UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF PART OF THE JOHNNY GULCH QUADRANGLE, MONTANA

By

Val L. Freeman

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

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ABSTRACT

An area of about 35 square miles, situated about 30 miles southeast of Helena, Montana, was mapped during the summer of 1952 at a scale of 1:24,000. The area includes a part of the eastern foothills of the Elkhorn Mountains, and is underlain by sedimentary and volcanic rocks of Cretaceous age that were intruded during late Cretaceous or early Tertiary time by several types of igneous rocks.

The oldest rocks in the map area are the nonmarine sandstone, shale, and limestone of the Kootenai formation. These are overlain disconformably by the black shale, siltstone, sandstone, and siliceous mudstone of the Colorado group that is subdivided into three map units; a lower black shale unit composed of black shale and silty shale with a basal clean sandstone, all of probable marine origin; a middle siliceous unit composed of sandstone, siltstone, and siliceous mudstone of both marine and nonmarine origin; and an upper black unit composed of black shale of marine origin. Conformably above the Colorado group are crystal lithic tuffs of the Slim Sam formation; in places these grade into and in other places are unconformably overlain by the Elkhorn Mountains volcanics composed of crystal tuff, breccia, flows, and bedded tuff of andesitic composition.

The rocks of the Elkhorn Mountains volcanics and older formations have been intruded by diorite porphyry and related rocks and by hornblende quartz monzonite. The diorite porphyry and related rocks include hornblende diorite porphyry, hornblende augite diorite porphyry, augite diorite porphyry, and basalt.

Resting with marked unconformity upon older rocks are volcanic sedimentary rocks of early Tertiary age that are locally overlain by thin rhyolite flows. Late Tertiary and Quaternary fans overlie the rhyolite flows. Alluvium, talus, and other mantle are present in small amounts in many parts of the area.

The sedimentary rocks of the area mapped form a part of the east flank of a major anticline. A major north-south syncline to the north of map area is believed to have been deflected to the east of the area because of the rigidity of large irregular plutons of diorite porphyry. The location of the plutons may have been controlled by the initiation of the major syncline, by a postulated pre-intrusive fault, or by both.

Most of the small-scale structural features are related to the emplacement of the plutons. During emplacement the intruded sediments yielded either by faulting or by folding; the deeper rocks failed by faulting and the shallower rocks failed by folding.

The area contains deposits of gold, silver, copper, lead, and zinc, none of which are currently being mined; and a deposit of magnetite which is being mined for use in cement.

INTRODUCTION

This report describes the geology of an area of about 35 square miles (pl. 1), within the eastern foothills of the Elkhorn Mountains. The area was mapped during the summer of 1952, as a part of a study by the U. S. Geological Survey of the geology and mineral deposits of the Boulder batholith and adjacent area. The area mapped includes sedimentary and volcanic rocks of Cretaceous and Cenozoic age and several types of intrusive igneous rocks. The Cretaceous sedimentary and volcanic rocks were folded, faulted, and intruded near the end of Cretaceous time; Cenozoic sedimentary and volcanic rocks rest unconformably upon the older sedimentary, volcanic, and intrusive rocks. Deposits of gold, silver, copper, lead, zinc, and iron have been mined in the area, but are not described in detail in this report.

Location of Area

The area included in this study (fig. 1) is entirely within the Johnny Gulch quadrangle, and lies between latitude 46° 07' 30" N. and latitude 46° 15' N. and between longitude 111° 37' 30" W. and longitude 111° 42' 57" W.

The small ranching and agricultural center of Radersburg lies on the eastern edge of the area and is joined by paved road to Toston 10 miles to the east. Toston is located on Highway U. S. 10N, 46 miles southeast of Helena, and on the Northern Pacific Railroad.

Topography

The area mapped includes a part of the eastern foothills of the Elkhorn Mountains. Along the western limit of the area the elevation ranges from 5,000 to 6,000 feet; the elevation along the eastern limit is about 4,300 feet. The principal streams flow eastward across the area to the range front, where their waters are diverted into irrigation ditches or sink into an alluvial apron that slopes toward the Missouri River about eight miles to the east.

In the western part of the area the land surface is characterized by irregularly spaced groups or clusters of hills; the easternmost part

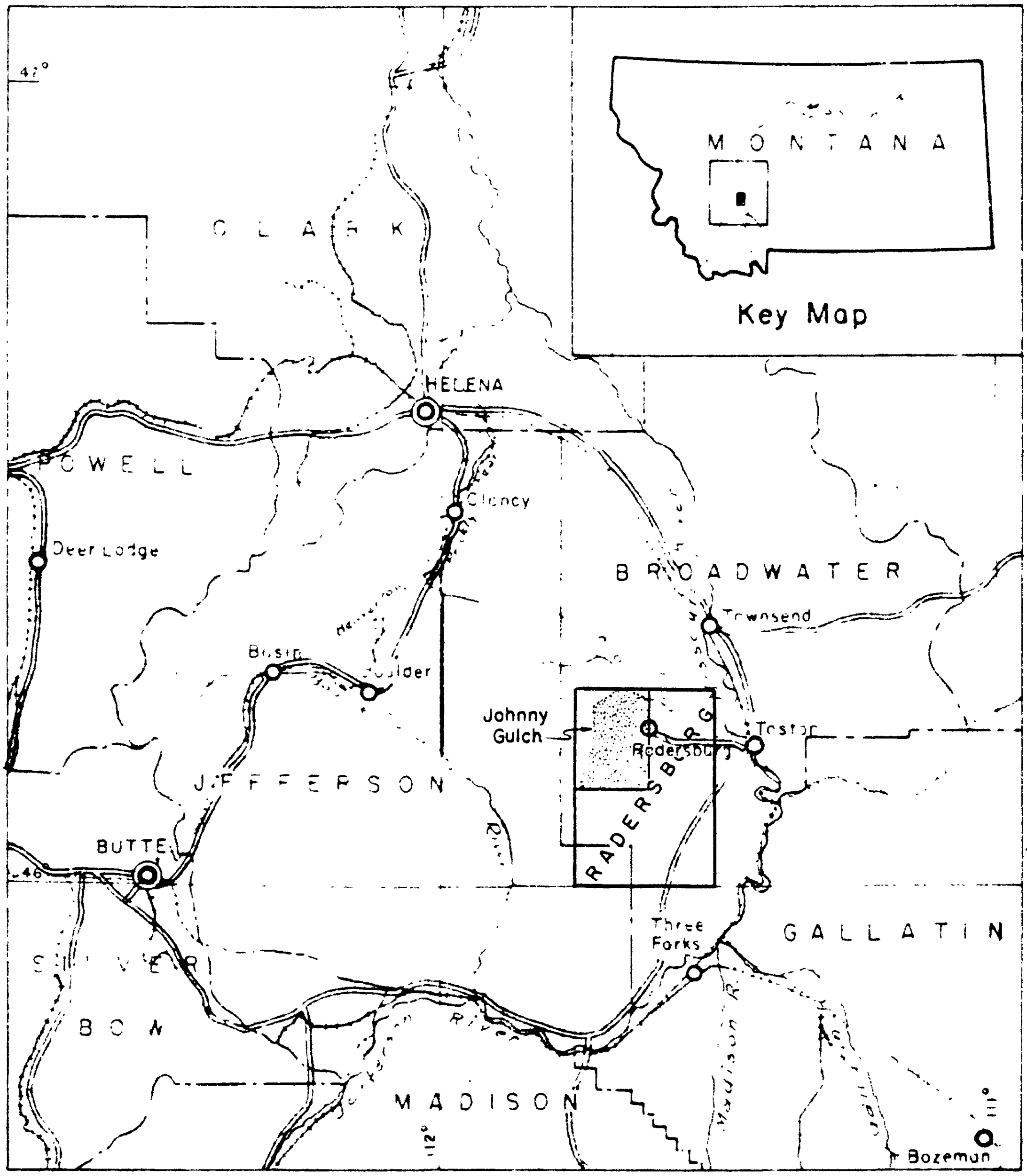


Figure I - Index Map showing location of Radersburg and Johnny Gulch Quadrangles. Area of this investigation shown by stippling

0 5 10 15 20 25 Miles

of the area is a pediment upon which an alluvial apron has been built. In the southeast corner of the map area Lone Mountain rises abruptly 600 feet above the pediment surface.

Field Work and Acknowledgments

The present investigation is part of a study by the U. S. Geological Survey of the geology and mineral deposits of the Boulder batholith and adjacent area. The area described in this report lies about 10 miles east of the batholith, and is composed of nearly equal areas of pre-batholith Cretaceous sedimentary and intrusive rocks, with a small area of intrusive rock that is similar in lithology to some rocks of the batholith and may be of the same age.

Field work leading to this report was done from July through October of 1952. The geology was mapped on an advance topographic base map having a scale of 1:24,000 made for the U. S. Bureau of Reclamation by Fairchild Aerial Surveys, using photogrammetric methods 1/. Stratigraphic sections were measured by Brunton Compass and tape methods.

The author is indebted to M. R. Klepper of the U. S. Geological Survey for advice on the stratigraphy and petrography of the area.

Previous Geologic Investigations

Early geologic work in this region was of a reconnaissance nature or was restricted to small areas of economic importance. The papers of Stone (1910), Knopf (1913), and Pardee and Schrader (1933), though primarily devoted to the ore deposits of the region, also include small-scale geologic maps and discussions of the principal geologic features. Reports on recent studies of adjacent areas have aided in understanding the more detailed features of stratigraphy and structure. These reports include those of Berry (1943), Klepper (1950), Ruppel (1950), Mertie, Fischer, and Hobbs (1951), and Klepper, Weeks, and Ruppel (in preparation).

SEDIMENTARY ROCKS

A brief summary of the sedimentary and volcanic rocks occurring in the area is given in the following table.

1/ The Johnny Gulch quadrangle has not been published for public distribution but the area is shown on the Radersburg quadrangle (pl. 1) published in 1949 by the U. S. Geological Survey.

Age	Formation	Thickness (feet)	Lithology
Quaternary			Alluvium, terrace gravel
Post-Oligocene	unnamed	0-100+	Fan gravel, basalt flow
Oligocene	unnamed	0-450+	Tuffs and volcanic sands and gravels
	angular unconformity		
Upper Cretaceous	Elkhorn Mountains volcanics	2,000+	Andesitic tuffs, tuff-breccias, breccias, flows
	local angular unconformity		
	Slim Sam formation	900±	Sedimentary tuffs, tuffs, and volcanic sandstones and mudstones
Upper and lower Cretaceous	Colorado group	1,500±	Black shales, siliceous mudstone, sandstones, siltstones
	erosional unconformity (?)		
Lower Cretaceous	Kootenai formation	450±	Red and green shales, "pepper-and-salt" sandstone, limestone

Cretaceous System

The Cretaceous system in this area includes approximately 3, 000 feet of sedimentary rocks and at least 2, 000 feet of volcanic rocks, mostly tuffs and breccias.

The nonmarine Kootenai formation at the base of the Cretaceous system is not present in its full thickness within this area, but measured sections obtained a short distance to the west and east show its thickness to be about 450 feet. Overlying the Kootenai formation with a probable slight erosional unconformity is a thick sequence of dark shale, siltstone, siliceous mudstone, and sandstone, that is equivalent to the Colorado group. These rocks are mostly of marine origin and are about 1, 500 feet thick. They grade upward into about 900 feet of tuffaceous sandstone sandy tuff, and tuff of acid to intermediate composition of the Slim Sam formation. At least 2, 000 feet of andesitic volcanic rocks, mostly tuff and breccia, rest unconformably on the Slim Sam formation; these rocks constitute the Elkhorn Mountains volcanics.

Kootenai formation

The oldest rocks exposed in the map area are those of the Kootenai formation. This formation lies upon the upper Jurassic Morrison formation with apparent conformity, but the correlation charts of Cobban and Reeside (1952) indicate a time gap of considerable magnitude. Neither structural nor paleontologic evidence suggesting such a disconformity has been found in the Elkhorn Mountains region, but in the Sweetgrass arch, Montana, Cobban (1945) found evidence for a period of folding and erosion after deposition of the Morrison and before deposition of the Kootenai.

The Kootenai formation is about 450 feet thick along the eastern front of the Elkhorn Mountains and apparently thickens to the westward. A three-fold division of the formation is recognizable, but only the upper part and a fraction of the medial part are present in the area mapped. The lower part of the formation is represented only by two small remnants in a diorite intrusion. The lower part, comprising from one-fourth to one-third of the formation, contains one to three characteristic beds of "pepper-and-salt" sandstone with interbedded siltstone and claystone. The uppermost 10 to 50 feet of the formation contains beds of limestone, usually fossiliferous, with interbeds of calcareous claystone and siltstone. The part of the formation between the uppermost "pepper-and-salt" sandstone and the lowermost limestone consists of siltstone, argillaceous siltstone, claystone, shale, and silty shale.

The "pepper-and-salt" sandstones (pl. 4-A) are gray, fine- to coarse-grained, locally conglomeratic, stream deposited sandstones showing scouring and cross-lamination. The sand grains are angular

PLATE 2

A. View looking south toward Cable Mountain. Terrace of Tertiary and Quaternary fan gravels along Johnny Gulch in middle of view.

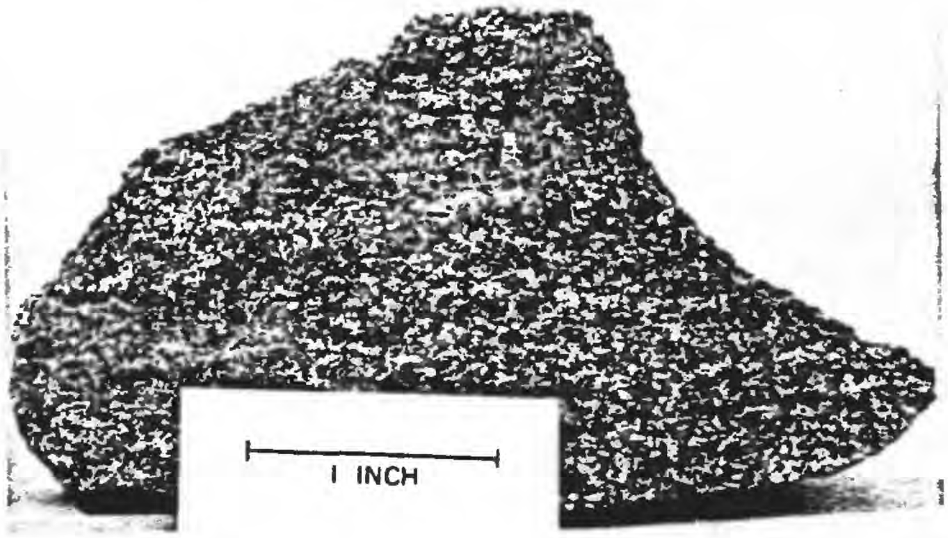
B. View looking south across Johnny Gulch. Terrace of Tertiary and Quaternary fan gravels along Johnny Gulch in middle of view.

PLATE 3

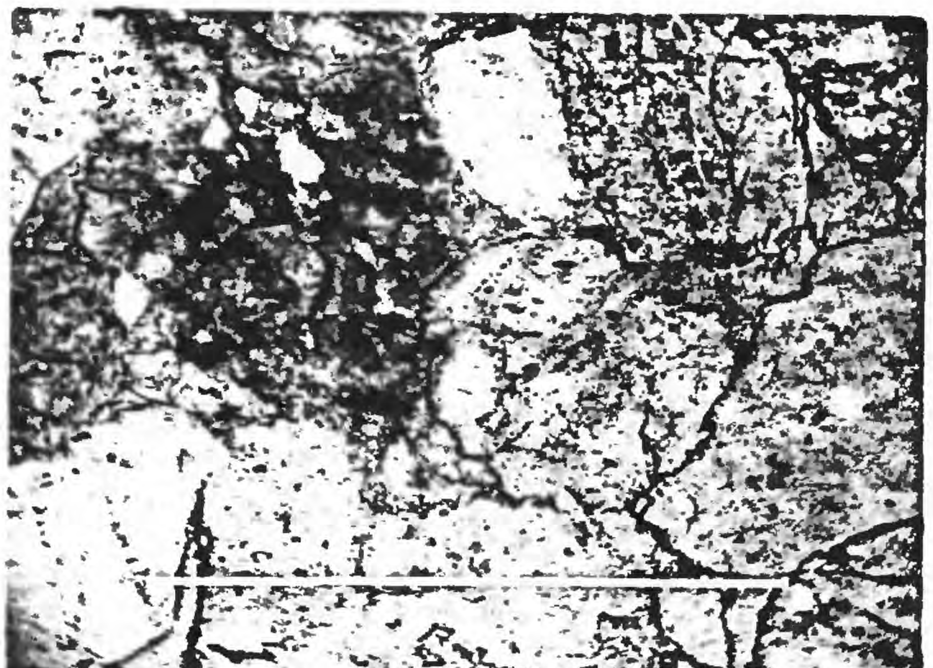
A. View looking west toward Rattlesnake Butte. Low outcrops in foreground are of Elkhorn Mountains volcanics.

B. Outcrops of quartz monzonite at Lone Mountain.

PLATE 4



A. Hand specimen of "pepper-and-salt" sandstone, Kootenai formation.



B. Photomicrograph of "pepper-and-salt" sandstone, Kootenai formation, showing microstylolites.

to rounded. poorly to well sorted. and are made up of chert and quartz: interstitial clay is commonly present Small and discontinuous conglomerate lenses contain fragments in a wide range of sizes with a maximum dimension of about three inches. The fragments are typically quartzite and chert, but locally include abundant limestone. The chert content of the Kootenai formation is greatest at the base, where it may form two-thirds of the grains in the "pepper-and-salt" sandstones, and decreases rapidly upward to about the middle of the formation where it disappears entirely.

Rock fragments and minerals other than quartz, chert, and the clay minerals are not abundant in the Kootenai sandstones. The most common of the sparse minerals are secondary chlorite and sericite as replacements of the clay minerals. Other minor minerals include iron oxides, leucoxene, tourmaline, zircon, and anatase. The cementing minerals are secondary quartz, mostly as enlargements of the original quartz grains, and calcite.

The "pepper-and-salt" sandstones are more resistant to weathering than the interbedded siltstones and claystones and so form noticeable ledges.

The claystones and siltstones of the central part of the Kootenai formation generally weather to form grassy slopes and are poorly exposed. Along Johnny Gulch at the western edge of the mapped area these rocks are well exposed; a stratigraphic section measured at this locality is included in the appendix. The beds are mostly olive-gray to greenish-gray with lesser thickness of beds colored grayish-red and grayish-purple. All the beds are calcareous, and irregular concretions of impure limestone are common to abundant in some beds. In general, the fine-grained clastic sediments of the lower part of the Kootenai formation are similar to those of the middle part but contain fewer limestone concretions.

The upper part of the Kootenai formation is characterized by dark gray limestone beds that form low ridges and weather to a light gray color. The limestones contain abundant fresh water fossils, principally gastropods, with some thin beds composed almost entirely of fossil material. Claystones interbedded with the limestones are similar to those below the limestones, and there is generally a bed of olive-colored argillaceous siltstone above the uppermost limestone bed.

The Kootenai formation in the Cut Bank oil and gas field of northern Montana (Sloss and Feray, 1948), about 275 miles north of the Elkhorn Mountains, is apparently quite similar to that in the Elkhorn Mountains. In both regions the lower one-third of the formation contains more sandstone than the upper two-thirds, and the chert content decreases stratigraphically upwards. In the lower sandstones Sloss and Feray found well developed microstylolites to which they devoted most of their paper. In the Elkhorn Mountains microstylolites are also found in the lower sandstones of the Kootenai formation (pls. 4-B and 5-A), but are rare and typically poorly developed. As in the Cut Bank field the structure was seen only between chert grains or between grains of chert and quartz, and was marked by a black seam of insoluble residue. The writer agrees with Sloss and Feray that the microstylolitic seams indicate a certain amount of dissolved silica, derived mostly if not entirely from chert grains, and redeposited as secondary enlargements on quartz grains in the same or adjacent beds. It seems impossible, however, to explain all the silica present as grain enlargements (in the Kootenai formation) as having dissolved at points of greatest pressure according to Reikie's principle, because although microstylolites are rare secondary enlargements of quartz are abundant.

Colorado group

The Kootenai formation is overlain, probably with a slight erosional unconformity, by about 1,500 feet of sedimentary rocks assigned on the basis of lithology and contained fossils to the Colorado group. The sediments comprise marine and non-marine sandstone, tuffaceous sandstone, and shale. In mapping, the Colorado group has been divided into three units; a lower black shale unit, a middle siliceous unit consisting of fine-grained sandstone, siltstone, and siliceous mudstone, and an upper black shale unit.

During the summer of 1950, J. B. Reeside, Jr., and W. A. Cobban spent three days examining and collecting fossils from the Colorado group in the Elkhorn Mountains area. Their opinions concerning the correlation of these rocks are summarized in the following chart 2/.

2/ Abstracted in part from a report on referred fossils by W. A. Cobban dated May 31, 1951. The same correlation is shown in correlation chart 10b prepared by the Committee on Stratigraphy of the National Research Council (Cobban and Reeside, 1952) where the section of Cretaceous rocks of the Elkhorn Mountains is shown in the left half of column 100.

<table>
<tr><th></th><th>European equivalents</th><th colspan="2">Composite Great Plains section</th><th>Elkhorn Mountains</th></tr>
<tr><td rowspan="6">Upper Cretaceous</td><td>Santonian</td><td colspan="2">Telegraph Creek formation</td><td>(Age of top is unknown)
Slim Sam formation</td></tr>
<tr><td rowspan="2">Coniacian</td><td rowspan="2">Niobrara fm.</td><td>Smoky Hill chalk member</td><td>Upper black shale unit</td></tr>
<tr><td>Fort Hays limestone member</td><td rowspan="5">Middle siliceous unit</td></tr>
<tr><td rowspan="2">Turonian</td><td colspan="2">Carlile shale</td></tr>
<tr><td colspan="2">Greenhorn limestone</td></tr>
<tr><td>Cenomanian</td><td colspan="2">Belle Fourche shale</td></tr>
<tr><td rowspan="4">Lower Cretaceous</td><td rowspan="4">Albian</td><td colspan="2">Mowry shale</td></tr>
<tr><td colspan="2">Newcastle sandstone</td><td rowspan="3">Lower black shale unit</td></tr>
<tr><td colspan="2">Skull Creek shale</td></tr>
<tr><td colspan="2">Fall River sandstone</td></tr>
</table>

Lower Black Shale Unit

The lower black shale unit consists of a basal very fine-grained quartz sandstone; a middle part of dark gray shale, often with well-developed fissility, and minor thin beds of siltstone; and an upper part of dark gray, carbonaceous, argillaceous, very fine-grained sandstone and siltstone. The unit is about 325 feet thick. On the basis of lithology and stratigraphic position, Cobban (personal communication) has concluded that the basal part of the unit is equivalent to the Fall River sandstone, the middle fissile shale part is equivalent to the Skull Creek shale, and the upper dark sandstone part is probably equivalent to the Newcastle sandstone. Fossils of Skull Creek age were collected from the middle fissile shale unit in an adjacent area.

The basal sandstone crops out to form low ledges of very pale orange or yellowish gray color. Bedding planes are irregular and closely spaced; the most massive beds are not more than four feet thick. The beds are often well-laminated and occasionally cross-laminated. The basal sandstone ranges from 10 to 30 feet in thickness with no apparent regularity.

Microscopic examination of thin sections of the basal sandstone unit show it to be a clean orthoquartzite of very fine to medium-sized, well-sorted grains that are 70 to 95 percent quartz and 3 to 25 percent chert. Minor accessory minerals include black iron minerals, muscovite, tourmaline, and zircon, with secondary chlorite and sericite. The grains are tightly interlocking and all pore space has been filled by quartz that occurs both as secondary enlargements of quartz grains and as cement unrelated to any grain in the plane of the thin section. The boundaries of the original grains can be detected only rarely by lines of inclusions; such boundaries show that the quartz grains were subrounded to rounded. The original boundaries of the chert grains have not been seen and the present boundaries are serrate. The chert has recrystallized to a quartz mosaic with increased grain size.

The middle part of the lower black shale unit is predominately fissile dark-gray shale that weathers easily yet forms very little soil. Scattered grains of silt are commonly present in the shale, and interbedded thin-bedded, blocky-weathering siltstones of olive and gray colors are common. Calcareous rusty weathering concretions up to 18 inches in maximum diameter in spheroidal and irregular rounded shapes are sporadically present. The middle part of the lower black shale unit is usually about 140 feet thick; variations in thickness are probably due more to incompetent yielding during folding than to depositional conditions.

The upper part of the lower black shale unit consists principally of dark argillaceous very fine- to fine-grained sandstone with some interbedded siltstone and shale. The dark color is due to the carbonaceous, argillaceous material that occurs interstitially and comprises

15 to 25 percent of the rock. The grains of quartz and chert, are angular to sub-rounded and occur in almost equal amounts accompanied by fewer grains of muscovite, biotite, and black opaque unidentified mineral. The grains have a maximum size of about 0.25 millimeter and grade downward into clay-sized particles. A few miles north of the mapped area several thin clean sandstone beds occur within this part of the lower thick shale unit; only one such sandstone was noted in the mapped area. These sandstone beds are composed of medium-grained, well-sorted, and probably originally rounded grains of quartz and chert that have become interlocking through development of secondary enlargements on the quartz grains. The upper part of the lower black shale unit is about 160 feet thick and shows variations in thickness similar to those of the middle part.

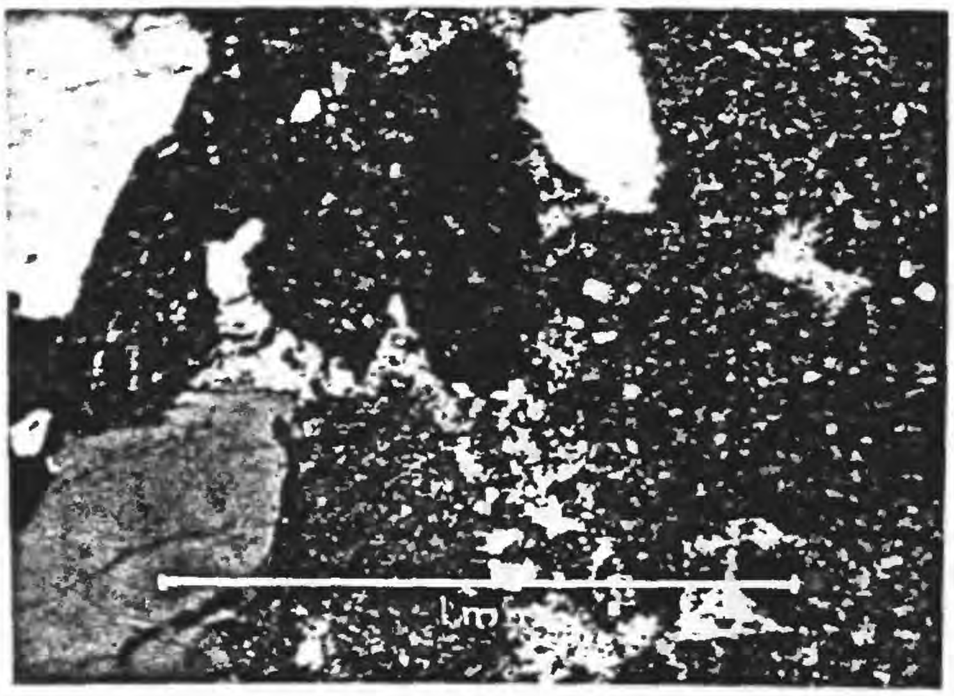
Middle Siliceous Unit

The middle siliceous unit of the Colorado group in this area consists of a lower part of siltstone and sandstone, a middle part characterized by siliceous mudstones, and an upper part dominantely of sandstone. On the basis of lithology, stratigraphic position, and contained fossils it is believed to be largely equivalent to the Mowry formation, but fossils of lower Carlile age and lower Niobrara age have been found near the top of the unit. As no pronounced depositional breaks are apparent in the middle siliceous unit, it probably also includes some beds of Belle Fourche and Greenhorn age. Beds of probable nonmarine origin containing carbonized plant fragments form a substantial part of the unit.

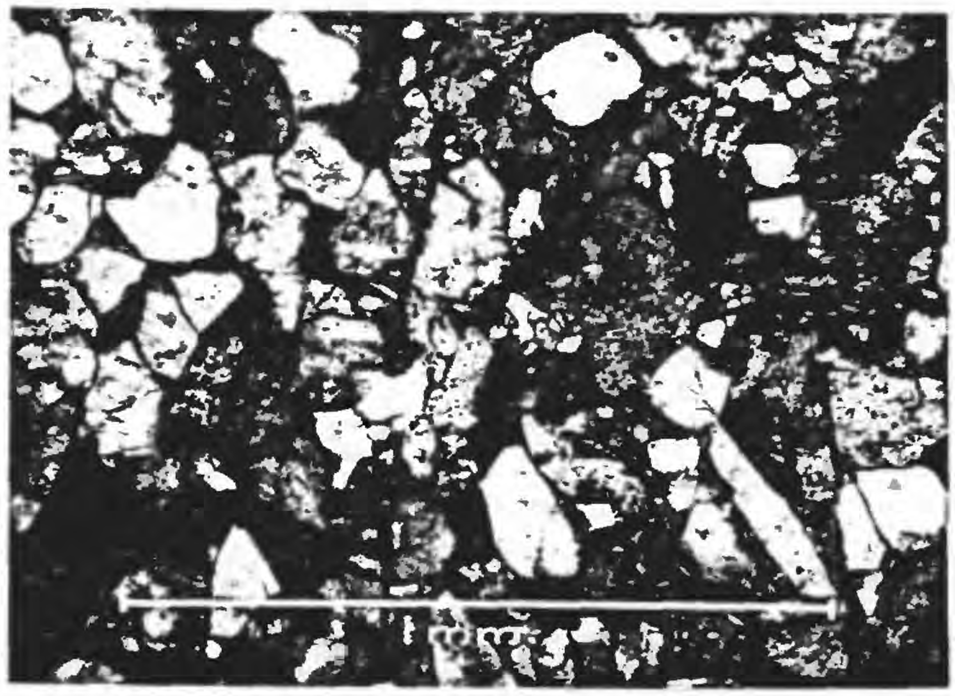
The middle siliceous unit lies conformably on the lower black shale unit. The contact is mapped at the base of a flaggy, light gray, fine-grained sandstone bed that is persistent throughout the area. The unit ranges in thickness from about 650 feet five miles north of the map area to about 900 feet at a section measured near the southwest corner of the map area. Near the center of the map area the outcrop width indicates a thickness of about 700 feet. There is local thinning probably due to undetected structure rather than to variation in sedimentation or to erosion prior to deposition of the upper black shale unit.

The lower one-third of the middle siliceous unit is composed of olive and gray siltstone and fine-grained sandstone (pl. 5-B), is typically thin bedded, and contains 20 to 30 percent of interstitial clay except in the basal bed. The grains are mostly quartz and chert in proportions that range from 10:1 to 1:1, with a trace of 20 percent of feldspar. Mica is the only heavy mineral consistently present though opaque minerals and zircon are also found. Secondary minerals include chlorite and calcite. The presence of many shard-like grains suggests admixture of considerable volcanic material. As no feldspar was noted by the author in the rocks of the Kootenai formation, and as only traces of feldspar were found in the rocks of the upper two-thirds of the middle siliceous unit the author believes that the sudden influx of feldspar is due to addition of material from a volcanic source.

PLATE 5



A. Photomicrograph of "pepper-and-salt" sandstone, Kootenai formation. Same view as plate 4-B. (Under crossed nicols.)



B. Photomicrograph of sandstone, middle siliceous unit, Colorado group.

The central part of the middle siliceous unit consists of siliceous, olive and dark- to light-gray mudstone with interbedded olive to gray siltstone and minor sandstone. The siliceous mudstone weathers white or very light gray and fractures to blocky or hackly pieces. Subrounded to shard-like grains of quartz and feldspar of silt size are commonly present in the mudstone; however the rock consists principally of a silicified sericitic-chloritic material apparently derived from clay minerals.

The siliceous mudstone is notable for its hardness; any fresh piece of the rock will scratch a penny and some pieces will scratch a hammer. Similar mudstone from the Mowry formation near the Black Hills was studied by Rubey (1929) who concluded that the unusual hardness was due to silica released from included volcanic material by the action of sea water. No invalidating evidence was found by the author; however the mudstones of the mapped area are often even harder than those described by Rubey (1929, p. 154), possibly because of their proximity to intrusive igneous masses.

The siltstone and sandstone beds found interbedded with the siliceous mudstone are thinly bedded, of olive and gray colors, and fracture to splintery or hackly fragments. They are composed of quartz and chert with lesser amounts of feldspar, mica, an unidentified opaque mineral, and fine-grained rock fragments. Alteration products of clay and locally abundant calcite are the cementing materials. Most grains are angular or shard-like, rarely subrounded. A large part of the material constituting the siliceous mudstone and interbedded siltstone and sandstone seems to be of volcanic origin.

The upper one-fourth of the middle siliceous unit consists of sandstone beds and minor interbeds of siltstone and fissile shale. The sandstone beds are of two types; light gray medium-grained conglomeratic "pepper-and-salt" sandstone and olive gray very fine- to fine-grained thinly laminated sandstone. Both types are composed mainly of angular to sub-rounded grains of quartz and chert with a small amount of interstitial clay minerals and secondary chlorite. Other allogenic minerals are uncommon; of these plagioclase and muscovite are persistent and an opaque mineral, often with leucoxene coating, zircon, and tourmaline are locally present. Introduced minerals are calcite and iron oxide, both occurring sporadically.

The "pepper-and-salt" sandstone of the middle siliceous unit is very similar to the sandstone at the base of the Kootenai formation except that it commonly contains grains of fibrous chalcedony (pls. 6-A and 6-B). The other sandstones of this unit are characterized by their dirty appearance--due to the presence of clay minerals partly altered to mica and admixed with calcite cement--and by the content of feldspar.

Upper Black Shale Unit

The upper black shale unit consists of dark gray to black fissile shale with numerous thin beds of very fine-grained sandstone and siltstone. Characteristic Niobrara fossils have been found in the upper part of the underlying siliceous unit, and in the lower part of the overlying Slim Sam formation, therefore the upper black shale unit is entirely of Niobrara age. This unit, which ranges from 250 to 280 feet in thickness, lies conformably upon the middle siliceous unit.

Although shales of the upper black shale unit are undistinguishable from the shales of the middle part of the lower black shale unit, two features are characteristic of the upper black shale unit. spheroidal brown-weathering limy concretions, generally from 8 to 12 inches in diameter, are relatively abundant and thin lenses of coarse feldspar crystals are locally present in the uppermost part.

Thin beds of very fine-grained sandstone and siltstone make up about 10 percent of the upper black shale unit. These beds consist of tightly packed angular grains of quartz and chert in a ratio of about 3 to 1; the matrix is commonly argillaceous. Other minerals present in very minor amounts include plagioclase, muscovite, biotite, tourmaline, and secondary calcite.

Slim Sam formation

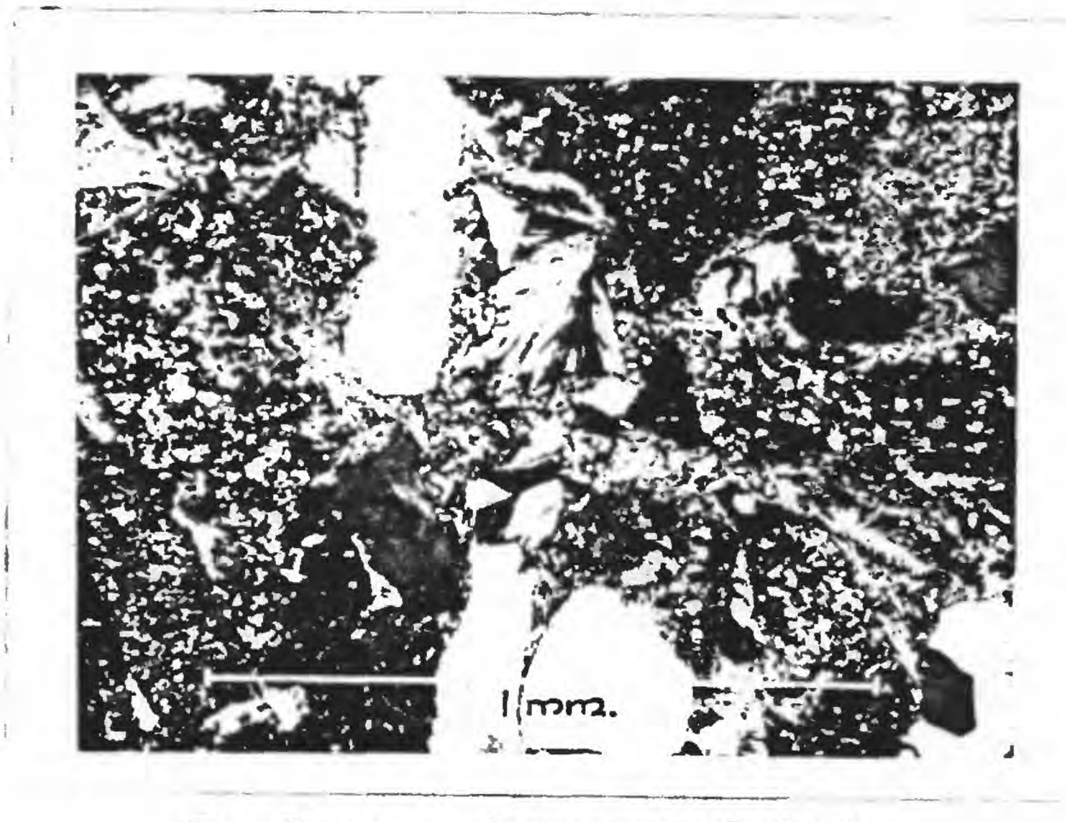
The Slim Sam formation consists almost entirely of bedded water-laid tuff that lies conformably on the upper black shale unit. Thin beds of black argillaceous material are commonly interbedded with the tuffs in the lower part of the Slim Sam formation. This suggests that the abrupt change in lithology between the upper black shale unit and the Slim Sam formation was due to the development of a nearby volcanic source that discontinuously supplied large quantities of ash to the Niobrara sea. The depositional conditions were not altered greatly by the volcanic activity and black shale continued to form between outbursts.

In the mapped area the Slim Sam formation is commonly about 900 feet thick. Near the southern limit of the area the formation thins as a result of tilting and erosion that occurred before the overlying Elkhorn Mountains volcanics were deposited. Two miles to the south of the map area the Slim Sam formation was entirely removed and is not known further to the south.

The Slim Sam formation can be divided into a lower and upper part on the basis of lithology although it was not subdivided in mapping. The lower part is thinly bedded and is characterized by the dominance of quartz over feldspar; but in the more massive upper part quartz makes up less than 5 percent and feldspar is dominant.

PLATE 6

A. Photomicrograph of "pepper-and-salt" sandstone, middle siliceous unit, Colorado group.



B. Same, under crossed nicols.

The lower part of the formation consists of very fine- to medium-grained sandy crystal-lithic tuff with common thin interbeds of black shale and thin lenses of coarse feldspar crystals of volcanic origin. The sandy crystal-lithic tuff comprises shard-like and sub-rounded quartz grains, rock fragments of microcrystalline texture, fresh biotite, plagioclase, white mica, and calcite cement (pl. 7-A). The plagioclase content increases at the expense of the quartz content from the base to the top of the lower part of the Slim Sam formation.

The upper part of the formation consists of fine- to medium-grained crystal-lithic tuff with at least two units of hard mudstone. The crystal-lithic tuff is composed of angular plagioclase grains, and less common grains of quartz, mica, opaque minerals and rock fragments; the microcrystalline matrix has altered to chlorite and sericite, (pl. 7-B). The mudstone of the Slim Sam formation is olive and dark gray, contains abundant sand-sized grains, is unusually hard, and often contains plant fragments. The mudstone is hackly weathering and is commonly poorly exposed.

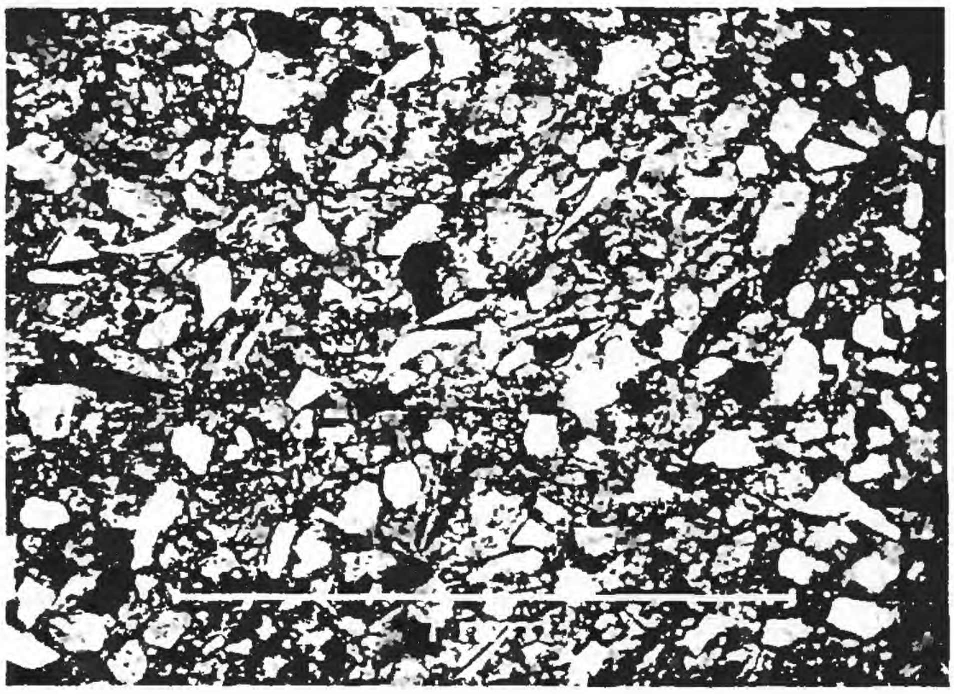
In general the bedding of the Slim Sam formation is thinner and more regular near the base. The lower beds are usually $\frac{1}{4}$ to 2 inches thick with rare beds to 4 inches thick (pl. 8-A). Interbeds of black shale are generally less than $\frac{1}{2}$ inch thick. The beds become thicker, ranging from 2 inches to 2 feet in thickness, and the black shale beds disappear near the middle of the formation. Small shallow cross-laminations are present but scouring is not apparent. Near the top of the Slim Sam formation massive bedding of the tuff is common. The contact with the overlying Elkhorn Mountains volcanics in places is marked by a sharp change of lithology and elsewhere is gradational with the tuff becoming coarser grained and more massive.

The Slim Sam formation was first described by Klepper, Weeks, and Ruppel (in preparation). The type locality is in the region known as the Slim Sam basin, north of the northwest corner of the area described in this report. A section measured in this area is given in the appendix. At the present time the formation is known only in the Elkhorn Mountains and in the foothills to the east. A few fossils of late Niobrara age have been found as high as 380 feet above the base of the Slim Sam formation but the upper part of the formation is undated.

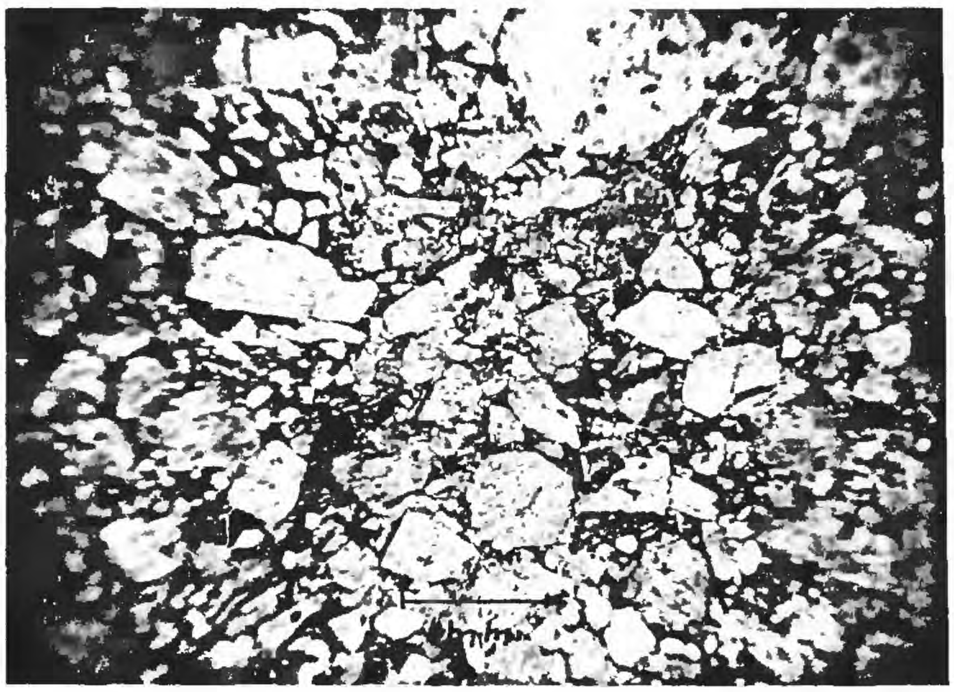
Elkhorn Mountains volcanics

In the mapped area the Elkhorn Mountains volcanics consist of a thick sequence of massive crystal tuff, tuff-breccia, and breccia with a few thin flows and thin units of well-bedded tuff. In the northern part of the area the volcanics rest with apparent conformity upon the tuff of the Slim Sam formation but in the southern part of the area a pre-volcanic erosion surface cuts deeply into the Slim Sam formation. Here the base of the Elkhorn Mountains volcanics is marked by a prominent breccia.

PLATE 7

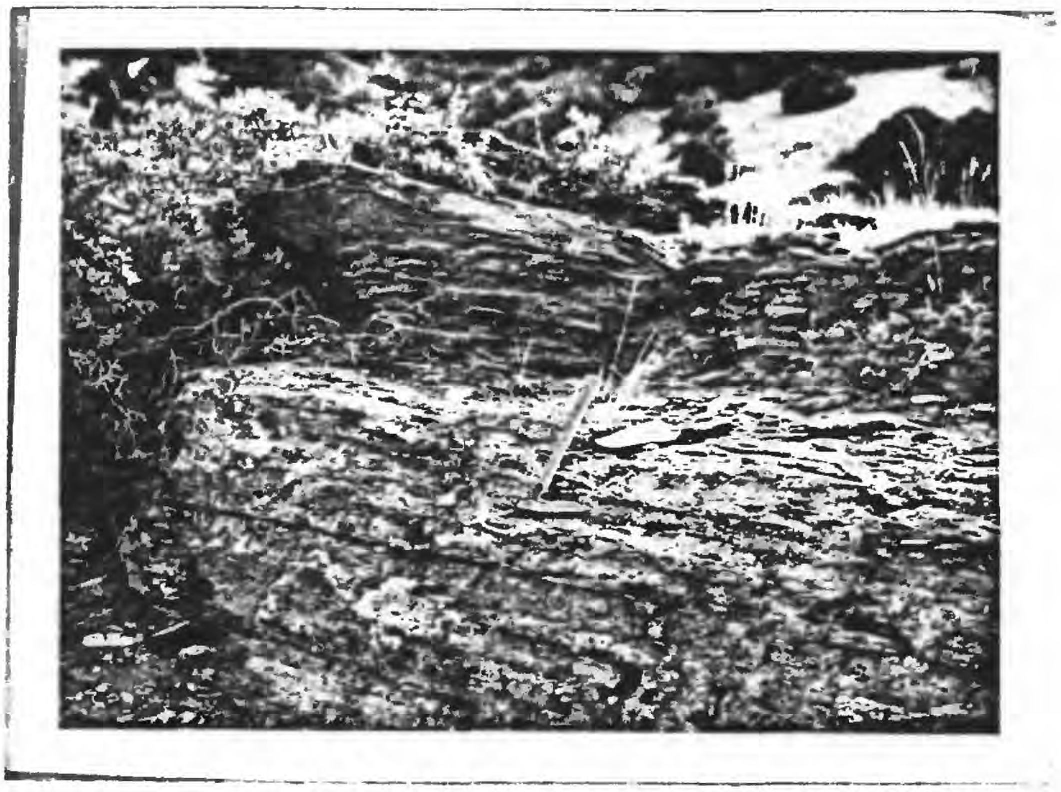


A. Photomicrograph of crystal-lithic tuff of lower Slim Sam formation. Shard-like clear grains are quartz.



B. Photomicrograph of crystal-lithic tuff of upper Slim Sam formation. Clear grains are plagioclase.

PLATE 8



A. Outcrop of lower part of Slim Sam formation.

B. Hand specimen of bedded tuff, Elkhorn Mountains volcanics.

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Spokane Regional Office

The total thickness of the volcanic rocks is unknown and cannot be determined in the map area. From the outcrop width it is apparent that at least 2,000 feet of volcanic rocks are present.

The Elkhorn Mountains volcanics in the map area are apparently entirely of andesitic composition, with recognizable phenocrysts of andesine, hornblende, and pyroxene. The crystal tuff and breccia have everywhere been epidotized and chloritized and have a green color due to these later minerals. The crystal tuff is composed mostly of plagioclase fragments and minor hornblende fragments set in a fine matrix that megascopically seems to be epidote and chlorite. The crystal tuff is massive and forms about 75 percent of the mass of the volcanic rocks in the mapped area. The volcanic breccia and tuff-breccia grade into tuff and were not separated from it in mapping except on Lone Mountain.

The breccia is composed of fragments of diorite porphyry which greatly resemble the diorite porphyry intrusives. The most persistent breccia unit is located at the base of the volcanic sequence in the southern part of the mapped area; this unit is several hundred feet thick and locally shows faint bedding. The breccia fragments of this unit are generally small; the maximum size is about one foot in length. The fragments contain abundant phenocrysts of plagioclase and the matrix contains fewer similar phenocrysts. This unit forms a low but noticeable ridge. The coarsest breccia occurs in the easternmost outcrop of volcanic rocks northwest of the town of Radersburg; here a block about 5 feet square was observed in the breccia.

On Lone Mountain, in the southeast corner of the Johnny Gulch quadrangle, and in the hills to the west, there are a few thin flow and well-bedded tuff units in the volcanic rocks. The flows are grayish red or dark gray in color and contain rock fragments and siliceous clots aligned to give streaky appearance; the matrix is very fine-grained. The bedded tuff is apparently water-deposited and shows thin, apparently graded laminae (pl. 8-B); where the bedded tuff has been recrystallized by adjacent intrusive igneous rocks the lamination has been completely destroyed.

The Elkhorn Mountains volcanics were named and are best described by Klepper, Weeks, and Ruppel (in preparation). These volcanic rocks occur widely within the Elkhorn Mountains but are found in greatest thickness to the northwest and north of the area of this report where at least 3,000 feet of the Elkhorn Mountains volcanics are present. The additional thickness is mainly due to the presence of beds stratigraphically higher than those present in the writer's area, but a greater thickness of flow and lapilli tuff units in the lower part is indicated.

Tertiary System

During Oligocene and Miocene time, several wide basins existed in the region of the headwaters of the Missouri River. The earliest deposits found in these basins seem to have been formed in a lacustrine environment during early Oligocene time; later deposits are probably largely of fluvial sediments with minor lacustrine sediments. The lacustrine sediments of early Oligocene age are more widespread than the later deposits and consist largely of material of volcanic origin.

The area mapped lies astride the western edge of one of these Tertiary basins, and probably received only early Oligocene deposits; to the northeast deposits of late Oligocene and Miocene age are present (T. E. White, oral communication).

Later deposits of Tertiary age, in the mapped area, include a local rhyolite flow overlain by pediment and fan gravels. These deposits have not been dated, but it is most likely that the pediment along the eastern and southern flanks of the Elkhorn Mountains formed during late Tertiary time, and that the overlying fans were formed during Quaternary time.

Volcanic sedimentary rocks

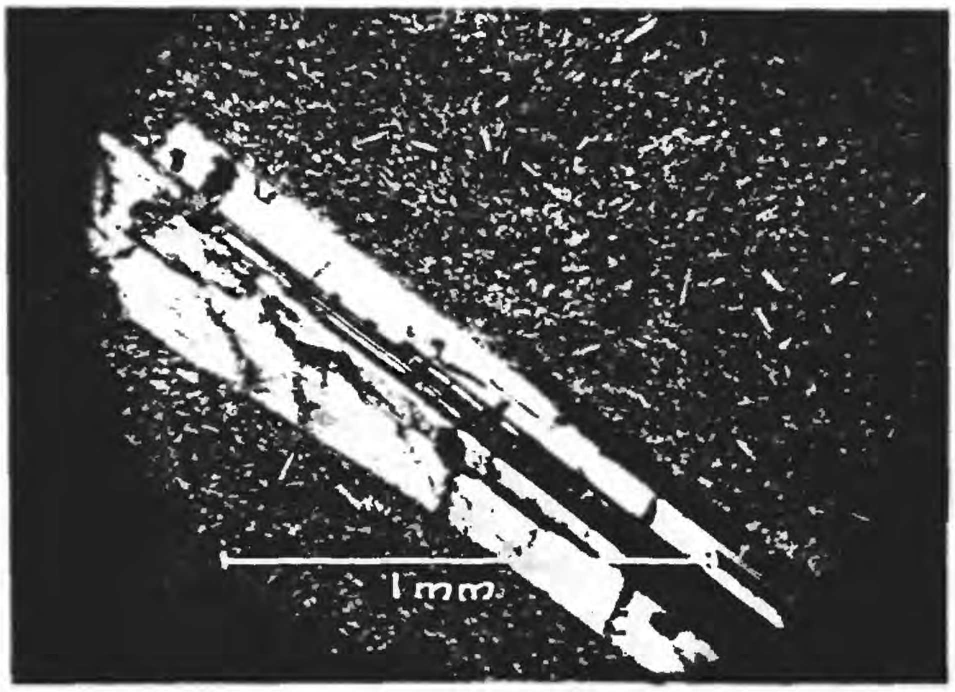
Deposits of poorly consolidated admixed volcanic and sedimentary material overlie older rocks with strong angular unconformity. These deposits are sedimentary tuff and gravel that have been locally cemented by calcite. They are horizontal to very gently tilted, except north of Rattlesnake Creek where they have been folded and dip as much as 25 degrees. The volcanic sedimentary rocks are present only at elevations below 5,000 feet and apparently were never deposited on the older rocks that crop out at higher elevations.

The sedimentary tuff is poorly sorted and contains grains and granules of older rocks, feldspar, and quartz in a light yellowish gray, bentonitic clay matrix (pl. 9-A). Along Keating Gulch and the dry gulches north of Keating Gulch many small outcrops of conglomerate are cemented by coarsely crystalline calcite. This conglomerate is composed of angular to sub-rounded fragments with a maximum diameter of 10 inches. Within a mile or two of the outcrops of older rocks the fragments are of local derivation, but farther east the fragments are largely derived from the Belt series. At one locality the presence of a travertine band interbedded with the conglomerate indicates probable hot spring activity contemporaneous with deposition of the conglomerate.

Along the western limit of the area mapped in the valley south of Johnny Gulch, and also west of the area mapped in Johnny Gulch are outcrops of leaf-bearing limestone with travertine bands. On the bases of plant remains and stratigraphic relations, the limestone deposit is considered of Oligocene age, within the age range of the volcanic sedimentary rocks. The limestone is believed to be of hot spring origin.

PLATE 9

A. Outcrop of Tertiary volcanic sedimentary rocks.



B. Photomicrograph of Tertiary rhyolite.

Vertebrate fossils collected from the tuff have been identified by Jean Hough of the U. S. Geological Survey (personal communication, 1952) as follows:

Mesohippus hypostylus
Leptomeryx esulcatus
Peltosaurus ?
Titanotheriomys
Paleolagus
Bathygenis

She states that this fauna is characteristic of the early Oligocene. The conglomerate along Keating Gulch overlies the fossil-bearing tuff and may be as late as Miocene in age; no means of dating these beds has yet been found.

The Tertiary volcanic sedimentary rocks are part of the Lower Series (Oligocene) of Pardee (1925) and extend throughout the Townsend Valley. They are lithologically similar to the Tertiary lake beds in neighboring valleys that have been extensively studied because of their contained vertebrate fossils.

Rhyolite flows

The most recent volcanic activity known in the area is manifested by a series of rhyolite flows that crop out along Crow Creek for a distance of seven miles. At the southernmost exposure the rhyolite overlies the Tertiary volcanic sedimentary rocks but are separated from them by a 5-foot thick zone of unconsolidated material composed mostly of tuffaceous debris but containing some angular fragments of older rocks as much as 9 inches in length; this zone appears to be a thin pre-rhyolite alluvium. The rhyolite flows were folded with the underlying sedimentary tuffs. Overlying the rhyolite are fan gravels of late Tertiary or Quaternary age.

The known thickness of the rhyolite flows is about 100 feet. The flows are generally gray to black, have subdued flow-banding, and are generally very fine-grained or glassy; they are sparsely vesicular, at least one scoriaceous zone is present. In the one outcrop where the base of the rhyolite is exposed, the heat from the lowest flow has oxidized the underlying rocks and lower few feet of the flow to a bright red color. The lower ten feet of the flow consists of thin bands of pumice and dense glass with many blocks of sedimentary and volcanic rocks as much as 18 inches in diameter. Some of these blocks have baked margins and appear to have been carried by the flow; although others bend down the banding below them and appear to have fallen or settled into place. No zone of autobrecciation was apparent at the base of the lowest flow.

Microscopic examination of the rhyolite indicates that it contains a few phenocrysts, with a maximum length of 2 mm., of labradorite, biotite, and an opaque mineral, probably magnetite. The matrix contains abundant microlites of plagioclase and an unidentified opaque mineral, with smaller grains of pyroxene and plagioclase (pl. 9-B). A specimen of the rhyolite taken about 5 miles northwest of the map area was analyzed by J. M. Dowd of the U. S. Geological Survey.

	Percent
SiO_2	69.1
Al_2O_3	15.0
Total Fe as Fe_2O_3	3.0
MgO	.27
CaO	1.4
Na_2O	3.8
K_2O	5.0
TiO_2	.34
P_2O_5	.09
MnO	.10
Ignition	2.2
	100.3

Tertiary and Quaternary

Fan gravel

Unconformably upon the Tertiary volcanic sedimentary rocks rests gravel that is mapped as Tertiary fan gravel. The thickness of the gravel is nowhere great, and over most of the area it is only a veneer covering the Tertiary sedimentary tuff and gravel. The fan gravel extends into the hills to the west along Johnny Gulch (pls. 2-A and 2-B). and to a lesser extent along Keating Gulch and Rattlesnake Creek. At the west edge of the map area on Johnny Gulch the fan gravel is about 100 feet thick. The gravel is composed of fragments of the consolidated rocks occurring in the mapped area and of the Paleozoic rocks occurring further west in Johnny Gulch. The fragments are mostly of pebble to cobble size; the matrix is fine-grained sand or sand and clay derived from the underlying Tertiary sedimentary tuff. In the northeast part of the area, along Crow Creek, the fan gravel is coarser than farther south and locally contains boulders up to four feet in diameter.

The fan gravel represents, in part, the gravel-veneered surface of a pediment that formed in late Tertiary time on the relatively unconsolidated, gently folded Tertiary sedimentary tuff and gravel. Later, probably during the Pleistocene, coalescing fans formed an apron of gravel along the front of the hills that mixed with and partially covered the thin layers of pediment gravel. At the present time the pediment and overlying alluvial apron are being dissected except for small areas where hillwash is maintaining the upper parts of the apron.

Quaternary System

Alluvium and terrace deposits

Only the alluvium of the stream valleys and the gravel of a small terrace along Johnny Gulch were mapped as Quaternary deposits. Small areas of landslide debris, talus, and other mantle were not mapped.

The alluvium of the different streams varies in texture and composition, but in general it is coarse, with cobbles and small boulders as much as 1 foot in length, and poorly sorted. The larger fragments are of the more resistant rock types found in and to the west of the mapped area; fine-grained volcanic and intrusive rocks dominate but with abundant quartzite and limestone fragments. The gravel of the small terrace along Johnny Gulch about 20 feet above the present stream is similar in composition to the alluvium but smaller in maximum size.

INTRUSIVE ROCKS

The intrusive rocks of the mapped area are divided into three groups; diorite porphyry and related rocks, basalt, and quartz monzonite. The diorite porphyry and related rocks occur as large irregular bodies, sills, and dikes. These intrusives are all of andesitic composition but range widely in texture and mineral composition; they are genetically related to the Elkhorn Mountains volcanics. Basalt occurs in a few small dikes that are intrusive into the earlier phases of the diorite porphyry and related rocks; however the basalt is believed to be closely related to a late basic phase of these rocks. Quartz monzonite occurs in stocks that intrude and metamorphose the andesite porphyry and basalt. It is believed to have been emplaced at about the same time as the quartz monzonite of the Boulder Batholith which, in part, is similar in lithology.

Diorite Porphyry and Related Rocks

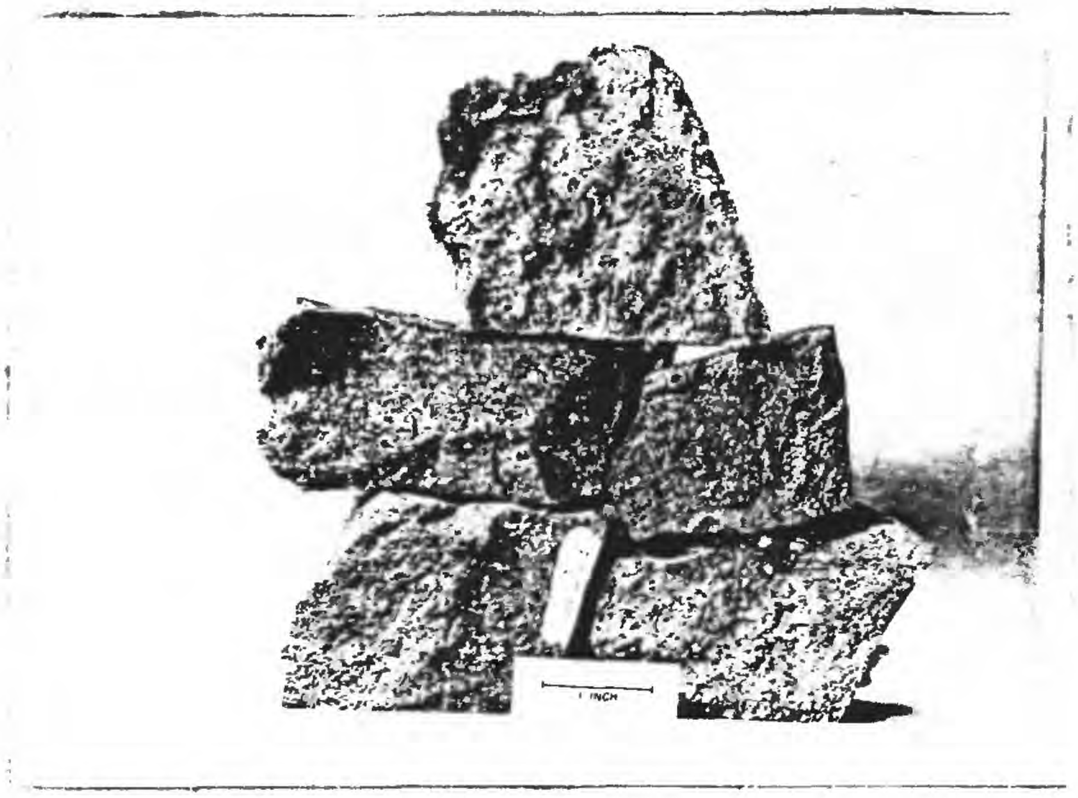
The rocks mapped as diorite porphyry and related rocks are all of andesitic composition but range widely in texture and mineral composition. These rocks, present as small dikes and as large irregular plutons, are the oldest and most abundant of the intrusive rocks in the area. The western margins of the irregular plutons are generally concordant with the sediments but the eastern margins are only locally concordant with the adjacent younger sediments and volcanic rocks.

Most of the diorite porphyry and related rocks are fine-grained porphyritic rocks in which phenocrysts are nearly equal to or predominate over the groundmass; many of these rocks could be termed andesite porphyries instead of diorite porphyry. The phenocrysts are plagioclase, hornblende, and augite, occurring in different proportions and relative size (pl. 10-A). Most commonly plagioclase and hornblende phenocrysts are present in about equal amounts and are about equal in size--1 to 2 mm. in length. Locally, the hornblende phenocrysts are as long as 3 cm. and occur in rosette-like clusters which give the rock a glomeroporphyritic texture. Similar clots of smaller augite phenocrysts were seen in thin section (pl. 10-B). Where augite is present, the three kinds of phenocrysts are all about the same size. In a few dikes and in a small pluton at the southern edge of the map augite phenocrysts are present with lesser amounts of plagioclase and hornblende phenocrysts; in these rocks the phenocrysts are subordinate to the matrix. These dikes of augite diorite have been mapped separately from the other diorite porphyries.

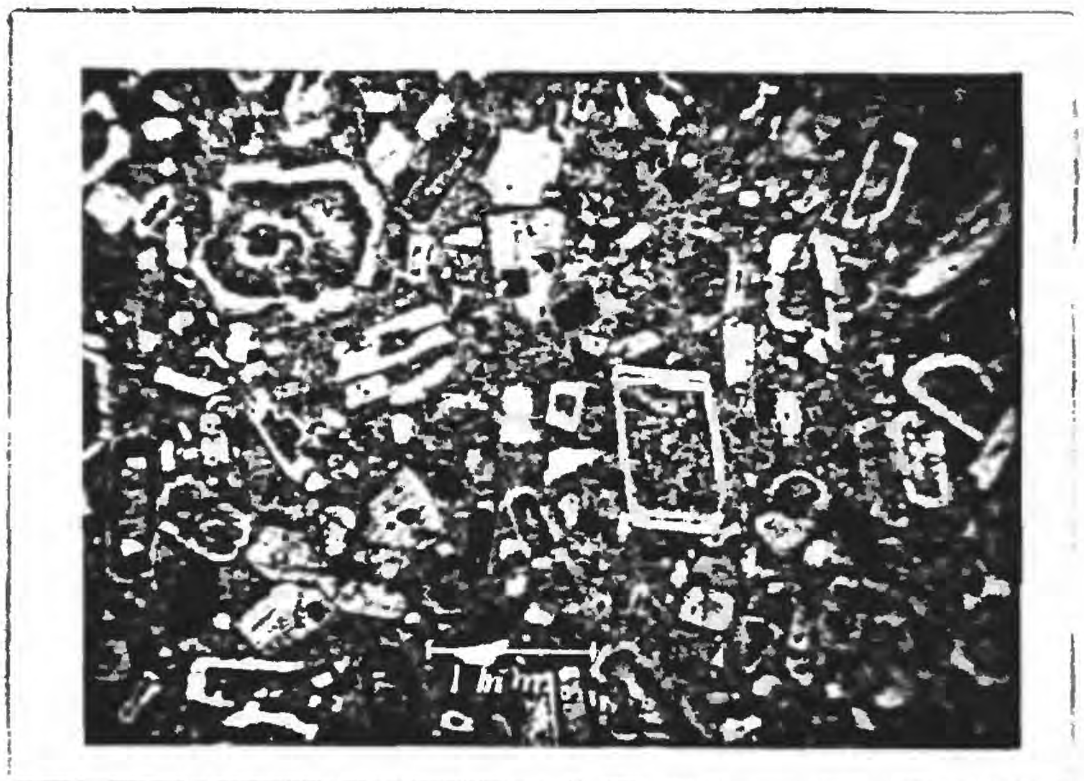
A distinct orientation of phenocrysts is apparent in many of the outcrops of the diorite porphyry. This orientation is especially noticeable where the hornblende phenocrysts are somewhat larger than the plagioclase phenocrysts, but it is also present in rocks where only the plagioclase laths are well developed. No attempt was made to determine a pattern from this orientation, but such a study might greatly aid the interpretation of the method of emplacement of these porphyries.

Examination of thin sections of these rocks indicates that, in most of them, the phenocrysts have a range of sizes but that there is still a hiatus between the smallest phenocryst and the groundmass (pl. 10-B). A few of the rocks assigned to this category are truly seriate and a few, principally those containing only augite as phenocrysts, are completely hiatal (pl. 11-A). In the rocks with seriate or partly seriate texture, phenocrysts of an iron mineral, probably magnetite, and phenocrysts of quartz are present among the smaller phenocrysts. The matrix of these rocks is very fine-grained and altered; the exact composition could not be determined but it is a felsic matrix in which feldspar predominates.

PLATE 10

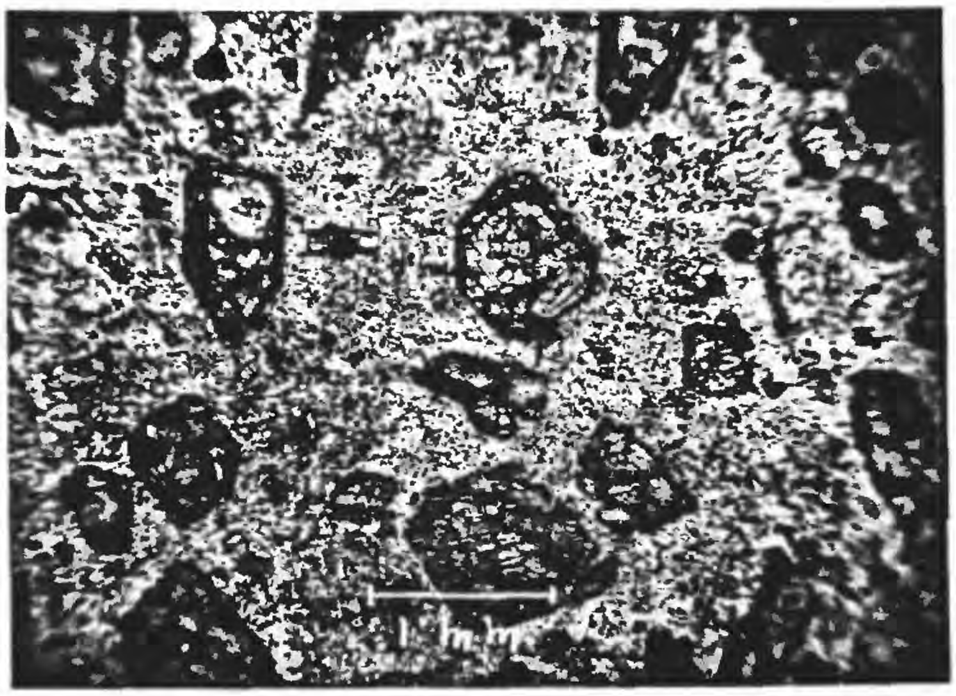


A. Hand specimens of diorite porphyry.



B. Photomicrograph of augite diorite porphyry; showing selective alteration of plagioclase and unaltered clusters of augite.

PLATE 11



A. Photomicrograph of augite diorite porphyry.

B. Keating mine and mill.

The phenocrysts of plagioclase normally show zoning and polysynthetic twinning. The average composition of these phenocrysts is andesine. The specific gravity of the diorite porphyries is about 2.7 but varies from 2.63 to 2.79. The less dense rocks include quartz-rich hornblende diorite that crop out on the east side of Lone Mountain; the more dense rocks are augite diorite.

The diorite porphyry and related rocks commonly have been altered, the alteration occurring in two periods. The first period of alteration is probably deuteric, since the alteration is widespread and not related to any detectable later structure. This alteration consisted of epidotization and chloritization of plagioclase and hornblende phenocrysts and, to a lesser extent, of the groundmass. In many hand specimens, plagioclase phenocrysts exhibit selective epidotization of original zones. Plate 10-B illustrates selective alteration of plagioclase in which the alteration materials were not recognized, and augite is apparently unaffected. In a few localities fine-grained spheroids, as much as one foot in diameter, of epidote-rich rock were formed within the diorite porphyries. The second period of alteration, of local importance, was related in time to the formation of mineral deposits and is discussed with them.

In composition and texture the diorite porphyry intrusives closely resemble the Elkhorn Mountains volcanics and are considered by the author to represent an intrusive phase of these rocks. The intrusive bodies now seen cutting the oldest sedimentary rocks of the map area are roughly concordant, and irregular sills occur just west of the map area. To the east the intrusive rocks cut younger rocks and have irregular shapes that are only locally concordant. The form of these intrusive bodies suggests that, as the magma rose, it first spread out along bedding planes to form sills, but as it reached a higher position in the stratigraphic column the lighter load permitted it to spread out into more irregular shapes. Some of this magma, when reaching the surface, may have formed the lower part of the volcanic sequence. Later upwellings of similar magma rose into the earlier formed volcanics before spreading out into the irregular plutons now exposed. How many such injections of magma are represented by the plutons and volcanic rocks now exposed is unknown. In the area studied, several zones of brecciation within the intrusive masses, and the numerous thin septa of intruded rocks (pl. 1) further suggest several pulses of intrusive activity. The intrusions of diorite porphyry must have at least as great a range in age as the Elkhorn Mountains volcanics exposed in the area. The presence of the irregular plutons in the youngest of the volcanic rocks suggests that the original thickness of volcanic rocks was considerably greater than at present, and that the intrusives were formed at relatively shallow depths.

The distinction of the volcanic rock from the related intrusive rocks caused the greatest difficulty in mapping the area. Both rock types have been slightly to extremely altered, and the intrusive rocks were often locally brecciated and then healed with similar magma causing them to resemble the breccias in the volcanic rocks. Generally, the intrusive rocks appear more massive and weather in a different manner than the volcanic rocks; but the topography does not reflect the underlying rock type.

Basalt

In the southern part of the area a few dikes were mapped as basalt. Microscopic study of thin sections from the basalt dikes shows augite phenocrysts and smaller phenocrysts of an opaque mineral, probably magnetite, set in a groundmass in which only plagioclase was recognized. Due to the small size and slight alteration of the plagioclase crystals it was difficult to determine the composition accurately; an approximate determination gives the composition as sodic labradorite. The mode of occurrence and the texture of the basalts suggest to the author that they are closely related to the augite diorite discussed under diorite porphyry.

Quartz Monzonite

Quartz monzonite crops out on the west side of Lone Mountain and along the front of the hills to the west and northwest of it. These outcrops possibly represent a single stock that has been largely covered by Tertiary deposits. Near the quartz monzonite the Elkhorn Mountains volcanics and diorite porphyry have been recrystallized; and apophyses of the quartz monzonite cut some of these adjacent rocks.

The outcrops of the quartz monzonite can be recognized from a distance by the development of the large rounded knobs and boulders typical of granitic rocks in semiarid climates (pl. 3-B). The quartz monzonite is medium-fine grained with a granitic texture and responds to mechanical weathering by crumbling into sand particles.

Feldspars compose about 75 percent of the rock and are made up of almost equal amounts of orthoclase and plagioclase. The plagioclase grains are zoned and range from about sodic andesine to calcite oligoclase. Quartz composes about 15 percent and hornblende about 8 percent of the rock. Magnetite with some biotite and apatitie are the remaining constituents. Faint lineation of the hornblende crystals is apparent.

The quartz monzonite in this area cannot be directly correlated with rocks of the Boulder batholith but it is similar in mineral composition to the principal rock type of the batholith and is probably about the same age. The quartz monzonite rocks of the batholith in general are somewhat coarser grained, contain more biotite, are often porphyritic, and rarely show lineation.

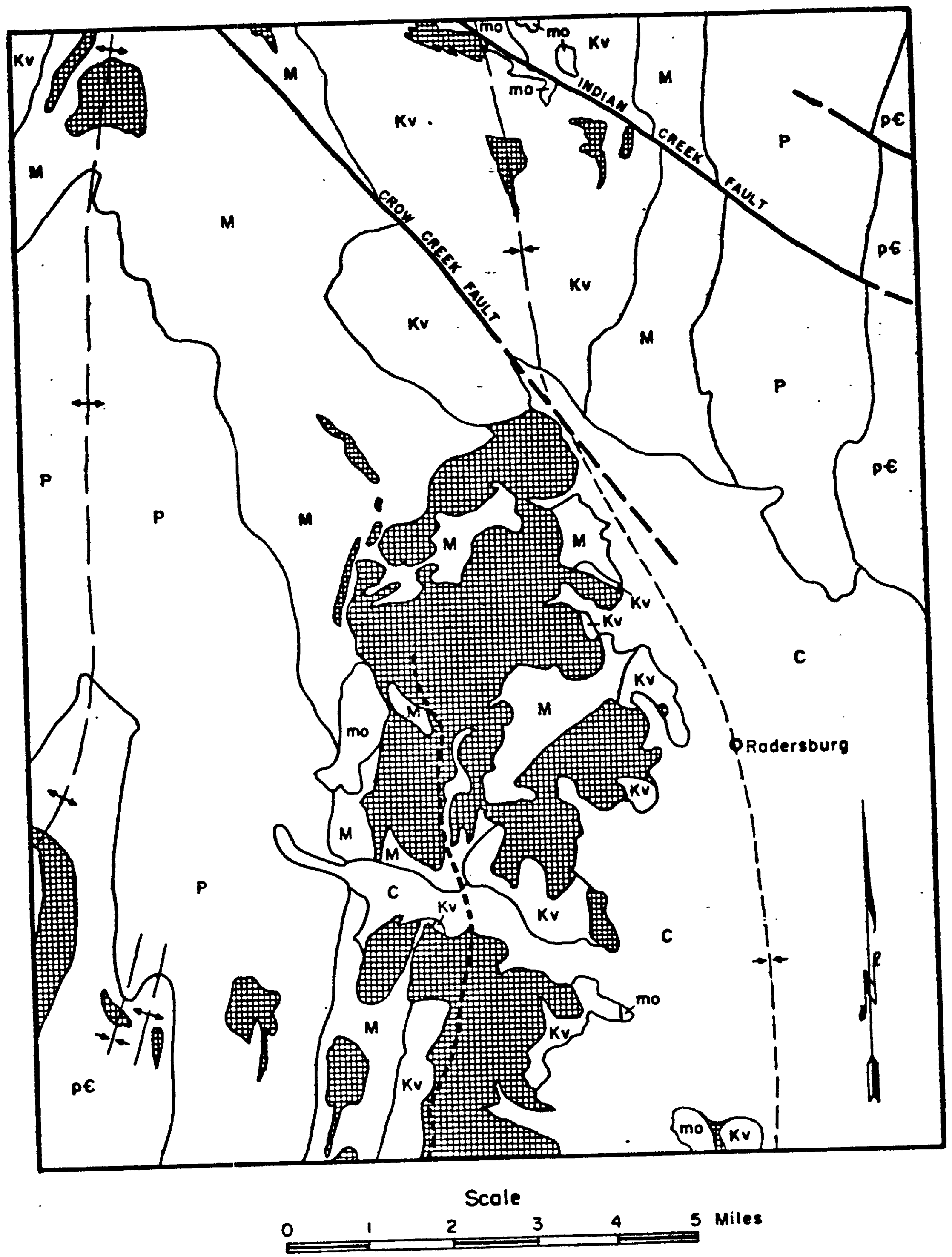
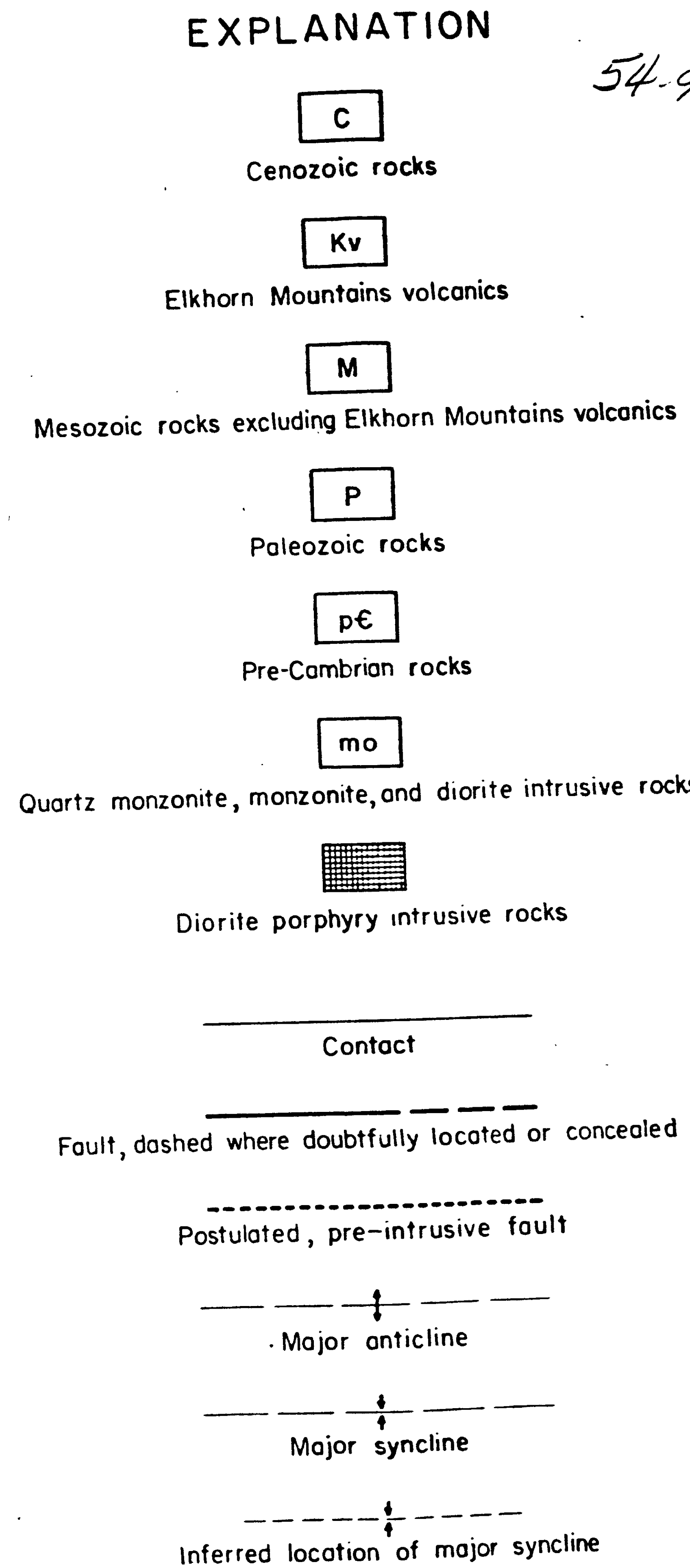


Figure 2 Structural features of Radersburg area, Montana



GEOLOGIC STRUCTURE

General Features

The area mapped is situated on the east flank of a major domal structure formed during very late Cretaceous or very early Tertiary time (Klepper, Weeks, and Ruppel, in preparation). The sediments in general strike north-south and dip to the east, and are invaded by large irregular plutons of diorite porphyry that were emplaced prior to the major folding. Many minor folds and faults are associated with the intrusion. The veins in the area are oriented north-south and were probably formed after the major folding, possibly associated with intrusion of the quartz monzonite. The localization of the diorite porphyry plutons provides the major structural problem. The plutons are disposed in a north-south belt and may have arisen along a zone of weakness caused by a preintrusive fault, by the inception of folding, or by both.

The postulated pre-intrusive fault shown on figure 2 may have formed before deposition of the Elkhorn Mountains volcanics when the older rocks were tilted. This fault is suggested by the presence, within the diorite porphyry intrusives, of remnants of Kootenai formation and lower Colorado group that have apparently been raised about 3, 000 feet stratigraphically. These remnants occur near the western edge of the intrusives from the southern edge of the map area to the north for six miles. The remnants all represent about the same stratigraphic unit, and the writer feels it is more probable that their position is a result of pre-intrusive movement along a later engulfed fault than that they have been floated into place by the intruding magma. Some movement of the remnants during intrusion is indicated, however, especially by the trend of the southernmost remnant that has been rotated 90 degrees to the regional attitude.

The postulated pre-intrusive fault may have served to control the location of the diorite porphyry intrusives; however, elsewhere in the Elkhorn Mountains (Klepper, Weeks, and Ruppel) it has been noted that diorite porphyry intrusives occur most commonly along the axes of the major folds. Figure 2 shows that the area mapped lies just south of a major north-south syncline, but mapping has shown that the syncline does not pass through the area. It is suggested that the major north-south folding started before emplacement of the diorite porphyries and had some controlling effect on the localization of these intrusives. If the diorite porphyry is essentially contemporaneous with the Elkhorn Mountains volcanics, as believed by the writer, then, since the Elkhorn Mountains volcanics are involved in the folding, the folding must have continued after the intrusives were emplaced.

Whether the intrusives were localized primarily by the beginning of folding, by the postulated pre-intrusive fault, or by both, they apparently were in place and were sufficiently resistant to folding to cause a shift to the east (as shown on figure 2) of the axis of the syncline north of the area mapped. On Lone Mountain there is an eastward flattening of the dip (cross-section A-A', pl. 1) that suggests the syncline lies along the eastern margin of the area mapped as shown in figure 2.

North of the area under consideration two prominent northwest trending faults developed shortly after or during the last phase of the major folding. R. A. Weeks (personal communication) estimates that the Crow Creek fault (fig. 2) has a length of at least 10 miles and that the movement in the strike direction has been about 2,500 feet with the northeast block moving relatively to the northwest. The Indian Creek fault (fig. 2) has a similar direction of motion. Crow Creek had cut to about its present depth, following the fault, before the Tertiary rhyolite was extruded, probably along the fault, and flowed down the valley.

Since the formation of the northwest trending faults, small north south folds, involving the Oligocene tuff and overlying Tertiary rhyolite flows, have been formed in the northeast corner of the mapped area. In late Tertiary and Quaternary time the northern part of the Elkhorn Mountains has risen along an eastern range-front fault zone. This fault zone probably dies out north of the map area.

Features Related to the Intrusive Activity

During the emplacement of the diorite porphyry intrusions, smal and large segments of country rock were left nearly in place. These segments of sedimentary and volcanic rocks were almost entirely unaffected chemically and mineralogically but yielded by faulting or by folding to the forces active during the period of intrusion.

The Slim Sam formation where it crops out about two miles west of Radersburg, has been deformed into a series of minor folds that plunge from 28 to 45 degrees to the northeast. This folding has not involved the older sediments to the west and the folds seem to be truncate by or to abut against the intrusive mass to the north. Another outcrop of Slim Sam formation about three miles northwest of Radersburg is poorly exposed but shows anomalous attitudes which may be the result of folding induced by magmatic intrusion.

Near the western edge of the map area north of Johnny Gulch there are several septa of Colorado group and Kootenai formation sediments which have yielded by faulting during the emplacement of the intrusive bodies. The faults are generally short and terminate abruptly against the diorite porphyry. Poor exposures and the short strike length of the faults prohibited determination of dips, but the faults seem to be steep; strike directions of the faults are randomly distributed. The northernmost septum of sediments that yielded primarily by faulting, had first been folded, but in general faulting and folding are mutually exclusive in the septa of country rock.

The control that determined whether a segment of country rock would yield by folding or by faulting is not clear. The folding has taken place in the sandstones of the Slim Sam formation and the faulting in the shales and sandstones of the Colorado group and Kootenai formation that are thought to be less competent. Since this is the reverse of normal yielding it is suggested that stratigraphic position rather than competency was the controlling factor in deformation. The younger higher lying rocks were folded and the older rocks faulted.

GEOLOGIC HISTORY

At the beginning of the Cretaceous period the region stood above sea level, but after deposition of the Kootenai formation it subsided. The Colorado group is characterized by interbedded marine and non-marine sediments, indicating a relatively rapid fluctuation of sea level. Deposition of the upper black shale unit of the Colorado group and the lower half of the Slim Sam formation occurred during the last submergence of the region. The volcanism that supplied the tuffs of the Slim Sam formation continued until the region was built above sea level. Following deposition of the Slim Sam formation the southern part of the region was tilted with the amount of tilting decreasing to the north.

Following tilting, intrusion of the diorite porphyries and the extrusion of the Elkhorn Mountains volcanics occurred as previously described. During the Laramide revolution the region was folded and faulted. Emplacement of the Boulder Batholith and similar rocks in the map area followed this major folding which is believed to have occurred near the close of the Cretaceous period.

At the close of the Eocene epoch, the region had been eroded to a low surface of moderate relief and the major physiographic features now present had been formed. During the early Oligocene widespread lacustrine conditions developed and the Tertiary tuff and gravel was deposited. Deposition continued in the deeper basins to the east of the mapped area until late Miocene time. The area rose throughout most of late Tertiary time but a temporary period of stability, probably in the Pliocene, permitted pediments to develop along the range fronts. During the Pleistocene coarse debris was deposited as an alluvial apron upon the pediment. At the present time the streams are cutting away the Pleistocene fans.

MINERAL RESOURCES

The mines of this district, known as the Radersburg or Ceder Plains district, have produced gold, silver, copper, lead, zinc, and iron. The largest producers were the Keating, (pl. 11-B), Ohio-Keating and Black Friday mines, all of which were primarily gold-silver mines although copper was an important byproduct. The Iron Cross mine, the only mine in the district now operating, produces magnetite that is sold to the Ideal Cement Company at Trident, Montana, for use in cement.

The ore deposits of the Radersburg district have never been studied in detail and all but the smallest mines are now inaccessible. Brief descriptions of the deposits are given by A. N. Winchell (1914), Pardee and Schrader (1933), and Reed (1951).

The majority of the mineral deposits in the mapped area are found in a north-south zone extending from the Monterey Mine at the south to the Rena mine at the north. Alteration apparently related to mineralization along this zone extends beyond the mines to the north and south boundaries of the area. Four miles north of the map area, the Hassel mining district is aligned with this same zone. The alteration along this zone is complex and has not been fully studied. Near the Keating mine two types of alteration were mapped (fig. 3); the rocks of the outer zone are characterized by common pyrite crystals whereas the rocks of the inner zone are characterized by complete bleaching. The contact between the two types of alteration is usually gradational over a short distance but it may be sharp. The rocks of the inner zone often contain voids that probably were the sites of pyrite crystals. Winchell (1914, p. 178) discusses briefly the chemistry of the bleached rock of the inner zone and concludes "-----this rock must have been formed not by processes of leaching alone but by actual introduction of potassia and by its combination with alumina and silica set free by removal of other bases."

The magnetite at the Iron Cross mine replaces favorable beds in the Slim Sam formation where it has been folded into steeply plunging northeast trending folds (pl. 12-A and B). The ore bodies are from six to twleve feet thick and have an aggregate strike length of about 1,000 feet. The present operators have mined and shipped more than 25,000 tons of ore containing more than 40 percent iron and as much as 9 percent titania. In the late nineteenth century some ore from this deposit was shipped for use as smelter flux.

East of the Keating mine an extensive area was placered for gold as shown on figure 3. The gold found in the placer deposits was apparently derived entirely from the lode deposits in the adjacent areas.

54-92

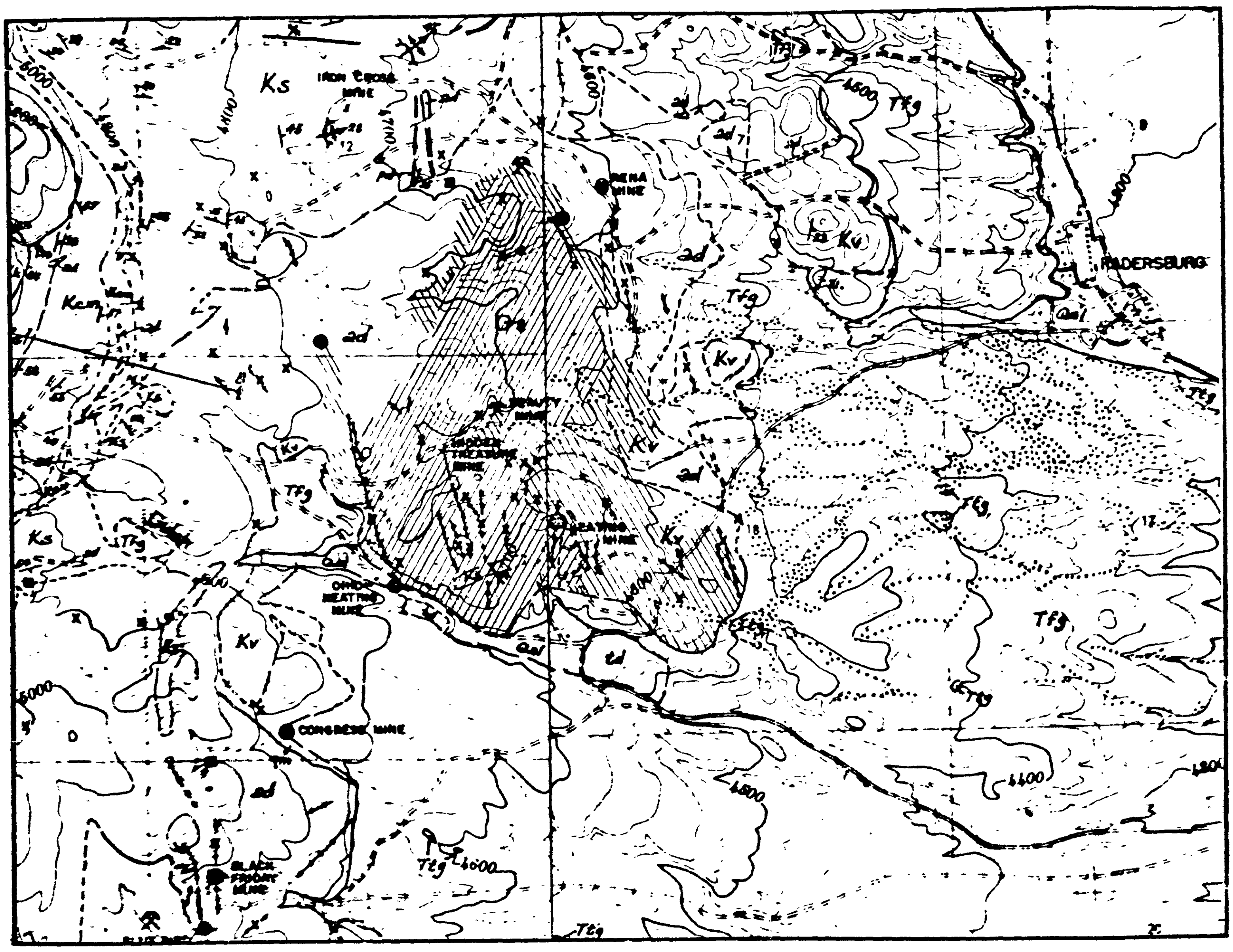


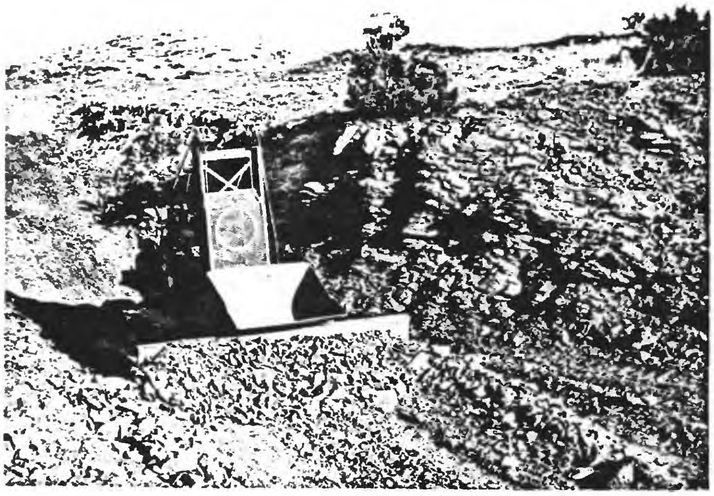
Figure 3 - Vicinity of Keating Mine showing areas of gold placering and bedrock alteration.

Area placered for gold

Area of pyritization

Area of bleaching

PLATE 12



A. Iron Cross magnetite deposit. Lower two-thirds of outcrop is magnetite, upper one-third of outcrop is tuff of Slim Sam formation.

B. Iron Cross magnetite deposit. Barren beds of Slim Sam formation stripped from above ore.

Section of Kootenai formation on north side of Johnny Gulch in $N\frac{1}{2}$ sec. 20, T. 5 N., R. 1 W.

(measured by V. L. Freeman and R. F. Gossman)

	Feet
Lower Cretaceous:	
Colorado formation:	
Lower black shale unit (basal beds only):	
Sandstone; very pale orange, very fine-grained; consists of well-sorted grains of quartz with limonite specks; in beds 2 to 4 feet thick with irregular bedding surfaces; well laminated ------	7.5
Mostly covered; probably underlain by olive-gray siltstone --	17.0
Sandstone; yellowish gray, very clean; consists of well-sorted, very fine grains of quartz. Beds are thin with irregular bedding and very small cross-laminations; not calcareous ------------------	4.5
Siltstone; argillaceous, light olive gray, forms slope ---	9.5
Siltstone; light olive gray, thinly laminated; forms ledge ---	2.0
Kootenai formation:	
17. Shale; calcareous, medium gray, somewhat silty; top 10 feet is limestone, yellowish gray with interbedded clayey siltstone and very fine-grained sandstone in thin even beds -----------------------	32.0
16. Limestone; medium light gray, medium-fine-grained crystalline; largely detrital and of coarse sand size. Gastropod fragments are abundant. Beds 1 inch to 3 feet thick with a few interbeds of calcareous shale that total 10 percent of unit. Forms ledge -----------------------	14.5
15. Siltstone; greenish gray, very clayey; grades in upper half to more yellowish color, locally calcite cements the coarser beds; weathers to very small hackly fragments -----------------------------	19.0

		Feet
14.	Claystone; silty, grayish red; bed of breccia with network of calcite-healed fractures at top; weathers to very small hackly fragments ----	34.0
13.	Siltstone and claystone; very limy, light greenish gray; thinly bedded ---------------------------	4.5
12.	Siltstone and argillaceous siltstone; greenish gray to light greenish gray, the cleaner beds are very hard and calcareous; in thin lenticular beds with many curved bedding surfaces, forms slight ledge --	6.5
11.	Silty shale and argillaceous siltstone; lower half is grayish red, upper half is alternating grayish red and light greenish gray; some limy zones throughout; weathers chippy or hackly -----------------	48.5
10.	Siltstone and sandstone (very fine- to fine-grained); greenish gray, argillaceous matrix gives color; grains of quartz and colorless mica seen; basal 2 feet is fine-grained sandstone; weathers to small chips with a few moderate brown weathering concretions up to 2 feet in diameter----------------	50.0
9.	Covered; offset on unit below-------------------	5.5
8.	Alternating limestone and siltstone; siltstone like unit below; limestone in three beds 1 to 2.5 feet thick, one at base, middle and top of unit; dark gray; very finely crystalline, slightly fetid, organic fragments common----------------------------	14.5
7.	Siltstone; clayey, olive gray in upper part; claystone medium gray with limy nodules in lower part; weathers to thin chips; poorly exposed ----------	18.0
	Sill, 14 feet thick; includes septum of shale about 3 feet thick	
6.	Shale; very silty, contains some sand grains, grayish purple with some greenish gray mottling at base, grading upward to greenish gray in upper half; several 1 to 1.5 foot beds of lumpy limestone that have been brecciated and recemented in part; contains isolated limestone nodules up to 8 inches in diameter ----------------------------	106.0

	Feet
5. Sandstone; light olive gray, fine-grained; consists of sub-angular grains of quartz and minor chert; basal 4 to 6 inches is conglomerate with pebbles up to 3 inches of quartzite and some chert; beds are 6 inches to 2 feet thick with laminations at a gentle angle to bedding; forms ledge; offset on base of this unit ----------------------------------	11.0
4. Claystone; silty, grayish red, hackly weathering; some irregular limy portions ------------------	22.0
3. Claystone; silty, greenish gray and subordinately grayish green; contains limy nodules that weather pale yellowish orange; some thinly laminated fine-grained argillaceous sandstone in upper part ----	23.0
Offset	
2. Sandstone; like unit below but mostly covered; in thin beds that have irregular bedding surfaces; argillaceous cement in some beds is more abundant than sand grains -------------------------------	28.0
1. Sandstone; medium gray, coarse-grained; consists of moderately well-sorted angular grains of quartz and chert (75%); tightly packed but contains some cement; occurs in cross-laminated beds with shallow cut-and-fill structures of moderate size --	18.0
Total thickness of Kootenai formation	455.0

Upper Jurassic:

Morrison formation (upper part only):

Covered; mostly siltstone and claystone fragments; near top are chips of silty, micaceous, dark gray shale --	67.0
Poorly exposed; siltstone; olive gray, with subordainte limestone, medium gray in 1 to 2 foot beds; one 18 inch bed of sandstone, fine-grained, very pale orange -------------------------------	45.0
Limestone; medium gray, very finely crystalline, very silty; irregularly weathering surface -------	1.0

	Feet
Sandstone; very fine-grained; siltstone; and claystone; light olive gray, calcareous, very hard; breaks with concoidal fracture; blocky weathering; in beds up to 2 inches thick with low angle cross-laminations and shallow channeling -------------	29.0
Siltstone; light olive gray, hard, dense, hackly weathering; forms slope under ledge; homogeneous unit --	4.5
Siltstone, light olive gray, limy zone at top, very hard; in beds 1 to 1½ inches thick with minor clayey laminations; thinly laminated ------------------	9.5

Section of Colorado group along shallow gully that approximately coincides with boundary between NE$\frac{1}{4}$ and SE$\frac{1}{4}$ sec. 4, T. 4 N., R. 1 W. (measured by M. R. Klepper)

	Feet
Upper Cretaceous:	
Slim Sam formation (part):	
Sandstone, light olive gray, thin-bedded, non-resistant; contains a few thin beds of siltstone in lower half	55
Gradational contact	
Colorado group:	
Upper black shale unit:	
66. Shale (80 to 90 percent), dark gray to very dark gray, chippy to fissile, and sandstone (10 to 20 percent), dark gray, very fine-grained, micaceous; shale contains sporadic moderate yellowish brown-weathering limestone concretions up to 6 inches in diameter	254
65. Covered interval	97
64. Shale, very dark gray and mudstone, olive gray; contains conspicuous brown-weathering limestone concretions	30
Total thickness of Upper black shale unit	381
Gradational contact	
Middle siliceous unit:	
63. Covered interval; sandstone float	22
62. Sandstone, coarse-grained, feldspathic (tuffaceous?), cross-bedded	4
61. Covered interval; float is sandstone similar to unit 62	24
60. Sandstone, quartzitic, medium light gray, very fine-grained, hard and blocky; contains scattered woody fragments	4

		Feet
59.	Covered interval	45
58.	Sandstone, quartzitic, medium dark gray	5
57.	Sandstone, light gray and olive, thin- to medium-bedded; some beds quartzitic, some feldspathic; contains a few interbeds of blocky mudstone	38
56.	Covered interval	56
55.	Sandstone, light gray, feldspathic, cross-bedded; contains abundant woody fragments near base and one bed of blocky quartzitic sandstone near top	37
54.	Mudstone, medium dark gray, siliceous, blocky	7
53.	Covered interval	37
52.	Mudstone, similar to unit 54	24
51.	Mudstone, yellow, olive, and gray, in layers from 4 inches to 1 foot thick, siliceous	19
50.	Covered interval	28
49.	Mudstone, siliceous, similar to unit 51; contains 4 foot bed of quartzite near top	22
48.	Covered interval	21
47.	Mudstone, very light to dark gray and olive gray, siliceous, blocky; contains a few thin layers of hard sandstone	18
46.	Covered interval	20
45.	Mudstone, medium gray, siliceous	2
44.	Sandstone, light olive gray, medium-grained, feldspathic	3
43.	Covered interval; float is blocky, siliceous mudstone	22
42.	Mudstone, pale greenish yellow and medium dark gray, siliceous, blocky to sub-conchloidal fracture	10

	Feet
41. Quartzite, very light gray with thin brown layers --	10
40. Covered interval ------------------------------	17
39. Mudstone, greenish gray, siliceous, blocky -----	4
38. Covered interval --------------------------------	12
37. Sandstone, very light gray, thin- and cross-bedded, feldspathic (tuffaceous?) ---------------	8
36. Mudstone, alternation of units from 1 foot to 6 feet thick colored grayish olive, light gray, and medium gray; contains 1 thin layer of siliceous mudstone and several of light gray sandstone ----	50
35. Sandstone, fine-grained-------------------------	3
34. Mudstone, grayish olive, hackly to chippy; contains a few thin layers of fine-grained gray sandstone --	14
33. Sandstone, speckled very light and medium gray; one coarse-grained bed at base ----------------	8
32. Mudstone, similar to unit 34 -------------------	20
31. Sandstone, olive and medium gray, fine-grained; contains a few thin beds of dark gray shale ------	63
30. Covered interval -----------------------------	10
29. Mudstone or shale, olive gray, medium gray, and medium dark gray, chippy to fissile ------------	35
28. Sandstone, siltstone, and shale with a few limestone concretions, drab-colored ----------------	39
27. Mudstone or shale, very dark gray; contains brown-weathering limestone concretions near base -----	6
26. Shale and sandstone, very dark gray ------------	4
25. Sandstone, similar to unit 23. -----------------	7
24. Mudstone, medium dark gray and olive gray, blocky --	12
23. Sandstone, medium gray, feldspathic and cherty--	7

		Feet
22.	Covered interval ------------------------------	6
21.	Sandstone, similar to unit 19 ------------------	8
20.	Covered interval; sandstone float --------------	24
19.	Sandstone, medium to light gray, very fine-grained; contains a zone of roundish calcareous sandstone concretions near middle of unit -------	11
18.	Covered interval; sandstone float --------------	11
17.	Sandstone, similar to unit 15 ------------------	2
16.	Covered interval -------------------------------	12
15.	Sandstone, medium light gray, cross-bedded, feldspathic (tuffaceous?); in beds averaging $\frac{1}{2}$ inch thick; calcareous sandstone concretions (2 to 3 inches in diameter) are abundant in upper few feet ------------------------------------	36
14.	Sandstone, similar to unit 15, with interbeds of medium gray shale --------------------------	23
	Total thickness of middle siliceous unit	930
	Gradational contact	
	Upper black shale unit:	
13.	Covered interval -----------------------------	17
12.	Shale, very dark gray ------------------------	9
11.	Sandstone and siltstone, medium gray, bedding is irregular and wavy -----------------------	37
10.	Covered interval; very dark gray shale float -----	34
9.	Sandstone, similar to unit 7 ------------------	2
	Fine-grained diorite sill 40 feet thick -----------	--
8.	Mostly covered; outcrops are sandstone similar to unit 7 ------------------------------------	47

	Feet
7. Sandstone, medium dark gray with limonitic specks, medium-grained; contains finely dispersed organic matter and grains of black shale; bedding typically wavy and irregular ------------------	19
6. Covered interval; very dark gray and dark gray shale float is predominant; sandstone float is subordinate ------------------------------------	106
5. Siltstone, dark gray and olive, thin-bedded and almost fissile; contains irregular limonitic concretions in upper 4 feet ----------------------	13
4. Shale, very dark gray, with a few 2 inch beds of rusty-weathering siltstone --------------------	19
3. Covered interval; olive gray siltstone float ------	10
2. Sandstone, very light gray, calcareous, in beds ½ to 3 inches thick, very fine-grained -----------	12
1. Sandstone, light olive gray, fine-grained --------	3
Total thickness of lower black shale unit	328

Kootenai formation -- not measured

Section of Slim Sam formation on northeast side of Aldrich Gulch along East margin of Slim Sam basin
NW$\frac{1}{4}$ sec. 22, T. 6 N., R. 1 W.

(measured by V. L. Freeman and Dante E. Brambilla)

Upper Cretaceous:

Elkhorn Mountains volcanics (basal part only):	Feet
Andesitic breccia with fragments up to 2 inches in maximum dimension of several types of hornblende and feldspar porphyry; matrix contains small feldspar and hornblende crystals. No bedding detected	
Gradational contact	
Slim Sam formation:	
21. Mostly covered; upper part is tuff; most beds consist of fragments of feldspar crystals up to 2 millimeters long in very fine-grained matrix. Lower part is andesitic tuff with some fragments up to 1$\frac{1}{2}$ inches long of hornblende and feldspar porphyry. Thin-bedding seen in float but not in outcrop ----------	133.5
20. Covered; float like unit below but finer-grained and with more distinct bedding. Upper 20 feet is probably lapilli tuff ----------	64.0
19. Sandy tuff; light olive gray, consists of coarse angular grains of feldspar with minor quartz and chert ----------	23.0
18. Covered; underlain in part by dark gray, hackly weathering, siliceous shale containing carbonized plant remains ----------	43.0
17. Sandy tuff; light olive gray, consists of fine- to medium-grained; poorly sorted, sub-angular grains of feldspar, quartz, mica, and chert in sparse clay matrix; somewhat calcareous. In beds $\frac{1}{2}$ to 1 inch thick, becoming somewhat thicker at top. At top is zone of iron oxide staining -----	15.0
16. Covered ----------	31.0

		Feet
15.	Covered; float suggests that lower 20 feet is hard dark shale. To northwest of section this interval is occupied by olive and dark gray mudstone consisting of many coarse crystal fragments in clayey and silty matrix; hackly weathering ------------------------	43.0
14.	Covered --	16.0
13.	Sandstone; between pale olive and dusky yellow in color, fine-grained, well-sorted sub-angular grains of quartz, feldspar, and chert in clayey matrix. In beds 1 to 2 inches thick ---------------------------	11.0
12.	Sandstone; continuous with unit below but slightly finer-grained and contains much iron oxide. Unit forms very dark brown zone at top of cliff formed by unit below. Zone is discontinuous and iron oxide appears to be secondary ---------------------------	5.0
11.	Sandstone; tuffaceous, light olive gray, yellowish on outcrop, medium- to coarse-grained, consists of moderately sorted sub-angular grains of quartz with much feldspar, slightly calcareous. Beds 2 inches to 2 feet thick with laminations $\frac{1}{2}$ to 1 inch thick, cross-laminations are mostly very shallow without strong scouring. Rare round concretions are about 1 foot in diameter. In general the unit is coarsest at base becoming finer upward, but there are scattered granules of a fine-grained material throughout the unit ---	43.5
10.	Poorly exposed; scattered outcrops in lower part are like unit below and in upper part are like unit above; probably gradational zone --------------------------	46.0
9.	Sandstone; yellowish gray to light greenish gray, fine- to very fine-grained with rare thin irregular beds of coarse grains; grains are well-sorted and sub-angular; calcareous. Unit weathers to a more yellow color than lower units and black shaley partings and chips are lacking. Beds 1 to 5 inches thick --------	35.0
8.	Sandstone; medium light gray, weathers light gray, very fine-grained; consists of well-sorted grains of quartz and chert (20 percent); with thin lenses and pods of coarse grains of feldspar, mica, and rarely quartz; all are crystals or fragments of crystals; calcareous; a few thin partings of black shale in thinly laminated beds. Unit includes some slightly coarser sandstone of yellowish gray color ----------------	70.5

	Feet
7. Covered; float like unit above	26.5
6. Covered; float like unit below	18.5
5. Sandstone; yellowish gray, very fine-grained, well-sorted sub-angular grains, with some interstitial clay, calcareous; contains common irregular chips of black shale or plant fragments and also thin lenses of feldspar crystals to 2 millimeters of volcanic origin. Bedding surfaces are rough; beds ½ to 1 foot thick	9.0
4. Mostly covered; float and a few low outcrops are the same as unit below but no shale seen	24.0
3. Sandstone; yellowish gray, very fine-grained, well sorted with minor argillaceous material; grains are sub-angular quartz and chert. In thin beds ¼ to 2 inches thick, thinly laminated; with thin (up to ½ inch) dark gray shale partings	20.0
2. Covered	145.0
Offset	
1. Sandstone; light gray, light olive gray, and medium gray, very fine-grained, moderately well-sorted, consists of sub-angular grains of quartz and chert; calcareous. Several thin lenses of very coarse feldspar and minor quartz grains in lower part of unit. Black clay chips and blobs are common. One 4-inch bed of silty limestone. All rocks of unit are somewhat argillaceous. Bedding is distinct with beds from ½ to 4 inches thick with rare bed to 4 feet thick. This unit measured at intersection of secs. 22, 23, 26, and 27, T. 6 N., R. 1 W.	83.0
Total thickness of Slim Sam formation	905.5

Contact not seen on line of main section, but its position can be estimated within ten feet.

Colorado formation (upper part only):

Shale, dark gray to grayish black; unit contains subordinate silty shale and sparse sand-sized grains; some mica flakes and plant remains present. Hackly weathering.

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