined beyond a point 1 mile up the river from the Cable Crossing. It could be seen clearly, however, that they are massive igneous rocks at least as far as the mouth of Ruby Canyon. All the rock in the Granite Gorge between Bass Canyon and Ruby Canyon was therefore mapped as intrusive quartz diorite, but the statement was made in the text of Bulletin 549 that the eastern limit of the diorite had not been located, and the eastern part of the exposure was indicated on the geologic map as outlines by a reconnaissance survey.

On the present trip, when what was supposed to be the quartz diorite was examined in Serpentine Canyon, the next canyon up the river from Bass Canyon where access to the Archean was possible, the rock was found to be a gray porphyritic hypersthene gabbro. Specimens Nos. 9 and 11 came from this locality. No. 10 is a specimen containing one of the phenocrysts. No. 13 is hypersthene gabbro from Ruby Canyon, 2 miles southeast of Serpentine Canyon. The hypersthene gabbro is exposed over an area of about 4 square miles and is the largest single body of massive igneous rock in the

[1] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, pp. 32–35, 1914.

[2] Idem, pp. 35, 36.

Granite Gorge. It is characterized throughout by a well-marked sheeting or jointing that strikes northwest and dips 20°–30° NE. It decays more readily than any other rock in the Archean, so the sides of the Granite Gorge in the area occupied by the gabbro have a much gentler slope than elsewhere and the Tapeats cliff has retreated nearly twice as far from the river as it has in the area between Bass Canyon and Serpentine Canyon where the diorite is exposed. The boundary between the diorite and the gabbro must be at the point where this change in the topography takes place and is therefore not far down the river from the mouth of Serpentine Canyon. It was not possible to visit the locality on the present trip, and the nature of the contact is unknown.

Petrography of specimens.

No. 11. *Hypersthene gabbro.*—Gray, with greenish tones when viewed at an angle to the surface, porphyritic with large poikilitic crystals of hornblende. Under the microscope the rock is found to have a poikilitic structure, large crystals of plagioclase and hornblende serving as hosts for hypersthene and augite, which are subhedral to euhedral and 3 millimeters in maximum length. The mineral composition of the rock may be represented approximately as follows: Plagioclase $>$ augite $\gtrless$ hypersthene $>$ hornblende $>$ biotite $>$ iron oxides $>$ chlorite $>$ epidote, apatite, zircon. The plagioclase is extensively altered to sericite, chlorite, and epidote but appears to have been at least as calcic as labradorite. The rock is granular and without schistosity or cataclastic structure and does not seem to have suffered any considerable metamorphism of the regional type.

No. 9. *Hypersthene gabbro.*—Similar to No. 11, but the feldspars are considerably more altered and the section shows hypersthene.

No. 13. *Hypersthene gabbro.*—This rock is very similar to No. 11, is medium grained and porphyritic, and contains large poikilitic phenocrysts of hornblende more than three-fourths of an inch long. Microscopic study shows the rock to be hypidiomorphic and granular and, save for the few large phenocrysts, to have a seriate fabric in which the individual crystals average between 1 and 2 millimeters in diameter, although the plagioclase may be as much as 4 millimeters in length. The composition of the rock may be represented as follows: Plagioclase $>$ hypersthene $>$ hornblende $\gtrless$ augite $>$ actinolite $>$ biotite $>$ chlorite $>$ epidote, with accessory magnetite, pyrite, and apatite. The plagioclase has the composition of labradorite (approximately $Ab_{45}An_{55}$) and is altering to sericite and epidote. The hornblende is changing to a mixture of actinolite and magnetite.

No. 10. *Altered gabbro.*—The hand specimen contains a large phenocryst of hornblende 15 millimeters long and 7 millimeters in diameter. In section the rock is found to consist of large euhedral crystals of hornblende and areas of chlorite aggregates, both of which include anhedral crystals of epidote. The section also contains considerable sericite (after plagioclase), iron oxides, and a small amount of biotite.

Both the diorite and the gabbro are cut by a great mesh of ramifying dikes of pink pegmatite, which is very conspicuous in contrast with the prevailing darker rock and may be distinguished many miles away from points along the rim of the canyon. These dikes, however, though widely distributed, form only a small part of the whole group of rock. In the gabbro many of them have been injected parallel to the sheeted structure. The pegmatite is very coarse and consists of quartz, microcline, and muscovite. In Ruby Canyon the gabbro is altered to a dark hornblende or biotite schist for a few inches away from the contacts of the pegmatite dikes.

GROUP IV. METABASITE AND METADIORITE.

At a point about a mile southeast of the mouth of Ruby Canyon the Granite Gorge narrows abruptly in response to a change in the character of the rock. There is a tremendous increase in the amount of pink intrusive material, and from this point to an undetermined point near the mouth of Turquoise Canyon, a distance of nearly 2 miles, the rocks are chiefly dark-green metabasites and metadiorites, cut by pink intrusives that in some places constitute at least half of the rock. The metabasites and metadiorites are in bands that have a more or less gneissoid structure. Metadiorite, or quartz diorite that has suffered little or no dynamic metamorphism, is the prevailing rock. Specimens Nos. 15, 16, 17, and 18 were obtained in Turquoise Canyon from separate bands, each of which has a width of several hundred feet. The strike is about due east or a little north of east and the dip from 45° to 60° S. Some of the bodies of pink intrusive rock are here more than 200 feet wide, and many of them send off numerous pegmatite veins and stringers into the metabasites. Graphic granite, fine-grained pink granite (No. 20), and coarse pink pegmatite consisting of quartz, microcline, and muscovite are the types present. Crystals of muscovite as much as 4 inches in diameter and crystals of microcline measuring as much as 6 inches were observed in the coarser pegmatite.

Petrography of specimens.

No. 15. *Metabasite.*—Dark-green coarse-grained, rather granular hornblende rock in which poikilitic crystals of hornblende 10 millimeters or more in length predominate over smaller crystals of biotite. In thin section the rock appears to be 80 per cent hornblende, which occurs in large crystals, including biotite, apatite, magnetite, epidote (possibly allanite), and garnet (?), named in the order of decreasing abundance. The constituent minerals are usually very ragged in outline, vary in size, and show no regularity of arrangement. Although the rock exhibits no schistosity or other evidence of dynamic metamorphism it has probably been entirely recrystallized, primarily through thermal agencies. It may have been derived from a basic rock such as gabbro, diabase, or pyroxenite. Rock of this type is not uncommon. In the Lake Superior area it has been called a greenstone, or hornblendite. Other workers have called it amphibolite, and still others metabasite. If a definite name is desired it seems best to use the term metabasite for these nonschistose, thermally metamorphosed rocks, reserving the terms amphibole or hornblende schist and amphibolite for the schistose phase of kindred metamorphic rocks. The term metabasite is applied to metamorphosed basic rocks ranging from metadiorites to amphibolitic schist.[1]

No. 16. *Metadiorite.*—Fine-grained dark-green granular rock. In section the rock has a seriate homeoid fabric in which the individual crystals are allotriomorphic, many of them nearly equant, and average about 0.5 millimeter in diameter. Plagioclase having the composition of calcic andesine is the predominant constituent, and plagioclase and hornblende are the essential minerals of the rock. The feldspar is altering to sericite, and some epidote has been developed. The hornblende crystals have a deep-green color, are of irregular shape, and may not be original. Quartz, if present, is subordinate. The rock also contains apatite, titanite, and iron oxides in accessory quantities. This rock shows no schistosity in thin section or in the small hand specimen. The character of the hornblende suggests that the rock has suffered some metamorphism. It was probably derived from a diorite, although it may have been originally a somewhat potassic gabbro.

No. 17. *Metabasite.*—Dark-green rock similar to No. 15, but finer grained. In thin section hornblende is found to constitute 90 to 95 per cent of the rock. Biotite, iron oxides, apatite, epidote, and possibly quartz are present in subordinate or accessory amounts. The hornblendes are anhedral and of ragged outline, average less than 1 millimeter in diameter, and show no regularity of arrangement. This rock is probably of the same origin as No. 15.

No. 18. *Metadiorite.*—Dark-green hornblende-rich rock resembling No. 16 but of slightly coarser grain. Under the microscope this rock is found to have a seriate fabric in which the individual crystals are anhedral and range from 0.5 to 2 millimeters in longer dimensions. It consists essentially of plagioclase, hornblende, biotite, and iron oxides, named in order of decreasing abundance. The plagioclase is altering to sericite but has the composition of andesine to labradorite. The rock contains a small amount of quartz and an accessory amount of apatite.

No. 20. *Granite.*—Medium-grained even-textured pink granite. In thin section this specimen has a seriate porphyroid fabric in which the individual crystals are anhedral and attain 4 millimeters in longer dimension but average about 1 millimeter. Mineralogically the rock consists essentially of quartz, microcline, soda plagioclase (ranging from oligoclase to albite), muscovite, and biotite named in the order of decreasing abundance. A small amount of orthoclase may also be present, and apatite and iron oxides occur in accessory amounts. Many of the feldspar crystals, particularly plagioclase, have a turbid, reddish appearance due to the presence of very finely divided iron oxides. They are also in small part altered to sericite.

The rocks of Group IV are very similar in character to those of the Gunnison River area in Colorado, as well as to certain pre-Cambrian rocks of the Lake Superior region.[2]

It was not possible to examine the boundary between the rocks of Group IV and the massive gabbro of Group III, but from a distance it had the appearance of an intrusive contact.

GROUP V. MICA SCHIST.

From a point near the mouth of Turquoise Canyon to a point about a mile below the mouth of Hermit Creek, a distance of 5⅔ miles, the rocks are a series of mica, quartz-mica, and chlorite schists in numerous roughly parallel alternating bands which vary in composition and texture and range from a few inches to several hundred feet in width. In a few places there are bands of hornblende gneiss and mica gneiss and a small amount of hornblende schist. All these rocks are very schistose. The prevailing strike is N. 40° E., and the dip ranges from steep northwest through vertical to steep southeast. There is a great deal of local faulting and some crumpling and mashing, so that there are many variations from the prevailing structure, which appears to be, roughly, that of a series of sharply compressed folds. The thickness of the series

[1] It has been used for similar rocks in Finland by G. V. Hackman and J. J. Sederholm.

[2] Williams, G. H., The greenstone schists of the Menominee and Marquette regions of Michigan: U. S. Geol. Survey Bull. 62, p. 146, 1890.

of banded schists can not be estimated, even approximately, but it is probably at least 5,000 feet. All the rocks of this group are cut by dikes of pink pegmatite of the character already described, but east of Agate Canyon the relative amount of this intrusive material is small.

Slate Creek occupies a long, straight canyon which runs about N. 40° E. Across Colorado River and directly in line with the canyon of Slate Creek is the still longer gorge of Crystal Creek, which drains the great Hindu Amphitheater. The rectilinear course of these two canyons is determined by a line of faulting in the Paleozoic strata which has guided their erosion. All the way down the inner gorge of Slate Creek and all the way up the inner gorge of Crystal Creek the strike of the bands of schist is parallel with the course of these gorges, and the dip is vertical or else steep to the northwest or southeast. The same bands of schist that are exposed in Slate Creek apparently continue across the river and on up Crystal Creek to the depths of the Hindu Amphitheater, where a small mass of strata of the Algonkian Unkar group overlies them, so that the total length of the exposure of these schist beds along the strike must be nearly 5 miles. A traverse was made across the upper part of the inner gorge of Slate Creek, in order to ascertain the general succession of the schist series in this locality. Here the structure is fairly simple, the dip being 75° SE. throughout the exposure examined. The section given below reads from west to east:

1. Beds of greenish-gray mica schist (specimens Nos. 22, 24, and 27), alternating with one another and with beds of pinkish-brown quartz-mica schist (No. 23). In some places the separate beds have a thickness of only a few inches; in others they are many feet thick. The contrast between the different types of schist is greater in the field than in thin section, owing to differences in color and in degree of weathering. In the field some of the layers, notably those represented by specimen No. 27, have a well-developed slaty cleavage and might be called slates. The name Slate Creek is derived from the occurrence of this rock. Many of the rocks were supposed in the field to be typical chlorite schists. The quartz-mica schists, owing to their density and fineness of grain, were supposed to be quartzites until the thin sections were examined. In the field there is a vague yet persistent suggestion in these layers of an original sedimentary cross-bedded structure which recrystallization and shearing had not been able entirely to obliterate. This feature and the variation in the schists across the strike suggested that they might be metamorphosed sediments. Thickness, 400 feet or more.
2. Hornblende gneiss (No. 26), apparently representing a metamorphosed quartz diorite that was intruded into the schists. In the field this rock resembles some of the metadiorite of Group IV. Thickness, 300 feet, more or less.
3. Fine-grained, finely banded granite gneiss, occurring, like the hornblende gneiss, in a band parallel with the schist bands. Thickness, 100 feet, more or less.
4. Mica schists of the same character as those of No. 1. Thickness, 200 feet or more.

Although the dominant strike is very persistent, there is a great deal of local folding and crumpling in the schists, and they are injected in places with pink feldspar and milky quartz.

In Boucher Canyon the rocks are essentially the same as on Slate Creek, but the structure is much more complicated by faulting and folding, so that it is difficult to pick out a dominant strike that is characteristic of the area. The dips, as elsewhere in the Archean, are very steep or vertical. The rocks are in alternating bands of varying composition; they are, however, rather more crumpled and mashed than those on Slate Creek. No. 31 is chlorite schist from this locality; No. 32 is quartz-mica schist which is hard to distinguish from quartzite in the field; No. 34 is a very fine grained fissile schist or slate. A bed of hornblende schist (No. 33) occupies a band 200 feet in width between the mica schists.

Petrography of specimens.

No. 22. *Mica schist* (chlorite schist).—Very fissile greenish-gray rock, with pronounced silvery sheen. In the thin section, cut parallel to the schistosity, the rock has a nearly equigranular fabric in which the individual grains range from 0.1 to 0.4 millimeter in diameter and, save for the micas, are equant to subequant. This particular section consisted essentially of quartz, muscovite, biotite, chlorite, altered feldspar, and epidote, named in about the order of decreasing abundance. A section cut transverse to the cleavage would give a better idea of the relative abundance of the mica. Zircon, apatite, garnet, magnetite, and other iron oxides are present in accessory amounts. The feldspars are sericitized, somewhat kaolinized, and stained with ferritic material, so that their character is not determinable. The section studied contains less chlorite than would be suspected from the hand specimen, but this is in part due to the softness of the chlorite and its consequent loss in grinding. These schists may well have been derived from sedimentary rock.

No. 23. *Quartz-mica schist.* — Dense pinkish-brown, very fine textured, banded quartzose rock. In thin section the rock manifests considerable lamellation and is nearly equigranular. The individual crystals average less than 0.1 millimeter in diameter and, save for the micas, are subequant to equant. The section consists of quartz, altered feldspar, muscovite, chlorite, and biotite, named in about the order of decreasing abundance. Curiously enough, the section shows more chlorite than that of specimen No. 22. Like No. 22 the schist contains a rather unusual amount of zircon and considerable magnetite, apatite, epidote, and garnet, all in accessory quantities. The feldspar is more abundant than in No. 22 and is very much altered and stained with iron oxides. Both orthoclase and plagioclase are present. The micas occur in minute individuals, a fact which accounts for the quartzose appearance of the schist in hand specimen.

No. 24. *Mica schist.*—Gray micaceous, very schistose rock with silvery sheen on cleavage surface. In thin section the rock is well lamellated and is made up of allotriomorphic grains mostly 0.3 to 0.5 millimeter in diameter. The essential mineral constituents are quartz, muscovite, and biotite, and the accessory minerals observed are zircon, magnetite, apatite, garnet, and chlorite. The schist contains very little if any feldspar but is richer in mica than No. 23.

No. 25. *Mica gneiss* (or granite gneiss).—Pink, very fine grained, delicately banded gneiss. In section the rock has a pronounced banded structure in which the individual crystals are allotriomorphic and average 0.15 millimeter in diameter. The rock consists of quartz, feldspar (microcline, soda plagioclase, orthoclase?), biotite, and chlorite, named in about the order of decreasing abundance. Epidote, apatite, zircon, magnetite, and other iron oxides occur in accessory amounts. The rock has the composition of a granite and might well be called a granite gneiss.

No. 26. *Hornblende gneiss.*—Dark-green medium-grained hornblendic rock with a strong suggestion of lamellation in the hand specimen. The thin section studied, probably cut parallel to the cleavage of the rock, displays little evidence of lamellation. It shows a seriate fabric in which the individual crystals are allotriomorphic and are 3 millimeters or less in longer dimension. The rock consists essentially of feldspar, quartz, hornblende, chlorite, and biotite, named in order of decreasing abundance. Epidote, zircon, apatite, iron oxides, and garnet are present in accessory amounts. The plagioclase is altered to sericite and is stained with iron oxides but probably has the composition of oligoclase. The hornblende and micas have very irregular and ragged outlines and are entirely without crystal boundaries. The rock represented by this specimen was probably derived from a rock having the composition of a quartz diorite.

No. 27. *Mica schist.*—Very fissile, slaty silver-gray schist. In a thin section cut nearly parallel to the schistosity the rock has a nearly equigranular fabric in which the constituent minerals are subequant to equant and average less than 0.2 millimeter in diameter. The dominant mineral constituents are quartz, muscovite, and biotite. The feldspar has nearly all been altered to sericite but may have constituted as much as 15 or 20 per cent of the rock. Zircon, apatite, epidote, and iron oxides are the commonest accessory minerals. The rock is a mica schist similar in composition to Nos. 22 and 24.

No. 31. *Chlorite schist.*—Silver-gray, micaceous, and very schistose. In a thin section cut nearly parallel to the schistosity the rock has a seriate fabric in which the individual grains are allotriomorphic and range in size up to 0.4 millimeter in length. Quartz, chlorite, biotite, and muscovite are the dominant mineral constituents, and iron oxides, zircon, apatite, tourmaline, epidote, and garnet occur in accessory amounts. Feldspar, in large part altered to sericite, is present in subordinate amount. The chlorite is probably slightly more abundant than either of the micas, so the rock may be called either mica schist or chlorite schist.

No. 32. *Quartz-mica schist.*—Gray compact quartzose schist with inconspicuous micas. In thin section the rock is found to be very fine grained, few of the largest crystals being as much as 0.2 millimeter across and the micas usually being measured in hundredths of a millimeter. It consists essentially of quartz, muscovite, biotite, feldspar, and chlorite, named in about the order of decreasing abundance. The feldspar is subordinate in amount and is in part plagioclase (about oligoclase) in fresh individuals, showing good albite twinning. Epidote, zircon, apatite, calcite, and iron oxides are the commonest accessory minerals.

No. 33. *Hornblende schist.*—Dark-green, moderately schistose hornblende rock. The thin section exhibits a schistose structure in which hornblende crystals making up 90 per cent of the rock, are as a rule from 0.5 to 1 millimeter in length and are entirely without crystal boundaries. Quartz, feldspar, and epidote occur in subordinate amounts; iron oxides, calcite, and apatite are accessory. The feldspar is probably all plagioclase, but is extensively altered to sericite.

No. 34. *Mica schist.*—Very fine fissile, gray schist with thin slaty cleavage. The thin section exhibits fine lamellation, in which the banding ranges from 0.02 to 0.06 millimeter in width, although the individual micas are commonly 0.3 to 0.5 millimeter in length. The principal constituents of the rock are quartz, muscovite, biotite, chlorite, iron oxides, and epidote. Feldspar is present in subordinate amounts, but owing to the fineness of grain and the abundance of dark minerals its relative proportion is difficult to determine.

The mica schists of Group V strongly suggest metamorphosed sediments, but, as is usually the case, microscopic evidence can be considered only auxiliary to the field evidence. The rocks of this group likewise resemble the quartz-mica schists of the Gunnison Canyon area, which have been separated from the more prevalent biotite schist type of that region.

The character of the boundaries between Groups IV and V and between Groups V and VI could not be determined on the present trip.

GROUP VI. GRANITE GNEISS AND AMPHIBOLITE.

From a point about a mile west of the mouth of Hermit Creek to a point about a mile west of the mouth of Clear Creek, a distance of about 9½ miles, the rocks are chiefly granite gneiss and amphibolite.

On Hermit Creek the prevailing rock is a coarse pinkish granite gneiss (No. 35). The gneissoid character is strongly developed, and the banding is very wavy and crumpled in detail. The strike of the gneissoid banding is N. 20° E. and the dip 80° SE. In places the mica in the gneiss is partly segregated in curious porphyritic lumps. No. 40 is a specimen of this phase of the rock. There are areas of a finer-grained gneiss (No. 38), and here and there narrow bands of chlorite schist (No. 39), probably inclusions.

The gneiss is everywhere crowded with pink pegmatitic injections. The pegmatite consists of quartz, microcline, muscovite, and biotite. Some of the bodies of pegmatite are several hundred feet wide and contain crystals of muscovite as much as 6 inches in diameter.

The gneiss in the canyon of Salt Creek (No. 45) is somewhat less micaceous than that on Hermit Creek but differs little in general appearance. It suggests a sheared granite in the field. The strike of the gneissoid banding is N. 20° E. and the dip 75° SE. The gneiss contains some bands of amphibolite (No. 46), which occur at intervals of about 100 feet and range from 1 foot to 6 feet in width. They have the same strike and dip as the gneisses.

The Archean was next visited at the "cork-screw" on the Cameron trail, where the trail descends to Pipe Creek in the line of the Bright Angel fault. The rock west of the fault is a pink medium-grained granite (No. 49) that is somewhat less gneissoid than the gneisses already described but otherwise resembles them in appearance. The rock on the east side of the fault and on the east side of Pipe Creek is a much-contorted greenish hornblende schist (No. 50), which is much injected with pink pegmatitic material. The strike is northeasterly and the dip nearly vertical. This hornblende schist was also found underneath the tiny cap of Unkar strata that lies below the end of the long promontory of Tapeats sandstone jutting out east of Pipe Creek, and it appears to be exposed over a considerable area to the southeast up Colorado River.

Petrography of specimens.

No. 35. *Granite gneiss.*—Coarse, lamellated micaceous rock with large crystals of feldspar and quartz. In thin section the rock exhibits evidence of crushing and partial granulation. The individual crystals have very ragged outlines and are entirely without crystal boundaries. They range in size from a fraction of a millimeter to 3 millimeters. The rock consists chiefly of quartz, biotite, muscovite, sillimanite, and feldspar, with accessory apatite, zircon, garnet, and magnetite. The larger quartz crystals show undulatory extinction. The feldspar is altered and iron stained, but is determinable as orthoclase and soda plagioclase. The sillimanite occurs in myriads of long, slender needles, which give it a fibrous appearance, and is probably of the variety called fibrolite.

No. 38. *Granite gneiss.*—Pinkish-gray, rather fine grained. The gneissoid structure of the rock is well shown in the thin section by the parallel arrangement of the micas. The individual crystals are of irregular outline, and the largest are 1.5 millimeters in longer dimension. Quartz is the most abundant constituent, and with altered feldspar, muscovite, biotite, and chlorite makes up most of the rock. Garnet, iron oxides, apatite, and zircon are the commonest accessory minerals. The feldspar is sericitized and stained with iron oxides, but is in part determinable as soda plagioclase. The gneiss was probably derived from a granite and may be called either a granite gneiss or mica gneiss.

No. 39. *Chlorite schist.*—Greenish-gray schistose rock. In thin section the schistosity of the rock is very pronounced. The bands of chlorite alternate with quartz and sericitic muscovite, which has apparently been derived from the alteration of feldspar. The rock is rather fine grained, the quartz crystals and pseudomorphs after feldspar being, as a rule, not more than 0.3 millimeter in longer dimension, although the chlorite crystals may be as much as 3 millimeters in length. Quartz, chlorite, and sericitic muscovite are the chief mineral constituents; subordinate amounts of feldspar and iron oxides, with accessory apatite, zircon, garnet, and epidote, are also present.

No. 40. *Segregation in gneiss.*—The chip is largely muscovite in a well-lamellated, contorted structure, with feldspar and quartz. The microscope reveals a mixture of quartz, altered feldspar, muscovite, chlorite, and iron oxides. Some of the muscovite crystals are very large and poikilitically include the other constituents. The feldspar is altered to sericite, somewhat kaolinized and iron stained, but apparently was originally orthoclase and soda plagioclase. Zircon and apatite were observed in accessory amounts. The

30830°—17——8

mineral constituents of the rock are entirely without crystal boundaries, and many of the mica crystals are contorted and broken.

No. 45. *Granite gneiss.*—Pinkish gray and well banded. The thin section exhibits gneissoid structure with a seriate fabric in which the individual crystals are allotriomorphic and range from a fraction of a millimeter to 5 millimeters in longer dimension. Quartz, feldspar, and mica are the dominant minerals; iron oxides, apatite, and zircon occur in accessory amounts. The feldspar consists of microcline, soda plagioclase, and orthoclase and is slightly altered to kaolin and, in a less degree, to sericite.

No. 46. *Hornblende schist or amphibolite.*—Dark green, medium grained, and very schistose. In a section cut nearly parallel to the cleavage the schistosity, which is well displayed in the hand specimen, is not at all evident. Hornblende, soda plagioclase, and quartz are the principal constituents; apatite, iron oxides, and zircon are present in accessory amounts. The plagioclase is largely altered to sericite but apparently had the composition of oligoclase to andesine. This schist is similar to No. 4, of Group I.

No. 49. *Granite.*—Pink medium-grained biotite granite. In thin section the rock has a seriate porphyroid fabric in which the individual crystals are allotriomorphic and range in size from a fraction of a millimeter to more than 2 millimeters. Quartz, feldspar, and biotite are the principal constituents; iron oxides, zircon, and apatite occur in accessory quantities. The feldspar is somewhat kaolinized and consists of microcline and plagioclase having the approximate composition of oligoclase.

No. 50. *Hornblende schist.*—Dark-green medium-grained schistose rock, with reddish feldspar. In section the rock shows a schistose structure produced by the parallel arrangement of the hornblende crystals. The individual minerals are allotriomorphic and range from a fraction of a millimeter to more than 2 millimeters in longer dimension. The rock consists essentially of hornblende, plagioclase, quartz, and biotite, named in about the order of decreasing abundance. The plagioclase, which has approximately the composition of andesine, has a reddish color due to inclusions of numerous minute specks of iron oxide. Apatite, titanite, epidote, iron oxides, and calcite were observed in accessory amounts.

About a mile west of the mouth of Clear Creek, on the north side of the river, there is a huge irregular body of what appears to be massive granite in the gneisses. Owing probably to its massive character this rock resisted the pre-Cambrian erosion and now projects well above the plane of the unconformity at the base of the Tapeats sandstone and excludes the sandstone entirely. This monadnock was noted by Davis.[1] It is, so far as known, the highest monadnock of Archean rock in the Kaibab division of the canyon, although it is several hundred feet lower than a number of the monadnocks of Algonkian quartzite.

GROUP VII. MICA SCHIST.

From a point half a mile west of the mouth of Clear Creek to a point near the mouth of Grapevine Creek, a distance of 3½ miles, the rocks are a series of mica schists and mica quartzites which strike northeast and dip vertically or steep northwest. These rocks, exposed southwest of Vishnu Temple, were named the Vishnu terrane by Walcott,[2] who recognized their sedimentary origin. In the exposure across the strike there is probably some duplication by folding or faulting, but the thickness must be at least 5,000 feet. The same rocks are exposed for a distance of 2 miles along their strike in the gorge of Clear Creek, on the north side of Colorado River.

In Lone Tree Canyon the prevailing rock is a fine-grained pinkish to greenish gray quartz-sericite schist (No. 53), which is the least metamorphosed rock of supposed sedimentary origin that was found in the Archean complex in the Grand Canyon. The original bedding can be made out in places and corresponds in the main with the direction of the schistose banding; the separate beds are distinguished by slight differences in color and texture. Nearly all the rocks have a very fine, almost paper-thin slaty lamination. Some beds display a faint cross-bedded structure. The prevailing strike is between N. 20° E. and N. 70° E., and the dip between 45° and 80° NW. They are cut by numerous faults of small throw. It seemed probable in the field that the rock was originally a micaceous shaly sandstone like the Dox sandstone of the Algonkian Unkar group or like many beds in the Cambrian Tonto group. Curiously, many of the beds show numerous small circular spots of a magenta color which are similar to the spots found all through the strata of the Unkar and Tonto groups.

Specimen No. 54 is a piece of sandstone from the overlying unmetamorphosed Tonto group taken for comparison with the Archean specimen No. 53. When the labels are removed it

[1] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Coll. Mus. Comp. Zoology Bull. 38, geol. ser., vol. 5, No. 4, fig. 15, p. 174, 1901.

[2] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Ariz.: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 506, 1894.

is impossible to tell with the unaided eye which is the unmetamorphosed rock, and in thin sections the resemblance is almost as close.

The rocks of Lone Tree Canyon greatly resemble in the field those of Group V in Slate Creek, in the Shinumo quadrangle, but are less metamorphosed. There are no pink intrusions in the schists of Lone Tree Canyon, but there is a small amount of milky quartz in thin veins and stringers.

In the canyon of Boulder Creek the rocks and structure are practically the same as in Lone Tree Canyon.

In the canyon of Grapevine Creek, near the east end of the exposures of Group VII, the rocks are mica schists and quartz-mica schists in alternating bands, injected by dikes of coarse pink pegmatite. There is a great deal of milky quartz in the schists, in veins and stringers. The pink intrusive rocks are of the same character as those in other groups of the Archean. In this locality they occur for the most part in very irregular masses, some of which appear to be mashed and folded with the schists. Specimen No. 56 is mica schist from the canyon of Grapevine Creek; No. 57 is quartz-mica schist. There is a great deal more evidence of metamorphism here than in Lone Tree Canyon. The schists are greatly mashed and contorted and no prevailing strikes and dips are obtainable. These rocks in the canyon of Grapevine Creek resemble in the field those near the eastern boundary of Group II, at the Cable Crossing, in the Shinumo quadrangle.

Petrography of specimens.

No. 53. *Quartz-sericite schist.*—White, with pink tones on cleavage surface. Thin-bedded, platy, with fine sandy texture on surface transverse to cleavage. In thin section quartz is the most abundant mineral and occurs in allotriomorphic grains usually less than 0.2 millimeter in diameter, although there are coarser segregations in which the crystals may be as much as 0.5 millimeter across. These coarser areas show less interstitial material and may represent pebbles in the original sediment. The quartz grains are cemented together by a finely comminuted aggregate composed chiefly of sericitic muscovite, chlorite, and epidote, which may have been derived from the cementing material of the original rock. Considerable feldspar may have originally been present, but it is now almost entirely altered to sericite and in minor degree to kaolin. Muscovite, biotite, and epidote occur in subordinate amounts; zircon, tourmaline, apatite, and iron oxides are the commonest accessory minerals. The rock has the appearance of a more or less metamorphosed shaly sandstone or grit, although it does not show pronounced evidence of recrystallization and pressure. The term quartz-sericite schist is suggested as indicating its content and structure without connoting its origin. The terms mica quartzite or sericite quartzite might be used equally well. The rock is strikingly similar in structure and composition to specimen No. 54, from the Cambrian Tapeats sandstone, although it is less even grained and apparently contains more interstitial material. However, a section oblique to the cleavage would have been more satisfactory for comparison of the two rocks than the one studied.

No. 54. *Tapeats sandstone.*—Bluish-gray thin, platy sandstone. The section, cut obliquely to the cleavage of this rock, resembles No. 53 rather closely. More than 90 per cent of the rock is quartz in grains of irregular shape, averaging about 0.2 millimeter in diameter. Mica, chiefly biotite, and sericitic muscovite have been developed and occur in bands about 0.5 millimeter apart, giving the rock its good cleavage. A few relics of much-altered feldspar are present, and chlorite, epidote, zircon, and iron oxides were observed in subordinate or accessory quantities.

No. 56. *Mica schist.*—Gray, with silvery sheen on cleavage surface, well lamellated and fine grained. In section the rock has a pronounced schistose structure in which the individual grains are allotriomorphic and are usually less than 0.2 millimeter in diameter, although the micas may be as much as 1 millimeter in longer dimension. Quartz, muscovite, and biotite are the chief mineral constituents of the rock. The feldspar has been almost entirely altered to sericite and kaolin but was probably subordinate to the minerals named. Epidote, zircon, apatite, and iron oxides were observed in accessory amounts.

No. 57. *Quartz-mica schist.*—Fine grained, compact, dark gray, quartzose. In thin section the rock has a vague schistose structure, and the individual crystals are allotriomorphic and average about 0.2 millimeter in diameter. Quartz, feldspar, biotite, and muscovite are the dominant mineral constituents, named in about the order of descending abundance. The feldspar is altering to sericite and in less degree to kaolin but apparently was originally orthoclase and soda plagioclase. The micas are not so abundant as in most of the other schists and occur in fine leaves. Zircon, apatite, epidote, and iron oxides are the commonest accessory minerals.

Specimens Nos. 56 and 57 resemble Nos. 31 and 32, respectively.

As was the case with most of the other groups of Archean rock, neither the eastern nor the western boundary of Group VII could be reached on the present trip because there was no place near them where a break in the Tapeats cliff would permit descent. Viewed from a distance, the boundary between Groups VI and VII appeared to be a fault, but the increasing intensity of metamorphism and the injected character of the eastern border of

Group VII suggested that the boundary between it and Group VIII may be an intrusive contact.

GROUP VIII. GRANITE GNEISS.

Group VIII is exposed from a point near the mouth of Grapevine Creek to the east end of the Granite Gorge, a distance of $3\frac{7}{10}$ miles. The rocks were examined in the small canyon half a mile east of Cottonwood Creek, in the canyon of Hance Creek, and in the Granite Gorge between Mineral Canyon and Red Canyon. In the locality east of Cottonwood Creek the prevailing rock is a much-contorted pinkish gneiss (No. 60), which in places grades into a more micaceous gneiss (No. 61). The gneiss is much injected by pink pegmatite and milky quartz, which appear to be folded with it, and is cut by younger bodies of pink pegmatite. Because of the intense crumpling of the gneiss there is no general strike and dip traceable over any large area.

The gneiss in the canyon of Hance Creek resembles that just described. There are two chief types which grade into each other—a pink granite gneiss (No. 62) and a gray micaceous gneiss (No. 63). The amount of pink pegmatitic material is even greater than in the locality east of Cottonwood Creek, and some of it may be folded and mashed with the gneiss. In places the gneiss itself grades into pegmatite and aplite. The contortion is so great that no prevailing strike and dip can be made out.

Between Mineral Canyon and the east end of the Granite Gorge the rocks are in gneissoid bands of varying composition, but the prevailing rock is pink granite gneiss (Nos. 64 and 66). There are scattered bands of garnetiferous mica schist (No. 65) and bands of biotite schist (No. 67), also considerable pegmatite. In general, the strike of the gneissoid banding is northeasterly and the dip nearly vertical.

Petrography of specimens.

No. 60. *Granite gneiss.*—Red, fine-grained, and banded. The section, which is cut parallel to the banding, exhibits a seriate porphyroid fabric in which the individual crystals range from a small fraction of a millimeter to more than 1 millimeter in diameter. Quartz, feldspar, and biotite are the principal constituents. The feldspar consists of orthoclase, microcline, and microperthite, in nearly equal amounts, and plagioclase having about the composition of oligoclase. The plagioclase and orthoclase particularly and the microcline to a less degree are weathered and stained and include numerous fine grains of iron oxides which give them a reddish color. The biotite is leached out and is altering to chlorite. Muscovite, apatite, zircon, and iron oxides occur in subordinate or accessory amounts.

No. 61. *Mica gneiss.*—Well-banded gneissoid rock containing considerable mica. Under the microscope the rock exhibits a gneissoid structure and is made up of allotriomorphic crystals, the majority of which range between 0.5 and 1.5 millimeters in longer dimension. Quartz, plagioclase (chiefly oligoclase), biotite, and orthoclase are present, named in about the order of decreasing abundance. As in No. 60, the feldspars are weathered and iron stained and the biotite is being leached and altered to chlorite. Zircon, apatite, and magnetite are present as accessory minerals; chlorite, iron oxides, and epidote are largely products of surface alteration. The composition of this rock hardly permits its being considered a metamorphosed granite of the normal microcline type. The uneven fracture, the segregation of the several constituents, and the general appearance in the hand specimen, together with the predominance of plagioclase over potash feldspar in the thin section suggest that it is an injection gneiss.

No. 62. *Granite gneiss* (or gneissoid granite).—Pink medium-grained granitic rock. The thin section exhibits a seriate intersertal fabric in which the individual crystals are allotriomorphic and range in diameter from less than 0.5 to 2 millimeters. The rock consists of quartz, microcline, soda plagioclase, orthoclase, biotite, and muscovite, named in approximately the order of decreasing abundance. The orthoclase and plagioclase are extensively altered to sericite and kaolin and are colored red by fine inclusions of iron oxides. Apatite, zircon, and magnetite occur in accessory amounts, and muscovite, epidote, chlorite, and iron oxides are for the most part products of alteration. Many of the larger individuals, particularly the microcline, show poikilitic structure in thin section, and a few of the quartz grains show undulatory extinction. This feature, together with the intersertal fabric, is indicative of the mashing and partial recrystallization suffered by the original granite.

No. 63. *Granite gneiss.*—Dark-gray medium-grained biotite-rich gneiss. In thin section the gneiss has a seriate fabric in which the individual crystals are of irregular shape and range from a fraction of a millimeter to more than 3 millimeters in longer dimension. Quartz, altered feldspar, biotite, and muscovite are the principal constituents. The feldspars are extensively weathered and iron stained, and kaolin is the chief alteration product, although considerable sericite has also been developed. Some of the biotite is brown and some green, and it is in many places leached or altered to chlorite and magnetite. Epidote, zircon, apatite, and iron oxides occur in minute quantities.

No. 64. *Granite gneiss.*—Pinkish fine-grained granite gneiss. In section the rock has but a suggestion of gneissoid structure and has a seriate intersertal fabric in which the individual crystals are allotriomorphic and are as a rule not more than 1 millimeter in longer dimension. Mineralogically the rock is very similar to Nos. 60 and 62 and consists essentially of quartz, soda plagioclase, microcline, muscovite, biotite, and possibly a small amount of orthoclase, with the usual accessory and secondary constituents. The undulatory extinction of the quartz, the poikilitic character of the larger crystals of microcline, and the intersertal fabric are evidences of the pressure and partial recrystallization suffered by the rock.

No. 65. *Coarse garnetiferous mica schist.*—Coarse, well-lamellated mica aggregates. The section shows a schistose mixture of biotite, muscovite, garnets, and iron oxides (chiefly magnetite). The micas are 10 millimeters or more in length. The garnets are pink, many of them include biotite and iron oxides, and a few are surrounded by rims of chlorite, to which the garnet is apparently altering. A few grains of zircon were observed, and a small amount of badly stained feldspar may be present in one of the two slides studied. No quartz was recognized in the sections, although a little may be present in the hand specimen.

No. 66. *Granite gneiss.*—Pinkish gray and gneissoid. Under the microscope the rock is found to have a seriate intersertal fabric in which the individual crystals are allotriomorphic and range in size from a small fraction of a millimeter for the interstitial crystals to 4 millimeters and more for the larger ones. The rock is very similar to the granite gneisses already described and consists of quartz, orthoclase, microcline, soda plagioclase, biotite, muscovite, and iron oxides, named in about the order of decreasing abundance. Apatite and magnetite occur in accessory amounts, and chlorite, sericite, kaolin, epidote, and iron oxides have resulted from weathering and other processes of alteration.

No. 67. *Biotite schist.*—Dark gray, with obscure pinkish tones; well foliated and reddish brown on weathered surfaces. A section cut parallel to the schistosity discloses a nearly equigranular fabric in which the individual crystals are allotriomorphic and, save for micas, are rarely as much as 0.2 millimeter in diameter. The micas are of irregular and ragged outline and are usually about 0.3 millimeter in longer dimension. Feldspar, extensively altered to sericite, quartz, and biotite, are the principal mineral constituents, and apatite, iron oxides, epidote, zircon, and garnet were observed in accessory amounts. The feldspar is too much altered for determination but was originally present in quantity equaling or exceeding the quartz. Inclusions of apatite prisms are unusually numerous, but muscovite of the sericitic variety is rare or absent. This rock has been entirely recrystallized and has been rendered completely schistose during the process of metamorphism, so that no trace of its original structure remains. However, it was most probably derived from a massive igneous rock of granitic character. It resembles Nos. 1, 3, and 4 and other mica schists already described, although under the microscope it is found to have a higher feldspar content. It is very similar to the most prevalent type of biotite schist of the Gunnison River area in Colorado.

CONCLUSIONS.

CORRELATION.

It will be apparent to the reader that the present study, which was made at points where the topography permitted access to the Archean rather than in places where the importance of Archean structure demanded attention, has yielded data that are rather too fragmentary to be of much value in solving the problems of Archean structure and history in the Grand Canyon region. Yet it has afforded a fair estimate of the general character of the rocks, and a few conclusions may be drawn.

The three groups of mica schist (Groups II, V, and VII) are apparently parts of a single series of rocks. They are practically identical in mineral composition, are similar in appearance in the field, and are supposed to have had, for the most part, a similar origin.

Groups I, VI, and VIII, chiefly granitic gneiss, hornblende gneiss, and amphibolite, comprise rocks which, collectively, are very similar in lithology and structure. They may be included in one series and called gneisses, although the rocks within the groups represent several periods of geologic time and doubtless when a detailed study is made they will be differentiated into more than one series on the evidence of their origin and history.

The relations of the greenstones comprising Group IV are uncertain, but the metabasites resemble many of those in the gneiss series. It seems probable that this group belongs with the gneisses, though further investigation may show that the metadiorite is a part of the diorite of Group III that has suffered thermal metamorphism.

The massive basic rocks are the quartz diorite and hypersthene gabbro of Group III. They probably represent postdeformation intrusions or, at any rate, relatively late intrusions in the complex.

The pink siliceous intrusive rocks comprise granite, aplite, and pegmatite and are the most widely distributed of the Archean rocks. They probably represent several periods of igneous activity. The older material is associated chiefly with the gneisses and in places appears to be mashed and folded with them. It does not appear to be associated with the schists except in places near the borders of the schist groups. The younger material is by far the most abundant and widely distributed rock of the series. It is chiefly coarse pegmatite, which occurs typically in dikes that cut every group of rock in the Archean.

Estimated roughly, the gneisses comprise perhaps 50 per cent of the rocks exposed in the Granite Gorge, the mica schists 30 per cent, the basic intrusive rocks 10 per cent, and the pink siliceous intrusive rocks 10 per cent. The relative amount of the pink siliceous rocks is hardest to estimate because of their wide though irregular distribution. It may be very much more than 10 per cent.

ORIGIN AND HISTORY.

The mica schists are clearly the products of regional metamorphism, for nearly everywhere they are thoroughly schistose and entirely recrystallized. Those in Lone Tree Canyon are the least metamorphosed, and in that locality there is evidence that they represent an originally sedimentary series. Inasmuch as the mica schists in all the other localities are very similar in mineral character to those in Lone Tree Canyon, it seems not improbable that they also are in large part, if not entirely, of sedimentary origin.

Both the field relations and the microscopic study indicate that the gneisses are igneous in origin, but it is clear that they have had a long and complex history. Most of them are medium to coarse grained rocks with a pronounced gneissoid structure, which is in general parallel in trend with the similar structure in the schists. These gneisses, with the schists, have gone through at least one period of regional metamorphism. Many of the gneisses are thoroughly recrystallized; some appear to represent metamorphosed quartz diorites; others, metamorphosed granites; still others, metamorphosed basic rocks. Some of the granite gneisses are injection gneisses; others, very little altered, are pressed granites. Throughout the gneisses granitic rock,[1] whether older and very gneissoid or younger and little sheared, is the predominating type. In places the gneiss contains bodies of chlorite or mica schist that are thought to be inclusions.

Perhaps the most important problem of the Archean geology of the region is the relation of the gneisses to the schists. If the schists are, as the evidence seems to indicate, a metamorphosed sedimentary series, are the gneisses the basement upon which these old sediments were laid down, or are the gneisses wholly or in part intrusive in the schists? The solution of this problem must depend on future study in the field. Unfortunately, on the present trip, none of the boundaries between the groups of rocks were near the places where access to the Archean was to be had, and so they could not be examined. These boundaries are the critical localities of the Archean, and the study of them will undoubtedly lead to the deciphering of much of the geologic history.

Some evidence that may aid in solving this problem was obtained on the present trip. On Slate Creek a broad band of hornblende gneiss was found between the prevailing bands of mica schist; associated with the hornblende gneiss is a band of mica gneiss or granite gneiss. The study of these gneisses in thin section indicates that the hornblende gneiss is a metamorphosed quartz diorite and that the mica gneiss is a metamorphosed granite. The hornblende gneiss and the mica gneiss appear to represent quartz diorite and granite intruded into the schists before the close of the period of regional metamorphism. Thus it is probable that a part, at least, of the rocks of the gneiss series are intrusive in the schists.

The great amount of pegmatitic material in the schists near the eastern boundary of Group VII suggests that this boundary may prove to be an intrusive contact between the schists and the granitic gneiss (probably an injection gneiss) of Group VIII.

It is the impression of the writers that when the history of the gneisses and schists is worked out it may be found that some of the greatly wrinkled and contorted granitic gneisses are the oldest rocks of the Archean and are a part of the original basement upon which the schist series of metamorphosed sediments was laid down; that both before and for some time after the deposition of the sediments there were long periods of complex igneous intrusion now represented by amphibolite, granite gneiss, and metadiorite; and that some of these intrusives penetrated the sediments after they were deposited.

The most obvious event in the Archean history is the regional metamorphism that in-

[1] The term granitic is used here in a broad sense for rocks that were originally granite, granodiorite, monzonite, or quartz diorite.

volved both the gneiss and schist series. As a result of it most of the rocks were recrystallized and nearly all of them acquired a gneissoid or schistose banding which has a dominant northeast strike and a nearly vertical dip. This structure suggests that the compressive forces acted either from the northwest or from the southeast. It may be noted that a similar structure characterizes the Archean complex in the Globe region described by Ransome,[1] and the complex on the west and southwest border of the Grand Canyon district, described by Schrader.[2]

The massive basic intrusive rocks of Group III may be younger than the period of regional metamorphism. The quartz diorite cuts the schists of Group II, but the relation of the gabbro to the diorite and that of both the gabbro and the diorite of Group III to the rocks of Group IV are not known. None of the earlier pink siliceous intrusives are found in the diorite and gabbro, which, however, are cut by the later pegmatites of the pink siliceous series.

The age of the earlier granite and pegmatite of the series of pink siliceous intrusives is not clear. Some of the material is associated with certain granite gneisses in such a way as to suggest that its intrusion accompanied or closely followed that of the material from which this gneiss was derived. It was rather difficult to determine whether this material has really suffered deformation, whether it was intruded during deformation, or whether it was intruded after deformation, following the contortions of an already deformed structure. Detailed study may show, therefore, that some of these rocks should be classed with the gneisses, if they prove to have suffered deformation. No doubt some of the pegmatitic injections accompanied the regional metamorphism. Others are thought to have been associated with certain injection gneisses whose relative age is not yet known.

There are many bodies of pink granite that are clearly later than the regional metamorphism. Perhaps the latest outburst of pegmatitic activity accompanied or closely followed the intrusion of these granites. The pegmatites of this latest outburst cut every group of rock in the Granite Gorge and record the latest decipherable event in the igneous activity of Archean time. Some of these pink granitic intrusives are usually visible, from whatever point the visitor may view the inner canyon. Because of their wide distribution and conspicuous appearance the name Granite Gorge is not inappropriate, although pure granite is far from being the most abundant rock in the gorge.

The following summary, by Lindgren,[3] of the igneous activity in the Cordilleran region in pre-Cambrian time is of interest in comparison with the present study of the Archean in the Grand Canyon. The agreement seems close enough to show that when the igneous history of the pre-Cambrian in the Grand Canyon is unraveled it will be found to differ little from that of the great region of which the Grand Canyon district is a part.

Pre-Beltian:
- Granitic gneisses (oldest); restricted areas.
- Surface lavas and tuffs; restricted areas.
- Granitic intrusions, now gneisses; small areas.
- Basic intrusions; small areas.
- Granitic intrusions; very large areas.
- Pegmatitic intrusions; large areas.

Beltian: Diabase intrusions, probably with basalt flows; small areas.

The pre-Beltian of Lindgren is the Archean of the Grand Canyon. The Beltian is the Algonkian Grand Canyon series; it is made up in the Grand Canyon, as elsewhere, of diabase intrusions and basalt flows.

The Archean complex of the Grand Canyon is now known as the Vishnu schist in the usage of the United States Geological Survey. It is evident, however, from the present study that the name includes two or more very different series of rocks. Doubtless it will be advisable at some future time to restrict the name Vishnu schist to the mica schist series and give another name or names to the gneisses, but until a more detailed study is made a change in the present usage would be premature.

[1] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, p. 24, 1903.

[2] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: U. S. Geol. Survey Bull. 397, p. 29, 1909.

[3] Lindgren, Waldemar, The igneous geology of the Cordilleras and its problems: Problems of American geology, p. 246, Yale University Press, 1915.