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AGE OF CATOCTIN VOLCANIC ROCKS IN VIRGINIA

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Abstract. This article discusses the Catoctin volcanic series in northern and central Virginia and its relation to associated rocks. Outcrops of these volcanics diverge near the Maryland-Virginia line to form two belts which extend as far as central Virginia. These belts occupy the eastern and western flanks of the Blue Ridge Province. Granites and granite gneisses compose the central part of the Blue Ridge Province. Granodiorite and granites underlie the western Catoctin belt, and metasediments generally underlie the Catoctin of the eastern or Bull Run - South Mountain belt. A normal fault delimits the eastern side of the Blue Ridge Province, and east of this fault the Catoctin and associated rocks are dropped down, and locally covered by Triassic sediments. Outliers in the Blue Ridge Province of Lower Cambrian sediments (Unicoi and Loudoun formations) unconformably overlie granodiorite, granites, Catoctin intrusions and Catoctin volcanics.

Evidence for the intrusion of granodiorite and granite into Catoctin of the Blue Ridge belt is as follows: Localities are known where definite intrusions may be seen in the Catoctin. This type of penetrating intrusion is not common; also locally, these intrusions are altered to unakite. Localities occur where fragments of Catoctin are found in the granodiorite. If the Catoctin flows were poured out over the weathered surface of the intrusions, as some believe, fragments of granodiorite and granite

should occur in the lower part of the flows, but no such ~~condition has~~ occurrences have been reported. The surface underneath the Catoctin is exceedingly irregular and bosses of granite and granodiorite crop out through the Catoctin in many places. The intrusive rocks are fine-grained and saussuritized locally near the Catoctin contact. Geologic mapping carried out on a regional scale indicates a close relationship between the occurrence of unakite and associated types of alteration, and the contact of the intrusives with the Catoctin. The primary copper ores which occur in the Catoctin are closely related to the intrusions.

Evidence as stated above remained unchallenged and was accepted until Jonas and Stose (1939, pp. 575-593) reported the occurrence of arkose and tuff (Swift Run formation) between the Catoctin and granodiorite at Swift Run Gap in Greene County. Later, R. O. Bloomer and R. E. Bloomer (1947, pp. 94-106) reported a similar formation (Oronoco) in the Buena Vista quadrangle, ~~concluding~~ and concluded that the Catoctin thus belongs to the lower part of the Unicoi formation and is Lower Cambrian in age. It is the contention of this writer that both the "Swift Run" formation and the "Oronoco" formation are actually outliers of the Unicoi which contain, locally, a basal Cambrian flow and also tuffaceous material (Lower Cambrian tuff, Catoctin and granite waste). These outliers occur above the Catoctin and the intrusions and at their contacts, but thus far, where direct contacts can be seen, no sediments have been observed between the Catoctin and the intrusions.

In the eastern Catoctin belt, flows are underlaid by

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the Fauquier formation in northern Virginia and Lynchburg gneiss in central Virginia. They are ~~overlaid~~ overlain by a pure, fine-grained white saccharoidal quartzite and mica schist in the Bull Run Mountain district, and locally contain beds of this quartzite. The Catoctin and its overlying metasediments are faulted down east of the Catoctin Mountain border fault, and exposed in a large anticline along James River in central Virginia where they have been described by the writer (Furcron, 1935).

Dikes of Catoctin age cut the Lynchburg gneiss and the Fauquier formation. Jonas and Stose (1939, p.590) and the Bloomers (1947, p.100) refer to certain pyroxene diabase dikes in the Blue Ridge belt, which cut the granodiorite and granite, as dikes of Catoctin age. There is evidence to indicate that these slightly altered dikes are in no way related to the Catoctin volcanics.

Jonas and Stose (1939, p.575) and the Bloomers (1947, p.106) have correlated these unmetamorphosed arkoses (Swift Run and Oronoco formations, respectively) with the highly metamorphosed Lynchburg gneiss. However, mapping shows that they are equivalent to Unicoi and Loudoun, which formations are known to be unconformable over Lynchburg gneiss, the Fauquier formation and the Catoctin.

Three geologic maps of different sections of the Shenandoah National Park area covering 200 square miles are submitted. These illustrate the distribution of the Catoctin volcanic rocks and their relation to intrusives and to Lower Cambrian sediments.

AGE OF CATOCTIN VOLCANIC ROCKS IN VIRGINIA

A. S. Furcron

INTRODUCTION

The Catoctin series of Virginia has been described by many writers in numerous articles; its distribution is well shown on the geological map of Virginia, 1928. Thus, in this paper, its petrology, distribution and description of associated rocks will be cut to a minimum. There is, however, considerable disagreement upon the geologic age of the Catoctin and its relation to associated sediments, volcanics and underlying intrusives. Several writers have expressed disagreement with the views expressed in a preliminary paper by Furcron which deals with these topics. Thus, the writer desires in this article to express his point of view upon these problems and to answer certain criticisms by others regarding his conclusions. The writer has had no chance to review the problem in the field since 1937, but prior to that time he has studied the rocks of both Catoctin belts, and this paper is based upon detailed mapping of the Warrenton quadrangle, and between Charlottesville and Lynchburg in central Virginia in the Bull Run - South Mountain belt, and of the western Blue Ridge belt between Front Royal and Crozet, and the Natural Bridge Special quadrangle.

All who have studied the problem agree that granodiorite and granite (injection gneiss of some writers) are pre-Cambrian, and are unconformable under the Lower Cambrian arkoses and quartzites which are usually referred to in this district as Unicoi formation. Opinion is divided, however, upon the relation of granodiorite and granite to the Catoctin, and this relationship is all important in the determination of its age. Keith, Weed, Watson, Cline, Phalen,

~~Furcron~~, Cloos ~~and~~ Hietanen have ~~written~~ stated that the underlying intrusives (granodiorite and granite) intrude the Catoctin series, and the writer and Mr. and Mrs. George W. Stose, the Bloomers and King, contend that the Catoctin series is younger and rests unconformably upon the underlying intrusives (see references).

All writers ~~believe~~ have expressed the belief that the Catoctin volcanics series is ~~are~~ pre-Cambrian in age, except the Bloomers (1947), who ascribe a Lower Cambrian age to ~~them~~ these rocks. The Bloomers draw their conclusions from a study of a small area in Amherst County at the southern end of the Blue Ridge belt (Buena Vista quadrangle). Since their conclusions are drawn for the entire area of the Catoctin series in Virginia, since ~~province, and because~~ they have especially attacked a preliminary paper by this writer (1934), and in the belief of this writer that they have confused the issues, particular attention will be given here to their paper. Unfortunately, they ~~do not~~ fail to cite definite localities or sections in their article, ~~which is difficult~~ would make it ~~to~~ be difficult to follow and interpret even by geologists who are familiar with the Catoctin problem. Their conclusions, drawn from the Buena Vista area, do not agree with observations made by this writer, and by many others ~~for~~ in other sections of the Catoctin belt.

ROCKS AND STRUCTURE OF THE NORTHERN BLUE RIDGE PROVINCE

The Blue Ridge Province of northern Virginia (not Blue Ridge) may be likened to an anticlinorium. The rocks in this province are for most part ~~are~~ igneous, and ~~its~~ The anticlinoral ~~character~~ structure must be inferred in considerable part from their mutual relationships. Also this province is structurally set off from other crystalline rocks by a normal fault on the east to which Mrs. George W. Stose has applied the term Catoctin Mountain Border fault. On the west side ~~it~~ the Province is separated from Paleozoic rocks of the Great Valley by a sharp topographic break, and locally by a great overthrust fault.

The central part of this anticlinorium consists of granite

gneiss, granodiorite and granite (Lovingston gneiss, hypersthene granodiorite and Marshall granite complex - Geologic map of Virginia, ~~State geologic map~~, 1928). The typical granite associated with and intruding the granodiorite in the western Catoctin or Blue Ridge belt ~~is~~ was named the Old Rag granite by the writer, Furcron, (1934) from Old Rag Mountain in Madison County. On each side of the central core ~~we have~~ a belt of Catoctin greenstone volcanics, ~~which~~ rocks overlie the intrusives, but ~~which are worn away~~ they have been worn away throughout the central portion of the structure. Uncontormably upon the Catoctin series and the intrusives ~~are~~ occur arkoses, quartzite and slates of Lower Cambrian age. These rocks may be studied on the east side of the Great Valley Province where they grade upward into fossiliferous Lower Cambrian beds; also, arms of Lower Cambrian rocks extend out to form connected tongues and isolated outliers over the crystallines, and many of these have been mapped all over the Blue Ridge range. These rocks, known to some writers as Chilhowee rocks, are usually referred to in this district as the Unicoi formation. These basal arkosic sediments, including the Blue Ridge outliers, contain volcanic material.

The Bloomers state ~~write~~ (1947, page 96) that the Unicoi formation does not rest upon the Catoctin series in central Virginia. However, other writers have found that the Unicoi rests upon the Catoctin locally throughout the entire extent of ~~this~~ the western Catoctin belt.

Basal Cambrian sediments overlie ~~lie over~~ all of the crystalline rocks, and east of the Blue Ridge ~~range~~ are usually referred to as the Loudoun formation. This term was given by Keith (1894, Harpers Ferry Folio) to a series of ~~these~~ arkoses, sandstones and slates in Loudoun County, Virginia. Keith included in the formation some rocks of pre-Catoctin age, as was first pointed out by Miss A. I. Jonas. The pre-Cambrian Fauquier formation was mistakenly included ~~misincluded~~ by Keith with the Loudoun. The Loudoun slates, arkoses and conglomerates occur as

Valley and other referred to as Iron Slate, and of organic origin referred to

far south as the vicinity of Lynchburg (~~State geologic map~~ Geologic Map of Virginia, 1928), and as far east ~~on the structure~~ omit? as the Catoctin Mountain Border fault, where they overlie unconformably Catoctin flows and intrusives, and sub-Catoctin metasediments (Furcron, 1939, Plate I). No volcanic rocks have been noted in the Loudoun formation, although it is believed to be merely the eastward extension of the Unicoi.

CONCLUSIONS OF OTHER WORKERS

The question of igneous sequence in the Blue Ridge of northern Virginia was raised by Keith (1892, pp. 366-368). He recognized epidotic diabase, granite and quartz-porphyry in this region. He states (1892, p. 366), "So far as known to the writer, the granite and quartz-porphyry do not come in contact. Between the granite and diabase, contacts are common. The granite occurs in the form of large masses and eruptive tongues in the diabase, and abundant evidence of its eruptive nature can be found in its irregular boundaries, offshooting tongues, and included fragments of diabase."

These volcanics are generally referred to by Keith in later publications as "Catoctin schist." Keith finally divided the period of Catoctin extrusion into two parts, so that granite intrudes lower volcanics but an upper diabase eruption came after the period of granite intrusion (1894, P. 318, 394).

In discussing rocks of the Blue Ridge near Harpers Ferry, (1894, P. 2), he states that Catoctin schist is intruded by granite and that this fact is made plain at contacts between the two "in the alteration of the schist next to the granite, in the smaller crystals of the granite, due to cooling, and in the fragments of schist included in the granite."

In 1906, Weed and Watson studied the relationship of

underlying intrusives to Catoctin greenstone along the western side of the Blue Ridge in the Luray region (pp. 318-319). "The relations between the syenite and basalt observed on Stony Man Mountain clearly indicate the later age of the first named rock. At most places the syenite is massive and topographically below the basalt."

Phalen wrote in 1906 (P. 140), "The chief mass of the basalt, or melaphyre, or greenstone, as it has been variously termed, is dense and dark green, except where thoroughly epidotized, when it assumes a lighter green hue. Its original constituents are not determinable without microscopic aid, save perhaps an occasional phenocryst of olivine. From the facts that bosses of syenite are seen in it in the region near Fisher's Gap and that it has been subjected to an intense metamorphism along its contact with the syenite on the west slope of the ridge and wherever the two rocks are contiguous, it is inferred that the syenite is the younger of the two rocks. This inference is strengthened by the perfectly fresh, holocrystalline character of the syenite at the immediate contact and by the lack of weathered fragments or bowlders of the syenite in the basalt. This contact metamorphism has resulted in a more or less schistose rock, quite different from that of the main mass which, in this particular district, is not regionally schistose."

The intrusion of granodiorite and granite into Catoctin greenstone has been reported also in other articles by Phalen (1904, pp. 306-316) and Watson and Cline (1916, pp. 193-234). Cloos and Hietanen write (1941, pp. 81, 192) that volcanics in South Mountain, Maryland, contain sill-like intrusions of granodiorite, and that foliation in the granodiorite parallels contact with volcanics.

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INTRUSION OF GRANODIORITE AND GRANITE INTO CATOCTIN

The Bloomers write (1947, p. 102), "Furcron agrees with Keith with regard to the pregranitic complex age of the Catoctin. He reached this conclusion because of an intrusion of 'pegmatite' in the Catoctin . . . " They are actually referring to a quotation cited by ~~Furcron~~ the writer (1939, p. 31) with which he did not agree. The granodiorite and granite of the Blue Ridge range are notable for the absence of true pegmatites.

Direct evidence for intrusion of granodiorite and granite into Catoctin greenstone may be discovered by patient work. On the west side of Rocky Branch near Hall School on the Stony Man quadrangle, granodiorite intrudes greenstone. At Compton Gap on the Skyline Drive, southwest of Front Royal, the writer discovered many inclusions of greenstone fragments in granite and granodiorite on the freshly-cleared right-of-way for the Parkway. Here small greenstone inclusions of fist and bowlder size were found in granite. Several thin sections of these greenstone inclusions in granite of this locality were examined. These sections are fresher and less altered than the normal greenstone. They are of very fine-grained diabase and prophyry which one would expect to find in a thick basalt flow. Stringers of red epidote-bearing granite were found cutting the greenstone on a side road near the old home site below the gap on the west side.

Fine-grained pink and greenish granite with scattered epidote grains intrudes Catoctin greenstone at the northwest end of Cave Mountaon on the Natural Bridge Special quadrangle, south of the Park area. At this locality an opening was made in greenstone and granite. The excavation is near the main road and on the north bank of Back Run. The stringers and narrow dikes of granite, accompanied

by pyritization, occur in massive greenstone. The granite tends to assimiliate greenstone in such a manner as to produce a dark, greenish granitic rock with red feldspar which is clearly of an hybrid character. All types from dark greenstone, through hybrid rock, to fine-grained pink granite occur here. This is a typical granodiorite-granite district.

The Bloomers (1937, p. 101) write that veins and masses of quartz, orthoclase and epidote are observed in the Catoctin formation. "Some of these vein-like masses containing approximately equal amounts of coarse-grained pink feldspar and quartz resemble pegmatite and granite." In other words, they are unakite, and are similar to the underlying granodiorite which they claim does not intrude the greenstone.

A large inclusion or engulfed fragment of greenstone was noted in the road up Yellow Branch, a tributary to Roach River in Greene County. Inclusions of Catoctin greenstone in granite and granodiorite were found on the north wall of Roach River Valley, northeast of Victory School.

GRANODIORITE - CATOCTIN CONTACT

Although Catoctin volcanics of the Park area tend to cap tops of mountains and are underlain by intrusives, they do not rest upon anything remotely resembling a horizontal floor, as suggested by the Bloomers. The base of greenstone over granite is subject to great variation in elevation within relatively short distances. For example, just west of Kinderhook in Greene County, greenstone occurs at an elevation of 950 feet, but only 1½ miles northwest of the locality the base of greenstone occurs at about 2750 feet. Also, bosses of granodiorite and granite tend to occur in greenstone at localities where we would expect it to be thickest. This condition

makes estimates of thickness of greenstone, as quoted by Bloomers, very hazardous; also, such relationships indicate a later age for granite.

Granodiorite and granite do not intrude the greenstone in textbook manner, but boss-like intrusions of various shapes and sizes are encountered in numerous places. These intrusions in Catoctin may be found at localities given below, and the writer can supply others: Old Rag granite on the trail up Dark Hollow, Madison County, 3/4 mile due east of Community School; Old Rag granite altered to unakite in Indian Run Valley, Rappahannock County, 1 8/10 miles southeast of Compton Gap; granodiorite and unakite body a mile long and one-half mile wide on west side of Matthews Arm, Page County, at headwaters of Flint Run south of Bentonville; granodiorite(mass about one-half unakite) Warren-Page-Rappahannock County line; granodiorite (unakite) at the head of Dark Hollow, just east of Fishers Gap, Stony Man quadrangle; granodiorite (locally unakite) Swift Run Gap; granodiorite body nearly a mile long on Conway River, Greene County, south of Shiloh Church; small boss of Old Rag granite near Flatgut Run, Greene County, 1 mile north 45° west of Victory School on Roach River; granodiorite and granite, Sugar Hollow above Whitehall, in Albemarle County.

ORIGIN OF UNAKITE

A perusal of ~~Furcron's~~ the writers' geologic map of the crystalline rocks of the Shenandoah National Park area (unpublished) reveals a striking correlation between occurrences of unakite in both granite and granodiorite, and its proximity to Catoctin greenstone. The finest examples of unakite occur near these contacts. For this reason the writer believes there is evidence to indicate that unakite was

produced by hydrothermal changes which took place during the period of granite and granodiorite injection, at which time ~~where~~ hot solutions had an opportunity of mingling with more basic Catoctin minerals. Throughout the Shenandoah National Park area, granite and granodiorite near epidote greenstone contain epidote. Also, in such occurrences, their feldspars contain sufficient ferric oxide to become pink and locally nearly red. Even where typical unakite is not mapped near contacts, there is alteration of granodiorite at such localities to saussurite, etc., which fades out away from greenstone contacts.

Why don't simply "phrase?"

~~Miss~~ Jonas (1935, p. 53) states that alterations in granodiorite where unakite occurs "proceed by a strong development of myrmekite. . . These changes are accompanied by considerable sericitization of the potassium feldspars, increase in saussuritization of the plagioclase, and alteration of hypersthene to hornblende, chlorite, and epidote." She states further, "Much of the epidote is clearly secondary, and has replaced the other constituents. . . the epidote is largely introduced, and has replaced other minerals." It is believed by the writer that Mrs. Stose (she) has described in detail in this excellent article the later hydrothermal effects in granodiorite and granite, but that where greenstone is involved, unakite was produced; also since myrmekite is typical of these intrusive rocks generally, unakite can be accounted for only where these later hydrothermal solutions from granodiorite and granite came in contact with greenstone. It should be pointed out here that unakitization affects the granites of the district as extensively as it does granodiorite (Figure 2). It is ~~this~~ the writer's opinion that the Air Point granite (Jonas, 1935, p. 52) is Old Rag granite converted to unakite. It is questionable if the large amount of additional

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calcium necessary to produce normal unakite could be obtained alone from granodiorite, and certainly not from granite; also the large amount of added ferric iron came probably from the greenstone.

ORIGIN OF COPPER DEPOSITS

Copper ores in Catoctin greenstone have been prospected in the past rather extensively throughout the western belt now included in the Shenandoah National Park. Weed and Watson (1906, pp. 317-323) and Phalen (1906, pp. 140-145) were first inclined to attribute these ores to local concentrations from downward circulating meteoric waters probably because similar views had been expressed in those days regarding the origin of the Michigan copper deposits.

The deposits are found near the base of the Catoctin greenstone, or at intrusive contacts. Ores are principally native copper and cuprite with small amounts of chalcopyrite and bornite. The more accessible prospects are at Dark Hollow and Stony Man (Stony Man quadrangle) where the ore-bearing greenstone adjoins granite. Phalen states (1906, pp. 142-143) that ascending magmatic waters may have been responsible for bringing such sulphides as chalcopyrite into the quartz veins. Watson* at a later date suggested that the primary ores probably were deposited by a reaction between magmatic waters and the ferric oxide of the greenstone. The writer believes that the composition of the primary ores, and their relation to the intrusives, indicate that Catoctin greenstone was mineralized by magmatic waters emanating from the underlying intrusives.

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* Oral communication, 1921.

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SEDIMENTARY ROCKS UNDER CATOCTIN

The protagonists of a Lower Cambrian Catoctin will receive very little encouragement from a study of its associated metasediments. In the western Blue Ridge Catoctin belt, sub-Catoctin sediments have not been discovered by this writer, but in the eastern Catoctin belt they occur beneath the flows so extensively that it is difficult to relate the Catoctin to intrusive granites which crop out west of the belt. In northern and central Virginia the Loudoun generally conceals the contact but not sufficiently to disguise the relation between the Catoctin and the rocks directly beneath it. In the Warrenton area, the writer ~~Furcron~~ (1939, pp. 37-41) has described the Fauquier formation which crops out on the west side of the Catoctin belt, and Catoctin may be seen directly overlying it, all dipping southeastward. These rocks consist of calcareous mica schists, marble, graphite schist, and fine-grained biotite gneiss. Inasmuch as new rock types in the Fauquier come in along the strike of the Catoctin-Fauquier contact southwestward, the Catoctin seems to rest upon an angular unconformity.

Re Jonas

Mrs. Stose believes that the Fauquier formation is equivalent to the Lynchburg gneiss. It is in the same structural belt and it is entirely possible that the two may be correlative. However, if this be the case, the Fauquier formation would appear to represent a different facies of the series, and because it is directly under Catoctin from northern Virginia as far south as Charlottesville, it may be over and younger than Lynchburg gneiss. Dikes of Catoctin cut the Fauquier formation in the Warrenton area. Also hornblende-metagabbro, metapyroxenite or amphibolite (intrusive equivalents of Catoctin) extensively intrude the Fauquier formation in the Warrenton area, University of Virginia area, etc. These

intrusives, similarly associated with the Catoctin, also intrude Lynchburg gneiss under the Catoctin in Central Virginia.

Thus, we have evidence in the Bull Run - South Mountain Catoctin belt of the presence of an extensive, highly metamorphosed sedimentary series of the Fauquier-Lynchburg gneiss type. This series is older than the Catoctin which was poured out upon its metamorphosed and eroded surface. These rocks do not resemble in composition or in degree of metamorphism essentially undeformed sediments which some other writers believe are under the Catoctin in the Blue Ridge belt.

In several cases schists and biotite gneisses resembling Fauquier-Lynchburg have been noted as inclusions in the granites which underlie the western Catoctin belt or which crop out between the two belts; thus it seems reasonable to believe that these old metasediments are absent in the western belt, because they were assimilated by the underlying intrusives, and also removed by erosion, as was the Catoctin in the central part of the Blue Ridge anticlinorium.

SEDIMENTARY ROCKS OVER CATOCTIN

East of the Catoctin Mountain Border fault, in localities where crystalline rocks are not covered by overlying Triassic sediments, these down-faulted post-Catoctin sediments are exposed along James River in an anticline affected by normal Triassic faulting (Furcron, 1935, pp.23-37, Plate I). The oldest rocks (Mount Athos greenstone) are amygdaloidal flows resembling Catoctin, and no base has been discovered for them thus far. Over them is quartzite with some mica schist (Mount Athos formation); it is similar to quartzite and schist over Catoctin in Bull Run Mountain immediately west of the Catoctin

Mountain fault called Weaverton by Keith (1894, Harpers Ferry Folio), and Loudoun on the Geologic Map of Virginia, 1928. Over the Mount Athos quartzite and schist are marbles referred to as Cockeysville. Over the marbles are mica schist referred to as Wissahickon. The terms Lynchburg gneiss, Cockeysville marble, and Wissahickon schist were first introduced into Virginia geology by ~~Miss~~ A. I. Jonas (1927, pp.837-845) and used in her classification of the crystalline rocks on the State map of 1928. These terms are retained for these rocks in the report by Furcron (1935).

Volcanic flows, accompanied by intrusives, continued into Wissahickon times (Furcron, 1935).

Thus, west of the Catoctin Mountain Border fault, we have the Lynchburg-Fauquier type of gneiss, the latter containing a variety of metasediments, including marble and graphite schist. This series is under the Catoctin, and is cut by intrusives of Catoctin age and composition (Furcron, 1939, P. 28, Pl. 1). Over the Catoctin flows, west of the fault, are remnants of post-Catoctin rocks - quartzites, muscovite and biotite schists. There is evidence locally that deposition of fine, white saccharoidal quartzite actually began before the conclusion of the Catoctin period because layers of this quartzite are interbedded with greenstone (Furcron, 1939, Plate 6). East of the fault this series reappears in a large anticlinal area along James River where younger post-Catoctin rocks are exposed. These rocks are classified by Furcron as pre-Cambrian because the Loudoun arkoses and slates are unconformable upon the pre-Catoctin, Catoctin and post-Catoctin rocks west of the Border Fault. It is obvious that younger post-Catoctin rocks should be preserved east of the Catoctin Mountain Border fault. Incidentally, the Bloomers have portrayed this great normal fault as an overthrust (1947, p. 105) with no reasons given.

In Virginia Bulletin 39, Furcron describes the Lynchburg gneiss separately and not included with post-Catoctin rocks east of the Border fault, but in the explanation on Plate I, its color block was placed beside that of the Wissahickon. If its color block be transposed to the bottom of the column beneath those for Catoctin and Mount Athos greenstone, and the two greenstone blocks be placed in apposition above it, then the explanatory column will be in proper sequence. Thus the writer recognizes two ages of marble, one in the Fauquier formation under Catoctin and one over the Mount Athos formation. Also, it is probable that the Mount Athos is correlative with quartzite and schist over Catoctin just west of the Border fault north of Warrenton. The term Mount Athos greenstone should now be abandoned in favor of Catoctin greenstone.

STATUS OF THE SWIFT RUN FORMATION

On the geological map of Virginia, 1928, ~~Miss~~ Jonas indicated that the Catoctin rocks were intruded by the underlying granodiorite and gneisses of the Blue Ridge province. In a later paper on hypersthene granodiorite, she calls attention to diabase dikes which cut that rock and which she believes are similar and closely related to the Catoctin intrusives; also, because she believes that intrusive relations to granodiorite into Catoctin have not been observed, she concludes that the Catoctin series is younger. In a later article dealing with this problem, Jonas and Stose (1939) describe a tuffaceous formation, which contains arkoses at the base of the Catoctin, as the Swift Run formation from Swift Run Gap in Greene County. At that time the writer was engaged by the Virginia

Geological Survey to map the geological formations of this district. The Stoses state that in 1933 they regarded similar slates and arkoses, prevalent in that part of the Blue Ridge range, as synclinal infolds of basal Cambrian Loudoun (pp.585-586), but that they have been convinced by later work in that area east of Swift Run Gap, on U. S. ~~Highway~~ Route 33 and other localities, that these rocks are not Loudoun but that they belong to the base of the Catoctin. They correlate the arkoses at Swift Run Gap, which they believe to be at the base of the Catoctin, with the Fauquier formation and the Lynchburg gneiss (pp.575, 593). This writer has not been able to discover field evidence to justify these conclusions. Also, the Swift Run rocks and other arkoses are merely sandstones of totally different composition; also Fauquier-Lynchburg rocks are in the same belt ~~yet~~ are highly metamorphic rocks cropping out on a regional scale. It should be remembered here that these debatable sediments are Loudoun-like, and ~~Mrs. Stose~~ Jonas (Va. State Geologic Map of Virginia ~~Map~~, 1928; 1927, pp.844-845), ~~Furcron~~ the writer (1935 and 1939), and others have mapped and separated the Loudoun from Lynchburg and Fauquier on the basis of lithology and degree of metamorphism; thus to remain consistent we cannot now correlate them with Lynchburg gneiss and Fauquier.

A peculiar tendency for these rocks to occur in many cases over contacts between Catoctin and granodiorite is discussed in another part of this paper where evidence is given by the writer to indicate that these sediments do not appear to be at the base of Catoctin but are remnants of Lower Cambrian arkoses which may contain tuffaceous material.

This writer does not wish in any way to discredit the possibility of occurrences of tuffaceous material at or near the

base of the Catoctin flows. As a matter of fact, such materials are known to occur and do occur in other parts of the Catoctin series. Widespread agglomerates at the base of the Catoctin have been described by ~~Furcron~~ the writer on the Warrenton quadrangle (1939, pp.20-22) in the Bull Run - South Mountain belt, but the writer has found no evidence to prove thus far existence of a sediment or of a tuffaceous material resembling Loudoun or basal Unicoi between the Catoctin and granodiorite and its associated granites.

For example, Jonas and Stose (1939, pp.585-586) state that the sediments here mapped as Unicoi at Bear Fence Mountain on the Skyline Drive (fig. 2) "are largely of tuffaceous origin and are interbedded with flows at the base of the Catoctin metabasalt and are not Loudoun." There is, perhaps, more "tuffaceous" material or Catoctin waste in the Loudoun here than usual, but except for the fact that it covers the Catoctin-granodiorite contact, there is no evidence that it is under Catoctin. If such deposits are classified as "Swift Run" then the entire Loudoun, and the Unicoi outliers, must also be placed beneath Catoctin.

Thus far, no one seems to have discussed the peculiar character of the sub-Unicoi crystalline surface which was an exceedingly uneven one. In some localities, such as Sugar Hollow in Moorman River Valley west of Charlottesville, arkoses crop out deep within the entrenched valley and in other localities they lie about upon the rocks with no special respect to topographic position.

Much has been said about the tuffaceous character of these sediments ("Swift Run," "Oronoco," basal Unicoi). ~~Furcron~~ The writer and Woodward (1936) were not sure of this condition until they had traced the flow at the base of the Unicoi from over a Catoctin

basement to a granodiorite basement in Cubbage Hollow. Thus assured of a basal flow in the Lower Cambrian, it became reasonable to believe that tuffaceous material of similar age could occur also in such rocks. The granite-waste composition of these rocks, however, has been somewhat over-emphasized because weathered Catoctin obviously produced a large amount of fine-grained chlorite, epidote, quartz, etc., which was incorporated locally into the lower beds of the Unicoi. It is significant that when we go eastward in the Blue Ridge range beyond the limits of the Catoctin that similar beds do not contain volcanic material. Special mention of the possible occurrence of large amounts of Catoctin waste, giving body, color and texture to the basal Unicoi sediments, is made here because outliers of these sediments have been placed by some under Catoctin with the assumption that they do not contain waste of weathered Catoctin greenstones, greenstone tuffs and slates.

GABBRO DIKES IN GRANODIORITE AND GRANITE

Metadiabase dikes which cut granodiorite and granite in the Blue Ridge and referred to by Jonas and Stose (1939, p.590) are encountered occasionally, as at the east end of the tunnel on the Skyline Drive at Marys Rock near Sperryville. The writer ~~Fureron~~ was unable to discover any genetic relation between them and Catoctin flows. Because of their generally fresh character he wrote in 1934 that these dikes might be Triassic, but later study shows that they represent original gabbro or gabbro diabases in which the pyroxenes are more altered than in Triassic diabase. Watson and Cline have described dikes which cut folded Paleozoic sediments in the Valley, but they are not known to be related to the ones under discussion. Also, these dikes may be Lower Cambrian, thus connected in origin

with the volcanics at the base of the Unicoi. Their age is not known but it should be Late pre-Cambrian or Paleozoic; thus, they may cut the Catoctin, but no examples of such relationship have been discovered thus far by the writer. Dikes of greenstone and amphibolite which belong to the Catoctin period of vulcanism have not been found in intrusive granodiorite under Catoctin of the Blue Ridge belt; they are present, and locally abundant, where they cut pre-Cambrian metasediments associated with Catoctin in the South Mountain - Bull Run belt and are discussed in another section of this paper.

The Bloomers ~~write~~ state (1947, p.100) that these gabbro dikes are "propylites;" however, they were unable to find them connected with the flows or intruding the flows. They write that the Catoctin flows once emanated from fissures represented by these dikes. This is a very questionable theory for the source of basic flows as thick and widespread as the Catoctin. It is much more probable that the original vents from which these lavas came were much farther to the east, because an extensive preliminary pyroclastic facies, Warrenton agglomerate, has been described by this writer from the eastern Catoctin belt. Dikes associated with flows occur around the old vents, and that is where the Catoctin dikes are found (Furcron, 1939, p.28, pl. 11.

"ORONOCO FORMATION" OF THE BLOOMERS

R. O. Bloomer and R. ~~E~~. R. Bloomer (1947) write that they have discovered a formation of arkose which lies stratigraphically between the intrusives and Catoctin greenstone. This formation is reported from the vicinity of western Amherst County in the northeastern part of the Buena Vista quadrangle, and named by them the "Orono formation." This name has no priority because the Stoses have

previously described a lithologically similar formation, the Swift Run formation, to this stratigraphic horizon in the district.

Unless this discovery of the Bloomers represents a bare or cliff-like outcrop where the arkose can be seen to occur between the two igneous types, their only proof of pre-Catoctin age for these sediments is their common occurrence at or near Catoctin-granodiorite contacts. The writer has seen and mapped deposits of arkose in this province from Front Royal to Natural Bridge, where they occur on Catoctin greenstone, on granite and granodiorite, and at the contacts between the two. These arkose deposits occur over all the crystallines, resemble Unicoi, and should be outliers of it. Farther east in the same province they have been mapped as Loudoun. Locally, in numerous places, belts of this sediment follow the contacts between the greenstone and granodiorite, which may lead some to conclude from limited occurrences that this fact proves that the arkose lies between the two rocks. However striking such occurrences may be, the belts will wander off from that position on all other rock types. In none of the numerous localities where it was possible to observe the contact of greenstone or granodiorite on clean or cliff-like slopes could any sediments be seen in this position; also, as may be seen from figures 2,3 & 4, large bosses of intrusives crop out in greenstone where no sediments are found between the two. The occurrence of these arkoses at the contact appears to be fortuitous, because although contacts between intrusives and greenstone on a geologic map made by the writer from Front Royal to Crozet in the Park involve hundreds of linear miles and many separate arkose deposits, the total amount of mileage represented by the position of arkose at the contact is very small. Observed contacts between Catoctin and

granodiorite are clean and without the presence of these arkoses.

In summary, distribution of these basal Cambrian outliers is peculiar, yet not adequately explained by those who would place them under Catoctin. There are localities in the Park area where a thousand feet or more of such sediments would be reduced to zero along the supposed contact within a few hundred yards. Also, it is reasonable to believe that it these sediments do occur between the Catoctin and intrusives, they should be seen in that position in the excellent tresh cuts along the Skyline Drive. Here, in many places, it is possible to put a finger on the contact, in many places a nearly vertical one, yet no sediments have been found by this writer and none have been reported to his knowledge from such places.

LACK OF EVIDENCE FOR AN "ORONOCO FORMATION"

Furcron and Woodward (1936, pp.45-51) described a basal Cambrian lava flow and tuffaceous deposit at the base of the Lower Cambrian Unicoi or Chilhowee along the west slope of the Blue Ridge, between Luray and Port Republic. This persistent volcanic zone lies unconformably upon the eroded surface of all the pre-Cambrian rocks; thus, may be seen at the base of the Unicoi unconformably overlying Catoctin, granodiorite and granite. There is evidence in the article by the Bloomers, and also in the article by King, to indicate that the Bloomers have confused this volcanic zone with a supposed formation (Oronoco) which they have placed at the base of the Catoctin.

Omit

Bloomer's work was done after ~~Furcron~~ the writer left Virginia, and Mrs. George W. Stose suggested the Buena Vista quadrangle for their investigation because it was a modern map of an area in the Catoctin belt not investigated by Furcron. The Stoses are familiar with the geology of that quadrangle and visited R. O. Bloomer twice in the

Omit

I suggest omitting this paragraph as being too personal

field. Mrs. Stose states* that he has correlated tuffs at the base of the Cambrian with his Oronoco formation.

The Bloomers include in their paper a figure to illustrate their assumption of the stratigraphic relation of the Catoctin in central Virginia. The flow at the base of the Unicoi they have called Oronoco and have placed it at the base of the Catoctin, thus the diagram is used to explain the widespread occurrence of this volcanic at the base of the Unicoi where no Catoctin is present. Incidentally, it is unfortunate that in their Fig. 1, showing the distribution of the Catoctin, they make no attempt to show the distribution of their Oronoco beyond the limits of the Buena Vista sheet. In fact, nowhere in their paper do they commit themselves to detailed specific localities.

King examined a section of the Swift Run formation on the south side of the East Branch of Naked Creek, a mile east of Jollett, and believes it to be the same as the "Oronoco" formation (1949, p.526). He states that it lies unconformable upon the injection complex and that "the Swift Run persists throughout the Elkton area as a nearly continuous stratum 50 or 100 feet thick between the Catoctin above and the injection complex below, an unlikely relation if the latter were intrusive into the former."

In Fig. 2, this writer submits a map of the formations of the Jollett section. The only rock seen by him which is similar to the Bloomers' Oronoco formation is a tuff and flow rock which may, and should, contain fragments of the underlying complex, but which occurs not under Catoctin but at the base of the Unicoi, and unconformably on granodiorite, granite and Catoctin rocks (mostly

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* Written communication, October 22, 1947.

Catoctin in this section). Also, it is quite extensive in the Elkton area, although it is very unpredictable, and as may be seen by the map, is locally missing.. It is the tuff and flow horizon described by Furcron and Woodward at the base of the Lower Cambrian Unicoi (1936). Thus, the Bloomers have taken volcanic rocks at the base of the Unicoi, and as nearly as can be judged from their article, the arkose outliers unconformable over the Catoctin, renamed them the "Oronoco" formation and placed them stratigraphically at the base of Catoctin volcanic rocks. This leads to their assumption that the Catoctin rocks are Lower Cambrian,and also the assumption that they are not intruded by underlying granodiorite and granite.

It should be noted here that those writers who believe that essentially unmetamorphosed arkoses similar to the Unicoi occur under the Catoctin will eventually find it necessary to agree with the Bloomers that the Catoctin is Lower Cambrian, and also that the Loudoun formation is beneath the Catoctin. Also, to remain logical, they will eventually find it necessary to correlate the Loudoun with the Fauquier-Lynchburg rocks, yet the Loudoun is known to be unconformable upon these rocks. The Bloomers (1947, p.106) suggest that their Oronoco formation (an essentially unmetamorphosed arkose) be correlative with the highly metamorphosed Lynchburg gneiss.

CONCLUSIONS

The oldest rocks of the Blue Ridge province in northern and central Virginia are highly metamorphosed sediments - the Lynchburg gneiss and Fauquier formation. Catoctin volcanics were poured out over the surface of these rocks, and this period of vulcanism was accompanied and followed by the deposition of younger pre-Cambrian sediments now only partially preserved along the eastern edge of the Blue Ridge province. Intrusions of Catoctin age cut the Fauquier formation and Lynchburg gneiss. The relation of the Lovingston gneiss to Catoctin is not certain but it appears to intrude Lynchburg gneiss in central Virginia. Granodiorite and accompanying granites intrude the Lovingston gneiss and Catoctin of the Blue Ridge belt. These intrusives contain unassimilated masses of Lynchburg-like gneiss.

The Blue Ridge province was domed up and eroded prior to deposition of the Lower Cambrian rocks, and Catoctin rocks were removed at that time from the central part of the "anticlinorium." Lower Cambrian sediments were deposited upon a surface of comsiderable relief, and are composed almost entirely of granite waste east of the Blue Ridge range. In the western section deposition was accompanied by volcanic action, thus the basal arkoses of the Blue Ridge may contain tuffs and locally flows. Pyroxene dikes of Cambrian or later Paleozoic age cut the granodiorites and granites of the Blue Ridge range.

During the Triassic, Catoctin and overlying metasediments were downfaulted east of Bull Run and South Mountain in northern and central Virginia, and in the basin thus formed shales and

sandstones were deposited to great thickness. Sills and some dikes were intruded into the sediments, and typical diabase dikes of that period intrude all of the rocks of the eastern side of the Blue Ridge province.

East of the Catoctin Mountain border fault in central Virginia, Catoctin and later pre-Cambrian metasediments are exposed in an anticline which is affected by Triassic faulting. Here Catoctin flows are overlaid in order by the Mount Athos quartzite, Cockeysville marble, and Wissahickon schist. Volcanic activity of the Catoctin type continued into Wissahickon times.

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Figure 1. Generalized section through the Blue Ridge province of northern Virginia (not to scale or locality). All rocks are regarded as pre-Cambrian except those otherwise designated.

Figure 2. Preliminary geologic map of the Jollett area, Page, Madison and Greene counties, Virginia. cgv, Catoctin greenstone volcanics; gd, granodiorite; gdi, granodiorite injected by Old Rag granite; gdu, granodiorite unakite; orgu, Old Rag granite unakite; €uv, basal Cambrian volcanics; €u, Lower Cambrian Unicoi formation.

Figure 3. Preliminary geologic map of Swift Run Gap district, Greene and Rockingham counties. cgv, Catoctin greenstone volcanics; gd, granodiorite; gdi, granodiorite injected by Old Rag granite; gdu, granodiorite unakite; org, Old Rag granite; orgu, Old Rag granite unakite; €uv, basal Cambrian volcanics; €u, Lower Cambrian Unicoi formation.

Figure 4. Preliminary geologic map of the northern part of the Shenandoah National Park area. Formation symbols same as Figure 3.

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GEOLOGIC AGE OF CATOCTIN VOLCANIC ROCKS IN VIRGINIA

A. S. Furcron

This discussion refers especially to a recent article by the Bloomers on "The Catoctin Formation in Central Virginia" (March, 1947) of the Journal of Geology. The writer disagrees with opinions expressed by these writers upon age of Catoctin volcanics. That terrain studied by the Bloomers between Buchanan and Afton, Virginia, is at the extreme southwest end of the occurrence of Catoctin volcanics. In the Natural Bridge area these volcanics are almost completely removed by erosion, and in part assimilated by later pre-Cambrian granites; thus they are exposed only as local patches of greenstone in granite. Opinions here expressed are based upon detailed mapping of Catoctin rocks upon the Warrenton quadrangle, and between Charlottesville and Lynchburg in central Virginia in the Bull Run-South Mountain belt, and of the western Blue Ridge belt between Front Royal and Afton, and the Natural Bridge special quadrangle. The Outline Map published by the Bloomers (Fig. 1) does not correctly portray the distribution of Catoctin volcanics, and it omits all important structural features.

There are some who would terminate the base of the Cambrian with the lowermost fossiliferous formation. In that case practically the entire Unicoi formation would be regarded as pre-Cambrian. Since these basal clastic sediments, unconformably overlie granodiorite, granite and Catoctin volcanics are composed of fragments of these basement rocks, and grade upward into fossiliferous sediments, the above view is not reasonable. The Bloomers, however, extend the Lower Cambrian rocks downward to include not only the Unicoi, but the entire Catoctin volcanic series and any sediments or metasediments which may occur between them and the underlying intrusives.

Obviously, if the underlying granite and granodiorite cut Catoctin volcanics, the latter are pre-Cambrian; also there could be no Lower Cambrian Oronoco formation as the Bloomers interpret it, because under such conditions any sediments beneath the Catoctin would be pre-Cambrian in age.

A principal source of controversy regarding the geologic age of Catoctin volcanics is the difficulty of finding actual cases of granite and granodiorite intrusion into greenstone. Such occurrences are local, and difficult of access. They can be found in the greenstone belt of the Blue Ridge mountains, but in the Bull Run - South Mountain belt of greenstone, which occurs along the east side of the Blue Ridge province, Furcron[1] has

[1] Furcron, A. S., Geology and Mineral Resources of the Warrenton Quadrangle, Virginia: Va. Geol. Survey, Bull. 54, 1939.

shown the presence of the underlying pre-Cambrian metasedimentary Fauquier formation which here generally separates these rocks from underlying intrusives. In the Warrenton area, the contacts between the Fauquier formation and granites are covered by the Loudoun formation. The Fauquier formation occupies a position ascribed by the Bloomers to their Lower Cambrian Oronoco formation in the western Blue Ridge area.

A second source of controversy involves the origin of certain sediments associated with the greenstone. Throughout the Park area isolated patches, stringers, and even large areas of arkose occur. Locally, they rest directly upon Catoctin volcanics; in other places they occur upon granite and granodiorite. In other localities they show a tendency to occur at contact between granite and granodiorite. Mr. and Mrs. Stose have described from the Shenandoah National Park area deposits of tuffaceous origin[2], which lie at the base of Catoctin metabasalt, which they believe are older than Catoctin. The writer is

[2] Stose, Anna J. and George W., Age relation of the pre-Cambrian rocks in the Catoctin Mountain - Blue Ridge - Mount Rogers anticlinoria in Virginia: Amer. Jour. Sci., Vol. 237, No. 8, Aug. 1939, pp. 575-93.

not opposed to the occurrence of tuffaceous beds at the base of the metabasalt because he has described extensive agglomerate and tuffaceous beds at the base of the greenstone. If the Bloomers have discovered sediments beneath the Catoctin volcanics in the Buena Vista area, they will have considerable difficulty in establishing a Lower Cambrian age for such rocks. Care should be used not to confuse any such materials with the Loudoun or Unicoi outliers and infolds which are so abundant over the region. For example, in Sugar Hollow in Albermarle County, the Loudoun formation covers five or six square miles, overlying from place to place all of the pre-Cambrian rocks mentioned above. However, this rock extends northeastward for a distance of nearly ten miles, where it follows the contact between the greenstone and granodiorite, finally running off on greenstone. Also, along the west side of Catoctin greenstone in the Blue Ridge area, Furcron and Woodward[3] have described a basal Cambrian lava flow between

[3] Furcron, A. S., and Woodward, H. P., A basal Cambrian lava flow in northern Virginia: Jour. Geology, Vol. XLIV, No. 1. 1936, pp. 45-51.

Luray and Fort Republic. At first glance, this flow might be considered as belonging to the Catoctin. However, it is actually below or at the base of the Unicoi; also, other Lower Cambrian flows occur locally within the Unicoi. In Cubbage Hollow south of Stanley, where granodiorite and Old Rag granite (the latter altered to unakite) are exposed under the Unicoi, this lava flow which occurs at the base of Catoctin also occurs over granodiorite directly under Unicoi; thus is not at all associated in age with Catoctin greenstone. The flows here mentioned as of basal Cambrian age are very different in appearance and composition from Catoctin volcanics, and they are not altered to epidote greenstone. This is another reason against confusing the Catoctin period of extrusion with local flows in the Unicoi and the dikes of the same possible age in granodiorite and granite.

Although Catoctin volcanics of the Park area tend to cap tops of mountains and are underlain by intrusives, they do not rest upon anything

remotely resembling a horizontal floor, as suggested by the Bloomers. The base of greenstone over granite is subject to great variation in elevation within relatively short distances. For example, just west of Kinderhook in Greene County, greenstone occurs at an elevation of 950 feet, but only 1½ miles northwest of the locality the base of greenstone occurs at about 2750 feet. Also, bosses of grandiorite and granite tend to occur in greenstone at localities where we would expect it to be thickest. This condition makes estimates of thickness of greenstone, as quoted by Bloomers, very hazardous; also, such relationships indicate a later age for granite.

Some isolated occurrences of grandiorite and old Rag granite in greenstone may be found in the Shenandoah National Park area at the following localities: Granite (unakite), Indian Run Valley, one and one-half miles southeast of Compton Gap; granite (unakite), headwaters of Flint Run, two and two-tenths miles south of Bentonville; grandiorite (mass about one-half unakite), Warren-Page-Rappahannock county line; grandiorite (unakite) at the head of Dark Hollow, just east of Fisher's Gap, Stony Man quadrangle; grandiorite (locally unakite) Swift Run Gap; grandiorite and granite, Sugar Hollow west of Whitehall, Albermarle County.

Direct evidence for intrusion of granodiorite and granite into Catoctin greenstone may be discovered by patient work. On the west side of Rocky Branch near Hall School on the Stony Man quadrangle, granodiorite intrudes greenstone. At Compton Gap on the Skyline Drive, southwest of Front Royal, the writer discovered many inclusions of greenstone fragments in granite and granodiorite on the freshly-cleared right-of-way for the Parkway. Here small greenstone inclusions of hand and bowlder size were found in granite. Several thin sections of these greenstone inclusions in granite of this locality were examined. These sections are fresher and less altered than the normal greenstone. They are of very fine-grained diabase and porphyry which one would

expect to find in a thick basalt flow. Stringers of granite, altered to red, epidote-bearing rock, were found cutting the greenstone.

Fine-grained pink and greenish granite with scattered epidote grains intrudes Catoctin greenstone at the northwest end of Cave Mountain on the Natural Bridge Special quadrangle, south of the Park area. At this locality an opening was made in greenstone and granite. The excavation is near the main road and on the north bank of Back Run. The stringers and narrow dikes of granite, accompanied by pyritization, occur in massive greenstone. The granite tends to assimilate greenstone in such a manner as to produce a dark, greenish granitic rock with red feldspar which is clearly of an hybrid character. All types from dark greenstone, through hybrid rock, to fine-grained pink granite occur here. This is a typical granodiorite-granite district.

A large inclusion bdlieved to be an engulfed fragment of greenstone, was noted in the road up Yellow Branch, a tributary to Roach River in Greene County. Inclusions of Catoctin greenstone in granite and grandiorite were found on the north wall of Roach River valley, northeast of Victory School.

The question of igneous sequence in the Blue Ridge of northern Virginia was raised by Keith in 1892[4]. He recognized epidotic diabase, granite

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[4] Keith, Arthur, The geologic structure of the Blue Ridge in Maryland and Virginia: American Geologist, Vol. 10, 1892, pp. 366-368.

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and quartz-porphyry in this region. He states[5], "So far as known to the writer

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[5] Ibid, p. 366

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the granite and quartz-porphyry do not come in contact. Between the granite and diabase, contacts are common. The granite occurs in the form of large masses and eruptive tongues in the diabase and abundant evidence of its eruptive nature can be found in its irregular boundaries, offshooting tongues, and included

fragments of diabase."

These volcanics are generally referred to by Keith in later publications as "Catoctin schist." Keith finally divided the period of Catoctin extrusion into two parts, so that granite intrudes lower volcanics but an upper diabase eruption came after the period of granite invasion.[6]

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[6] Keith, Arthur, Geology of the Catoctin Belt: U. S. Geol. Survey, 14th Ann. Rept., Pt. 2, 1892-3, pp. 318, 394.

In discussing rocks of the Blue Ridge near Harpers Ferry[7], he states

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[7] Keith, Arthur, Harpers Ferry Folio (10), 1894, p. 2

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that Catoctin schist is intruded by granite and that this fact is made plain at contacts between the two "in the alteration of the schist next to the granite, in the smaller crystals of the granite, due to cooling, and in the fragments of schist included in the granite." The writer finds that these opinions of Keith still apply in this area.

In 1906, Weed and Watson studied the relationship of underlying intrusives to Catoctin greenstone along the western side of the Blue Ridge in the Luray region.[8] "The relations between the syenite and basalt observed

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[8] Weed, W. H., and Watson, T. L., The Virginia copper deposits: Econ. Geol., Vol. 1, 1906, pp. 318-19.

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on Stony Man mountain clearly indicate the later age of the first named rock. At most places the syenite is massive and topographically below the basalt."

Phalen[9] wrote in 1906, "The chief mass of the basalt, or melaphyre,

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[9] Phalen, W. C., Copper deposits near Luray, Va., U. S. Geol. Survey Bull. 285, 1906, p. 140.

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or greenstone, as it has been variously termed, is dense and dark green, except where thoroughly epidotized, when it assumes a lighter-green hue. Its original constituents are not determinable without microscopic aid, save perhaps an

occasional phenocryst of olivine. From the facts that bosses of syenite are seen in it in the region near Fisher's Gap and that it has been subjected to an intense metamorphism along its contact with the syenite on the west slope of the ridge and wherever the two rocks are contiguous, it is inferred that the syenite is the younger of the two rocks. This inference is strengthened by the perfectly fresh, holocrystalline character of the syenite at the immediate contact and by the lack of weathered fragments or bowlders of the syenite in the basalt. This contact metamorphism has resulted in a more or less schistose rock, quite different from that of the main mass which, in this particular district, is not regionally schistose."

The Bloomers state, p. 103, "In central Virginia, no rocks resting upon the Catoctin formation are exposed. Farther north, however, the Catoctin is unconformably overlain by the Loudoun formation." In the writer's opinion, all sedimentary rocks in the Natural Bridge area are well exposed, especially the Unicoi, which overlies pre-Cambrian granites. Moreover, in this district, Catoctin consists of residual greenstone remnants included in pink granite and these rocks are unconformable under Lower Cambrian clastic sediments. Catoctin rocks of the South Mountain belt, in Central Virginia, unconformable under Loudoun arkose, were mapped and described may years ago.[10]

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10 Virginia Geological Survey, Geologic Map of Virginia: 1928. (Geology of the crystalline rocks by Anna I. Jonas). Virginia Geological Survey, Bull. 39, 1935, Furcron, A. S., James River iron and marble belt,

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The intrusion of granodiorite and granite into Catoctin greenstone has been reported also in other articles.[11]

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11 Phalen, W. C., A new occurrence of Unakite — A Preliminary Paper: Smithsonian Misc. Collections, Vol. 45, 1904, pp. 306-316.

Watson, Thomas L., and Cline, J. H., Hypersthene syenite and related rocks of the Blue Ridge region, Virginia: Geol. Soc. Amer. Bull., Vol. 27, 1916, pp. 193-234.

Furcron, A. S., Igneous rocks of the Shenandoah National Park area: Jour. of Geol., Vol. 42, 1934, pp. 400-410.

Furcron, A. S., and Woodward, H. P., Geology and mineral resources of the Stony Man Quadrangle, Virginia: Unpublished manuscript in files of the Virginia Geological Survey.

The Bloomers' belief that Catoctin volcanics are of Lower Cambrian age is based upon this view that there is a sedimentary formation unaltered, and resembling Loudoun or Unicoi beneath Catoctin. This, they call the Oronoco formation. The writer has studied and mapped the Catoctin of the Shenandoah National Park area from Front Royal southward to Crozet, and thus far has not been able to demonstrate the presence of such a formation. The contact between Catoctin volcanics and intrusives is sharp and clearcut in the western Blue Ridge. If the flows are younger, it is unlikely that they would have been poured out over so great an area upon an absolutely clean floor, and erosion along the west side of the Blue Ridge offers ample opportunity for study of this interesting contact. The Bloomers' Oronoco formation is described from the Buena Vista quadrangle at the southern end of the western Catoctin belt.

A perusal of my geologic map of the crystalline rocks of the Shenandoah National Park area (unpublished) reveals a striking correlation between occurrences of unakite in both granite and granodiorite, and its proximity to Catoctin greenstone. For this reason, the writer believes there is evidence to indicate that unakite was produced by hydrothermal changes which took place probably at the close of the period of granite and granodiorite injection, where hot solutions had an opportunity of mingling with more basic Catoctin minerals. In the Bull Run-South Mountain area, where granite is not in contact, as a rule, with Catoctin, unakite is not discovered. Throughout the Shenandoah National Park area, granite and granodiorite near epidote greenstone contain epidote. Also, in such occurrences, their feldspars contain sufficient ferric oxide to become pink, locally nearly red. Where granites intrude greenstone, later hydrothermal action is prone to

create such effects.

Mrs. Stose[12] states that alterations in granodiorite when unakite occurs "proceed by a strong development of myrmekite.....These changes are accompanied by considerable sericitization of the potassium feldspars, increase is saussuritization of the plagioclase, and alteration of hypersthene to hornblende, chlorite, and epidote." She states further, "Much of the epidote is clarly secondary, and has replaced the other constituents.....the epidote is largely introduced, and has replaced other minerals." It is believed by the writer that Mrs. Stose has described in detail in this excellent article the later hydrothermal effects in granodiorite and granite. Where greenstone is involved, unakite was produced; also since myrmekite is typical of these rocks generally, unakite can be accounted for only where these later hydrothermal solutions come in contact with greenstone.

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12 Jonas, A. I., Hypersthene Granodiorite in Virginia: Bull. Geol. Soc. Amer., Vol. 46, pp. 47-60, 1935.

Grandiorite and granite (especially granite) may be altered to unakite where not in contact with greenstone. In such localities, later hydrothermal solutions appear to have been especially active; also an inspection of the geological map indicates that in many of these localities the overlying greenstone may have been present but later was removed by erosion. Also, locally, where later solutions were less active, there is little or no visible saussuritization and unakitization of contacts between the intrusives and Catoctin greenstone.

There is no reason why sandstone or quartzite beds cannot occur in the volcanic rocks of the Blue Ridge of the Park area. The writer has not found them, but is entirely willing to admit that they may be there. Their

presence would have little bearing upon age of the flows. Quartzite beds in the Catoctin rocks were first described by Furcron from the Warrenton area[13]. At that time, Furcron was inclined to regard them as of Loudoun age but later work indicates that they occur only in and over Catoctin greenstone, and are not arkosic, they should not be classified with the Loudoun.

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13 Ibid, page 23, Plate 6.

White, sugary, quartzite beds, described by Furcron as occurring in Catoctin of the Warrenton area, do not resemble the arkoses of the Loudoun formation of that area, nor the Unicoi or Loudoun formation of the Park area. In Bull Run Mountain of Fauquier County, as at High Point near The Plains, Virginia, thick beds of white, sugary quartzite (probably the Weverton sandstone of Keith) overlie the Catoctin. In other places on the Warrenton quadrangle, this type of quartzite occurs as beds in the Catoctin. These rocks, including the "Weverton" of Keith, are regarded by Furcron as of Catoctin or closely related age; thus he questions the Lower Cambrian age of the quartzite of Bull Run Mountain (Weverton of Keith).

Bloomers state that "the age of the Catoctin has been in dispute since Keith described it..." However, it does not appear that Keith's opinion was disputed until 1935, at least 40 years after Keith's original article. The Stoses[14] at that time offered reason for believing the Catoctin to be younger than the intrusives. They write that the dikes which cut the granodiorite

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14 Ibid, pp. 576, 590, 593.

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are related in composition to the Catoctin. The writer believes this will be very difficult to prove. As a matter of fact, these dikes may have been intruded at other times because they do not resemble dikes of known Catoctin

age described by Furcron from other localities[15]. It seems likely that they could have been intruded in Lower Cambrian times; thus, they may be of the same period as the Lower Cambrian flows.

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[15] Bull. 54, p. 28.

The Bloomers state that Keith believed the Catoctin to be the oldest rock in the Blue Ridge; however, Keith[16] described it as "Algonkian," thus he

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[16] Ibid, see Geologic Map.

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actually described it as of late pre-Cambrian age.

The Bloomers state that the writer concluded that the granite of the Blue Ridge is younger than the Catoctin "because of an intrusion of 'pegmatite' in the Catoctin." This is a misunderstanding of a quotation used by Furcron. The writer has never recognized or described a pegmatite from this terrain. The Blue Ridge block adjacent to the Greater Appalachian Valley, is notable for absence of true pegmatites. Our mica-pegmatites occur much to the east, and in Georgia are cut only by Triassic dikes. The writer believes them to be of Late Paleozoic age; thus, their presence proves little or nothing about age of enclosing rocks. The writer has never regarded Old Rag granite as a true pegmatite, although it is a later facies or "pegmatitic" facies of the granodiorite. "Epithermal dike-like masses" of the Bloomers have never been described in any of the writer's publications as pegmatite.

Copper ores in Catoctin greenstone have been prospected in the past rather extensively throughout the western belt now included in the Shenandoah National Park. Early writers[17] were first inclined to attribute these ores to local concentrations from downward circukating meteoric waters probably because

such views had been expressed in those days regarding the origin of the Michigan copper deposits.

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17 Weed, W. H. and Watson, T. L., Virginia Copper deposits, Econ. Geol. Vol. 1, pp. 317-323, 1906.

Phalen, W. C., Copper deposits near Luray, Virginia, U. S. Geol. Survey, Bull. 285, pp. 140-145, 1906.

The deposits are found near the base of the Catoctin greenstone, or at intrusive contacts. Ores are principally native copper and cuprite with small amounts of chalcopyrite and bornite. The more accessible prospects are at Dark Hollow and Stony Man (Stony Man quadrangle) where the ore-bearing greenstone adjoins granite. Phalen[18] admits that ascending magmatic waters may

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18 Phalen, W. C., op. cit., p. 142-3.

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have been responsible for bringing such sulphides as chalcopyrite into the quartz veins. Watson[19] at a later date suggested that the primary ores

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19 Watson, Thomas L., Personal communication to A. S. Furcron, 1921.

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probably were deposited by a reaction between magmatic waters and the ferric oxide of the greenstone. The writer believes that the composition of the primary ores, and their relation to the intrusives, indicate that Catoctin greenstone was mineralized by magmatic waters emanating from the underlying intrusives.

In summary, Furcron believes that Catoctin volcanics are older than granite and granodiorite for the following principal reasons:

1. Local evidence of intrusion of granite and granodiorite into Catoctin volcanics.

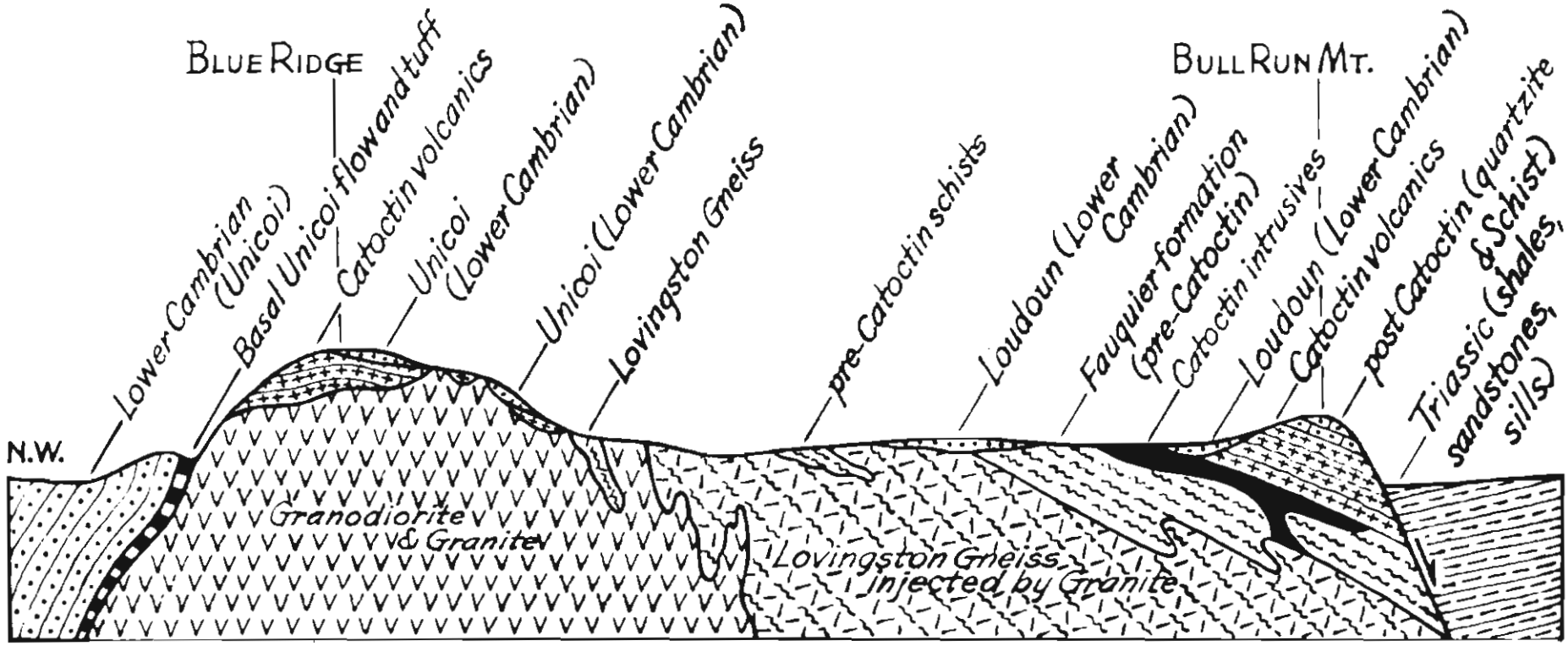
2. Local inclusion of greenstone fragments in granodiorite and Old Rag granite, and lack of included granite fragments in the base of the flows.

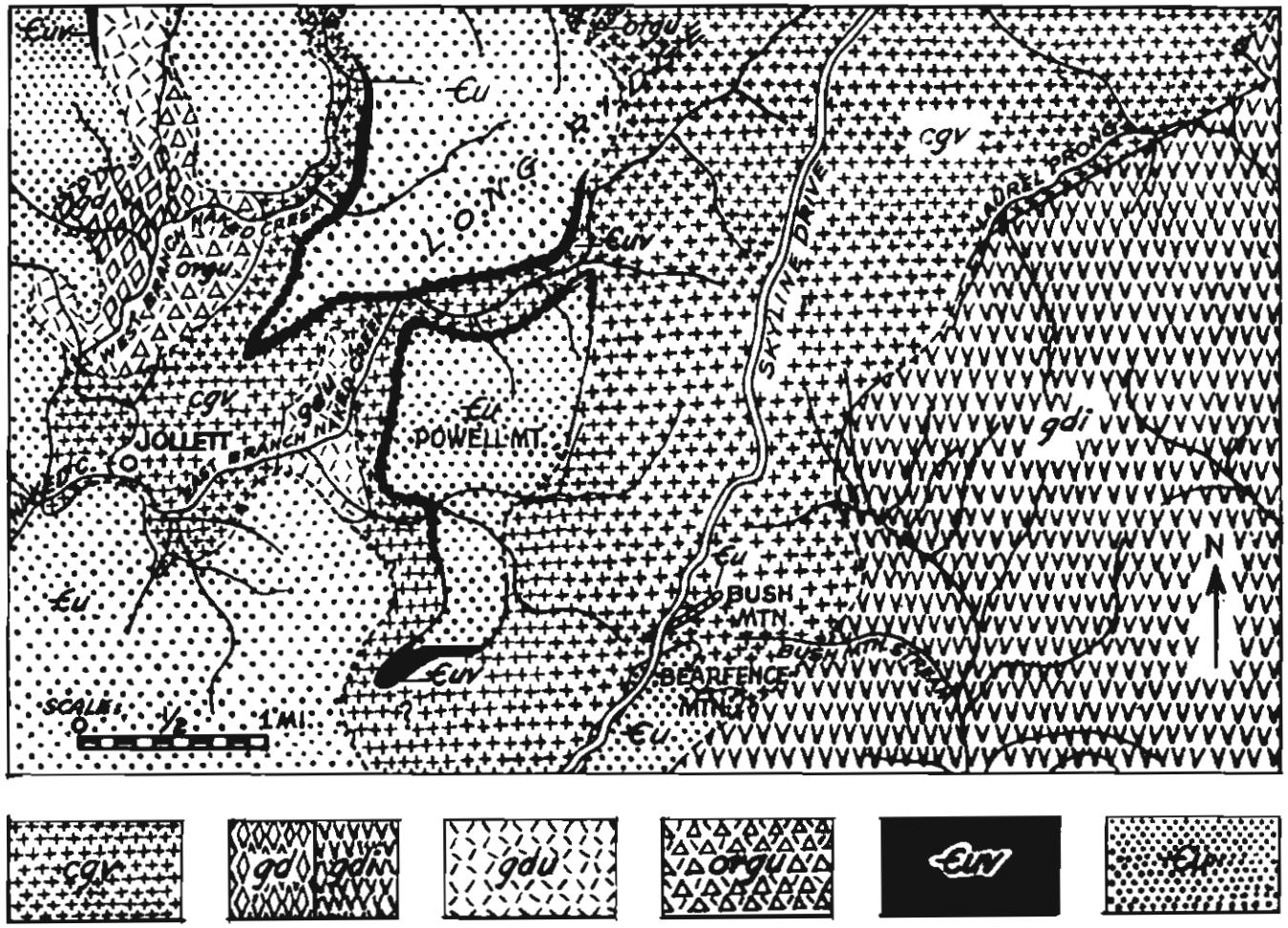
3. Tendency to production of "unakite" in granodiorite and Old Rag granite near contact with Catoctin greenstone.

4. Local occurrence of quartz-epidote rock (epidosite) at contact of Catoctin greenstone with granite.

5. Great differences in elevation within short distances of the floor of the greenstone, and bosses of granodiorite and granite within greenstone where it normally would have been considered to be of great thickness.

6. Composition, distribution, and association of the primary copper ores in the Catoctin volcanics indicate the intrusive relationship of underlying granodiorite and granite.


BLUE RIDGE
BULL RUN MT.
N.W.
Lower Cambrian (Unicoi)
Basal Unicoi flow and tuff
Catoctin volcanics
Unicoi (Lower Cambrian)
Unicoi (Lower Cambrian)
Lovingston Gneiss
pre-Catoctin schists
Loudoun (Lower Cambrian)
Fauquier formation (pre-Catoctin)
Catoctin intrusives
Loudoun (Lower Cambrian)
Catoctin volcanics
post Catoctin (quartzite & Schist)
Triassic (shales, sandstones, sills)
Granodiorite & Granite
Lovingston Gneiss injected by Granite


Ꞓu
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POWELL MT.
JOLLETT
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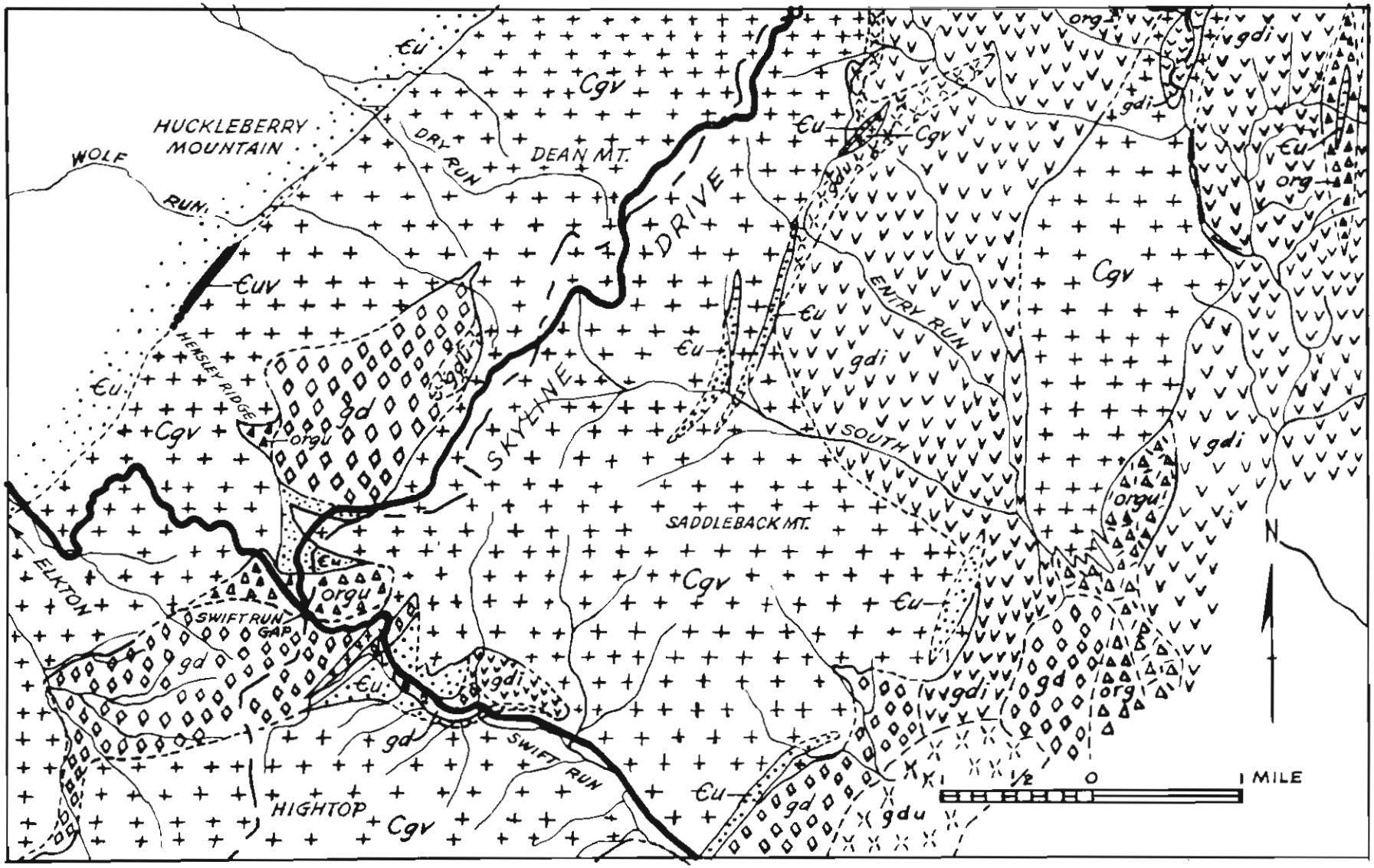
Fig. 2


HUCKLEBERRY MOUNTAIN
WOLF RUN
DRY RUN
DEAN MT.
SKYLINE DRIVE
HENSLEY RIDGE
ENTRY RUN
SOUTH
SADDLEBACK MT.
ELKTON
SWIFT RUN GAP
SWIFT RUN
HIGHTOP
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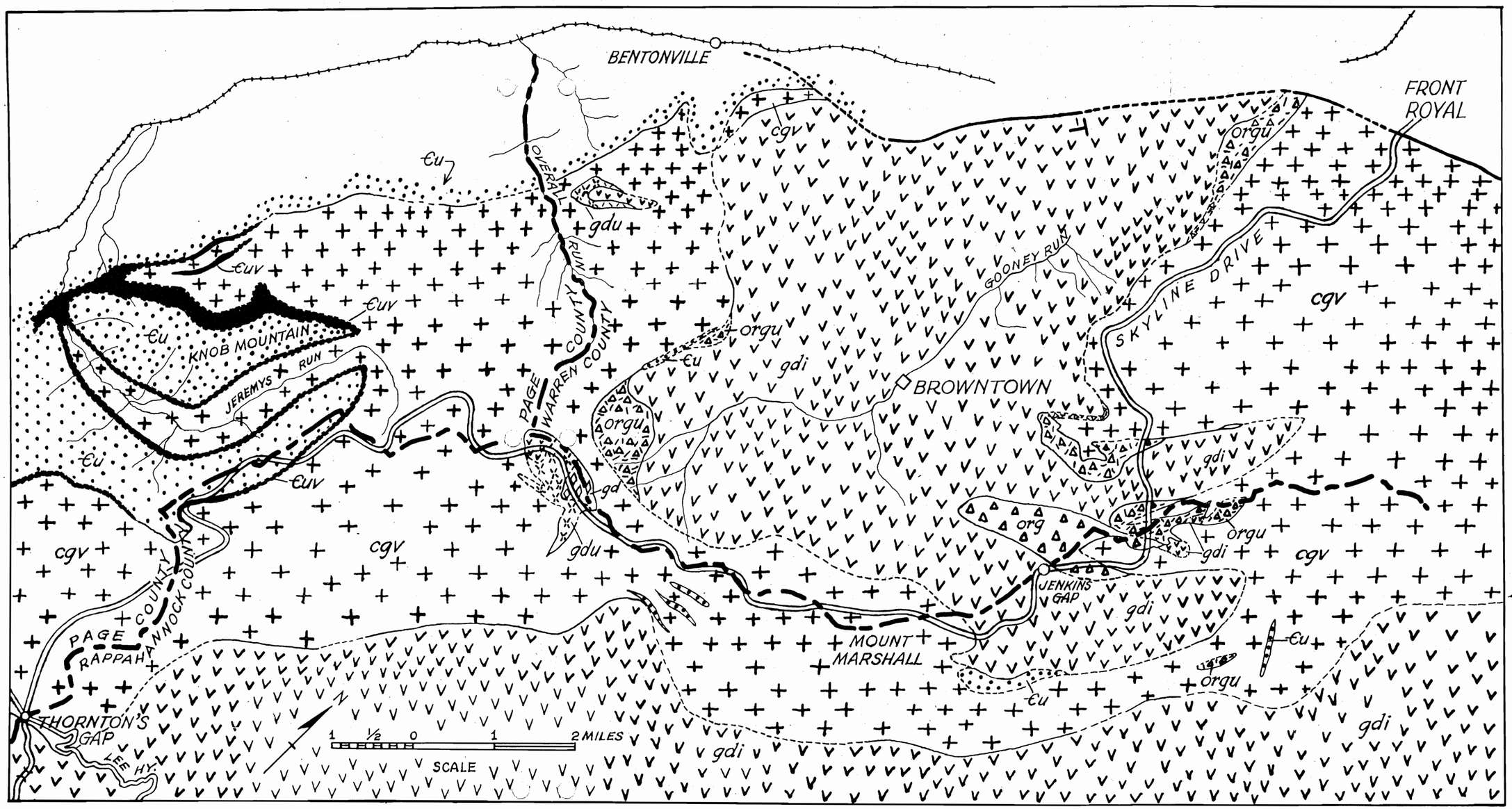

Fig 4

Geology of Page County in Gaspar Thomas map, IX