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PRECAMBRIAN GEOLOGY ALONG PARTS OF THE GUNNISON UPLIFT OF SOUTHWESTERN COLORADO

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INTRODUCTION

The Gunnison Uplift of southwestern Colorado consists of extensive Precambrian rocks along the south side of the Gunnison River that extend for as much as 120 km from the Black Canyon area through the Powderhorn district and eastward to Cochetopa Creek (fig. 1). The part of the Gunnison Uplift discussed in this report occupies an area of about 60 by 30 km and is a part of the Uncompahgre-San Luis Highlands. The Cimarron fault bounds the Gunnison Uplift on the south and is well exposed in the valley of the Lake Fork of the Gunnison River, where the Upper Cretaceous Mancos Shale is faulted downward on the south against Precambrian rocks. The fault block in this region is tilted 5 to 10 degrees to the north-northeast. Along the Gunnison River, the Precambrian rocks dip under the cover of Upper Jurassic and Cretaceous sedimentary rocks, and the contact slopes northward forming a part of the south flank of the Piceance Creek Basin.

The Precambrian rocks have been separated into two major formations, the younger dominantly metasedimentary Black Canyon Schist and the older dominantly metavolcanic Dubois Greenstone. The Black Canyon Schist is at least 10,000 m thick, and in the Black Canyon W. R. Hansen (1971) recognized five different map units. In the Powderhorn region, the Dubois Greenstone is at least 8,000 m thick and the base of the formation is not exposed. Olson and Hedlund (1973) separated the Dubois Greenstone into three main rock types: (1) metabasalt and meta-andesite flows, (2) felsite porphyries and metatuffaceous rocks, and (3) epiclastic rocks derived from the older volcanic strata. The purpose of this paper is to give a review of the Precambrian stratigraphy, structure, and intrusive activity.

Uplift and erosion in the late Paleozoic and (or) Triassic resulted in the removal of all Paleozoic strata and peneplanation of the Precambrian basement prior to the deposition of the Upper Jurassic Junction Creek Sandstone. Laramide movement on the Cimarron fault resulted in at least 610 m of displacement. Subsequent erosion removed Upper Jurassic and Cretaceous sedimentary rocks from most of the area prior to the eruption of extensive Oligocene lavas, laharic breccias, ash-flow tuffs, and Miocene or Pliocene flows onto the stripped surface of Precambrian rock.

Numerous small gold and silver mines within the Dubois Greenstone gave rise to the term Gunnison Gold Belt, and such small

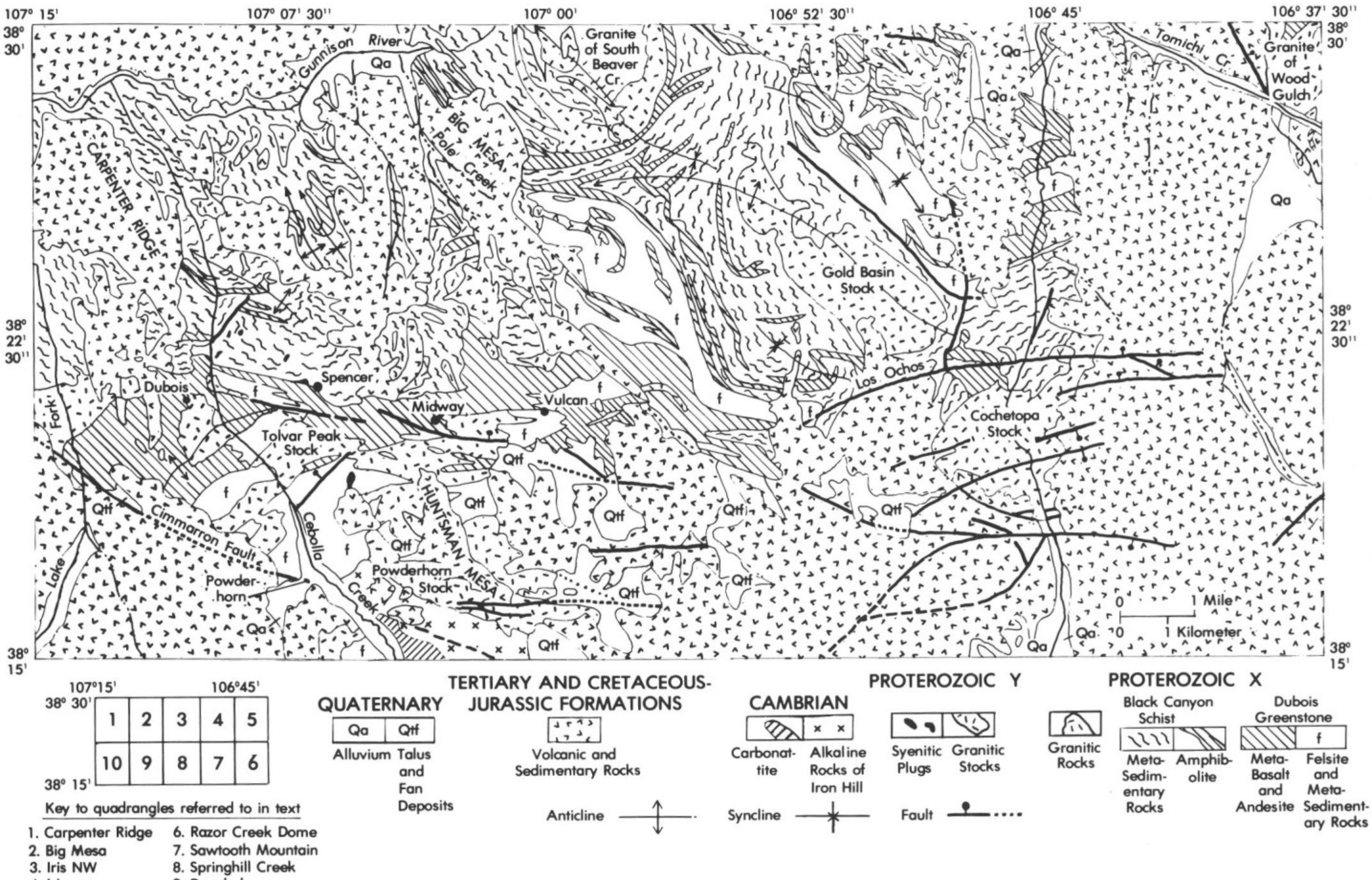

Figure 1. Generalized geologic map of part of the Gunnison Uplift, Colorado.

mining towns as Dubois, Spencer, Vulcan, and Midway were formed in the late 1880's. In the middle and late 1970's, with the recognition of volcanogenic massive sulfide deposits in the region, there was a renewed interest and exploration of the gold- and silver-bearing stratabound base-metal sulfides. D. M. Sheridan, W. H. Raymond, and L. J. Cox (this guidebook) discuss this type of mineralization in an accompanying paper (see also Drobeck, this guidebook).

PRECAMBRIAN STRATIGRAPHY

Dubois Greenstone

The Dubois Greenstone was first described by Hunter (1925, p. 28-36) who named the formation after the old mining camp of Dubois (fig. 1). The Dubois Greenstone can be divided into three parts: (1) metavolcanic hornblende schist, amphibolite, and chlorite-hornblende schist with intercalated purplish-gray metachert beds; (2) felsitic metavolcanic rocks including quartz porphyry flows and dikes and thinly interlayered muscovite-chlorite schists locally containing kyanite, staurolite, spinel, garnet, and sericitized andalusite; and (3) diverse metamorphosed epiclastic and pyroclastic rocks.

Amygdules and pillow structures are locally present in the hornblendic gneiss and schist (fig. 2). Chemical analyses of these metavolcanic rocks suggest a tholeiitic basalt composition (Table 1). Generally the Dubois Greenstone is more schistose in the Powderhorn-Lake Fork region and shows some retrograde chloritization, whereas to the east in the Cochetopa Creek area the greenstone is less deformed and relatively nondeformed pillows are still recognizable. Pillow lavas are well exposed in road cuts on the east side of Cochetopa Creek about 1,500 m south of the Gunnison-Saguache County line. Among the felsitic rocks are "quartz-eye" porphyries that represent rhyolitic flows and tuffs (fig. 3). The "quartz-eyes" are generally devoid of inclusions, are locally lensoid, and commonly display a bluish irridescence. A pronounced bimodal basalt-rhyolite series of flows is recognized within the Dubois Greenstone.

Figure 2. Pillow within metabasalt of the Dubois Greenstone.

Table 1. Chemical analyses of Precambrian metamorphic rocks.

Sample No.--	150041	150040	3418	R82	3306-A
Rock type---	Amphibolite, Dubois Greenstone	Amphibolite, Dubois Greenstone	Felsite porphyry, Dubois Greenstone	Metatuff Felsite	Quartz biotite schist, Black Canyon Schist
SiO_2--------	51.0	47.5	73.2	77.0	73.3
Al_2O_3-------	15.3	17.9	12.2	12.0	13.3
Fe_2O_3-------	2.3	2.5	1.5	1.3	0.8
FeO---------	7.8	6.2	3.7	0.96	1.8
MgO---------	7.0	7.1	0.73	0.83	1.4
CaO---------	10.9	10.8	3.0	1.1	1.4
Na_2O--------	2.1	2.5	2.8	3.1	3.2
K_2O---------	0.37	0.81	0.94	2.2	3.2
TiO_2--------	0.80	0.36	0.34	0.17	0.22
P_2O_5--------	0.09	0.10	0.12	0.01	0.04
MnO---------	0.20	0.18	0.14	0.00	0.08
H_2O---------	1.3	2.0	0.90	0.07	0.65
CO_2---------	0.14	0.34	0.09	0.02	0.38
Sum---------	99.3	98.3	99.7	98.8	99.8

Analyses by P. L. D. Elmore and S. D. Botts, U.S. Geological Survey.

Figure 3. Microphotograph (15×) of "quartz-eyes" in felsite porphyry from the Dubois Greenstone.

This metavolcanic formation also contains a thick (>4,300 m) sequence of submarine pyroclastic flows with interbedded epiclastic rocks (Olson, 1976a; Afifi, 1980, this guidebook). Graded bedding, lithic and crystal clasts, and stretched and deformed shard and pumice fragments have been recognized and are especially well shown in the Iris quadrangle (Olson, 1976a).

Black Canyon Schist

The best exposures of the Black Canyon Schist* are along the walls of the Black Canyon where Hunter (1925, p. 10-22) described a thick section of quartz-biotite schist and gneiss, migmatite, sillimanitic quartz-muscovite-biotite schist and gneissic amphibolite. Migmatite is most common in the Carpenter Ridge and Big Mesa quadrangles (Hedlund and Olson, 1973, 1974) (fig. 1) and farther west in the Black Canyon (Hansen, 1971) where the migmatite is pervaded by pegmatite dikes and pods. Most of the Black Canyon Schist is of metasedimentary origin, and relict stretched pebbles and cobbles are present locally within discontinuous metaconglomerate beds (fig. 4). Chemical analyses indicate about 36 percent normative quartz and 2 percent normative corundum for some samples of schist. Thin layers of intercalated gneissic amphibolite within the quartz biotite schist commonly occur as boudins and locally are contorted or abruptly terminated. An alignment of the amphibolite layers generally indicates the strike or attitude of the original bedding within the schist, and most probably these layers are metamorphosed basaltic or andesitic flows.

AGE RELATIONS OF PRECAMBRIAN METAMORPHIC ROCKS

The metamorphism of the Black Canyon Schist occurred about 1.7 billion years ago based on Rb-Sr dating (Hansen and Peterman, 1968). Age determinations have not been made on the Dubois Greenstone, but the Dubois metavolcanic rocks were probably metamorphosed to amphibolite grade about 1.7 to 1.8 billion years ago as based on isotopic ages from similar rocks in other areas of southwestern Colorado (Hutchinson, 1976). The intrusion of large and small granite bodies, some of which are synkinematic

*The Black Canyon Schist is an accepted formational name of use in a restricted area, but of limited general application (Tweto, 1977).

Figure 4. Metaconglomerate in the Black Canyon Schist.

and associated with migmatization, probably occurred about the time of metamorphism, although some may be as young as 1.35 to 1.4 billion years. The granite of Tolvar Peak has some chemical and lithological similarities to the felsite porphyry in that the Na_2O/K_2O ratio (3-5/1) is relatively high and the quartz grains are similar (Tables 1 and 2). The granite of Tolvar Peak probably is approximately coeval with the felsitic and metabasaltic rocks of the Dubois Greenstone and intruded the volcanic pile shortly after extrusion of the mixed flows and clastics.

The metasedimentary schists of the Black Canyon are concordant with the metavolcanic rocks of the Dubois Greenstone except in areas where there has been intense shearing or intrusion along the formational contact by granite. Moreover, both formations are of similar metamorphic grade—that is, amphibolite facies — and except in the Gateview quadrangle show similar fold patterns. Where pillows have been observed in the Dubois Greenstone the flow tops indicate a younger flow sequence toward the contact with the Black Canyon Schist.

STRUCTURE

Folds

The Black Canyon Schist and the infolded felsite and amphibolite of the Dubois Greenstone in the northwestern part of the area form a large synclinorium with minor smaller folds striking northwest (fig. 1). The thick felsitic mass in the Pole Creek area in the southwestern part of the Iris NW quadrangle and another in the Milkranch Gulch area in the west-central part of the Powderhorn quadrangle (Hedlund and Olson, 1975), together with extensions from these folded masses toward the east, form the V-shaped outcrop pattern of the flanks of a synclinorium plunging northwestward. Younger rocks therefore occupy the trough of the synclinorium progressively northwestward, passing from felsite to the thick locally pillowed basaltic sequence of the Dubois Greenstone to the very thick metasediments of the Black Canyon Schist. Above and northwest of the Dubois metavolcanics, the first sedimentary rocks commonly are quartzofeldspathic schists, as found in the

Table 2. Chemical analyses of Precambrian igneous rocks.

Sample No.----	D 100330	150044	150039	150045	150046
Rock type-----	Powderhorn granite	Granite of Tolvar Peak	Augite syenite	Augite syenite	Biotite syenite
SiO_2----------	73.15	73.2	48.5	53.8	44.7
Al_2O_3---------	13.45	14.2	10.4	11.9	9.2
Fe_2O_3---------	1.25	2.5	4.6	3.0	2.1
FeO-----------	1.19	0.85	3.3	4.7	6.3
MgO-----------	0.57	0.24	10.9	9.2	13.3
CaO-----------	1.86	0.81	7.2	6.6	9.8
Na_2O----------	3.73	5.6	1.3	2.2	1.0
K_2O-----------	3.43	1.2	8.4	5.8	4.8
TiO_2----------	0.16	0.25	0.81	0.82	1.5
P_2O_5----------	0.10	0.01	1.3	0.66	1.7
MnO-----------	0.07	0.02	0.14	0.14	0.13
H_2O-----------	0.11	0.62	0.71	0.56	1.4
CO_2-----------	0.21	0.08	0.68	0.16	1.8
Sum-----------	99.3	99.6	98.2	100	97.7

Analyses by P. L. D. Elmore and S. D. Botts, U.S. Geological Survey.

northwestern and northeastern corners of the Powderhorn quadrangle and the southeastern part of the Big Mesa quadrangle. The greater feldspar content of these metasedimentary rocks, corn pared to the more quartzose, micaceous, fine-grained character of typical Black Canyon Schist in a large area in the Carpenter Ridge and Big Mesa quadrangles, is interpreted as having been derived from nearby volcanic rocks.

The crescentic structure in the northwest corner of the Iris NW quadrangle is interpreted to be a northwest-plunging syncline that is about 10 km across, shows closure to the southeast, and has an axial plane that strikes N.35°W. The synkinematic granite of South Beaver Creek outlines the limbs and crest of the fold. The amphibolite layer that forms a crescentic band just southeast of the granite body is interpreted to be correlative with the similar unit in the southern half of the Iris NW quadrangle just east of the thick felsite mass of Pole Creek, where it is in part a pillow lava.

A relatively small anticlinal fold is well shown in the Dubois Greenstone and associated felsite layers just east of the Lake Fork of the Gunnison River (fig. 1). The foliation and layering are bent from their common N.40°E. strike to an east and slightly southeast strike. This flexing of the axial plane possibly is related in part to drag along a major shear zone with right-lateral displacement.

In the Iris quadrangle, epiclastic and metamorphosed rocks are folded into a tightly compressed syncline that plunges steeply southeast. The keel of the fold just northwest of Green Mountain is delineated by folded amphibolite layers (Olson, 1976a). (See also Afifi, this guidebook.)

Numerous other small folds make up a part of the large synclinorium, and some of the larger ones are represented in the northwestern part of Figure 1. In most places the foliation in the metamorphosed rock is approximately parallel to the bedding and is generally steep throughout the region, except for the relatively flat foliation surfaces within the Black Canyon Schist of the Carpenter Ridge quadrangle.

Faults

Faults of Precambrian, Cambrian, and Laramide ages are recognized in the region and most are dated by either association or displacement of known types of mineralization—for example, thorium veins and the stratabound massive sulfides—or by displacement of Mesozoic sedimentary rocks. The Precambrian faults are most difficult to date owing to the absence of a Paleozoic sedimentary rock cover and the local occurrence of Mesozoic sedimentary rocks.

Shearing and dislocation of probable Precambrian age is illustrated by one major zone that trends about N.80°W. across the northeastern part of the Gateview quadrangle and into the Powderhorn quadrangle. This fault displaces parts of the near-vertical northeast limb of a broad steep fold in the Dubois Greenstone. The shearing is distributed along many shear planes in a zone about 500 m wide. In this wide belt, chlorite- and sericite-rich schists are common and were formed by retrograde metamorphism of rocks that had attained the staurolite-kyanite grade of metamorphism (fig. 5).

Some Precambrian(?) faults are mineralized by veins that locally contain base-metal sulfides. One such fault about 0.5 km south of Midway in the Powderhorn quadrangle is at least 6 km long and trends west-northwest. Many of the base-metal sulfides are not clearly fault-controlled but show evidence of deformation, and the pyrite, pyrrhotite, arsenopyrite, and sphalerite grains are deformed. Many of the stratabound sulfide deposits are parallel to the foliation and layering in the Dubois Greenstone.

Cambrian faults are commonly dated by association with thorium veins that are along open and brecciated faults that strike dominantly either northwest or N.60°E. to due east. These faults and veins are reddened, jasperized, and commonly contain barite as well as thorogummite and thorite. Because many of these veins and coextensive faults are proximal to the alkaline intrusions of the complex at Iron Hill and to the thin trachyte porphyry dikes in the region, they are probably the same late Precambrian or Early Cambrian age as the intrusive at Iron Hill, about 570 m.y. old (Olson and others, 1977).

Laramide faults such as the Cimarron fault, the Los Ochos and several other unnamed faults in the Sawtooth Mountain quadrangle (Olson and Steven, 1976), a fault in the southeast corner of the Powderhorn quadrangle, and a fault in the northwest corner of the Big Mesa quadrangle all displace Upper Jurassic formations and (or) Mancos Shale of Late Cretaceous age. The Cimarron fault, the largest, has about 610 m of displacement, and may represent a rejuvenated Precambrian fault. Along the south side of Cebolla Creek near Powderhorn, its trend is marked by hot springs and travertine spring aprons. The Los Ochos fault can be traced for about 20 km, and east of Cochetopa Creek the fault has been the site of uranium mineralization (Malan and Ranspot, 1959). The Laramide fault in the southeast corner of the Powderhorn quadrangle and southwest corner of the Spring Hill Creek quadrangle contains breccias that were locally prospected for fluorspar (Olson and others, 1975).

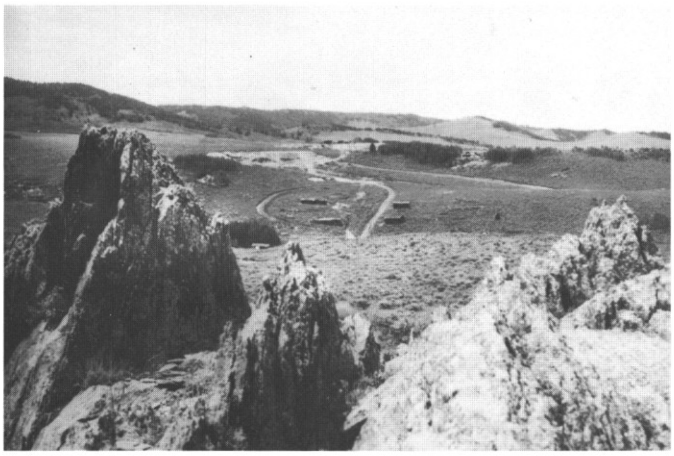

Figure 5. View east to Vulcan mines. Steeply dipping chlorite schist within felsites of the Dubois Greenstone in the foreground.

METAMORPHISM

The metasedimentary and metavolcanic rocks are metamorphosed in the biotite-chlorite to epidote amphibolite facies. The grade of metamorphism is generally lowest in the eastern part of the area and increases northwestward to the sillimanite zone in the Carpenter Ridge quadrangle. In areas of migmatized quartz biotite schist in the northwest corner of the map area (fig. 1), a sparse amount of fibrolitic sillimanite is present within the more micaceous schist. The occurrence of sillimanite coincides with the presence of numerous pegmatitic dikes and pods along the Gunnison River in the Carpenter Ridge quadrangle. In small areas locally higher grades show varying amounts of staurolite, kyanite, garnet, and sparse spinet. One such area is in a belt 500 to 700 m wide that strikes N.75°W. in the northeastern corner of the Gateview quadrangle. The rocks in this area were originally sediments rich in quartz, alumina, and iron with interlayered rhyodacite tuffs or flows. In a typical quartz-chlorite-biotite-staurolite-kyanite schist the black layers, less than 3 mm thick, and containing biotite and staurolite porphyroblasts, alternate with grayish-green layers of quartz, chlorite, and locally kyanite. Dark-brown, twinned staurolite porphyroblasts commonly stand out in relief on weathered surfaces. The staurolite-kyanite rocks indicate medium- to high-grade metamorphism involving strong deformation under relatively high stress, as shown by crenulations, drag folds, and strong shear zones in some of the felsites and metasediments.

After regional metamorphism, a rather pervasive northeast-striking foliation, accompanied by shearing and retrograde metamorphism, was superimposed on the earlier formed structural features in some areas.

PRECAMBRIAN INTRUSIONS

Precambrian intrusives include a diverse group of rocks ranging from diorite to granite to syenite. Isotopic ages have been determined for the syenitic rocks, 1,330 to 1,390 m.y. old, but the other intrusive rocks are probably mostly 1,750-1,800 m.y. in age. Hunter (1925, p. 38, 39) named the "Powderhorn granite group" and considered them to be the oldest in the region. However, it is highly probable that the granite of Tolvar Peak, the smaller dioritic bodies in the Big Mesa quadrangle, and the synkinematic granite of South Beaver Creek are somewhat older. These various intrusives are discussed in order of probable age.

Dioritic Rocks

Some of the earliest rocks intrusive into the metavolcanic and metasedimentary rocks are the numerous small plutons and dikes that are mostly quartz diorite or metadiorite but range from gabbro to granodiorite in composition. These intrude all the older metamorphic rocks described above, but are cut by granites. About 50 such small bodies were mapped in the Big Mesa and Gateview quadrangles.

Granitic Rocks

The granitic rocks, including granodiorite, quartz monzonite, and granite, are exposed over an area of 78 km' within the Precambrian basement. These rocks occur in three principal belts that trend east-northeast throughout the region: (1) a belt along the south and southeast margin of the mapped area consists of extensive bodies of granitic rocks and only small areas of metamorphic rock. The belt contains the Powderhorn Granite, the quartz monzonite of Cochetopa Creek, and the granite of Wood Gulch; (2) a central east-northeast-trending belt dominated by metavolcanic and metasedimentary rocks, but containing small syntectonic granitic bodies that are generally concordant with the foliation of the enclosing metamorphic rocks. This belt contains the granite of Tolvar Peak, the granite and quartz diorite of Gold Basin, the granites of the Sugar and Pole Creek areas within the Big Mesa quadrangle, and the arcuate granitic bodies of South Beaver Creek; and (3) a group of leucogranite and biotite granite bodies that form irregular discordant stocks and dikes within areas of migmatite and quartz biotite schist in the northwest part of the mapped area, in the Carpenter Ridge and Big Mesa quadrangles.

Alkalic Rocks

About 20 small plugs of augite syenite, biotite syenite, and leucosyenite crop out in the region, many of them in an area just northwest of Spencer and east of Cebolla Creek. Some of the plugs have leucosyenite cores with marginal wall zones of biotite syenite; others are unzoned and are of augite syenite. The intrusives are characterized by a high K_2O content, which ranges from 5 to 8 percent, whereas the Na_2O values are generally less than 2 percent (Table 2). Relatively high values of TiO_2 and P_2O_5 can be attributed to the rutile inclusions in biotite and to the abundance of accessory apatite.

The alkalic plugs have intruded the Dubois Greenstone and the Black Canyon Schist and have yielded K-Ar ages of 1,330 to 1,390 m.y. (Olson and others, 1977). These alkalic plugs are clearly older than the 570-m.y. alkaline rocks of Iron Hill but are younger than the 1,700 to 1,800-m.y. regional metamorphism. Although there is some uralitization of the augite grains in the augite syenite, the other minerals or original texture show little modification.

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