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A descriptive report of the geology, mineral deposits, and mines in an area east of the Boulder batholith

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By M. R. Klepper, E. T. Ruppel, V. L. Freeman, and R. A. Weeks

ABSTRACT

The Elkhorn Mountains are an oval-shaped mountain mass in west-central Montana that is located between the city of Helena and the valley of the Jefferson River. This report describes the geology and mineral deposits of the east flank of this mountain mass, a strip about 6 miles wide and 26 miles long.

The stratified rocks include a thick and, for the most part, conformable sequence of marine and nonmarine sedimentary rocks, which are overlain by a volcanic pile of Late Cretaceous age and by consolidated and unconsolidated sediments of Cenozoic age. The prevolcanic sedimentary rocks range in age from Middle Cambrian to Late Cretaceous and include a sequence about 4,000 feet thick of marine limestone, dolomite, and subordinate clastic rocks of Paleozoic age and a sequence almost as thick of marine and nonmarine rocks of Mesozoic age that are dominantly shale, mudstone, siltstone, and fine-grained sandstone, but that also includes limestone and some coarser grained clastic rocks. The youngest of these sedimentary rock units is the Slim Sam Formation, a sequence that is mainly marine sandstone in the lower part and nonmarine tuff in the upper part.

The Slim Sam is gradationally overlain by the Elkhorn Mountains Volcanics of Late Cretaceous age, which in this area comprises mainly rhyodacitic and trachyandesitic pyroclastic rocks of the lower member of the formation and rhyolitic welded tuff, trachyandesitic and rhyodactic tuff, and tuff breccia of the lower part of the middle member; the upper part of the middle member and the upper member of the Elkhorn Mountains Volcanics have been eroded.

The sedimentary and volcanic rocks are cut by many bodies of intrusive igneous rocks, including fine-grained rocks, mainly porphyries, related to and of the same age as the Elkhorn Mountains Volcanics that were emplaced before or at the outset of folding, and by younger generally coarser grained intrusive rocks that were emplaced subsequent to volcanism and folding. The intrusive equivalents of the Elkhorn Mountains Volcanics comprise porphyritic rhyodacite, trachyandesite, and trachyandesite in sills, dikes, and small partly concordant bodies ranging to syenodiorite porphyry and granodiorite porphyry in larger partly concordant bodies; the largest of these, the Rattlesnake intrusive, crops out over an area of 20 square miles and is imperfectly laccolithic in form.

The younger intrusive rocks form small, commonly discordant stocks or bodies of unknown configuration, and they range in composition from gabbro to granite. These rocks span about the same compositional range and were emplaced during approximately the same time interval as the Boulder batholith to the west. A few small stocks and dikes consist wholly of mafic rocks, ranging from syenogabbro to calcic syenite; many stocklike bodies, from a few acres to a few square miles in outcrop area, consist of felsic rocks ranging in composition from syenodiorite to granite; in the central part of the area a few small intrusive bodies are composite and consist of one or more mafic rock types and one or more felsic types. Where age relations can be determined the mafic rocks are older than the felsic rocks. For descriptive purposes the felsic rocks can be subdivided into three petrographic groups: (1) medium-grained equigranular rocks, mainly granodiorite but ranging from syenodiorite and monzonite to quartz monzonite, (2) porphyritic quartz monzonite characterized by conspicuous K-feldspar megacrysts, and (3) porphyries ranging from granodiorite to granite in composition. Age relations of rocks within the felsic group could nowhere be determined. Medium-grained equigranular rocks are widespread and much more abundant than the other petrographic types which are restricted to small bodies in the north half of the area.

The structure of the mapped area is simple in gross aspect but is complex in detail. In late Cretaceous and early Tertiary time the layered rocks were folded into a broad syncline, which trends north through the central part of the area, and is broken by many faults of similar trend that formed contemporaneously with the folding; the syncline is one of a series of north-trending folds between the Boulder batholith to the west and the Lombard thrust to the east. Later, the rocks were broken by northeast- and northwest-trending tear faults. The youngest faults are range-front faults that bound the mountain front in the north part of the area; movement along the range-front faults began before deposition of Cenozoic sediments and has been recurrent almost to the present time.

The east flank of the Elkhorn Mountains has been a significant source of metallic minerals and has yielded metals valued at about $17 million. Gold mined from lode deposits in the Radersburg, Winston, Park, and Hassel districts and from placer deposits at Radersburg, along Indian Creek, and along Weasel Creek accounts for about three-fourths of the total value. Silver, lead, zinc, and copper account for most of the remainder.

The metallic mineral deposits comprise auriferous pyrite veins that contain sparse quartz, quartz veins that contain auriferous pyrite, base- and precious-metal veins that typically have quartz gangue, silver-lead-zinc replacement deposits in carbonate rocks, skarn deposits at or near intrusive igneous contacts, a titaniferous magnetite deposit, and gold placers. Most of the deposits in the Radersburg and Hassel districts are auriferous pyrite veins; the deposits in the Winston area are quartz veins with auriferous pyrite and base- and precious-metal veins. Gold placers were mined at Radersburg, along Indian Creek from Hassel to the mouth, and along Weasel Creek. The replacement deposits of silver, lead, and zinc are mainly in the Quartzite Ridge area.

The principal skarn deposits are west of Radersburg and at Diamond Hill; titaniferous magnetite has been mined west of Radersburg. Perhaps as much as half the ore mined from the several types of vein deposits has been oxidized or partly oxidized; only a few veins have been profitably mined below the zone of oxidation.

Despite extensive mining and prospecting, the area is considered favorable for discovery of additional mineral deposits. For example, auriferous pyrite veins or ancient gold placers might be concealed beneath the relatively thin Cenozoic deposits south of the Keating and Ohio Keating mines near Radersburg, and the untested outwash gravels along and near Cold Springs Gulch would seem to warrant testing for gold.

INTRODUCTION

LOCATION AND ACCESS

The oval-shaped mountain mass west of the Missouri River valley between Helena, Mont., and the Jefferson River valley is generally referred to as the Elkhorn Mountains. This report describes the geology of the east flank of that range and the adacent part of the Townsend Valley, an area of about 150 square miles (fig. 1) encompassing the west half of the Townsend 15-minute quadrangle and the northwest quarter of the Radersburg 15-minute quadrangle.

U.S. Highway 287 and the Northern Pacific Railway cross the northeast corner of the area. Townsend, the seat of Broadwater County, is on the highway and railroad about 6 miles east of the area and 34 miles southeast of Helena. Two villages, Radersburg and Winston, are within the area. Both were formerly centers of mining activity but are now inhabited mainly by ranchers. The area is uninhabited except for these communities, a few ranches near them, and, from time to time, small mining camps in the mountains. The former mining community of Hassel (also known as St. Louis) is uninhabited.

Most parts of the area, except the headwaters of Beaver Creek, are accessible by mountain roads. Altitudes range from 4,200 feet in the Townsend Valley to 8,600 feet along the divide between Beaver and Crow Creeks.

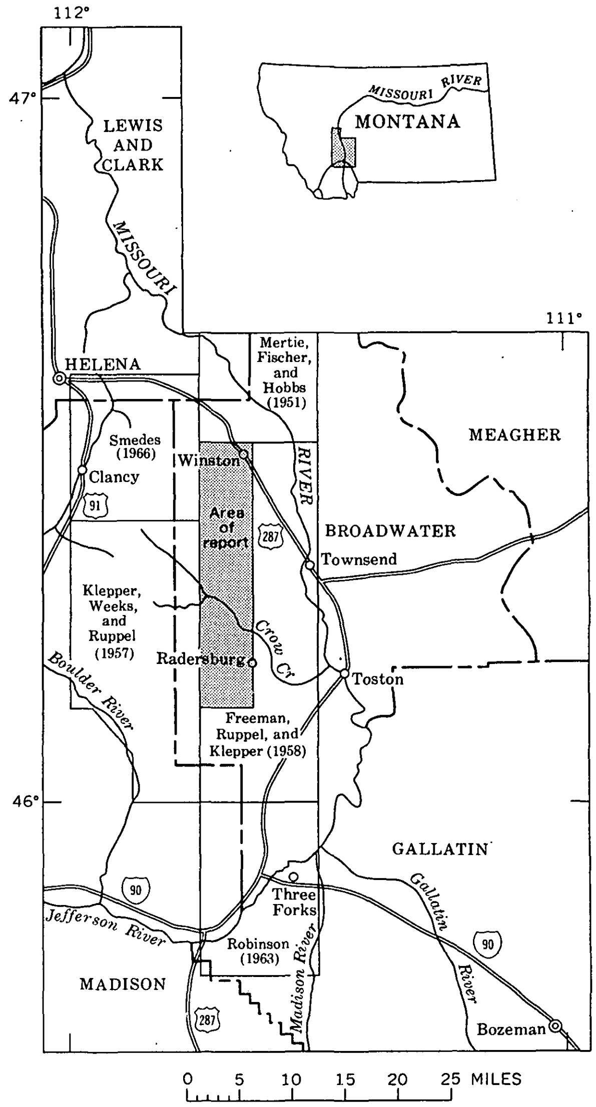

FIGURE 1.—Index map showing location of present report area and of adjacent areas described in recent reports.

FIELDWORK AND ACKNOWLEDGMENTS

The area described in this report is part of a large region in and around the Boulder batholith that has been mapped by the authors and their associates. Most of the fieldwork on which the report is based was done between 1949 and 1953. The geology of the area was plotted directly on preliminary topographic maps prepared at a scale of 1:24,000 by Fairchild Aerial Surveys, Inc., except for a strip about 2 miles wide along the west edge of the Radersburg quadrangle, within which the geology was plotted on aerial photographs in the field and subsequently transferred to the topographic base map by use of a Mahan Plotter. Principal responsibility for mapping different parts of the area is shown on plate 1. E. J. Lyons, H. W. Smedes, D. E. Brambilla, D. M. Pinckney, H. B. Nickelson, A. W. Berg, and R. F. Gosman assisted in the fieldwork at various times.

The authors are indebted to many individuals and mining companies for information and maps of mining properties. Particularly helpful were Albert Dance, Harry Anders, Palmer Engh, and Fred Schneider of Townsend, Arthur Berg of Radersburg, Arthur and Harold Hogan and Mrs. Charles Muffley of Winston, the late Carl Trauerman of Butte, Herb Carver of Helena, Harry Kleinschmidt of Lincoln, Al Nugent of

Wallace, Idaho, Edmund E. Pohl of Seattle, Wash., and officials of the Anaconda Co. The authors also are indebted to W. A. Cobban and the late J. B. Reeside, Jr., both of the U.S. Geological Survey, for material assistance in interpretation and correlation of the Cretaceous sedimentary rocks.

PREVIOUS WORK

Several previous geologic studies and investigations of mineral deposits included parts of the area. Stone (1911) examined the mineral deposits and mapped the geology of part of the area in reconnaissance. Bard (1910) and Winchell (1914) briefly described the geology and some of the ore deposits of the Radersburg district, Condit, Finch, and Pardee (1928, p. 177–178) reported on occurrence of phosphate rock in the Elkhorn Mountains, and Corry (1933) described some of the gold placer deposits in and adjacent to the mountains. Reed (1951) summarized available information, including production data for mines in Broadwater County. Reports by Knopf (1913), Billingsley (1916), Billingsley and Grimes (1918), and Pardee and Schrader (1933), provide valuable information on the regional stratigraphy, structure, petrology, and ore deposits. The following geologic maps and reports have been published recently of the areas that surround the present mapped area: The Canyon Ferry quadrangle to the north mapped by Mertie, Fischer, and Hobbs (1951), the Elkhorn Mountains to the west mapped by Klepper, Weeks, and Ruppel (1957), Smedes (1966), and Knopf (1963), the Three Forks quadrangle to the south mapped by Robinson (1963), and the Townsend Valley to the east mapped by Freeman, Ruppel, and Klepper (1958), Lorenz and McMurtrey (1956), and Nelson (1963). The ore deposits of the north part of the Park mining district have recently been discussed by Schell (1963), and those of the Winston mining district, by Earll (1964). Gravity and aeromagnetic data have been published by Kinoshita, Davis, Smedes, and Nelson (1964) and Kinoshita, Davis, and Robinson (1965).

SEDIMENTARY ROCKS

A sequence of consolidated sedimentary rocks about 13,000 feet thick and ranging in age from late Precambrian to Cretaceous is exposed in and near the Elkhorn Mountains. These rocks underlie a volcanic pile of Late Cretaceous age that in places was at least 10,000 feet and perhaps as much as 15,000 feet thick. The Cretaceous and older rocks are strongly folded and faulted and are cut by the Boulder batholith and related intrusive rocks of Late Cretaceous age. The major valleys that flank the mountains are filled with ash-rich sediments of Tertiary age, most of which are only weakly consolidated.

Most of the sedimentary and volcanic units are rather uniform throughout the Elkhorn Mountains and nearby. They have been fully described by Klepper, Weeks, and Ruppel (1957), Freeman, Ruppel, and Klepper (1958), Robinson (1963), Nelson (1963), and Smedes (1966), and accordingly most of them are treated only summarily in this report. New information, such as measured sections and lists of fossils, is included, however.

PALEOZOIC ROCKS

Paleozoic sedimentary rocks are exposed in two north-trending belts, one about a mile wide along the southwest margin of the area, and the other about half a mile wide along the east margin, north of Crow Creek. Rocks in the western outcrop belt are on the east flank of a broad north-trending dome (Klepper and others, 1957). Those in the eastern outcrop belt are part of the east flank of the broad syncline north of Crow Creek (Freeman and others, 1958).

PARK SHALE

The oldest formation exposed is the Park Shale of Middle Cambrian age, which crops out along Johnny Gulch at the west margin of the area. The formation consists mainly of olive-green, gray, and brown shale but contains a few thin beds of argillaceous limestone, siltstone, and silty sandstone. The formation is 215 feet thick on the north slope of Johnny Gulch (Klepper and others, 1957, p. 10).

PILGRIM DOLOMITE

The Pilgrim Dolomite overlies the Park Shale with apparent conformity. It is 482 feet thick along the north slope of Johnny Gulch in SE¼ sec. 17, T. 5 N., R. 1 W. (Klepper and others, 1957, p. 11). The lower part of the formation, about 50 feet thick, is oolitic and pebbly bluish-gray limestone overlain by dolomite that weathers mottled light and dark gray. The middle part of the formation, about 200 feet thick, is mainly gray limestone with mottles and ribbons of yellowish-gray silty dolomite; it closely resembles the mottled limestone of the lower and upper parts of the Cambrian Meagher Limestone, not exposed in this area. The upper part, about 230 feet thick, is medium-bedded, partly oolitic, mottled light- and dark-gray dolomite overlain by very resistant, rough-weathering, thick-bedded light-gray dolomite.

The Pilgrim Dolomite is considered to be Late Cambrian. Fossils from 10 feet above the base, at the south end of the Limestone Hills, about a mile east of the mapped area (250 ft northwest of an abandoned quarry in NE¼ sec. 4, T. 5 N., R. 1 E.), are typical of the lower *Cedaria* subzone (A. R. Palmer, written commun., 1951); the collection contains: *Cedarina cordillerae* (Howell and Duncan), *Bolaspidella wellvillensis* (Lochman and Duncan), *Nixonello* cf. *N. montanensis* Lochman.

Fossils from the middle part of the formation about 4½ miles southwest of the area are characteristic of the middle *Cedaria* subzone (Klepper and others, 1957, p. 11).

RED LION AND MAYWOOD FORMATIONS

Varicolored argillaceous rocks and impure carbonate rocks above the Pilgrim Dolomite are 134 feet thick on the north slope of Johnny Gulch in NE¼ sec. 17, T. 5 N., R. 1 W. (Klepper and others, 1957, p. 13). The lower part of the sequence is referred to the Red Lion Formation of Late Cambrian age, and the upper part, to the Maywood Formation of Middle and Late Devonian age (Klepper and others, 1957). The Red Lion appears to lie conformably on the Pilgrim Dolomite. The Maywood is disconformable on the Red Lion; in fact, near the south end of the Limestone Hills about a mile east of the area, the Red Lion was largely or wholly removed by erosion before the Maywood was deposited. Because the two formations are similar, thin, and generally poorly exposed, they were mapped as a single unit. The unit is wholly or partly equivalent to the Dry Creek Shale of earlier literature (Deiss, 1936; Emmons and Calkins, 1913; Lochman-Balk, 1950; Sloss and Laird, 1947; Hanson, 1952, Robinson, 1963).

Along Johnny Gulch the Red Lion Formation is 93 feet thick and consists of varicolored siltstone, shale, and fine-grained sandstone; most of the rocks are calcareous and weather to shades of red and yellowish brown. The overlying Maywood Formation is 41 feet thick and consists mainly of silty dolomite and dolomitic or calcareous siltstone and shale; the rocks weather to shades of gray and yellowish brown.

JEFFERSON DOLOMITE

The Jefferson Dolomite of Late Devonian age consists mainly of fetid dolomite that weathers to a dark-gray nodular rock commonly with a brownish cast, but the formation also contains beds of gray limestone and dolomite, which weather lighter shades of gray, and a few thin beds of intraformational pebble conglomerate. Much of the rock is formed of clastic carbonate grains. Most beds are a few inches to a few feet thick, some are laminated, and some are cross-laminated; small channels are present locally. Small lenses and discontinuous thin layers of chert and partings of yellowish-gray mudstone are present sparingly in the lower half of the formation. Small lenses and discontinuous thin layers of dark dolomite breccia, some of which do not conform to bedding and probably were formed by collapse, are present locally. The uppermost 25–40 feet of the formation is distinctive faintly mottled light-gray dolomite in beds 1–3 feet thick.

The formation appears to lie conformably on the Maywood Formation and to be overlain conformably by the Three Forks Shale. It is 478–727 feet thick in measured sections nearby (Klepper and others, 1957, p. 14–15; Freeman and others, 1958, p. 548–549) and appears to be 500–600 feet thick in this area.

THREE FORKS SHALE

The Three Forks Shale is poorly exposed in several narrow strike valleys along and near the west margin of the area southward from sec. 8, T. 5 N., R. 1 W. It is about 300 feet thick and consists largely of dark-gray, greenish-gray, and brown shale. About 200 feet above the base, fossiliferous argillaceous gray limestone, 10–25 feet thick, in places crops out as a low ledge. The upper part of the formation, about 50 feet thick, is dolomitic and calcareous siltstone and mudstone that weathers yellowish brown and yellowish gray.

The Three Forks Shale is largely of Late Devonian age. The upper part is probably a correlative of the Sappington Sandstone Member as used by Berry (1943) of nearby areas and therefore probably contains beds of Mississippian age near the top. Recently, Robinson (1963, p. 34–38) provided detailed new information and summarized the extensive literature on the age of the Sappington Member of the Three Forks.

MADISON GROUP

The Three Forks Shale is conformably overlain by a thick sequence of gray limestone assigned to the Madison Group of Mississippian age. The lower part of the sequence, assigned to the Lodgepole Limestone, is about 700 feet thick and consists largely of thin-bedded limestone. The upper part of the sequence, about 1,000 feet of thick-bedded limestone, is assigned to the Mission Canyon Limestone. These formations crop out in a belt about a mile wide extending southward along the west edge of the mapped area from sec. 32, T. 6 N., R. 1 W., and in a narrower belt along the east edge of the area north of Crow Creek.

The Lodgepole Limestone consists almost entirely of thin and distinctly bedded medium-gray limestone, typically with a distinct bluish cast on weathered surfaces. Much of it is lithified carbonate sand. Many beds are fossiliferous and have a fetid odor; some consist largely of waterworn fossil debris. In the lower part of the formation the beds range in thickness from 1 inch to 1 foot and average 3–4 inches; thin interbeds and partings of yellowish- or reddish-gray calcareous shale or mudstone are characteristic. In the upper part of the formation, beds 2–3 feet thick are interlayed with much thinner beds, mudstone partings are rare, fossiliferous beds are less abundant, and thin siliceous seams and chert lenses are sparingly present.

The Lodgepole rests with abrupt but apparently conformable contact on calcareous or dolomitic siltstone of the Three Forks. It grades upward into the Mission Canyon through a thickness of 100–200 feet. The contact was placed at the top of the uppermost unit of thin-bedded limestone.

The Mission Canyon Limestone consists largely of thick and indistinct beds of medium- to light-gray fine- to coarse-grained limestone; a few beds of darker gray limestone are present near the top and bottom of the formation. The upper half contains sparse nodules, lenses, and thin layers of gray chert. Beds containing abundant small twiglike bodies of white crystalline calcite are common in the middle part.

The formation weathers light gray to medium gray and is locally mottled light olive gray. Weathered surfaces differ in detail; some are rough and cuspate and others are smooth or only slightly rough. Thin, irregular, siliceous crusts coat some surfaces and stand in slight relief.

One or more zones of solution breccia approximately parallel to bedding are present in the upper part of the Mission Canyon at most places. The lowest and most conspicuous breccia zone is about 200 feet below the top of the formation and is 10–75 feet thick. The breccia is believed to have formed by collapse of solution caverns in the Mission Canyon before Big Snowy rocks were deposited (Klepper and others, 1957, p. 20).

BIG SNOWY GROUP AND AMSDEN FORMATION

The Mission Canyon Limestone is overlain by an assemblage that consists mainly of red siltstone and gray carbonate rock but includes beds of mudstone, shale, and sandstone. Along the east edge of the area about a mile north of Crow Creek, the measured thickness of these rocks is 259 feet (Freeman and others, 1958, p. 550) and in sec. 32, T. 7 N., R. 1 E., on the slopes northwest of Indian Creek, it is 313 feet. In both places, and generally throughout the area, the lower part is very poorly exposed but appears to consist mainly of red siltstone. The middle part, 40–50 feet thick, is mainly gray limestone and dolomite. The upper part, also generally poorly exposed, consists of red, reddish-brown, and yellowish-gray silty, argillaceous, sandy and carbonate rocks that grade upward into alternating beds of light-colored quartzitic sandstone and dolomite of the Quadrant Formation. The assemblage is probably 250–320 feet thick in most places, but it may be as thin as 200 feet in a few places along the western belt of outcrop and perhaps is as much as 350 feet thick in the vicinity of Indian Creek; at Indian Creek, however, the pattern of rock distribution is peculiar and the apparent thickness may be greater than the true thickness as a result of repetition of beds by unrecognized minor folds and faults of small displacement or of deposition on an irregular surface of moderate local relief, perhaps a karst.

Though the contact with the underlying Mission Canyon Limestone was nowhere observed, indirect evidence indicates that it is a disconformity (Klepper and others, 1957, p. 19–20). Lenses and layers of limestone breccia are abundant in the upper part of the Mission Canyon Limestone. Some of the breccia is cemented or partly cemented by red and yellow limy mud. In a few places the mud is laminated and inclined at the same angle as the enclosing limestone. The observations indicate that the breccia formed, probably by collapse of caverns, and was cemented prior to regional folding. The similarity of some of the cave fillings to the overlying rocks suggests that near-surface caves formed and collapsed just before or while the Big Snowy and Amsden rocks were being deposited. In most places the surface on which the Big Snowy and Amsden was deposited seems to have been without appreciable relief. The peculiar pattern of rock distribution in the vicinity of Indian Creek mentioned above, however, might indicate deposition on an irregular karst surface with local relief of 50–75 feet.

Blake (1959) measured a section near Indian Creek (sec. 32, T. 7 N., R. 1 E.) and assigned the rocks at that locality to the Big Snowy Group. He correlated the lower unit of predominant red siltstone with the Kibbey Formation and assigned the overlying rocks to a newly described Lombard facies of the Big Snowy Group.

Dutro and Sando (1963), measured the Indian Creek section described as the Amsden Formation by Klepper, Weeks, and Ruppel (1957, p. 20) and Freeman, Ruppel, and Klepper (1958, p. 498, 550) and found that the uppermost beds of the medial gray limestone-dolomite unit contain *Caninia* and *Spirifer brazerianus*, an occurrence indicating middle Chester age. Beds near the base of the limestone-dolomite unit contained *Striatifera brazeriana*, an occurrence indicating early Chester age. These fossils strongly suggest that the lower red siltstone and the medial limestone-dolomite units are part of the Big Snowy Group, and that the lower red siltstone is a correlative of the Kibbey Formation as Blake (1959) suggested. The upper red siltstone probably is part of the Amsden Formation.

In the Three Forks and Toston quadrangles, Robinson (1936, p. 44–49; 1967) assigned a lithologically varied assemblage of rocks locally as much as 400 feet thick to the Big Snowy Formation. The thickest sequence, in the Hossfeldt Hills about 15 miles southeast of the south margin of the area of the present report, consists of yellowish-gray and yellowish-brown siltstone, mudstone, and sandstone, dark shale, and olive-gray and dark-gray limestone. No sequence similar to this is present in the Elkhorn Mountains. Overlying the rocks assigned to the Big Snowy Group are rocks similar in lithology and generally comparable in thickness to the sequence in the Elkhorn Mountains that the authors refer to the Amsden Formation. Robinson also assigned these rocks to the Amsden Formation on both lithologic and faunal grounds.

QUADRANT FORMATION

The Amsden Formation grades upward into the Quadrant Formation, which consists of alternating beds of light-colored quartzitic sandstone and light-gray dolomite. Dolomite predominates in the lower part of the formation; the number and thickness of beds of quartzitic sandstone increase upward, and quartzitic sandstone constitutes about 75 percent of the uppermost 100 feet. Typically, one or two ledge-forming beds of massive quartzite as much as 25 feet thick are present in the upper 100 feet. Some of the quartzite beds are conspicuously crossbedded. The formation is 327 feet thick in NW¼ sec. 29, T. 6 N., R. 1 E., about a mile north of Crow Creek (Klepper and others, 1957, p. 20–21). Outcrops suggest that the thickness is about the same throughout the area.

The Quadrant Formation is more resistant to weathering and erosion than the overlying and underlying rocks, and it typically forms ridges. The formation behaved as a competent but brittle unit during deformation, and therefore it formed broad folds and broke along numerous fractures. Many small cross-faults displace the Quadrant but die out in overlying and underlying less competent rock, as is well illustrated south of Johnny Gulch. Some of the faults shown on the map (pl. 1) and other parallel fractures along which displacement was negligible channeled ore-bearing solutions; along or adjacent to many of these fractures lead and silver minerals and gold replaced favorable dolomite beds in the Quadrant Formation.

PHOSPHORIA FORMATION AND RELATED STRATA

The Phosphoria Formation and related strata in the Elkhorn Mountains consist mainly of chert and quartzitic sandstone, but in places includes one or two thin beds of phosphate rock, dark-colored shale or mudstone, and gray carbonate rock. Throughout the area they are poorly exposed and in some places have been mapped with the underlying Quadrant Formation. These rocks and the Quadrant Formation appear to intergrade over a few feet, and alternations of quartzite and dolomite give way upward to interbedded quartzite and chert. The Phospharia and related strata are about 125 feet thick a few miles south of the area (Freeman and others, 1958, p. 500) and about 50 feet thick where thickness could be measured or closely estimated within the mapped area.

One or two beds of phosphate rock and a few beds of quartzite or sandstone containing pellets of phosphatic material crop out locally, but none of the phosphate rock is of minable grade and thickness. Near the top of the Phosphoria, along the east edge of the area; a 4-foot-thick quartzite bed contains fragments and chips of phosphatic material, and a lower bed, as much as 9 inches thick, is phosphate rock. The lower bed is probably the source of a sample reported to contain 25.35 percent tricalcium phosphate (Condit and others, 1928, p. 177–178).

McKelvey and others (1959, pl. 2) have suggested a revised nomenclature for rocks of Phosphoria age in the western phosphate field. According to their usage the Permian rocks of the area, and of the Elkhorn Mountains in general, would be referred to the Shedhorn Sandstone and to the Tosi Chert Member and the Retort Phosphatic Shale Member of the Phosphoria Formation (McKelvey and others, 1959, pl. 3, South Boulder Creek Section and pl. 2, East Madison Section). In the thickest section of phosphatic rocks of Permian age in and near the area (Klepper and others, 1957, p. 22–23), the lower quartzitic part, about 25 feet thick, would correlate with the lower member of the Shedhorn Sandstone of their usage, the overlying 28 feet of chert and phosphate rocks represents the Retort and Tosi Members of the Phosphoria Formation, and the remainder of the formation is the upper member of the Shedhorn Sandstone. In thinner sections consisting almost entirely of quartzite and chert and devoid of phosphate rock, such as the one along Indian Creek, correlation with the formal and informal units proposed by McKelvey and others is uncertain. For this reason and because these rocks constitute at most a single cartographic unit at the scale of the present study, the authors chose to retain the familiar term Phosphoria Formation and related strata.

The Phosphoria Formation is overlain disconformably by the Swift Formation of Late Jurassic age. The disconformity between the Phosphoria and Swift Formations represents all of Triassic time, most of Jurassic time, and perhaps part of Permian time. Regionally, the

Phosphoria Formation and its equivalents thin northward and eastward from southwestern Montana. Northward thinning of all units of Phosphoria age and the absence of phosphate rock or phosphatic mudstone from the middle part of the sequence north of Indian Creek indicate that most of the thinning is due to nondeposition. Locally, however, part of the formation may have been eroded before the Swift Formation was deposited.

MESOZOIC ROCKS

SWIFT FORMATION

The Swift Formation is an inconspicuous 15- to 30-foot-thick unit of brown and brownish-yellow friable calcareous marine sandstone speckled with grains of black chert and limonite. In places, one or more beds near the base are crowded with broken and specifically unidentifiable shells of *Eumicrotis*, *Ostrea*, and *Camptonectes* (R. W. Imlay, oral commun.). A basal conglomerate as much as 3 feet thick, consisting of pebbles and cobbles of chert in a matrix of medium- to coarse-grained sandstone, is present at many localities, and small pebbles are present in some higher beds. Imlay (oral commun.) examined these rocks in the field and referred them to the upper unit of the Swift Formation of the Ellis Group of Late Jurassic age (Imlay and others, 1948, chart). The relatively uniform, though slight, thickness of the formation in and near the area indicates that it was deposited on a nearly flat surface, and the disconformity between it and the underlying Phosphoria Formation represents a long time of nondeposition but probably only slight erosion.

The formation is too thin to be mapped separately and is included with the Morrison Formation on the geologic map.

MORRISON FOMATION

The Morrison Formation, a continental deposit of Late Jurassic age, overlies the Swift Formation with apparent conformity. It consists of varicolored beds of shale, mudstone, siltstone, fine-grained sandstone, and limestone. At most places the formation is 425–550 feet thick, but in a few places, perhaps as a result of deformation, the apparent thickness is as much as 750 feet.

The formation consists predominantly of mudstone and siltstone but includes many thin beds of fine-grained sandstone, shale, and dense limestone, many of which weather yellowish brown or yellowish gray. Red shale and mudstone are relatively abundant in some places, as in the section measured just south of the area (p. 52–53), and are almost absent elsewhere, as in the vicinity of Indian Creek (p. 49–52). The proportions of other rock types also differ from place to place. In some places, the upper 40–100 feet of the formation includes dark-gray shale and one or a few thin lenticular beds of impure lignite overlain by alternating varicolored dominantly argillaceous rocks, and salt-and-pepper sandstone, speckled with dark chert grains, similar to that in the overlying Kootenai Formation. The interbedding of sandstone of Kootenai aspect with argillaceous rock of Morrison aspect suggests that in these places the two formations intergrade. On the other hand, dark-gray shale and salt-and-pepper sandstone were not recognized and are probably absent in other places, which suggests that elsewhere there is a disconformity at the top of the Morrison Formation and that locally as much as 50 feet of beds of the Morrison was eroded before the Kootenai was deposited. The latter interpretation is in harmony with that of Cobban and Reeside (1952, chart), who indicated that rocks of earliest Cretaceous age are probably not present in Montana.

KOOTENAI FOMATION

The Kootenai Formation of Early Cretaceous age, a heterogeneous assemblage of continental rocks, crops out in two north-trending belts, one near the west edge of the southern part of the area and the other near the east edge between Crow Creek and Whitehorse Gulch. The lower part of the formation consists chiefly of coarse- to medium-grained speckled quartz-chert (salt-and-pepper) sandstone. The middle and thickest part consists mainly of red shale and mudstone or claystone and green or greenish-gray siltstone. The upper part is gray limestone interbedded with dark shale and siltstone. The formation is 445 feet thick along the north slope of Johnny Gulch (Klepper and others, 1957, p. 25) and 529 feet thick half a mile south of Indian Creek (p. 53–54). The thickness of the formation seems to be within this range throughout most of the area, but in a few places it may be as great as 700 feet, judging from outcrop width and attitude of bedding.

The base of the formation is marked by fairly resistant crossbedded salt-and-pepper sandstone 15–50 feet thick that contains abundant chert grains and that resembles but is generally thicker than the lenticular sandstones in the upper part of the Morrison Formation. Similar sandstone is interlayered with shale, mudstone, and siltstone throughout the formation, except near the top, but the beds are generally lenticular and thinner, and most are finer grained and contain less chert than those at the base of the formation.

The salt-and-pepper sandstones are gray, medium to coarse grained, and locally conglomeratic and show scour markings and cross-lamination. The sand grains in different beds and in some single beds are angular to rounded and poorly sorted to well sorted. The dark-colored grains are chert; most of the light-colored grains are quartz. Most sandstone beds contain interstitial clay minerals, and some also contain sparse chlorite and sericite that appear to replace clay minerals. Small and discontinuous conglomerate lenses contain pebbles and cobbles of quartzite and chert as much as 3 inches across. A few lenses also contain pebbles and cobbles of limestone. Chert grains form as much as two-thirds of some sandstone beds in the basal part of the formation but are much less abundant in the middle part of the formation and are absent or sparse in the upper part of the formation. Accessory minerals are leucoxene, iron oxides, tourmaline, zircon, and anatase. The grains are cemented by secondary quartz, mostly as enlargements of quartz grains, and by calcite.

The middle part of the formation, generally 350–400 feet thick, consists of varicolored beds of siltstone, argillaceous siltstone,[1] claystone,[1] shale, silty shale, and fine-grained sandstone. Olive gray to greenish gray, grayish red, and grayish purple are the most common colors. Most of the beds are calcareous, and some contain abundant irregular concretions of limestone.

The upper part of the formation, generally about 50 feet thick, is characterized by beds of dark-gray limestone that form low ridges and weather light gray. Some of the limestone beds contain abundant fresh-water fossils, principally gastropods, and some thin beds are composed almost entirely of fossil detritus. Dark claystone and siltstone are interbedded with the limestone, and in places dark-gray or olive argillaceous siltstone overlies the uppermost limestone bed.

T. C. Yen (written commun., 1952) identified the following Prosobanchian gastropods, species that are common in the Kootenai Formation elsewhere, in collections from limestone beds near the top of the formation about one-half of a mile south of Indian Creek: *Lioplacodes* cf. *L. convexiculus* Yen, *Lioplacodes* cf. *L. cretaceus* (Stanton), *Charydrobia* cf. *C. cretaccea* Yen, *?Reesidella* sp. undet.

The lithologies of the Kootenai and Morrison Formations are similar enough that it is difficult to distinguish between them in areas of poor exposure. Placement of the contact between the two formations is particularly difficult where lenticular salt-and-pepper sandstones are present and dark gray shale is absent or inconspicuous in the upper part of the Morrison Formation. In such places the contact was arbitrarily mapped at the bottoom of the first thick salt-and-pepper sandstone beneath predominantly red and green argillaceous rocks and may deviate by 50–100 feet from a consistent stratigraphic position. In most places, however, the lithologic sequence is distinctive and exposures are good enough to permit placement of the contact within 10–20 feet.

[1] Included in the term "mudstone" in the measured section (p. 53–54).

COLORADO FORMATION

The Colorado Formation consisting of marine and nonmarine sandstone, shale, and siliceous mudstone, crops out along the east edge of the mapped area from Crow Creek to Whitehorse Creek and thence discontinuously northward along the range front to Beaver Creek. Another discontinuous belt of outcrop extends from near the southwest corner of the area to the junction of Crow Creek and Muddy Lake Creek. The contact with the underlying Kootenai Formation is probably a minor disconformity, because in some places the basal sandstone of the Colorado Formation rests on limestone whereas in other places as much as 40–50 feet of dark argillaceous rocks lies between the limestone and the sandstone.

The formation has been subdivided into three units (Klepper and others, 1957, p. 26–28), the lower and upper units consisting chiefly of dark shale and the middle unit, chiefly of sandstone and siliceous mudstone. The formation is 1,542–1,639 feet thick near the south margin of the area (p. 54–56), 1,140 feet thick along Indian Creek (p. 56–58), 1,211 feet thick near the Iron Mask mine (p. 58–60), and 858 feet thick about 4 miles north of the area (Smedes, 1968, p. 13). The greater part of the northward decrease in thickness is due to thinning of the lenticular nonmarine sandstones in the middle unit of the formation, but the upper black shale unit also appears to thin northward from about 275 to 66 feet (Smedes, 1966, p. 12). Local inconsistencies in apparent thickness, as for example the great apparent thickness of the lower black shale unit in the vicinity of Slim Sam Gulch, are probably due to unrecognized deformation.

LOWER BLACK SHALE UNIT

The lower black shale unit comprises: (1) quartzitic sandstone and siltstone (bottom), (2) dark-gray to grayish-black shale and a few thin interbeds of siltstone, and (3) dark-gray carbonaceous argillaceous fine-grained sandstone and siltstone. The unit is 328 feet thick at the south edge of the area and 240–255 feet thick in the vicinity of Indian Creek and the Iron Mask mine. Its true thickness is probably within or near these limits throughout; local discrepancies are probably due to unrecognized faults or minor folds. The basal quartzitic sandstone may rest on an erosion surface, but the relief of this surface must have been negligible, for the thickness of the sandstone is relatively constant.

In all well-exposed sections the basal part of the formation is sandstone, a few feet to 20 feet thick, overlain by siltstone and thin interbeds of sandstone and dark shale, aggregating 30–45 feet in thickness. Many bedding surfaces are irregular, are coated by films of dark clay and micaceous minerals, and exhibit ropy markings resembling worm trails. Some beds are laminated and some are cross-laminated. The basal sandstone is fine to medium grained and is in beds as much as 4 feet thick. It typically weathers very pale orange or grayish yellow and crops out as discontinuous low ribs. The siltstone is generally greenish gray or gray, thinly bedded, and argillaceous and carbonaceous. It weathers to blocky or slabby fragments. The sandy and silty rocks grade upward into dark shale.

In thin section the basal sandstone is a clean orthoquartzite, consisting of very fine to medium-sized well-sorted tightly interlocked grains, of which 70–95 percent are quartz, 3–25 percent are chert, and a trace to a few percent are chlorite, muscovite, clay minerals, tourmaline, zircon, and black iron minerals. Original pore space has been filled by quartz, which occurs partly as secondary enlargements of quartz grains and partly as cement unrelated to grains in the plane of the thin section. Original boundaries of a few rounded to subrounded quartz grains can be detected by lines of inclusions. The chert has largely recrystallized to a mosaic of very fine grained quartz. The boundaries of the recrystallized chert grains are serrate.

The basal sandstone and siltstone is overlain by a sequence about 100 feet thick consisting mainly of fissile dark-gray to grayish-black shale and silty shale but containing many thin beds of olive and gray siltstone. Roughly spheroidal calcareous concretions as much as 18 inches in diameter are sporadically present; they weather to a rusty color. The shale breaks down readily to thin chips or flakes that resist decomposition and form very little soil.

Overlying the shale is a sequence consisting mainly of dark fine-grained argillaceous sandstone with interbeds of siltstone and shale. This sequence is about 165 feet thick at the south end of the mapped area and 100–110 feet thick farther north, between Indian Creek and Whitehorse Gulch. The dark color is due to carbonaceous and argillaceous material that comprises 15–25 percent of most of the rocks. The fine-grained sandstone is made up of angular to subrounded grains of quartz and chert in roughly equal amounts, together with lesser amounts of muscovite, biotite, clay, and black opaque minerals. Locally, some of the sandstone beds are speckled with limonite and weather rusty. At a few places north of Crow Creek several thin beds of clean sandstone are exposed. These are composed of medium-grained well-sorted and probably originally rounded grains of quartz and chert that are interlocked by secondary outgrowths on quartz grains.

The basal sandstone and siltstone is probably equivalent to the Fall River Formation of the typical great Plains section (Cobban and Reeside, 1952) and to the Flood Member of the Blackleaf Formation of the Sweetgrass Arch section (Cobban and others, 1959). The overlying black shale yielded fossils determined by Cobban (written commun., 1952) as "*Inoceramus comancheanus* and *I. bellvuensis*, guide fossils to the Skull Creek shale of the Black Hills and the Purgatoire formation of Colorado." The lower part of the dark sandstone above the shale also yielded an *Inoceramus*, probably *I. bellvuensis* at one locality (p. 56, unit 11 of section in sec. 4, T. 4 N., R. 1 W., USGS Mesozoic location 23028) and is accordingly also a probable equivalent of the Skull Creek.

MIDDLE SILICEOUS MUDSTONE AND SANDSTONE UNIT

The middle siliceous mudstone and sandstone unit of the Colorado Formation comprises: (1) fine-grained sandstone, siltstone, and mudstone (bottom), (2) mudstone and siliceous mudstone, and (3) sandstone. The unit is largely nonmarine. It ranges in thickness from 930 feet near the south end of the area to about 600 feet in the vicinity of Indian Creek and the Iron Mask Mine. Four miles north of the area it is 578 feet thick (Smedes, 1966, p. 13). Part of this variation may be due to undetected small faults, but most of it is probably due to original depositional differences and perhaps to intraformational erosion, as suggested by lenticular coarse-grained conglomeratic sandstone beds in the upper part.

The base of the unit has been mapped at the bottom of a distinctive flaggy greenish-gray to medium-light-gray fine-grained sandstone that crops out throughout the area. The top has been mapped at the bottom of a sequence that consists mainly of dark-gray shale.

Except for a relatively clean basal sandstone, the rocks in the lower part of the unit are chiefly thin-bedded olive-gray and gray siltstone and fine-grained sandstone that consist largely of quartz and chert, in proportions that range from 10:1 to 1:1, but also contain a trace to 20 percent of feldspar and 20–30 percent interstitial clay. Secondary chlorite and calcite and very small amounts of mica, opaque iron minerals, and zircon also are present. The relative abundance of fresh feldspar, which was not observed in any of the underlying rocks, and the presence of many shardlike grains of quartz suggest admixture of material from a contemporaneous but probably distant volcanic source. The thickness of this sequence in which sandstone and siltstone predominate ranges from about 400 feet near the south end of the mapped area to about 200 feet in the vicinity of Indian Creek and the Iron Mask Mine.

The overlying sequence, which consists of olive and dark- to light-gray siliceous mudstone interbedded with olive to gray mudstone, siltstone, and subordinate sandstone, ranges in thickness from 200 to 300 feet. The siliceous mudstone, described in detail by Klepper, Weeks, and Ruppel (1957, p. 27–28), is characterized by white, light-gray, and light-greenish-gray colors on weathered surfaces, by blocky, hackly, or splintery fracture, and by abnormal hardness. Subrounded to shardlike silt-sized grains of quartz and feldspar are commonly present in a cryptogranular matrix that may be either devitrified glass (pumiceous dust) or a product of the decomposition of siliceous ash by sea water with penecontemporaneous deposition of the released silica (Rubey, 1929, p. 168–169). The siltstone, sandstone, and nonsiliceous mudstone interbedded with the siliceous mudstone are thin-bedded olive and gray rocks that fracture to splintery or hackly fragments. These rocks are composed of quartz and chert grains and lesser amounts of feldspar, mica, opaque minerals, and fine-grained rock fragments. Clay minerals and locally abundant calcite are the cementing materials. Most grains are angular or shardlike. A large part of the material is probably from a contemporaneous but distant volcanic source.

The upper part of the unit, 165–240 feet thick, consists of sandstone and subordinate siltstone, shale, and conglomerate. The sandstone beds are of two types: light-gray, medium-grained quartz-chert (salt-and-pepper) sandstone and olive-gray, very fine grained to fine-grained thinly laminated sandstone. The salt-and-pepper sandstone commonly contains scattered pebbles of chert and locally contains lenticular beds of chert-pebble conglomerate. Both types of sandstone are composed mainly of angular to subrounded quartz and chert grains and a small amount of interstitial clay minerals, secondary chlorite, and accessory plagioclase, muscovite, opaque iron minerals, zircon, and tourmaline and are locally cemented by calcite and iron oxide. The salt-and-pepper sandstone is similiar to the basal sandstone of the Kootenai Formation, except that it contains grains of fibrous chalcedony. The other sandstones are characterized by small amounts of feldspar and by a dirty appearance due to interstitial clay minerals, chlorite, and calcite cement. Some of the argillaceous sandstones are characterized by undulose beds, ripple marks, and fossil-worm trails. They are probably lagoon deposits.

The lower and middle parts of the middle siliceous mudstone and sandstone unit are correlated with the Mowry Shale of the reference sequence for the Western Interior (Cobban and Reeside, 1952, chart 10b) on the basis of sparse fossils and lithology, particularly the peculiar siliceous mudstones of probable volcanic origin. Rocks 140–145 feet below the top of the measured section along Indian Creek (p. 56) contain fossils indicative of Greenhorn or early Carlile age, and rocks 30–35 feet below the top of the unit (p. 56) contain fossils indicative of middle Carlile age (W. A. Cobban, written commun., Sept. 15, 1958). The lower part of the overlying upper black shale unit in the same section contains fossils indicative of latest Carlile and earliest Niobrara age (W. A. Cobban, written commun., May 31, 1951, and Sept. 15, 1958; J. B. Reeside, Jr., written commun., Oct. 3, 1952).

Lists and age interpretations of fossils collected from measured sections are incorporated in pages 56–58. Information on fossils collected elsewhere in the area are summarized below:

A collection (USGS Mesozoic loc. 23833) from the middle part of the siliceous mudstone and sandstone unit in the center of sec. 27, T. 5 N., R. 1 W., contains *Tempskya grandis* Read and Brown, "a widespread and typical Mowry species" (J. B. Reeside, Jr., written commun., Sept. 24, 1952).

A collection from poorly exposed rocks that are faulted and cut by igneous intrusions in the SE¼NW¼ sec. 35, T. 6 N., R. 1 W., (USGS Mesozoic loc. 23885) contains:

Inoceramus n. sp. aff. *I. fragilis* Hall and Meek
Inoceramus sp. fragments of very large shells
Lucina aff L. *juvenis* Stanton
Collignoniceras woollgari (Mantell) var. *praecox* Hass

Another collection nearby, in the center of the NW ¼ sec. 35, (USGS Mesozoic loc. 23884) contains:

Lucina juvenis Stanton
Pseudomelania? sp.
Haminea? sp.
Collignoniceras sp., fragments

These collections indicate equivalence to the lower part of the Carlile Shale (J. B. Reeside, Jr., written commun., Sept. 24, 1952). Accordingly, the rocks are probably equivalent to rocks in unit 24 of the Indian Creek section (p. 57).

UPPER BLACK SHALE UNIT

The upper black shale unit consists of dark-gray to black fissile shale and, particularly in the lower part, thin interbeds of very fine grained sandstone and siltstone. Spheroidal, brown-weathering limestone concretions 8–12 inches in diameter are locally abundant in the shale, and thin layers rich in feldspar crystals are interbedded in the uppermost part. In small isolated exposures, it is difficult or impossible to distinguish between the black shales of the lower and upper units.

Thin beds of very fine grained sandstone and siltstone comprise most of the lower 50 feet of the unit and 5–10 percent of the rest. These beds consist of tightly packed angular grains of chert and quartz in a proportion of about 3:1; the matrix is commonly argillaceous. Accessory minerals include plagioclase, muscovite, biotite, tourmaline, and secondary calcite.

The unit is about 280 feet thick in the vicinity of Indian Creek and the Iron Mask Mine (pl. 1) and may be thicker at the south end of the mapped area, though the apparent thickness of 381 feet there (p. 55) may be greater than the true thickness due to repetition of beds by unrecognized strike faults similar to those mapped in secs. 19, 30, and 31, T. 9 N., R. 1 E. Four miles north of the area the unit is only 66 feet thick (Smedes, 1966, p. 13).

The upper black shale unit contains a fauna similar to that of the lower two faunal zones of the Niobrara Formation of the reference sequence for the Western Interior (Cobban and Reeside, 1952). Lists and age assignments of fossils collected from a well-exposed section along the Indian Creek road and from a section near the south boundary of the area are included among the measured sections (p. 54–58). In the Colorado Shale of north-central Montana and in the Cody Shale of Wyoming, about four more Niobrara faunal zones are known above the zone of *Scaphites ventricosis* (W. A. Cobban, written commun.), the highest zone recognized in the east flank area.

SLIM SAM FORMATION

The Colorado Formation grades upward into a sequence that consists mainly of sandstone in the lower part and of tuff in the upper part. The name Slim Sam Formation was assigned to these rocks by Klepper, Weeks, and Ruppel (1957, p. 28–31), and the type locality was designated along the east margin of the Slim Sam Basin, in the area of the present report. The formation crops out along the eastern front of the Elkhorn Mountains from Staubach Creek southward to Crow Creek (pl. 1) and along the west edge of the area from Eureka Creek southward to the Slim Sam Basin. Farther south it has been faulted and disrupted by large intrusive masses and is present only discontinuously.

The lower part of the formation, 250–450 feet thick, is chiefly gray, greenish-gray, and yellowish-gray thin-bedded to medium-bedded sandstone, largely or wholly of nearshore marine origin. Most beds consist mainly of quartz and chert grains and contain some argillaceous matrix; a few beds contain a little feldspar and mica. Partings and thin beds of dark shale, some containing layers rich in feldspar crystals, and a few beds of volcanic sandstone also are present. The volcanic sandstone contains subrounded to angular and shardlike grains of quartz, crystals of plagioclase, flakes of fresh biotite and of an altered mica, and small fragments of microcrystalline volcanic rock; in some beds calcite cement is moderately abundant. Most of the material in the volcanic sandstone is probably slightly reworked debris of contemporaneous ash falls from a nearby source. The subrounded quartz grains are probably nonvolcanic. In general, quartz decreases and plagioclase increases in abundance from the bottom to the top of this part of the formation.

At many places, and perhaps generally, one or a few beds of sandstone consisting largely or entirely of detrital titaniferous magnetite are present in a gradational zone between rocks with sparse volcanic material below and rocks with abundant volcanic material above. The magnetite-rich rocks probably accumulate as placers along beaches of a receding sea.

The upper part of the formation, 400–700 feet thick in most places but perhaps as much as 1,000 feet thick locally, consists mainly of crystal tuff, crystal-lithic tuff, and volcanic sandstone but contains beds of lapilli-tuff, sandstone, mudstone, and siliceous mudstone. The tuff and lapilli-tuff consist of angular grains of plagioclase and small fragments of fine-grained volcanic rock and less abundant grains of quartz, mica, hornblende, and opaque minerals in a matrix of indeterminate microcrystalline material, possibly devitrified glass, that is partly altered to chlorite and sercite. The sandstones are similar to the same rock types in the lower part of the formation. The mudstone is olive and dark gray; most beds contain abundant sand-sized grains, and many are hard and siliceous and break to hacky fragments. In general, bedding is less distinct and beds are considerably thicker in the upper part of the formation than in the lower part. Some beds are cross-laminated.

The few fossils collected from the lower part of the formation indicate that it is of Colorado age and mainly if not entirely of marine origin. *Scaphites* cf. *S. ventricosus* Meek and Hayden, common in the Niobrara Formation, and probably of the faunal zone next above the basal zone of the formation (W. A. Cobban, written commun., 1952), was collected from alternating black shale and flaggy sandstone beds in the basal 50 feet of the formation on the east side of Eureka Creek, about one half of a mile west of the mapped area (SW¼ SW¼ sec. 20, T. 7 N., R. 1 W.). "*Mactra*" *arenaria* Meek, "a pelecypod not known from rocks as young as the Montana group" (W. A. Cobban, written commun., 1952) was collected from beds near the top of the dominantly nonvolcanic lower part of the formation, 300 and 375 feet above the base in NE¼ sec. 4, T. 4, N., R. 1 W., and from about 200 feet above the base of the formation south of Kimber Gulch.

The upper part of the formation contains carbonized wood in many places and a silicified tree stump, apparently in place, at one locality, but no identifiable fossils were found. Consequently, its age has not been fixed as closely as the age of the lower part. It could be of late Niobrara, Telegraph Creek, or early Eagle age of the reference sequence for the Western Interior (Cobban and Reeside, 1962, pl. 10b), but it is no younger, for the overlying Elkhorn Mountains Volcanics are older than rocks of early Claggett age (equivalent to lower part of Pierre Shale of the reference sequence), as discussed elsewhere in this report.

The titaniferous magnetite zone in rocks transitional from the lower to the upper parts of the formation is believed to have accumulated as placer deposits along beaches as the sea retreated eastward. A similar but thicker and more persistent zone of titaniferous magnetite farther north in Montana is at the top of the Virgelle Member of the Eagle Sandstone (W. A. Cobban, oral commun.) which Stebinger (1915, p. 62–63) considered to be a sandy beach or nearshore deposit laid down in a retreating sea. Though the magnetite-bearing rocks in these two areas are mineralogically similar and accumulated under similar conditions, they are not necessarily contemporaneous. The gradational relation between the lower and upper parts of the Slim Sam Formation in the present area suggests uninterrupted deposition of fossiliferous marine rocks, not more than 50 feet below the magnetite zone, and the magnetite-rich rocks. If this is true, the upper part of the Slim Sam Formation is more likely to be of late Niobrara and Telegraph Creek age than of early Eagle age. On the other hand, at a few places within the area the lower part of the Slim Sam is abnormally thin, and some of it may have been removed by erosion before the upper part was deposited. A few miles north of the area the upper part of the Slim Sam is unconformable on rocks of the lower part and is overlain with angular unconformity by the Elkhorn Mountains Volcanics (Smedes, 1966, p. 16, 21 112). The magnetite zone has not been recognized here. Whether its absence is due to nondeposition or erosion is not known. Though these relations suggest a significant time lapse between the lower and upper parts of the Slim Sam Formation, they seem to indicate a more significant lapse between the Slim Sam and the Elkhorn Mountains Volcanics. Accordingly, the earlier tentative correlation of the upper part of the Slim Sam Formation with the Telegraph Creek Formation of the reference sequence for the Western Interior (Klepper and others, 1957, p. 26) is strengthened.

At some places in and around the Elkhorn Mountains, including most of the east flank, the Slim Sam Formation appears to grade upward into the Elkhorn Mountains Volcanics. But in other places nearby, the Elkhorn Mountains Volcanics rest with angular discordance on Slim Sam and older rocks (Klepper and others, 1957, pl. 1, south-central part; Freeman and others, 1958 pl. 42, northwest part T. 4 N., R. 1 W.; Smedes, 1966, p. 21). In these places Slim Sam and older rocks were folded and eroded before the Elkhorn Mountains Volcanics were extruded. The evidence is compelling that folding affected some parts of the area east of the Boulder batholith after the Slim Sam Formation was deposited and before the Elkhorn Mountains Volcanics were extruded, and a few miles north of the east flank area weak folding concurrent with deposition of the Slim Sam Formation is inferred (Smedes, 1966, p. 21). In the area of the present report, however, the general apparent conformity within the Slim Sam Formation and between the Slim Sam Formation and the Elkhorn Mountains Volcanics indicates little prevolcanic deformation.

TERTIARY ROCKS

Tertiary sedimentary rocks include two units of waterlaid tuff and one of calcareous tufa. The tuffs are part of the basin fill in the Townsend Valley; one is of Oligocene age and one, of uncertain age, and both are small parts of more extensive units discussed by Pardee (1925), Mertie, Fischer, and Hobbs (1951), Lorenz and McMurtrey (1956), Freeman, Ruppel, and Klepper (1958), Nelson (1963), Kinoshita, Davis, Smedes, and Nelson (1964), Robinson (1967), and White (1954).

OLIGOCENE SEDIMENTARY TUFF

Gently warped beds of sedimentary tuff are poorly exposed south of the Limestone Hills and along Johnny Gulch. They overlie the pre-Tertiary rocks with marked angular unconformity and are overlain by several units of Quaternary and perhaps late Tertiary age. Beneath the mantle of younger deposits the unit is probably continuous with the Oligocene sedimentary tuff that crops out to the east and south (Freeman and others, 1958; Dunbar Creek Formation in Robinson, 1963, 1967) and is also considered equivalent to the Tertiary unit 2 described by Mertie, Fischer, and Hobbs (1951) in the north end of the Townsend Valley.

The sedimentary tuff includes beds of shale, mudstone, sandstone, and small lenses of poorly cemented conglomerate and conglomeratic sandstone that contain angular to subrounded fragments as much as 10 inches long of pre-Tertiary rocks. Bedding ranges from thin and distinct to very thick and indistinct. The rocks are soft, porous, typically cream and buff colored, slightly consolidated, poorly sorted, and contain granules of older rocks, angular grains of feldspar and quartz, and glass shards in a light-yellowish-gray matrix of calcite and bentonitic clay. The content of volcanic material in different beds ranges from nearly 0 to 100 percent and typically is more than half. Some beds are composed largely of bentonite; grayish-brown compact fine-grained rocks when fresh, they swell and become porous and cream colored on weathering. The lenses of conglomerate and conglomeratic sandstone typically contain little or no megascopically identifiable volcanic material.

The greatest exposed thickness of Oliogocene sedimentary tuff in the mapped area is about 150 feet, but the thickness probably ranges from 0 to as much as 300 feet. The rocks thicken southward possibly to about 1,000 feet (Freeman and others, 1958, p. 508) and to the east where Robinson (1967) found the Dunbar Creek Formation to be as much as 1,600 feet thick.

Vertebrate fossils of early Oligocene age from the sedimentary tuff at four localities in and adjacent to the mapped area were identified by the late M. Jean Hough (written commun., Oct. 25, 1950, and Dec. 5, 1952) as follows (see also Freeman and others, 1958, p. 509, 510):

NW¼SE¼ sec. 18, T. 5 N., R. 1 E.
- *Mesohippus hypostylus* Osborn
- *Leptomeryx esulcatus* Cope
- *Peltosaurus*? sp.

NW¼SW¼ sec. 19, T. 5 N., R. 1 E.
- *Titanotheriomys* sp.
- *Palaeolagus* sp.
- *Bathygenys* sp.

S½ sec. 2, T. 4 N., R. 1 W.
- *Brontotherium* sp.
- *Titanotheriomys* cf. *T. veterior* (Matthew)
- *Palaeolagus* cf. *P. brachydon* Matthew
- *Hyracodon* sp.

NE¼NW¼ sec. 20, T. 4 N., R. 1 W.
- *Cylindrodon* cf. *C. fontis* Douglass
- *Leptomeryx esulcatus* Cope

Lithology and bedding suggest that some of the Oligocene sedimentary tuff was formed partly of airborne pyroclastic debris that was deposited directly in a body of standing water and partly of mixed volcanic and nonvolcanic material washed from the surrounding hills. A small part of the unit seems to have been deposited in a fluviatile environment, perhaps as a delta.

SEDIMENTARY TUFF OF UNCERTAIN AGE

In the northeast corner of the mapped area, poorly exposed rocks resembling the Oligocene sedimentary tuff have been mapped separately. The rocks include pale-orange to yellowish-gray silty tuff, some of which is bentonized, gray and white calcareous volcanic siltstone, and deeply weathered conglomerate. Bedding is obscure and poorly exposed, but in a few places the beds seem to be horizontal or to dip gently eastward. The thickness of the unit is unknown.

Mertie, Fischer, and Hobbs (1951, p. 31) suggested that these rocks are probably a part of the Oligocene sequence. Freeman, Ruppel, and Klepper (1958, p. 512) favored the interpretation that they are younger and rest unconformably upon the Oligocene rocks.

OLIGOCENE TUFA

Calcareous tufa and banded travertine, probably ancient spring deposits, are exposed along Johnny Gulch near the west edge of the mapped area and in an unnamed tributary south of Johnny Gulch. The larger exposure, in Johnny Gulch, is about 2,500 feet long, 500 feet wide, and 200 feet thick. Most of the rock is very pale yellowish brown, gray-weathering, finely crystalline, porous calcareous tufa; the rest is hard compact travertine. Fibrous, laminated, and twiglike structures are present locally.

The tufa contains leaf imprints or molds from which the late R. W. Brown (written commun.) identified *Sequoia affinis* Lesquereaux and *Alnus* or *Betula* sp. indicative of Oligocene age. Relative ages of the Oligocene tufa and the Oligocene sedimentary tuff are indeterminate.

UNCONSOLIDATED TERTIARY AND QUATERNARY DEPOSITS

FAN DEPOSITS AND MANTLE

A poorly exposed group of surficial deposits of diverse origin were mapped as fan deposits and mantle. Gravel that was deposited in alluvial fans along the east flank of the Elkhorn Mountains, especially north of Indian Creek, comprises most of the unit; the rest consists of pediment gravel, eolian silt, poorly sorted hillwash, and local deposits of alluvial gravel and finer debris. Pediment gravel and eolian silt, the "mantle" of Freeman, Ruppel, and Klepper (1958), form a veneer on the Oligocene sedimentary tuff and older rocks south of Crow Creek. Deposits of hillwash and alluvium are scattered throughout the area.

The unit includes deposits that range in age from Pliocene (?) to Holocene. The pediment gravel was deposited during the Pliocene Old Valley cycle of Pardee (1950), and the oldest fan gravel may be as old.

The youngest parts of the fans as well as the hillwash and alluvium are Holocene.

The fan deposits and mantle are composed of gravel with a sand and clay matrix. The gravel is entirely of local origin, and its composition reflects the bedrock exposed at higher altitudes nearby. The source of the eolian silt is unknown, but its distribution, centered on a broad divide between the Townsend and Three Forks valleys, offers a clue. Robinson (1963, p. 85–86) suggested that the silt was removed from Oligocene sedimentary tuffs by northerly winds and was deposited where the sweep of the wind was obstructed.

GRAVEL DEPOSITS OF UNCERTAIN AGE

Gravel deposits of uncertain but probable late Pliocene or early Pleistocene age and origin were mapped in a few places. A veneer of gravel covers three small areas near the front of the range east of Sheps Gulch. The gravel is of local origin and probably is contemporaneous with the gravel that forms the apron along the mountain front. An elongate body of very coarse debris east of the mouth of Cold Springs Gulch is composed of cobbles, boulders, and a few blocks, as much as 15 feet across, of Quadrant quartzite and Madison limestone derived from the Limestone Hills to the east. The debris appears to fill a channel and is older than gravel referred to older outwash fan deposits. A train of coarse locally derived debris in an unnamed tributary of Johnny Gulch south of the Keating Gulch stock appears to grade into and be of the same age as the older outwash fan deposit in Johnny Gulch.

QUATERNARY DEPOSITS

Surficial deposits of Pleistocene age are widespread along the east flank of the Elkhorn Mountains. They include glacial deposits and related outwash fans, deposits formed by mass wasting, and alluvial deposits.

GLACIATION AND GLACIAL DEPOSITS

Glaciers accumulated on the high main mass of the Elkhorn Mountains, west of the mapped area, at least three times during the Pleistocene (Klepper and others, 1957, p. 43; Ruppel, 1962, p. 12), and at least twice the glacial ice was so extensive that it spread into canyons in the east flank area. The earliest glaciation in the range, probably early Pleistocene, seems also to have been the most extensive, for its poorly preserved moraine deposits are present near the mouth of Beaver Creek at altitudes of about 5,000 feet and in Crow Creek at altitudes of about 5,700 feet. The most striking deposit of this early glaciation is the large older outwash fan of Beaver Creek near Winston. The older moraines and the older outwash fans are similar in composition; both are characterized by deep weathering that destroyed nearly all but the most resistant volcanic rocks. The moraines at the mouth of Beaver Creek consist of subrounded to subangular resistant fragments of volcanic and intrusive rocks as much as 18 inches across in a closely packed heterogeneous matrix. A few exceptionally large blocks are preserved; one on a hill north of Beaver Creek is 30 feet on a side. Some of the larger blocks have polished faces and are faintly grooved and striated. The deposits in Crow Creek are generally similar to those in Beaver Creek but are obscured by vegetation and soil. They are composed of cobbles and boulders of Elkhorn Mountains Volcanics and related intrusive rocks in a matrix of sand and pebbles and have no apparent sorting or stratification. In a few places, the boulders are as much as 25 feet long, and many are distinctly blocky or angular. On the hill north of the Vosburg mine (sec. 34, T. 8 N., R. 1 W., pl. 1), a small deposit of large boulders, some of which are deeply disintegrated and one of which is striated, is believed to have been deposited during this older period of glaciation.

The large older outwash fan forming the prominent hills east and west of Winston and extending eastward (Freeman and others, 1958, p. 513–514) beyond the mapped area is made up of coarse bouldery and cobbly debris of volcanic and dioritic intrusive rocks from the Beaver Creek drainage. The debris is unusually coarse and contains relatively abundant subangular pieces, some several feet across. Though most of the debris is of little-weathered resistant rocks, other pieces are deeply weathered. This deep weathering, the advanced dissection and the destruction of the surface form of the fan and of related moraines, and the overlapping by younger fan deposits strongly support an early Pleistocene age for these deposits.

Coarse gravel of the older outwash fan flanks the valley of Crow Creek from Radersburg almost to Power Gulch and extends up Cold Spring Gulch to Indian Creek. The gravel consists of slightly weathered cobbles and boulders, mostly subrounded to rounded and less than a foot across, of resistant fine-grained volcanic rocks and dioritic intrusive rocks. South of Crow Creek the gravel is more than 200 feet thick in many places, but north of Crow Creek it is probably much thinner, or only a veneer. The deposit is thought to be a remnant of a large composite outwash fan built by Crow Creek and Indian Creek during the early period of glaciation and is probably of about the same age as the old fan at the mouth of Beaver Creek. The saddle at the head of Cold Spring Gulch clearly was a spillway for melt water from Indian Creek. The Indian Creek outwash fan was built southward during the early period of glaciation to coalesce with the outwash fan being built in Crow

Creek, and thus there is no old fan at the present mouth of Indian Creek comparable to those at the mouths of Beaver Creek and Crow Creek. The present canyon of Indian Creek, below Hassel and the Cold Spring Gulch spillway, probably was cut in later Pleistocene time by a headward eroding stream that pirated the ancestral Indian Creek.

Relatively thick, coarse older outwash gravel deposits, composed mainly of sedimentary rocks from the middle and upper reaches of Johnny Gulch, are preserved along the lower reaches of Johnny Gulch. Though the head of Johnny Gulch was not occupied by glaciers, the coarse gravel probably was deposited during a period of greatly accelerated erosion that coincided with the early Pleistocene glaciation. Thus, the gravel on Johnny Gulch is probably a correlative of the old Beaver Creek and Crow Creek-Indian Creek fans. The fan-shaped part of the deposit has been much dissected, and it grades imperceptibly into gravelly mantle that may include old pediment veneer as well as material that was redistributed as the fan was dissected.

The deposits of the two late Pleistocene (Wisconsin?) glacial episodes have not been mapped separately, although both episodes must be represented in the extensive younger outwash fan deposits and in the few morainic deposits. All the deposits are characterized by fresh rock fragments and by fairly well preserved surface form.

The best preserved moraine is near the junction of the South Fork, Badger Creek, and Beaver Creek, where a terminal moraine marks the maximum advance of the last valley glaciers to occupy these valleys; this last advance was probably in late Wisconsin time, for the moraine is not dissected and it contains little-weathered boulders as much as 15 feet across. Other boulder deposits that may be partly destroyed moraines are preserved in Weasel Creek.

Younger outwash fans similar in rock content and degree of preservation to the late Pleistocene moraines in the Elkhorn Mountains (Klepper and others, 1957, p. 43; Ruppel, 1962, p. 12) are much more widespread in the mapped area than deposits of till. Before these fans were deposited, the older outwash fans were partly eroded. The younger fans occupy about the same sites as the older fans, but they were graded to a lower level; their tops are 200–300 feet below adjacent remnants of older fans.

The younger Beaver Creek fan consists of unweathered cobbles and boulders of volcanic rocks and dioritic intrusive rocks, mostly subrounded or rounded. The south edge of the fan distinctly overlaps the upper part of the mountain front gravel apron, but it grades into the lower part of this apron east of the mapped area. To the north of Beaver Creek, fans at the mouths of Staubach, Pole, and Antelope Creeks were deposited at about the same time. Beaver Creek is now entrenched into its fan. At the head of the fan the trench is 40–50 feet deep, about 200 feet wide, and is mostly cut in bedrock. Downstream the trench is progressively broader and shallower and is wholly in gravel. East of U.S. Highway 287 the fan is not trenched and is probably still accumulating.

The younger Crow Creek fan differs from the younger Beaver Creek fan in that it has not been incised by the creek but is still being constructed. It consists largely of rounded or subrounded boulders and cobbles of volcanic rocks and dioritic intrusive rocks but also includes quartzite and other rocks from resistant Paleozoic and Mesozoic sedimentary formations.

Terrace deposits related to the glacial deposits of late Pleistocene age are present at several places along Beaver and Crow Creeks as gravel veneers on rock benches (Klepper, and others, 1957, p. 62). The benches were probably cut and veneered with gravel during the maximum outwash phase of the last glacial period. The deposits consist of coarse rounded gravel containing boulders several feet long. The surface of the gravel deposits slope at about the same angle as the modern streams, which are entrenched from 20 feet to as much as 75 feet below them, and they appear to be graded to the surface of the younger fan deposits.

DEPOSITS RESULTING FROM MASS WASTING

Surficial deposits resulting from mass wasting include debris originally deposited by glaciers, by streams as alluvial fans, and by weathering of the bedrock. These deposits have been so modified by postglacial mass-wasting processes, probably mainly soil creep, solifluction, and frost action, that near-surface features attributable to the original depositional process have been largely destroyed. Accumulations of rock waste in clearly recognizable landslide deposits were mapped separately from the other mass-waste deposits.

ALLUVIUM

Deposits mapped as alluvium include gravel, sand, and silt accumulating in the valleys of the present streams, and similar deposits in small fans now forming or recently formed at the mouths of many gulches. Many other such deposits are present but are too small to be shown.

IGNEOUS ROCKS

Extrusive and intrusive igneous rocks are abundant along the east flank of the Elkhorn Mountains. Extrusive rocks of the Elkhorn Mountains Volcanics of Late Cretaceous age cover about one-half of the area, and remnants of much younger, probably middle to late Tertiary, basalt and rhyolite flows crop out in the central part. The many bodies of intrusive rocks fall into two main groups: (1) intrusive equivalents of Elkhorn Mountains Volcanics, for convenience called volcanic intrusives, and (2) intrusives younger than Elkhorn Mountains Volcanics. The volcanic intrusives comprise mainly seriate syenodiorite or granodiorite porphyry in larger partly concordant bodies and hiatal rhyodacite and trachyandesite porphyry in smaller sills and dikes that were emplaced before folding or during the earliest stages of folding.

The nomenclature used in this report for igneous rocks that are coarse grained enough for thin-section modes to be determined is shown in figure 2. Finer grained volcanic rocks for which modes cannot be determined are classified on the basis of chemical composition of representative samples, in accordance with the system proposed by Rittman (1952). Though the term "andesite" was applied to many rocks in the field, none of the analyzed rocks are andesite in the Rittman classification. The terminology applied to fragmental volcanic rocks is that of Wentworth and Williams (1932, p. 43–53). The term "porphyry" is used for rocks of both hiatal and seriate texture if a substantial part of the groundmass is too fine grained to be identified by conventional microscopic methods. Medium- and coarse-grained rocks with conspicuous phenocrysts are referred to as porphyritic. The term "phenocryst" is used without genetic connotation for crystals that stand out from a finer grained goundmass.

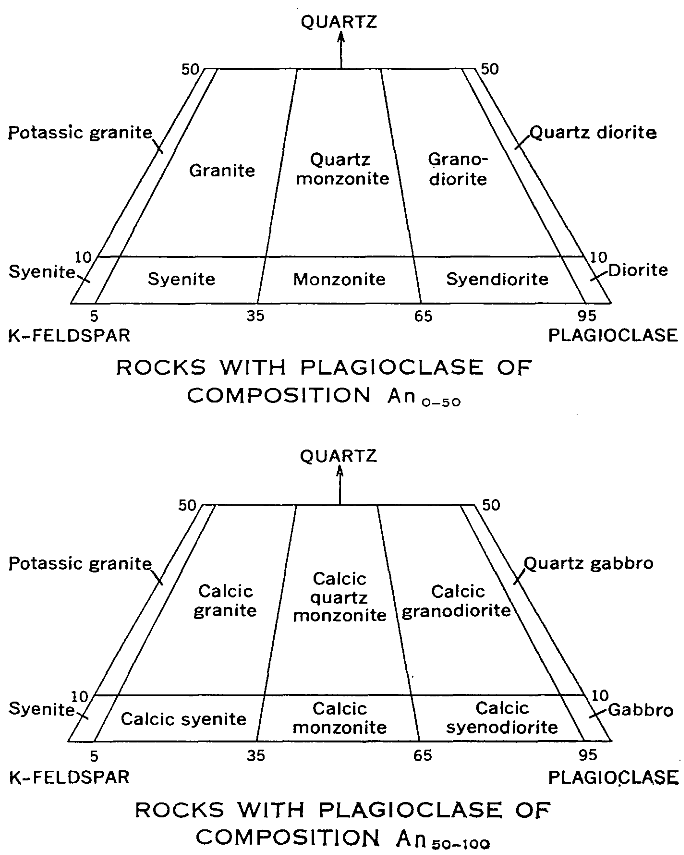

FIGURE 2.—Nomenclature of coarser grained intrusive igneous rocks.

The younger intrusive rocks form generally discordant stocks, plugs, or bodies of unknown subsurface configuration that were emplaced after the enclosing rocks had been folded. Most of the bodies consist of medium-grained and subequigranular rocks, but a few are made up of porphyry. Compositionally, the rocks can be conveniently assigned to one of two groups: (1) mafic rocks and (2) intermediate to felsic rocks. Some bodies are simple and comprise only one rock type; some are composite and consist of one or more mafic and felsic types. Lead-alpha age determinations of zircon from two post-volcanic intrusives are 72–76 million years (Jaffe and others, 1959, p. 80–81), determinations indicating Late Cretaceous age according to the time scale of Holmes (1959); these age determinations are in the same age range as rocks of the Boulder batholith 10–20 miles to the west.

Four thin dikes of quartz latite porphyry probably are equivalent to the Lowland Creek Volcanics of Eocene age (Smedes, 1962) nearby.

ELKHORN MOUNTAINS VOLCANICS

The Elkhorn Mountains Volcanics of Late Cretaceous age (Klepper and others, 1957, p. 31–41), comprise three members in the type locality: a lower member consisting mainly of rhyodacitic and trachyandesitic pyroclastic rocks, a middle member characterized by rhyolitic welded tuffs alternating with andesitic and rhyodacitic tuff and tuff breccia, and an upper member composed mainly of airlaid tuff and of waterlaid tuff and conglomerate that are largely debris eroded from the lower members. Only the lower and middle members are present along the east flank of the Elkhorn Mountains.

Rocks of the lower member underlie most of the eastern slope of the Elkhorn Mountains in the northern part of the mapped area and much of the mountainous central part. Farther south, they form part of the roof of the Rattlesnake intrusive body. Cenozoic sediments in the southeastern part of the mapped area are probably underlain at shallow depth by rocks of the lower member. The lower part of the middle member occupies much of the northwestern part of the mapped area, but south of Indian Creek it is present only in a small fault block in sec. 2, T. 6 N., R. 1 W. Rocks of the upper part of the middle member and the upper member are not present probably due to erosion rather than to nondeposition.

North of Johnny Gulch the Slim Sam Formation grades upward into the Elkhorn Mountains Volcanics. South of Johnny Gulch, however, the volcanics truncate Slim Sam and older rocks that had been tilted or gently folded at the beginning of the volcanic episode (Freeman and others, 1958, pl. 42). The volcanics are unconformably overlain by Oligocene and younger rocks and by unconsolidated sediments.

The volcanic pile is cut by several large irregular intrusive masses that are broadly concordant with but that locally sharply crosscut the enclosing rocks and by many dikes and sills; most, if not all, of these rocks are of about the same composition and age as the Elkhorn Mountains Volcanics and are products of the same magma or magmas that yielded the volcanic rocks. The Rattlesnake mass, south of Crow Creek, is the largest of these.

LOWER MEMBER

The lower member of the Elkhorn Mountains Volcanics ranges in thickness from 2,500 to 5,000 feet and consists mainly of tuff, tuff breccia, and breccia interlayered with a few lava flows and a few thin units of welded tuff. These rocks are mostly dark gray, greenish gray, and grayish green, but shades of brown, red, and purple are common. Chemical analyses of three composite samples indicate that the average composition of the lower member (table 1, samples 1–3) is in the trachyandesite-rhyodacite range.

Tuffs form massive unstratified units that probably accumulated from air falls of ash and stratified units of which at least some were deposited in water. Crystal tuffs and crystal-lithic tuffs are the dominant rock types; by an increase in abundance and size of lithic fragments these rocks grade into tuff breccias and breccias, which are very poorly sorted and commonly exhibit complete size gradation from the largest lithic fragments to cryptocrystalline matrix. Most of the finer grained tuff is well bedded and delicately laminated and is locally crossbedded, channeled, and mud cracked; these features indicate that the ash was deposited in shallow water. Thick, poorly bedded units of breccia and tuff breccia are probably mud flows. The fact that most of the crystal and lithic fragments are angular, even in the well-bedded rocks, indicates a minimum of transport and reworking.

Fragments of intermediate plagioclase and of volcanic rocks are by far the predominant clastic components. The plagioclase is complexly twinned, commonly shows progressive and oscillatory zoning, and ranges in composition from An_{40} to An_{65}. Other crystal fragments include quartz, magnetite, pyroxene, and hornblende (partly or completely replaced by aggregates of chlorite, epiodote, magnetite, quartz, and leucoxene), sparse biotite (partly altered to chlorite and sphene), and rare K-feldspar. Most rock fragments are trachytic, pilotaxitic, or cryptofelsic trachyandesite and rhyodacite; some are amygdaloidal basalt and brown devitrified glass. Fragments of prevolcanic sedimentary rocks are extremely rare.

Because of greater permeability the pyroclastic rocks are more altered than the associated flows, dikes, and sills. Hornblende and pyroxene are completely replaced, and plagioclase is saussuritized in many of these rocks. Calcite and epidote are common in veinlets and irregular replacement masses.

The lava flows in the lower member, as much as 100 feet thick, consist of trachyandesite and amygdaloidal basalt. The flows are mineralogically and texturally closely similar to the related dikes and sills but are generally more altered.

Thin units of welded tuff are interlayered with the pyroclastic rocks of the lower member. The welded tuff is gray to greenish gray and contains abundant flattened and bent pieces of dark chloritic devitrified pumice as much as an inch long, angular rock fragments, and broken crystals of labradorite surrounded by microcrystalline intergrowths of quartz, feldspars biotite, chlorite, sericite, magnetite, and indeterminate material. Mafic minerals are completely replaced by chlorite, calcite, epidote, and magnetite. Chemical analysis indicates that a representative sample (table 1, sample 4) is quartz latite.

MIDDLE MEMBER

The middle member of the Elkhorn Mountains Volcanics consists of rhyolitic welded tuff interlayered with crystal tuff and lapilli tuff and less abundant volcanic breccia. The fragmental rocks are similar to those in the lower member. A measured section of the lower 2,500 feet of the middle member is given on pages 60–62. The total exposed thickness is about 3,000 feet. Farther west, the middle member is as much as 7,500 feet thick (Smedes, 1966, p. 26).

Welded tuff units range in thickness from a few feet to about 200 feet, but most are between 20 and 60 feet thick. They range in color from light to dark shades of gray, greenish gray, red, and purple. Only a few thin dark-greenish-gray units resemble the quartz latite welded tuff of the lower member. Some of the units appear nearly homogeneous and apparently are welded from bottom to preserved top; others consist of a strongly welded base that grades upward into a poorly welded or unwelded zone. Most of the welded rocks contain abundant flattened fragments of devitrified

TABLE 1.—*Chemical analyses, norms, and modes of igneous*

Sample No.	Field No.	Laboratory No.	Rock type [1]	Geologic occurrence	Location
			Elkhorn Mountains Volcanics		
1	52W142	53-81CW [3]	Trachyandesite	Middle part of lower member (composite of chips).	NE¼ sec. 25, T. 7 N., R. 1 W.
2	52W143	53-82SCW	Labradorite trachyandesite	Lower member (composite of chips from basal 1,000 ft).	Iron Mask mine crosscut, sec. 30, T. 7 N., R. 1 E.
3	52K1	53-71CW	Labradorite rhyodacite	Lower member (composite of chips across 1,200 ft).	SE¼ sec. 16, and NE¼ sec. 21, T. 8 N., R. 1 W.
4	52R65	53-77CW [3]	Quartz latite	Welded tuff, lower member	NE¼ sec. 19, T. 7 N., R. 1 E.
5	52K7	53-72CW [4]	Rhyolite	Welded tuff, middle member	NE¼SW¼, sec. 16, T. 8 N., R. 1 W.
			Intrusive rocks related to Elkhorn Mountains Volcanics		
6	52R66	53-78SCW [3]	Syenodiorite porphyry	Small stock in lower member of Elkhorn Mountains Volcanics.	NW¼ sec. 19, T. 7 N., R. 1 E.
7	61K659	158775 [5]	Calcic granodiorite	Thick sill east of Santa Anita mine	NE¼ sec. 4, T. 4 N., R. 1 W.
8	52K127	53-736W [3]	Calcic syenodiorite	Sill in middle member of Elkhorn Mountains Volcanics.	NE¼NW¼ sec. 9, T. 8 N., R. 1 W.
9	Winchell No. 1	None given [7]	Andesite (Winchell's (1914) usage).	Rattlesnake mass	Rena mine, sec. 7, T. 5 N., R. 1 E.
10	49K13	51-939CW [9]	Syenodiorite	Dutchman intrusive, southeastern lobe of body.	NE¼ sec. 32, T. 5 N., R. 1 W.
11	51K15	53-69SCW [3]	Syenodiorite porphyry	Small intrusive in lower member of Elkhorn Mountains Volcanics.	NW¼NW¼, sec. 30, T. 7 N., R. 1 E.
12	49K12	51-938CW [9]	Syenodiorite	Dutchman intrusive 600 ft northwest of sample 14 locality.	NE¼ sec, 32, T. 5 N., R. 1 W.
13	52R6	53-76SCW [3]	Syenodiorite porphyry	Stock near Iron Mask mine	Sec. 19 T. 3 N., R. 1 W.
14	49K14	51-941CW [9]	Granodiorite	Dutchman intrusive, central part	Boundary between secs. 29 and 32, T. 5 N., R. 1 W.
			Younger intrusive rocks		
15	49K9	51-931CW [9]	Granodiorite	Keating Gulch stock	NE¼ sec. 16, T. 5 N., R. 1 W.
16	60S599	G-3167 [9]	Syenogabbro	Orphan Boy mafic dike	NE¼NE¼ sec. 4, T. 8 N., R. 1 W.
17	49K10	51-936CW [9]	Syenodiorite	Keating Gulch stock	SE¼ sec. 9, T. 5 N., R. 1 W.
18	49K11	51-937CW [9]	Granodiorite	Slim Sam stock	NW¼SE¼ sec. 20, T. 6 N., R. 1 W.
19	49K8	51-934CW [9]	do	Keating Gulch stock	NE¼ sec. 16, T. 5 N., R. 1 W.
20	52K184	53-64SCW [3]	do	Antelope Creek stock	SW¼SW¼ sec. 33, T. 9 N., R. 1 W.
21	52K191	53-75SCW [3]	do	Antelope Creek stock (composite of samples throughout stock).	
22	61K6600	158776 [6]	Quartz monzonite	Lone Mountain stock	SW¼NE¼ sec. 6, T. 4 N., R. 1 E.
23	49K7	51-933CW [9]	Granodiorite	Keating Gulch stock	NE¼ sec. 9, T. 5 N., R. 1 W.
24	51K1a	53-68SCW [4]	Porphyritic quartz monzonite.	Vosburg stock	Kleinschmidt mine, SW¼SE¼ sec. 34, T. 8 N., R. 1 W.

Sample No.	Field No.	Laboratory No.	Rock type [1]	Geologic occurrence	Location
			Elkhorn Mountains Volcanics		
1	52W142	53-81CW [3]	Trachyandesite	Middle part of lower member (composite of chips).	NE¼ sec. 25, T. 7 N., R. 1 W.
2	52W143	53-82SCW [3]	Labradorite trachyandesite	Lower member (composite of chips from basal 1,000 ft).	Iron Mask mine crosscut, sec. 30, T. 7 N., R. 1 E.
3	52K1	53-71CW	Labradorite rhyodacite	Lower member (composite of chips across 1,200 ft).	SE¼, sec. 16, and NE¼ sec. 21, T. 8 N., R. 1 W.
4	52R65	53-77CW [3]	Quartz latite	Welded tuff, lower member	NE¼ sec. 19, T. 7 N., R. 1 E.
5	52K7	53-72CW [4]	Rhyolite	Welded tuff, middle member	NE¼SW¼, sec. 16, T. 8 N., R. 1 W.
			Intrusive rocks related to Elkhorn Mountains Volcanics		
6	52R66	53-78SCW [3]	Syenodiorite porphyry	Small stock in lower member of Elkhorn Mountains Volcanics.	NW¼ sec. 19, T. 7 N., R. 1 E.
7	61K659	158775 [5]	Calcic granodiorite	Thick sill east of Santa Anita mine	NE¼ sec. 4, T. 4 N., R. 1 W.
8	52K127	53-736W [3]	Calcic syenodiorite	Sill in middle member of Elkhorn Mountains Volcanics.	NE¼NW¼ sec. 9, T. 8 N., R. 1 W.
9	Winchell No. 1.	None given [7]	Andesite (Winchell's (1914) usage).	Rattlesnake mass	Rena mine, sec. 7, T. 5 N., R. 1 E.
10	49K13	51-939CW [9]	Syenodiorite	Dutchman intrusive, southeastern lobe of body.	NE¼ sec. 32, T. 5 N., R. 1 W.
11	51K15	53-69SCW [3]	Syenodiorite porphyry	Small intrusive in lower member of Elkhorn Mountains Volcanics.	NW¼N, sec. 30, T. 7 N., R. 1 E.
12	49K12	51-938CW [9]	Syenodiorite	Dutchman intrusive 600 feet northwest of sample 49K14 locality.	NE¼ sec., 32, T. 5 N., R. 1 W.
13	52R6	53-76SCW [3]	Syenodiorite porphyry	Stock near Iron Mask mine	Sec. 19 T. 3 N., R. 1 W.
14	49K14	51-941CW [9]	Granodiorite	Dutchman intrusive, central part	Boundary between sec. 29 and 32, T. 5 N., R. 1 W.

See footnotes at end of table.

rocks from the east flank of the Elkhorn Mountains

Chemical analyses (weight percent)													Norms (percent)												
SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Loss on ignition [2]	Total	q	or	ab	an	wo	en	fs	mt	il	ap	cc	c	hm
Elkhorn Mountains Volcanics—Continued																									
54.8	0.76	17.0	4.5	3.4	0.16	3.6	6.6	3.6	1.6	0.31	3.0	99.3	9.5	9.5	30.4	25.5	2.2	9.0	1.6	6.5	1.4	0.7			
56.2	.66	16.8	4.0	3.1	.18	2.6	5.4	2.6	3.0	.38	5.1	100.0	15.2	18.9	23.1	25.6	.0	6.8	1.9	6.8	1.4	1.0		0.4	
59.6	.72	17.4	3.3	3.2	.16	2.6	5.2	2.6	3.4	.34	1.5	100.0	16.4	20.1	22.0	23.6	.0	6.5	2.3	4.8	1.4	.8		.8	
60.7	.74	16.6	1.7	3.5	.12	1.8	4.2	2.1	5.0	.32	2.3	99.1	16.8	29.5	17.8	18.7	.0	4.5	4.0	2.5	1.4	.8		.9	
69.4	.56	15.4	1.7	0.86	.08	.37	1.6	2.6	6.3	.09	.80	99.8	26.5	37.2	22.0	7.3	.0	.9	.0	1.4	1.1	.2		1.6	0.7
Intrusive rocks related to Elkhorn Mountains Volcanics—Continued																									
53.4	1.0	17.2	4.2	5.0	0.22	3.6	6.0	3.0	2.8	0.39	2.4	99.2	6.5	16.5	25.4	25.2	0.8	9.0	4.5	6.1	1.9	0.9			
54.9	.63	17.0	4.6	3.6	.20	3.9	8.1	2.8	2.1	.42	[6] 2.0	100.0	9.8	12.4	23.7	27.6	4.0	9.7	2.1	6.7	1.2	1.0	0.1		
55.4	.74	13.4	3.3	5.5	.68	6.8	7.8	2.0	2.1	.49	1.1	99.3	10.0	12.4	16.9	21.4	5.9	16.9	7.4	4.8	1.4	1.2			
56.61	.71	17.91	4.22	2.7	.58	2.21	6.88	3.10	2.71	.46	(8)	99.84	11.9	16.0	26.2	27.0	1.5	5.5	1.3	6.1	1.3	1.1	.3		
57.3	.66	17.1	2.8	3.6	.08	2.8	7.0	3.8	2.6	.47	2.3	100.5	8.0	15.4	32.1	21.9	4.1	7.0	3.4	4.1	1.3	1.1			
57.8	.68	17.1	3.8	3.6	.16	2.6	6.0	3.2	2.1	.35	1.9	99.3	14.5	12.4	27.1	26.1	.6	6.5	2.6	5.5	1.3	.8			
58.1	.57	17.4	3.9	2.1	.15	2.4	6.9	3.4	2.9	.34	1.8	101.0	11.6	17.1	28.8	23.7	3.5	6.0	.0	5.6	1.1	.8			
58.6	.44	16.8	3.6	2.6	.18	2.5	6.0	3.6	2.2	.26	2.8	99.6	13.8	13.0	30.4	23.2	2.0	6.2	1.4	5.2	.8	.6			
60.2	.52	17.2	3.6	2.2	.17	2.0	5.6	3.5	2.8	.32	1.6	99.7	15.4	16.5	29.6	23.0	1.1	5.0	.5	5.2	1.0	.8			
Younger intrusive rocks—Continued																									
55.2	1.1	16.4	4.1	5.0	0.18	4.1	7.3	3.0	2.3	3.1	0.66	100.0	8.2	13.6	25.4	24.5	4.0	10.2	4.3	5.9	2.1	0.7			
55.46	.81	16.93	2.12	5.63	.16	4.01	7.22	3.01	3.18	.36	[6] .71–.13	99.7	4.2	18.8	25.5	23.3	4.1	10.0	7.5	3.1	1.5	.9	0.1		
56.2	.76	18.9	4.6	3.0	.13	2.7	7.0	3.7	2.4	.42	1.0	101.0	8.2	14.2	31.3	27.9	1.7	6.7	0.7	6.7	1.4	1.0			
60.5	.62	17.2	3.4	2.5	.14	2.4	5.8	3.4	2.6	.30	1.2	100.0	15.8	15.4	28.8	24.0	1.2	6.0	1.0	4.9	1.2	.7			
61.3	.58	18.1	3.0	2.9	.14	2.1	5.8	3.6	1.7	.28	1.2	101.0	18.1	10.0	30.4	26.9	.0	5.2	2.1	4.3	1.1	.7		0.5	
61.6	.53	16.5	2.5	3.2	.68	2.6	5.2	3.4	3.0	.22	.88	100.0	15.3	17.7	28.8	20.9	1.4	6.5	3.2	3.6	1.0	.5			
63.5	.50	15.7	2.6	2.8	.14	2.4	4.6	3.3	3.2	.21	1.4	101.0	18.8	18.9	27.9	18.6	1.2	6.0	2.4	3.8	1.0	.5			
63.5	.55	15.6	3.9	1.4	.14	2.2	3.9	4.2	3.6	.38	[6] .84	100.0	15.6	21.3	35.5	13.1	1.4	5.5	.0	3.4	1.1	.9	.1		1.6
65.8	.50	16.2	3.2	1.0	.07	1.4	4.4	3.3	3.4	.20	1.0	101.0	22.9	20.1	27.9	19.4	.5	3.5	.0	2.0	1.0	.5			1.8
66.4	.29	16.4	1.6	1.3	.11	.76	4.2	4.2	3.6	.12	1.0	100.0	19.1	21.3	35.5	15.3	2.0	1.9	.8	2.3	.6	.3			

Quantitative spectrographic analyses (parts per million) [10] [11]											Mode (volume percent)						
Cu	Pb	Co	Ni	Ga	Cr	Sc	La	Zr	Be	Ba	Plagioclase	K-feldspar	Quartz	Biotite	Hornblende	Augite	Other [12]
Elkhorn Mountains Volcanics—Continued																	
0.012	0.0042	0.0020	0.0021	0.0042	0.011	0.0015	0.0	0.0094	0.0001	0.014							
.0044	.011	.0025	.0007	.0036	.0009	.0022	.0078	.0090	.0001	.18							
Intrusive rocks related to Elkhorn Mountains Volcanics—Continued																	
											50 (An_{42})	24	3	10 chlorite		8	4
											53 (An_{43-55})	14	4		23	2	4
0.0029	0.0037	0.0022	0.0009	0.0054	0.0013	0.0032	0.0	0.012	0.0001	0.21	45 (An_{40-52})	15	4		19	12	5
											50 (An_{40-60})	24	7	2	1	14	2
.0012	.0037	.0018	.0	.0046	.0009	.0010	.0	.0085	.0	.14	60 (An_{40})	19	3		9	6	3
											52 (An_{45})	17	10		15	3	3

TABLE 1.—*Chemical analyses, norms, and modes of igneous rocks*

Sample No.	Field No.	Laboratory No.	Rock type [1]	Geologic occurrence	Location
			Younger intrusive rocks		
15	49K9	51-931CW [9]	Granodiorite	Keating Gulch stock	NE¼ sec. 16, T. 5 N., R. 1 W.
16	60S599	G-3167 [9]	Syenggabbro	Orphan Boy mafic dike	NE¼NE¼ sec. 4, T. 8 N., R. 1 W.
17	49K10	51-936CW [9]	Syenodiorite	Keating Gulch stock	SE¼ sec. 9, T. 5 N., R. 1 W.
18	49K11	51-937CW [9]	Granodiorite	Slim Sam stock	NW¼SE¼ sec. 20, T. 6 N., R. 1 W.
19	49K8	51-934CW [9]	Granodiorite	Keating Gulch stock	NE¼ sec. 16, T. 5 N., R. 1 W.
20	52K184	53-64SCW [3]	Granodiorite	Antelope Creek stock	SW¼SW¼ sec. 33, T. 9 N., R. 1 W.
21	52K191	53-75SCW [3]	Granodiorite	Antelope Creek stock (Composite of samples throughout stock).	
22	61K6600	158776 [6]	Quartz monzonite	Lone Mountain stock	SW¼NE¼ sec. 6, T. 4 N., R. 1 E.
23	48K7	51-933CW [9]	Granodiorite	Keating Gulch stock	NE¼ sec. 9, T. 5 N., R. 1 W.
24	51K1a	53-68SCW [4]	Porphyritic Quartz monzonite.	Vosburg stock	Kleinschmidt mine, SW¼ SE¼ sec. 34, T. 8 N., R. 1 W.

[1] Volcanic rocks (samples 1-5) are named according to Rittman (1952); intrusitive rocks (samples 6-11) are named on basis of their modes (fig. 2).
[2] Includes gain due to oxidation of FeO.
[3] Chemical analysis by rapid method by J. M. Dowd, Katherine White, and F. S. Borris.
[4] Analysis by rapid method by J. M. Dowd.
[5] Analysis by rapid method by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and G. W. Chloe.
[6] Reported as H_2O; <0.05 CO_2.

pumice. Chemical analysis (table 1, sample 5) indicates that a composite sample of typical welded tuff from this member is rhyolite.

The welded tuffs consist of plagioclase and biotite phenocrysts, rock fragments, and flattened chunks of devitrified pumice in a devitrified groundmass. Plagioclase in anhedral angular fragments that are generally zoned, twinned, and unaltered makes up less than 10 percent of most rock, and biotite phenocrysts comprise less than 5 percent; magnetite grains, which are oxidized to hematite near the margins of the phenocrysts are abundant. Rock fragments compose 5–50 percent of different units and are mainly of trachyandesite, basalt containing chlorite-filled vesicles, microcrystalline rhyodacite, and chunks of brown devitrified spherulitic glass. Collapsed pumice, ranging from 5 to 30 percent in different units, is crumpled and cut by perlitic cracks. Groundmass and pumice are devitrified and in some rocks are recrystallized to mosaics of very fine grained quartz, feldspars, chlorite, biotite, sericite, magnetite, minor calcite, and abundant leucoxene dust. The reconstituted pumice typically contains more sericite than does the groundmass.

INTRUSIVE ROCKS RELATED TO THE ELKHORN MOUNTAINS VOLCANICS

Several large irregular partly concordant bodies consisting mainly of syenodiorite porphyry and granodriorite porphyry (fig. 3) and many dikes and sills of trachyandesite porphyry and rhyodacite porphyry cut Elkhorn Mountains Volcanics and olders rocks. These intrusives are similar in composition to the associated volcanics and are products of the same magma or magmas. Lithic fragments in the tuffs and breccias, except for rare fragments of underlying sedimentary rocks, are indistinguishable from the principal types of intrusive rocks; most lava flows also closely resemble one or another of the intrusive rocks, so much so that in areas of poor exposures and structural complexity flows cannot be distinguished from intrusives with confidence. Similarly, plagioclase, augite, and hornblende, in that order, are the most abundant large mineral grains in flows, intrusives, and fragmental rocks, and their optical properties are identical or closely similar.

The intrusive bodies range in size from dikes and sills less than a foot thick and a few tens of feet long to the large grossly concordant Rattlesnake mass that is exposed over about 20 square miles. Most of the sills are a few tens of feet thick, but some are several hundred feet thick; several are more than 2 miles long. Sills are more abundant in shales of the Kootenai Formation and Colorado Formation. Different bodies were emplaced at different times during the period of volcanic activity as indicated by crosscutting and truncating relations. All the concordant and quasi-concordant masses were almost certainly emplaced before the major episode of folding. The texture of the rocks and the shapes of most bodies indicate emplacement at relatively shallow depth.

The larger intrusive masses consist mainly of seriate syenodiorite porphyry that grades either into granodiorite porphyry or toward diorite porphyry. Some of the rocks in the Dutchman intrusive are medium grained subequingranular. Smaller dikes and sills, however, are mainly hiatal rhyodacite or trachyandesite porphyry with abundant indeterminate groundmass. The rocks are mainly gray, greenish gray, and purple and consist of plagioclase, augite, hornblende, magnetite, and rarely hypersthene and olivine. On plate 1, map symbols distinguish those rocks in which hornblende is the dominant mafic mineral as determined in the field and those in which augite or olivine is dominant; many intrusive bodies, particularly the larger ones, contain *from the east flank of the Elkhorn Mountains*—Continued

Quantitative spectrographic analyses (parts per million) [10, 11]											Mode (volume percent)						
Cu	Pb	Co	Ni	Ga	Cr	Sc	La	Zr	Be	Ba	Plagioclase	K.feldspar	Quartz	Biotite	Hornblende	Augite	Other [12]
Younger intrusive rocks—Continued																	
											51(An_{45-50})	9	8	13	9	8	2
											49(An_{30-70})	20	3	8	7	11	2
											53(An_{42-60})	18	7	---	16	2	4
											55(An_{42})	18	14	3	7	---	3
											55(An_{40})	12	13	5	13	---	2
..0012	0.0029	0.0	0.006	0.0030	0.0013	0.0012	---	0.0075	0.0001	0.15	56(An_{30-45})	18	10	6	9	---	1
0.0014	.0037	.0	.0011	.0028	.003	.0012	.0078	.0096	.0002	.13							
											45(An_{28-32})	30	12	1	8	1	3
											51(An_{35-26})	22	16	---	9	---	2
											50(An_{20-33})	28	15	---	6	---	1

[7] Analysis by Chase Palmer (Winchell, 1914, p. 176).
[8] Other constituents reported include 0.29 percent H_2O-, 1.16 percent H_2O+, 0.13 percent CO_2, 0.03 percent S, and 0.14 percent BaO.
[9] Analysis by rapid method by S. M. Merthold and E. A. Nygaard.
[10] Quantitative spectrographic analyses by E. L. Hufschmidt.
[11] Elements not detected: B, Ag, Ge, Mo, W, Sn, As, Sb, Bi, Zn, Tl, In, Y, and Nb.
[12] Includes apatite, epidote, opaque minerals, sphene, chlorite, calcite, and sericite.

both hornblende and augite. For example, in some parts of the Rattlesnake mass, hornblende needles are conspicuous, in other parts hornblende and augite appear to be roughly equal, and in some places neither is conspicuous. Groundmass textures in narrow dikes and sills generally are pilotaxitic or trachytic; in larger bodies such as the Rattlesnake and Dutchman intrusives the groundmass is typically a fine-grained mosaic of plagioclase, K-feldspar, and magnetite, with lesser amounts of augite, quartz, chlorite, and an interstitial carbonate mineral. Accessory minerals include sphene, leucoxene, hematite after magnetite, apatite, and zircon. Small vugs in some rocks are filled by one or more of the following minerals: Quartz, epidote, actinolite, chlorite, and K-feldspar.

Percentages of phenocrysts in samples of syenodiorite porphyry examined under a microscope range as follows (table 1, fig. 3): plagioclase, 19–41; augite, 3–11; hornblende, 0–12; hypersthene, 0–6; and magnetite, 2–5 percent. Plagioclase phenocrysts are equant to lathlike euhedral crystals 5 mm (millimeters) to less than 0.5 mm long and are strongly zoned from An_{70} cores to An_{20} rims. Delicate oscillatory zoning is common, and many grains have zones of "glass" inclusions. Albite and combined albite-Carlsbad twinning are most common; pericline twinning, less so. Augite phenocrysts occur either as single euhedral prismatic grains <0.5–3.5 mm long or in clumps of smaller subhedral crystals. They are faintly pleochroic from pale green to colorless and have a $2V=51–58\pm2°$. Most of the grains are zoned, and multiple twinning is common. Hornblende forms euhedral laths as much as 5 cm (centimeter) long and is fresh or partly replaced along the margins by finely granular clinopyroxene and magnetite. It has distinct pleochroism (X=colorless to pale brown; Y=olive green; Z=deep green) and an extinction angle of about 18°. Twinned and nontwinned grains are about equally abundant. In rocks having augite as the dominant mafic phenocryst, the hornblende typically is altered to oxyhornblende with oxidized margins, small extinction angle, and the following pleochroism: X=medium brown; Y=medium olive brown; Z=dark olive brown. Euhedral to subhedral equant crystals of magnetite as much as 0.5 mm across are scattered in a groundmass or as inclusions in hornblende and augite.

Many of these rocks are deuterically altered, and the original groundmass minerals and textures are replaced by fine-grained intergrowths of albite, epidote, calcite, sericite, chlorite, magnetite, and quartz. Sericite replaces the calcic cores of plagioclase phenocrysts, augite phenocrysts are altered to chlorite, hypersthene and olivine phenocrysts are changed to serpentine, and hornblende phenocrysts are partly replaced by chlorite, magnetite, epidote, and sphene. Thin veinlets of calcite and chlorite which cut phenocrysts and groundmass are common. Where cut by younger intrusives, the rocks have been thermally metamorphosed and the groundmass recrystallized to a mosaic of albite, orthoclase, quartz, epidote, and magnetite, which superficially resembles the original micrograniitic texture, but is mineralogically different and is restricted to rocks in which the phenocrysts also are recrystallized.

A few distinctive dikes and sills in the vicinity of Kimber Gulch and Whitehorse Gulch are olivine-rich syenodiorite porphyry that contains phenocrysts of olivine, augite, and a few of biotite in a groundmass consisting chiefly of cryptoperthite and plagioclase. These olivine-bearing rocks cut the Slim Sam Formation and are cut by hornblende- and augite-bearing syenodiorite porphyry. They are clearly older than most of the syenodiorite porphyry and probably are intru-

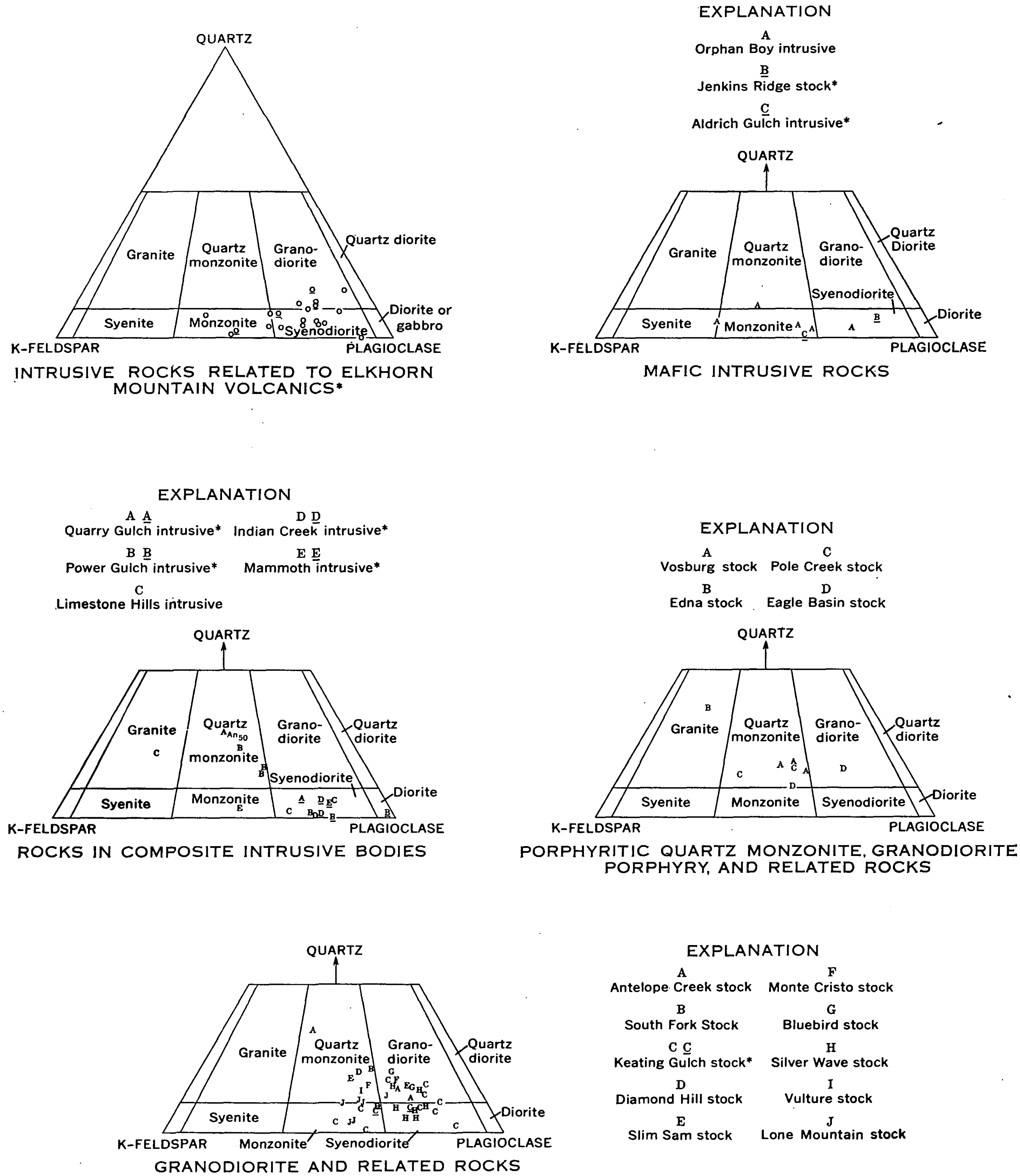

FIGURE 3.—Modes of intrusive rocks, east flank of Elkhorn Mountains, Mont. Mafic minerals subtracted and mode recalculated to 100 percent. *, underscore indicates a calcic ($An>_{50}$) rock.

sive equivalents of some of the lowest Elkhorn Mountains Volcanics.

The Rattlesnake intrusive body, which is crudely laccolithic or sill-like, extends 10 miles southward from Crow Creek to about a mile beyond the southern limit of the area; it is 1–3½ miles wide. Most of the rocks are syenodiorite or granodiorite porphyry consisting largely of hornblende, augite, and plagioclase in differing proportions. Quartz and K-feldspar are sparse or unrecognizable in thin section but are significant components of norms of similar rocks. The base of the mass, along its west side, though discordant in detail, is grossly concordant with rocks of the Colorado Formation, the Slim Sam Formation, and the lower part of the Elkhorn Mountains Volcanics. The contact with the Elkhorn Mountains Volcanics that forms the roof is irregular but appears to be broadly concordant. Remnants of older rocks within the mass are abundant, and some are large; most of the larger remnants are severely faulted and are locally folded. The mass is thought to have been emplaced as follows: sheets of magma, probably fed through a north-trending zone of steep fractures, were emplaced along bedding surfaces in the Colorado Formation and younger rocks. As the sheets grew they swelled and coalesced, disrupting septa of the host rocks and strongly deforming and embaying the roof rocks, which were at most a few thousand feet thick. Locally, the magma probably burst through to the surface as suggested by the abundance nearby of coarse debris of probable mudflow origin consisting of the same petrographic types that constitute the Rattlesnake mass. For the most part the roof was shouldered up and aside but not engulfed; and accordingly, the blocks of older rocks are not products of stopping but rather are remnants of septa that once separated sills. Large inclusions of older rocks are abundant, but small inclusions are rare; no features suggest assimilation. In several places zones of healed intrusion breccia separate rocks of slightly different lithology or texture.

The Dutchman intrusive body crops out along the west margin of the Radersburg quadrangle (pl. 1 and section *I–I′*) in secs. 29 and 32, T. 5 N., R. 1 W. Its westward continuation has been mapped by Klepper, Weeks, and Ruppel (1957, p. 45). The body is strongly discordant along its north and east margins in the mapped area but is roughly concordant with the enclosing Devonian rocks along most of its west margin. Several sill-like offshoots extend southward from the body, and the outcrop pattern of the entire intrusive body suggests that it is crudely sill-like. Field study, examination of thin sections (table 1, fig. 3), and chemical analyses of three representative samples (table 1, samples 10, 12, 14) indicate that the Dutchman intrusive is relatively homogeneous and that it consists of rocks ranging from quartz-poor granodiorite to syenodiorite; most of the rock has the texture of a porphyry, but some is medium-grained subequigranular. The Dutchman intrusive closely resembles the Rattlesnake mass in chemical and mineralogical composition but is generally coarser grained and contains little unidentifiable groundmass, lacks large inclusions, is more regularly shaped, and has not strongly disrupted the enclosing rocks. These similarities and differences probably result from emplacement and crystallization of batches of similar magma at significantly different depths beneath the surface, the Rattlesnake mass beneath a cover no more than a few thousand feet thick and the Dutchman mass about a mile deeper.

YOUNGER INTRUSIVE ROCKS

The Elkhorn Mountains Volcanics and related shallow intrusives are cut and thermally metamorphosed by younger Upper Cretaceous and Paleocene generally coarser grained intrusive rocks, in stocks, dikes, plugs, and bodies of unknown subsurface configuration. The rocks range from gabbro to granite (table 1, fig. 3); most are medium- to coarse-grained equigranular rocks; a few of the smaller bodies are fine-grained porphyry. The rocks can readily be assigned to either a mafic group or an intermediate and felsic group. The mafic rocks range from gabbro to calcic syenite. The more felsic rocks range from syenodiorite to granite; rocks in the larger bodies are mainly equigranular and range from syenodiorite to quartz monzonite. Three stocks of porphyritic quartz monzonite and several small bodies of granodiorite porphyry, quartz monzonite porphyry, and leucocratic granite porphyry cut the Elkhorn Mountains Volcanics and related intrusives in the north half of the area. In the central part of the area a few composite bodies similar to the composite intrusives of the southern Elkhorn Mountains (Klepper and others, 1957, p. 51) consist of one or more mafic rock types and one or more felsic rock types. In each of the few examples where age relations can be determined, felsic intrusive rocks are younger than associated mafic intrusives.

Relative age of the several compositional and textural varieties of felsic and intermediate intrusive rocks, however, could not be determined with certainty. In only one place, near Hassel, are rocks of two different masses of intermediate and felsic intrusive rocks in contact with one another. There, the Silver Wave and Diamond Hill stocks are in contact, but relatively intense hydrothermal alteration and poor exposures obscure the contact relations. The Silver Wave stock is finer grained and rather strongly hydrothermally altered. The Diamond Hill stock is porphyritic in places, is cut by aplite and quartz veins, and is less affected by hydrothermal alteration in the vicinity of the contact with the Silver Wave stock. As shown on section *C–C*, plate 1, the Silver Wave stock is interpreted as the older of the two.

Differences in types of mineral deposits seem to be associated with different rock types of the intermediate and felsic group. South of the Diamond Hill mine, for example, the intrusives are dominantly intermediate in composition and are equigranular and fine to medium grained, and the veins are notably poor in quartz and have been valuable primarily for gold associated with abundant pyrite. North of the Diamond Hill mine, the intrusives are generally more felsic and richer in quartz, and some are porphyritic; in this area the veins are dominantly quartz and havev been valuable for their gold, silver, lead, and zinc content.

MAFIC ROCKS

The Aldrich Gulch intrusive, (pl. 1, section *D–D*) Jenkins Ridge stock, and two dikes, all west of Glendale Butte in the south-central part of the mapped area, the Orphan Boy intrusive (pl. 1, section *A–A*) in the northern part, and the mafic parts of several small composite intrusive bodies in the central part consist mainly of calcic syenodiorite and calcic monzonite but include rocks ranging from mafic syenite to gabbro. Most of the mafic rocks form part or all of small discordant stocks or plugs; a few form dikes. An intrusive just west of the mapped area similar to the Orphan Boy intrusive has been described by Smedes (1960; 1966, p. 64, 66) as a segment of a ring dike marginal to the Antelope Creek stock.

Most of these rocks are dark gray, medium to coarse grained, equigranular to porphyritic, and are characterized especially by their content of mafic minerals, which in most rocks ranges from 30 to 55 percent, and by their relatively high potassium content in the form of K-feldspar or biotite, or both. The rocks are hypidiomorphic granular to porphyritic aggregates of feldspar and mafic minerals, and they contain phenocrysts and phenocrystic clusters of mafic minerals. The mafic minerals are olivine, augite, and hypersthene, hornblende, and biotite in different combinations and proportions. Olivine is in part replaced by serpentine and in part rimmed by pyroxene and biotite; pyroxene is replaced and rimmed by hornblende and biotite, and hornblende and biotite are replaced in part by chlorite and sparse calcite. Magnetite and perhaps other black opaque minerals are associated with the mafic minerals and probably formed as a result of release of iron during replacement reactions. Plagioclase, forming 25–50 percent of different rocks, ranges from labradorite to andesine, and typically is in slightly zoned subhedral laths smaller than the associated mafic minerals. The cores of some crystals are slightly altered. K-feldspar in subhedral to anhedral interstitial grains commonly forms about 10 percent of most of the rocks examined under the microscopic but reaches as much as 30 percent. The K-feldspar includes cryptoperthite, anorthoclase or sanidine, and cloudy microperthite that poikilitically encloses plagioclase and in places is in micropegmatitic intergrowth with quartz. The K-feldspar is intergrown with the marginal part of plagioclase crystals in some rocks. A small amount of quartz, commonly less than 5 percent, is present in small anhedral interstitial grains. Accessory minerals include apatite, sphene, and zircon.

The mafic rocks are younger than the Elkhorn Mountains Volcanics and related intrusive rocks and, wherever relations can be determined, they are older than felsic intrusive rocks. They are discordant and intrude rocks of the Colorado and Slim Sam Formations and the Elkhorn Mountains Volcanics. One of the dikes appears to be truncated by the South Fork stock. Rocks of the Orphan Boy intrusive (pl. 1, section A–A′), which strongly metamorphosed Elkhorn Mountains Volcanics, are in turn recrystallized by granodiorite of the Antelope Creek stock. The rocks are similar to the mafic facies of the composite intrusives of the southern Elkhorn Mountains (Klepper and others, 1957, p. 51–52), and to gabbroic to monzonitic rocks that are among the oldest rocks of the Boulder batholith (Knopf, 1957, p. 90–91).

INTERMEDIATE AND FELSIC ROCKS

Rocks ranging in composition from syenodiorite to granite (table 1, fig. 3) comprise many stocklike intrusive masses along the east flank of the Elkhorn Mountains. All these masses, which range in area from a few acres to a few square miles, are sharply discordant, and different masses cut folded rocks ranging in age from Devonian to Late Cretaceous. Most consist of medium- to coarse-grained subequigranular rocks, but a few small bodies consist of fine-grained porphyry and a few are coarse grained and porphyritic. Three groups are defined on the basis of composition and texture: (1) granodiorite and related rocks, (2) porphyritic quartz monzonite, and (3) granodiorite porphyry and related rocks.

GRANODIORITE AND RELATED ROCKS

Rocks clustering near the boundary between granodiorite, syenodiorite, quartz monzonite, and monzonite (table 1; fig. 3) are the most abundant and widespread of the younger intrusive suite and make up most of the larger masses of that suite. The rocks are mainly medium gray to greenish gray, fine to medium grained, and subequigranular; seriate or porphyritic textures are rare. Mineral composition falls generally within the following limits: plagioclase, 40–60 percent; K-feldspar, 15–35 percent; quartz, 1–20 percent; and mafic minerals, 15–35 percent. Plagioclase typically is in weakly zoned subhedral to anhedral crystals that range in composition from about An_{55} at the core to An_{35} at the border; the highest and lowest An contents observed were An_{75} in a core an An_{25} in a rim. The centers of zoned crystals are replaced to some extent by clinozoisite or epidote, calcite, albite, sericite, or by mixtures of these minerals. Most of the K-feldspar is orthoclase, but locally, anorthoclase and (or) orthoclase cryptoperthite(?) are present. K-feldspar forms anhedral interstitial grains, which are generally smaller than the accompanying grains of plagioclase, and larger irregularly shaped crystals that poikilitically enclose and replace plagioclase and mafic minerals. Part of the K-feldspar is in micropegmatitic intergrowth with quartz. The orthoclase typically is cloudy and speckled with brown, semiopaque mineral dust; anorthoclase and (or) orthoclase cryptoperthite(?) are clear. Quartz forms small interstitial anhedral grains and appears to have been the last mineral to crystallize.

The mafic minerals are hornblende, pyroxene, and biotite. They range in size from grains a few hundredths of a millimeter long in the groundmass to phenocrysts as much as 20 mm long. The mafic grains in most rocks are about the same size as the felsic ones, but hornblende and pyroxene crystals are generally larger than biotite crystals in the same rocks. Hornblende is the dominant mafic mineral in most rocks, and it occurs as subhedral to ragged anhedral crystals that are partly altered to biotite, chlorite, epidote, and calcite. Pyroxene is widely present but is rarely dominant; it is in ragged subhedral crystals that typically are rimmed and partly replaced by uralitic hornblende and brown biotite. Most pyroxene is colorless or faintly pleochroic from colorless to pale green, has an extinction angle ($Z \wedge c$) of 45–50°, a 2V of 40–60°, and is probably pigeonitic. Biotite typically is in small subhedral to anhedral flakes replacing hornblende and pyroxene or, less commonly, is disseminated through the rock; much of it is partly altered to chlorite and epidote.

Accessory minerals includes apatite, sphene, magnetite, and small amounts of hematite and ilmenite commonly associated with partly altered mafic minerals and very sparse small crystals of zircon.

Lone Mountain stock.—The Lone Mountain stock, named and described by Freeman, Ruppel, and Klepper (1958, p. 520–521), underlies an area of several square miles in the south of the mapped area (pl. 1 and section *F–F′–F″*). The stock cuts sharply across gently dipping Elkhorn Mountains Volcanics and has thermally metamorphosed them in a zone at least several hundred feet wide. The stock consists of medium-grained subequigranular rocks of uniform appearance that cluster around the intersection of the monzonite, syenodiorite, quartz monzonite, and granodiorite fields (fig. 3; table 1); locally, near the margins subequigranular rocks grade into rocks with porphyritic or seriate textures. A lead-alpha age of 76 million years was determined on zircon from rocks of the Lone Mountain stock (Jaffe and others, 1959, p. 81).

Keating Gulch stock.—The Keating Gulch stock cuts sharply and irregularly across upper Paleozoic and Mesozoic rocks. Two small bodies west of the stock and one to the south consist of rocks that resemble those in the stock and are probably connected with it at depth. The stock and its outliers consist of gray or greenish-gray medium-grained, locally porphyritic rocks; the main body of the stock consists of granodiorite and syenodiorite, and two smaller outliers to the west are monzonite (fig. 3; table 1). The marginal part of the stock includes quartz-rich rocks of peculiar texture that are probably metasomatically replaced sedimentary rocks.

Slim Sam stock.—The intrusive body cutting upper Paleozoic, Jurassic, and Lower Cretaceous sedimentary rocks in and west of secs. 20, 21, 28, and 29, T. 6 N., R. 1 W., (pl. 1, section *D–D′*) was named the Slim Sam stock by Klepper, Weeks, and Ruppel (1957, p. 50), who briefly described the rock and reported one chemical analysis. Though exposures are poor, the map pattern suggests that the stock is discordant in most places but may be concordant along its northeast margin. The stock consists of relatively homogeneous medium-grained granodiorite and quartz monzonite (fig. 3).

South Fork stock.—The South Fork stock, along the South Fork of Crow Creek, is a discordant mass of medium- to fine-grained subequigranular hornblende-biotite quartz monzonite near granodiorite (fig. 3) that cuts folded sedimentary rocks of the Colorado and Slim Sam Formations. The rocks resemble those of the Slim Sam stock about a mile to the south.

Silver Wave stock.—The Silver Wave stock on Indian Creek cuts discordantly across the Elkhorn Mountains Volcanics and is inferred to be cut by the Diamond Hill stock (pl. 1, sections B–B′, C–C′), though contact relations are obscured by hydrothermal alteration and poor exposure. The rocks of three large outcrop areas are believed to be connected at shallow depth. The northern part of the stock is separated from the central part by Holocene alluvium; the central and southern parts are separated by a plate of intensely recrystallized Elkhorn Mountains Volcanics. A small elongate body of intrusive rock along Cold Springs Gulch is similar to the stock and probably part of it. The stock consists mainly of syenodiorite but includes granodiorite, monzonite, and diorite (fig. 3). Most of the rocks are fine- to medium-grained subequigranular; some are seriate and a few are porphyritic. Grain size of rocks near the border of the stock averages 1 mm or less, and grain size of rocks from the central part of the stock averages 1–2 mm. The rocks near the border of the stock contain a few small inclusions of country rock and are a little darker than the coarser grained rocks in the central part. In the vicinity of the Diamond Hill mine the rocks are hydrothermally altered.

Diamond Hill stock.—The Diamond Hill stock, at the junction of Indian Creek and its West Fork (pl. 1, section C–C′), consists of biotite quartz monzonite of uniform composition (fig. 3). The dominant rock type is medium gray, fine to medium grained, sparsely porphyritic, and contains biotite and plagioclase crystals as much as 5 mm long in a xenomorphic intergrowth of smaller grains of K-feldspar, quartz, and plagioclase. In a few places the rock is conspicuously porphyritic, and it contains euhedral pink phenocrysts of K-feldspar as much as 4 cm long and 2 cm wide that enclose small biotite flakes. Locally, small pegmatite and aplite dikes and irregular veinlets of quartz, some of which contain a little pyrite, chalcopyrite, and galena, cut the stock. The surrounding volcanic rocks are thermally metamorphosed in a zone at least several hundred feet wide. Along the east margin of the stock, the contact metamorphic zone is thin or absent and is inferred to have been cut off by a fault (pl. 1).

Monte Cristo stock.—The Monte Cristo stock, near the junction of Beaver Creek and its South Fork, discordantly cuts rocks of the middle member of the Elkhorn Mountains Volcanics and related intrusive rocks. The rocks of the stock are medium- to light-gray fine-grained subequigranular quartz monzonite and granodiorite (fig. 3). Mafic minerals are slightly more abundant near the margins of the stock than in the central part. A representative sample from the peripheral part is biotite granodiorite (fig. 3); one from the central part is quartz monzonite that contains fewer mafic minerals and has more hornblende than biotite. The central part of the stock is cut by a few small aplite dikes and many quartz veinlets, adjacent to which the quartz monzonite is bleached.

The volcanic rocks adjacent to the stock are thermally metamorphosed and cut by a few dikelike apophyses of the stock in a zone several hundred feet wide. Several pyritic quartz veins have been explored within the stock and the thermally metamorphosed border rocks.

Antelope Creek stock.—The Antelope Creek stock, in the northwest corner of the area (pl. 1, section *A*–*A′*), extends northward and westward beyond the mapped area. The part to the north was briefly described by Mertie, Fischer, and Hobbs (1951, p. 44–45), and that to the west, by Smedes (1966, p. 66–67). The stock is composed of medium- to fine-grained subequigranular granodiorite of uniform appearance and composition (fig. 3; table 1). It cuts and strongly metamorphoses rocks of the middle member of the Elkhorn Mountains Volcanics. The Orphan Boy mafic intrusive is separated from the stock by a screen of basalt of the Elkhorn Mountains Volcanics; both are thermally metamorphosed. The stock is cut by thin dikes of aplite, by many stringers and veinlets of quartz, and by a few quartz latite dikes.

Other stocks.—The Bluebird stock, near the Bluebird mine in secs. 7 and 18, T. 6 N., R. 1 E., and secs. 12 and 13, T. 6 N., R. 1 W., is composed of homogeneous medium- to fine-grained subequigranular to porphyritic hornblende granodiorite (fig. 3). It is a small, strongly discordant body that cuts the Elkhorn Mountains Volcanics and related intrusive rocks.

The Vulture stock, near the Vulture mine in secs. 8 and 9, T. 7 N., R. 1 W., is a small discordant body of fine- to medium-grained subequigranular hornblende-biotite quartz monzonite cutting the Elkhorn Mountains Volcanics (fig. 3).

PORPHYRITIC QUARTZ MONZONITE

The Vosburg, January, and Freiburg stocks, along Weasel Creek in the north-central part of the mapped area, consist of porphyritic quartz monzonite (fig. 3) distinctly different in appearance from the subequigranular granodiorite and related rocks. The rock is a medium-grained aggregate of anhedral quartz, K-feldspar, subordinate plagioclase, and sparse biotite and hornblende studded with large tabular phenocrysts (as much as 6 cm long) of K-feldspar, somewhat smaller subhedral phenocrysts of plagioclase, and sparse phenocrysts of chloritized biotite and hornblende. The K-feldspar phenocrysts are euhedral in general outline but in detail are ragged and intergrown with granular quartz. Many K-feldspar crystals enclose small ragged grains of plagioclase, hornblende, and biotite. Some are faintly perthitic, and some have a faint grid twinning suggestive of microcline. In parts of the Vosburg stock the K-feldspar phenocrysts are strongly alined. Plagioclase is in zoned subhedral laths most of which have oligoclase rinds and are partly embayed by granular aggregates of finer grained K-feldspar and quartz. The maximum range of composition observed is An_{43} to An_{20}. Plagioclase in the groundmass is in ragged to anhedral grains, some of which are remnants of larger crystals that have been replaced by granular quartz and K-feldspar, and some of which are more sodic plagioclase that crystallized along with the K-feldspar and quartz. Hornblende and biotite are in embayed euhedral crystals and ragged grains; both minerals are largely replaced by intergrowths of chlorite, epidote, calcite, iron oxide, apatite, and sphene. Accessory minerals are tourmaline, apatite, sphene, zircon, and possible allanite.

The Vosburg, January, and Freiburg stocks lie along the N. 30° E.-trending Weasel Creek fault zone, which may have controlled their emplacement. They cut discordantly across and strongly metamorphose the Elkhorn Mountains Volcanics. The contact zone of the January stock is cut by narrow aplite dikes. Most of the exposed rock in the January and Freiburg stocks is hydrothermally altered; the altered rocks have relict textures similar to rocks of the Vosburg stock. Some of the larger mineral deposits in the area are within and adjacent to these stocks.

QUARTZ MONZONITE PORPHYRY AND RELATED ROCKS

The rocks, characterized by abundant phenocrysts in a fine-grained groundmass, form four small stocks in the central and northern parts of the mapped area. They range in composition from granodiorite porphyry to granite porphyry, but all contain comparatively large phenocrysts of plagioclase, K-feldspar, and quartz in a fine-grained sugary-textured groundmass composed of K-feldspar, quartz, and biotite. Typically, phenocrysts and groundmass each make up about half the rock, although proportions of phenocrysts to groundmass and proportions of plagioclase, K-feldspar, and quartz phenocrysts to each other differ from one rock to another.

In most of the rocks the most abundant phenocrysts are plagioclase in zoned (An_{27-55}) subhedral laths as much as 5 mm long; in the more silicic rocks of the group the plagioclase is sericitized or replaced by groundmass minerals. K-feldspar phenocrysts generally are less abundant than plagioclase phenocrysts but are conspicuous because of their large size, as much as 1.5 by 3 cm, and their subhedral to euhedral shape. K-feldspar is perthitic to microperthitic, and in general the degree of sericitization or replacement of plagioclase by groundmass increases with increasing K-feldspar content. Quartz phenocrysts are mostly subhedral to euhedral and are a few millimeters across. Biotite, partly altered to chlorite, opaque iron oxides, and apatite, forms small euhedral to subhedral phenocrysts that contain inclusions of zircon and rutile.

The groundmass is a fine-grained (0.1 mm or less) sugary-textured aggregate of K-feldspar, quartz, and subordinate biotite; it typically irregularly embays the feldspar and quartz phenocrysts.

Eagle Basin and Coburg Basin stocks.—Two small stocks of quartz monzonite porphyry grading to granodiorite porphyry (fig. 3) cut Elkhorn Mountains Volcanics in Eagle Basin and Coburg Basin, in the west-central part of the mapped area (pl. 1, section *B–B′*). Some of the rocks in each stock contain conspicuous large subhedral to euhedral phenocrysts of K-feldspar, and the plagioclase in these rocks is more altered than that in rocks lacking large crystals of K-feldspar. Small aplite dikes and quartz veins also are common in the K-feldspar-rich rocks.

Edna and Pole Creek stocks.—The rocks in the Edna and Pole Creek stocks in the vicinity of Beaver Creek are quartz monzonite porphyry and granite porphyry (fig. 3) and are more siliceous and potassic than the otherwise similar rocks in Eagle Basin and Coburg Basin. Both stocks intrude Elkhorn Mountains Volcanics.

The Edna stock (pl. 1, section *A–A′*) is composed of light-colored granite porphyry that contains large phenocrysts of K-feldspar. The stock and the rocks around it are cut by many quartz veins, some of which have yielded gold and lesser amounts of silver, lead, zinc, and copper. The veins are bordered by zones of intense sericitic alteration.

Rocks in the Pole Creek stock are similar to those in the Edna stock, but they contain less quartz and more plagioclase (table 1) and are quartz monzonite porphyry rather than granite porphyry. The rocks in these stocks are similar, and both are cut by many quartz veins, but many veins in the Edna stock are sulfide-bearing, whereas few in the Pole Creek stock are.

COMPOSITE INTRUSIVE BODIES

Most of the composite intrusive bodies are in the central part of the mapped area, south, west, and east of the Silver Wave stock. These bodies of Late Cretaceous and Paleocene age are strongly discordant irregular plugs, small stocks, or parts of larger subjacent bodies and consist of rocks that are indistinguishable from some of the mafic and felsic rock types already described. Whenever possible, the mafic and felsic components of the composite intrusives have been mapped separately and are identified on the geologic map (pl. 1) by the same symbols used for the same rock types in the more homogeneous intrusive masses. Contacts between the different rock types in the composite intrusives are rarely exposed, but the absence of intermediate rock types suggests that the contacts are sharp rather than gradational. In each instance where unequivocal relations could be determined, felsic rocks cut mafic rocks.

The composite intrusive bodies of the east flank of the Elkhorn Mountains are similar to the composite or hybrid intrusives in the southern part of the Elkhorn Mountains described by Klepper, Weeks, and Ruppel (1957, p. 51–52).

Limestone Hills intrusive.—The Limestone Hills composite body, cutting upper Paleozoic sedimentary rocks in sec. 20, T. 6 N., R. 1 E. (pl. 1, section *D–D′*), consists of a central mass of syenodiorite rimmed by light- to medium-gray, medium- to fine-grained chlorite granite. The contact is nowhere exposed, but as intermediate rock types are lacking, it is inferred to be sharp rather than gradational. The bulk of the intrusive is a dark-gray porphyritic olivine-biotite-pigeonite syenodiorite (fig. 3), consisting of about 30 percent pigeonite and 7 percent olivine, mostly as phenocrysts as much as 3 mm across, in a fine-grained groundmass of plagioclase, K-feldspar, and quartz. The two small tongues at the south margin of the stock are medium-dark-gray porphyritic biotite-pigeonite syenodiorite; about 20 percent of the rock is phenocrysts of pigeonite as much as 2.5 mm across; the groundmass is made up of grains less than 0.6 mm across.

The mineral composition of the single thin section of granite examined is 54 percent K-feldspar, 18 percent plagioclase, 20 percent quartz, 7 percent chlorite, and 1 percent calcite. Plagioclase (sodic andesine) tablets 0.5–0.8 mm long are intergrown with cloudy anhedral to subhedral grains of K-feldspar. Some of the tablets have a distinctly ragged appearance and appear to have been embayed along margins and twin planes of K-feldspar. Quartz is present in small anhedral interstitial grains and in micropegmatite. The mafic mineral was probably originally biotite, but it has been completely replaced by chlorite (penninite?).

Quarry Gulch intrusive.—About a mile west of the Limestone Hills intrusive the Quarry Gulch mass cuts sharply across the middle unit of the Colorado Formation in sec. 19, T. 6 N., R. 1 E (pl. 1, section D–D′) and metamorphoses it in an aureole at least a few hundred yards wide, relations suggesting that the intrusive body enlarges in depth. Most of the rock is fine-grained subequigranular chloritic quartz monzonite (fig. 3), but mafic augite-biotite-hornblende syenodiorite crops out locally at the margin. The quartz monzonite is strongly altered; cores of zoned plagioclase consist largely of aggregates of sericite and clay minerals; the more sodic rims are less strongly altered. The original mafic mineral or minerals, probably mainly biotite and perhaps including some hornblende, are completely replaced by chlorite and opaque iron oxides. The mafic minerals in the syenodiorite tend to be clustered, and large crystals of augite are partly rimmed and replaced by smaller subhedra of hornblende and biotite.

Power Gulch composite body.—The Power Gluch body cuts Elkhorn Mountains Volcanics in the central part of sec. 11, T. 6 N., R. 1 W., and consists of two mappable masses of olivine-bearing mafic rocks that partly rim a larger mass of quartz monzonite (pl. 1); similar mafic rocks in bodies too small to map crop out elsewhere along the margins. The mafic rocks are calcic syenodiorite and gabbro (fig. 3), that contain 50–70 percent mafic minerals, including olivine, hypersthene, augite, and biotite, along with subordinate plagioclase and K-feldspar. Plagioclase is notably sparse in the olivine-rich rocks. The felsic rocks of the mass are remarkably uniform quartz monzonite and closely resemble the K-feldspar-rich rocks of the granodiorite and related-rocks suite.

The typical grain size of all the rocks ranges from 1 to 2 mm. Texture of the mafic rocks and most of the felsic rocks is subequigranular to seriate; some of the lighter colored rocks have an inconspicuous porphyritic appearance owing to a tendency toward clustering of mafic minerals.

Mammoth composite body.—The Mammoth intrusive body, on the west side of Eagle Creek in the N½ sec. 28, T. 7 N., R. 1 W., cuts Elkhorn Mountains Volcanics and related older intrusive rocks and consists of monzonite and calcic syenodiorite. The monzonite is a subequigranular medium- to medium-fine-grained felsic rock. The calcic syenodiorite resembles medium- to coarse-grained mafic rocks in other mafic and composite intrusive bodies; it grades in places to a finer grained facies and appears to be chilled against the Elkhorn Mountains Volcanics and associated older intrusive rocks.

Indian Creek composite bodies.—Four small intrusive bodies of varied composition form a cluster in the Kootenai Formation north of Indian Creek in the SW¼ sec. 29 and NW¼ sec. 32, T. 7 N., R. 1 E. The intruded rocks are intensely thermally metamorphosed around and between these four bodies, and the metamorphism suggests that they are the exposed apices of a larger stock. The largest area of outcrop is syenodiorite; the sill-like projection from the south margin of this mass is olivine-biotite-augite syenodiorite. A small dike of hornblende-quartz monzonite cuts the northwesternmost small mass of syenodiorite and indicates that the felsic rocks are younger than the mafic rocks.

The mafic rocks in these small intrusive bodies are similar to the mafic rocks elsewhere along the east flank of the Elkhorn Mountains. The felsic rocks, though severely altered, appear to have been subequigranular monzonite or quartz monzonite consisting of approximately equal amounts of plagioclase (sodic andesine?) and K-feldspar, subordinate quartz (and as much as 10 percent each of epidote and opaque iron oxides. The plagioclase is strongly embayed and replaced by K-feldspar.

THERMAL METAMORPHISM

Most intrusives associated with the Elkhorn Mountains Volcanics were emplaced at relatively shallow depth into volcanic rocks or older sedimentary rocks. Visible effects of metamorphism are generally negligible adjacent to small dikes and sills. Adjacent to larger bodies, host rocks typically are baked or hardened and perhaps slightly recrystallized in zones ranging from a few inches to several tens of feet across. The most conspicuous metamorphic effect is adjacent to the Dutchman intrusive, where Paleozoic limestone has been recrystallized and notably coarsened as much as a few hundred feet from the contact.

Metamorphism adjacent to younger intrusives is much more severe, and the host rocks around some bodies have been metamorphosed in relatively broad aureoles. Adjacent to the Keating Gulch stock, for example, limestone, impure carbonate rocks, and shale have been recrystallized to marble, calc-silicate rocks, and hornfels as far as 500 feet from the nearest exposures of igneous rock. Adjacent to the Silver Wave and Lone Mountain stocks, Elkhorn Mountains Volcanics have been recrystallized to hornfels and, locally along fractures, to garnet-epidote-chlorite rock, in a zone several hundred feet wide. Lenses of skarn, some of which contain pyrite and sparse chalcopyrite, have formed in carbonate rocks adjacent to several stocks. Volcanic rocks have been converted to spotted hornfels for several hundred feet adjacent to the Vosburg stock.

The broadest metamorphic aureole and greatest intensity of metamorphism surround the Antelope Creek stock and Orphan Boy intrusive. The aureole extends at least 1,500 feet south and about a mile east of these intrusive masses. The breadth of the aureole suggests that intrusive rocks underlie a large area east of the exposed contact at relatively shallow depth. Immediately adjacent to the Orphan Boy mass, rocks of the middle member of the Elkhorn Mountains Volcanics have been converted to granular pyroxene-biotite-hornblende-plagioclase-quartz-K-feldspar rocks with an average grain size of about 0.2 mm. Farther to the east and south, Elkhorn Mountains Volcanics and Slim Sam Formation have been recrystallized to hornfels of varied composition and appearance. Nearer the intrusives the rocks are wholly or largely recrystallized to fine-grained hornfels having different combinations and proportions of hornblende, biotite, plagioclase, quartz, cordierite, muscovite, K-feldspar, and magnetite; the combinations and proportions probably depend largely on the original composition of the rock. Farther away only the finer grained components of the original rock are recrystallized; larger crystals of plagioclase and mafic minerals in the original rocks are unaffected or recrystallized only at their margins. In general, the average grain size of recrystallized rock increases toward the stock. Field relations indicate that rocks adjacent to the Orphan Boy intrusive were strongly metamorphosed by it, but that the bulk of the metamorphic aureole was formed during emplacement of the Antelope Creek stock, which affected both the volcanic rocks and the Orphan Boy intrusive.

QUARTZ LATITE PORPHYRY DIKES OF EOCENE(?) AGE

North of Beaver Creek, a dike of Eocene(?) age cuts the Slim Sam Formation, the Elkhorn Mountains Volcanics and associated intrusive rocks, the Orphan Boy dike, and the Antelope Creek stock. A short distance to the west similar dikes cut rocks of the Antelope Creek stock (H.W. Smedes, oral commun., 1966), and elsewhere in the region they cut the Boulder batholith. The dikes closely resemble and are probably related to the quartz latite Lowland Creek Volcanics (Smedes, 1962; Smedes and Thomas, 1965) of early Eocene age. The dike rocks are biotite-hornblende-quartz latite porphyry and are similar to rocks elsewhere in the region described as dacite by Knopf (1913) and by Pardee and Schrader (1933). They contain phenocrysts of plagioclase, biotite, hornblende, and subordinate quartz in a very fine grained indeterminate groundmass and are classified as quartz latite on the basis of chemical analyses of similar rocks reported by Becraft, Pinckney, and Rosenblum (1963, p. 26–28).

BASALT FLOWS

Remnants of basalt flows crop out along and near Crow Creek from Sagebrush Creek eastward. Near Cold Springs Gulch, the remnants are parts of at least two flows, for near the center of sec. 30, T. 6 N., R. 1 E., the vesicular top of one flow grades upward into a sublateritic weathered zone as much as 10 feet thick that is in turn overlain by a basalt flow having a chilled vesicular base. About a mile to the south (NW¼SW¼ sec. 31, T. 6 N., R. 1 E.), Oligocene sedimentary tuff and an overlying basalt flow are separated by 5 feet of unconsolidated prebasalt mantle that contains fragments of sedimentary tuff and angular fragments, as much as 9 inches long, of older rocks; the lower 10 feet of the flow consists of pumiceous basalt and dense glass in which are embedded many blocks of sedimentary and volcanic rocks as much as 18 inches long. The form and outcrop relations of the basalt flows suggest that they were confined to valleys that were as much as 150 feet deep.

The basalt near Cold Springs Gulch is black to dark gray and weathers reddish brown. Some of it is dense and porphyritic, some is amygdaloidal and porphyritic, and some is highly vesicular or pumiceous, glassy or finely crystalline, and conspicuously flow-banded. The dense porphyritic rocks have an intersertal groundmass of plagioclase, pyroxene, and opaque minerals, and phenocrysts of labradorite, pyroxene, opaque iron oxides (probably magnetite), and olivine(?) that is almost completely replaced by a serpentinelike or fibrous mineral. In both the vesicular and amygdaloidal rocks, the openings are rimmed by mineral aggregates that include quartz, chlorite, calcite, leucoxene(?), and one or more unidentified minerals, probably zeolites. Some specimens consist mainly of glass or devitrified glass in which are embedded microlites of plagioclase, pyroxene, and iron oxides. The basalt flows rest on Oligocene sedimentary tuff and appear to have been gently folded with the tuff. This episode of folding has not been precisely dated but probably is of late Pliocene age (Freeman and others, 1958, p. 527–528). It thus seems most probable that the basalt is late Miocene or early Pliocene, but it could be as old as Oligocene.

RHYOLITE FLOW

Scattered outcrops of rhyolite of Miocene or Pliocene age along Crow Creek near Jenkins Gulch probably are remnants of a single flow. The rock is medium gray to black, dense to sparsely vesicular, locally scoriaceous, and is sparsely porphyritic, and much of it is conspicuously flow banded. Where the base is exposed, the underlying rocks and the lower few feet of the flow are oxidized bright red. Columnar jointing is conspicuous, especially near the mouth of Weston Creek. Phenocrysts form 1 percent or less of the rock. Most of them are labradorite (An_{55}) in euhedral to rounded, partly resorbed crystals; a few are small euhedral crystals of pyroxene and an opaque mineral, probably magnetite. The groundmass ranges in texture from glassy to microgranular and contains microlites of plagioclase of undetermined composition, a mafic mineral that is probably pyroxene, and opaque iron minerals.

That the flow is a rhyolite is shown by the following analysis.

Chemical analysis and norm, in percent, of a representative sample of rhyolite flow along Crow Creek

[Analyzed by J. M. Dowd, U.S. Geological Survey. Field No. 51RW–C40, laboratory No. 53–70CW]

Chemical analysis

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
Sum	100.3

Norm

Quartz	25.0
Orthoclase	30.0
Albite	33.0
Anorthite	6.1
Corundum	1.1
Hypersthene	2.0
Magnetite	1.9
Ilmenite	.6
Apatite	.3
Sum	100.0

The plagioclase computed in the norm is oligoclase (An_{16}), whereas the phenocrysts in the rock are labradorite, about An_{55}. This discrepancy suggests that the few phenocrysts were carried up from depth and were not in equilibrium with the lava that rapidly chilled to form the groundmass. The partly resorbed form of the labradorite crystals supports this interpretation.

The rhyolite flow and the basalt flows occupy similar settings along and near Crow Creek valley and are probably of about the same age. Their relative ages, however, are indeterminate.

STRUCTURAL GEOLOGY

The structure of the mapped area (pl. 1) is simple in gross aspect but complex in detail. The layered rocks are folded into a broad syncline that trends north through the central part of the mapped area. North of Whitehorse Gulch dips are gentler, the rocks are more complexly faulted, and the fold loses its identity; south of Crow Creek the large Rattlesnake intrusive obscures and partly obliterates the fold (pl. 1, sections *D–D′*, *E–E′*). Folding in adjacent areas began before volcanism, perhaps before the end of Niobrara time and certainly before Judith River time (Klepper and others, 1957, p. 40; Freeman and others, 1958, p. 523–524), and was recurrent during and after the period of volcanism.

In the east flank area, the contact between the Slim Sam Formation and the Elkhorn Mountains Volcanics appears to be gradational and there is no evidence of prevolcanic deformation.

The folded rocks are cut by many north- and east-trending steep faults. Many of these faults displace Elkhorn Mountains Volcanics and related intrusive rocks and were formed following volcanism, during the principal episode of folding. Others, however, are occupied by dikes related to the Elkhorn Mountains Volcanics and were formed during volcanism, probably during the early stages of folding. Northwest-trending cross faults appear to have formed too, as brittle rocks failed to accommodate the folding.

The compression that produced the north-trending folds and associated faults culminated in eastward thrust faulting on the Lombard fault zone east of the mapped area (Freeman and others, 1958, p. 525), and the rocks in the mapped area were broken by northwest- and northeast-trending tear faults at about the same time. Still younger are range-front faults, along which there has been recurrent movement from pre-Oligocene time to the present (Freeman and others, 1958, p. 526–529).

FOLDS

The pre-Tertiary layered rocks between the Boulder batholith and the Missouri River (fig. 4) are folded into a series of gently plunging anticlines and synclines that trend north to N. 20° E. The mapped area (pl. 1) covers part of the flanks of the two well-defined anticlines and the intervening broad syncline. The anticline to the west is described by Klepper, Weeks, and Ruppel (1957, p. 56) and that to the east, by Freeman, Ruppel, and Klepper (1958, p. 524).

In the central part of the area, in Cold Springs Gulch, the syncline is well defined and simple. The east limb dips more steeply than the west limb, and both limbs are complicated by minor folds. North of Indian Creek the Silver Wave and Diamond Hill stocks occupy the approximate position of the trough (pl. 1, section *C–C′*). Between these stocks and the Whitehorse fault, the rocks are massive, almost structureless volcanic breccias, and the position of the trough line cannot be recognized. South of Crow Creek the rocks have been invaded and disrupted by the Rattlesnake intrusive, and the synclinal trough has been largely obliterated.

FAULTS

FAULTS ASSOCIATED WITH FOLDING

Faults that formed during folding are the oldest faults recognized in the mapped area. They include north-trending faults that parallel the axial traces of the major folds and east-trending faults normal to the trends of the folds.

The north-trending faults are the oldest faults recognized in the mapped area, and some are contemporaneous with the early part of the folding. Many of them are very steep reverse faults, and in a general way they flank the synclinal trough, a location suggesting that they formed during later stages of folding as the trough area was squeezed between the flanking anticlines. Some, however, must have formed during the early stages of folding for they are cut by younger faults or are cut or occupied by dikes related to the Elkhorn Mountains Volcanics that were intruded during early stages of folding (Freeman and others, 1958, p. 524).

A noteworthy example of these old north-trending faults is the Whitehead Ranch fault, which trends north-northwest from the vicinity of the East Pacific mine to the Antelope Creek stock. North of Beaver Creek it is mostly concealed by gravel flanking the range front. South of Beaver Creek it displaces a sill of older intrusive rock; to the north, however, it is truncated by a sheet of older intrusive rock. The displacement is greatest just north of Beaver Creek where rocks near the base of the middle member of the Elkhorn Mountains Volcanics are faulted against rocks of the Slim Sam Formation, a stratigraphic displacement of about 3,000 feet. A mile south of Beaver Creek the displacement is not more than a few hundred feet. Though the fault bounds the range north of Beaver Creek, the topographic relief and the displacement are in opposite directions, and the front of the range is a fault-line scarp.

The east-trending faults which are nearly vertical faults along the mountain front south of Winston and between Eureka Creek and Slim Sam Gulch, trend west-northwest to about east-west and displace Cretaceous sedimentary and volcanic rocks as much as 500 feet. These faults cut and are cut by north-trending faults, and thus both sets formed during the same time interval. Both are cut by all the other fault systems. The faults most probably are tensional breaks produced during folding.

Faults of similar trend displace Paleozoic and Mesozoic rocks as much as 100 feet along the north-trending ridge in the southwest corner of the area. These faults are best developed in the Quadrant Formation and are part of a system that radiates from the large dome west of the area (Klepper, and others, 1957, p. 57) and that formed during folding as brittle beds failed to accommodate. Two of these faults, just south of Johnny Gulch, displace a sill of diorite porphyry similar to the Rattlesnake intrusive mass.

Sulfide minerals, in places in minable concentrations, have been deposited along and adjacent to many east-trending faults.

NORTHWEST- AND NORTHEAST-TRENDING FAULTS

Northwest- and northeast-trending faults and lineaments are among the most prominent structural features of the east flank of the Elkhorn Mountains, for they control parts of the valleys of some of the main streams. The Indian Creek fault clearly displaces Cretaceous and older rocks southeast from the Diamond Hill stock but is recognized only as a prominent lineament to the west. The fault is vertical or nearly so, and the movement along it appears to have been principally left-lateral, for east of Hassel it displaces a steep north-trending fault about 2,000 feet. In the Limestone Hills, east of the mapped area, the fault has been described as a tear fault (Freeman, and others, 1958, p. 525).

Crow Creek parallels Indian Creek and the Indian Creek fault but is not so clearly controlled by a fault. The valley of Crow Creek and of Wilson Creek, one of its principal tributaries west of the mapped area, is almost straight for 12 miles and forms a striking lineament. But if this exceptional valley is controlled by a fault, the displacement cannot exceed a few hundred feet. Most probably it is controlled by a sheared or closely jointed zone along which there has been little if any displacement.

The Weasel Creek fault extends south-southwest from the northeast corner of the Elkhorn Mountains along upper Weasel Creek to the Kleinschmidt mine and may be continuous with a fault in Eureka Creek. The fault splits north of the Freiburg stock and may be hinged, for north of the Freiburg stock the block east of the fault has been dropped, perhaps more than 1,000 feet near the front of the range, whereas the block east of the fault in Eureka Creek has been uplifted at least a few hundred feet and perhaps as much as 1,000 feet.

The northeast-trending Whitehorse fault occupies upper Whitehorse Gulch and cuts across the spur north of Whitehorse Gulch at the front of the range. The block north of the fault has dropped 500–1,000 feet. The fault may merge with the Weasel Creek fault to the west; to the east it is cut off by the range-front fault system.

South of the Vosburg stock a steep fault that trends west-northwest and that parallels the Indian Creek fault separates rocks of the lower and middle members of the Elkhorn Mountains Volcanics. The block north of the fault has been dropped at least several hundred feet and perhaps much more. The fault terminates eastward against the Weasel Creek fault. West of the mapped area (South Fork fault of Smedes, 1966, p. 97–98) the relative displacement is about 3,000 feet, north side down, and the fault terminates westward against the Beaver Creek fault, which is subparallel with the Weasel Creek fault.

The northeast and northwest-trending faults are complementary sets that occupy theoretical shear positions for east-west compression. However, movement on many of the northeast-trending faults has been dominantly vertical rather than horizontal as would be required in the proposed model. Thus it seems likely that many of the faults were subjected to different stresses that resulted in vertical displacements after they had formed by shearing during east-west compression. Some of them may also have acted as tears during the thrusting that culminated the compressive episode (Freeman and others, 1958, p. 525–526). A few small northeast- and northwest-trending faults are cut by rocks related to the Elkhorn Mountains Volcanics, and thus they were formed early in the period of compression. Most or all the displacement along the larger faults, such as the Indian Creek and Weasel Creek faults, was later, however, for these faults displace even the youngest rocks of the Elkhorn Mountains Volcanics and related intrusions.

RANGE-FRONT FAULTS

A system of linked and branching, roughly north-trending steep normal faults cuts rocks along the front of the range between Indian Creek and the Beaver Creek fan. The principal fault (or faults) of this range-front system is covered by fan gravel; the block to the west has been uplifted at least 2,500 feet, for in sec. 8, T. 7 N., R. 1 E., the middle part of the Kootenai Formation is faulted against rocks of the lower member of the Elkhorn Mountains Volcanics. Recurrent displacement along some of these faults was an important factor in outlining the basin (now the valley of the Missouri River) in which Oligocene and younger sediments were deposited, and the range was lifted again along some of there faults after the youngest rocks and unconsolidated sediments in the valley had been deposited (Freeman and others, 1958, p. 527–529). The youthful appearance of the range front suggests that much of the displacement occurred in late Pliocene or early Pleistocene time. In a few places there are faint suggestions of north-trending scarps in fan gravel of probable Pleistocene age east of the range front, but there is no indication that younger Pleistocene or Holocene fans have been displaced.

OTHER FAULTS

On the south side of Indian Creek west of Diamond Hill, faulted welded tuff and other rocks of the middle member of the Elkhorn Mountains Volcanics form a graben within rocks of the lower member. The displacement along the faults that bound the graben need be no more than 500 feet, for the surrounding rocks are probably within 500 feet of the top of the lower member of the formation and the rocks in the graben are the basal part of the middle member. The proximity of the graben to the Silver Wave stock and its outliers suggests that the graben may have formed by collapse of part of the roof of a magma reservoir.

A few other faults have no apparent relation to regional structures, and probably are related to nearby intrusive bodies. The sedimentary and volcanic rocks within and next to the Rattlesnake intrusive body, for example, are cut by many short faults of diverse trend. These faults almost certainly were formed during the emplacement of the body, for they are restricted to the rocks near the body and are not part of the regional pattern. Most of these faults are truncated by the nearby intrusive, but a few of them displace the intrusive. Most complexly faulted are isolated remnants of sedimentary rocks surrounded by intrusive rocks, within which displacements of several hundred feet occur. Most of the blocks within the intrusive probably were septa between sill-like bodies during the early stage of emplacement and were severely disrupted during a later more forceful stage of emplacement; some may have been carried up by magma that rose along a north-trending feeder dike or dikes, and some may have foundered from the roof.

Small faults near the mafic intrusive along the ridge south of Jenkins Gulch may be associated with the emplacement of the mafic intrusive or with the emplacement of the South Fork stock.

SUMMARY OF LATE CRETACEOUS AND TERTIARY TECTONICS

The Elkhorn Mountains, of which the present study area is a part, were the site of marine sedimentation during much of Paleozoic time, but beginning in Mesozoic time they began to emerge and be covered by nonmarine sediments. The margin of the seas advanced and withdrew across the area several times during the Cretaceous, as indicated by several alternations of marine and nonmarine rocks.

Folding and volcanism within or near the area are first recorded in rocks of the Slim Sam Formation which contains shardlike quartz crystals and feldspar crystals and which locally was weakly folded before the Elkhorn Mountains Volcanics were erupted, mainly or entirely during Campanian time. Faulting and locally weak folding accompanied volcanism, but the main episode of folding and most of the faulting followed volcanism. In the Elkhorn Mountains and nearby the major folds trend about north and presumably resulted from east-west compressive forces. A single broad troughlike fold covers most of the mapped area. It is cut by many faults that developed at several different stages, some during and some subsequent to folding. Intrusive masses are abundant in the trough of the fold; the earliest of these are hypabyssal bodies related to the Elkhorn Mountains Volcanics; many of them are concordant or partly concordant and were probably injected during the initial stages of folding.

Many faults formed during folding as rocks in the trough were squeezed between adjacent anticlinal or domal folds. Steep north-trending normal and reverse faults are occupied or cut by older intrusives, and these relations indicate that they formed during an early stage of folding. East-trending faults of about the same age appear to represent failure of brittle rocks in tension. Some north and east-trending faults displace intrusive rocks related to the volcanics; others appear to control the margins of such bodies; many contain concentrations of sulfide minerals. The evidence indicates that the faults are of several different ages, or that if all were formed at about the same time, different ones were later reactivated.

The conjugate shear directions for eastward-directed compression is represented by extensive northwest- and northeast-trending faults. The northwest-trending faults are well developed; horizontal motion is indicated along a few, and vertical movement is dominant along most. One of the northwest set of faults becomes a tear fault associated with eastward displacement on the Lombard fault, a major thrust east of the present map area. Dominant movement along the northeast-trending fault appears to have been vertical. The pattern of faulting established during folding and the emplacement of the older intrusives established structural blocks which have responded individually to subsequent regional and local stresses.

The younger intrusives were emplaced after the folding and related faulting. Some of them appear to occupy zones of weakness developed during the deformation. These show little evidence of forceful injection; directed textures are present only locally along the margins of a few of the larger bodies.

The east front of the Elkhorn Mountains is partly bounded by a system of north- to northwest-trending linked faults, along which the mountains appear to have been elevated repeatedly, and east of which a major basin developed during Tertiary time. This fault system is complex and may represent the integrations, at least in part, of a number of preexisting faults.

MINERAL DEPOSITS

HISTORY AND PRODUCTION

The east flank of the Elkhorn Mountains (fig. 4) has been a significant, but intermittent, source of metallic minerals since about 1866. The total recorded value of metal produced there through 1956 is about $17 million and is distributed as shown in table 2. Gold accounts for about 75 percent of the total value of the metals produced; perhaps as much as 10 percent of this was won from placers at Radersburg, along Indian Creek, and along Weasel Creek; the remainder was from lodes. More than 40 percent of the total value is accounted for by gold from the Radersburg (Cedar Plains) district,

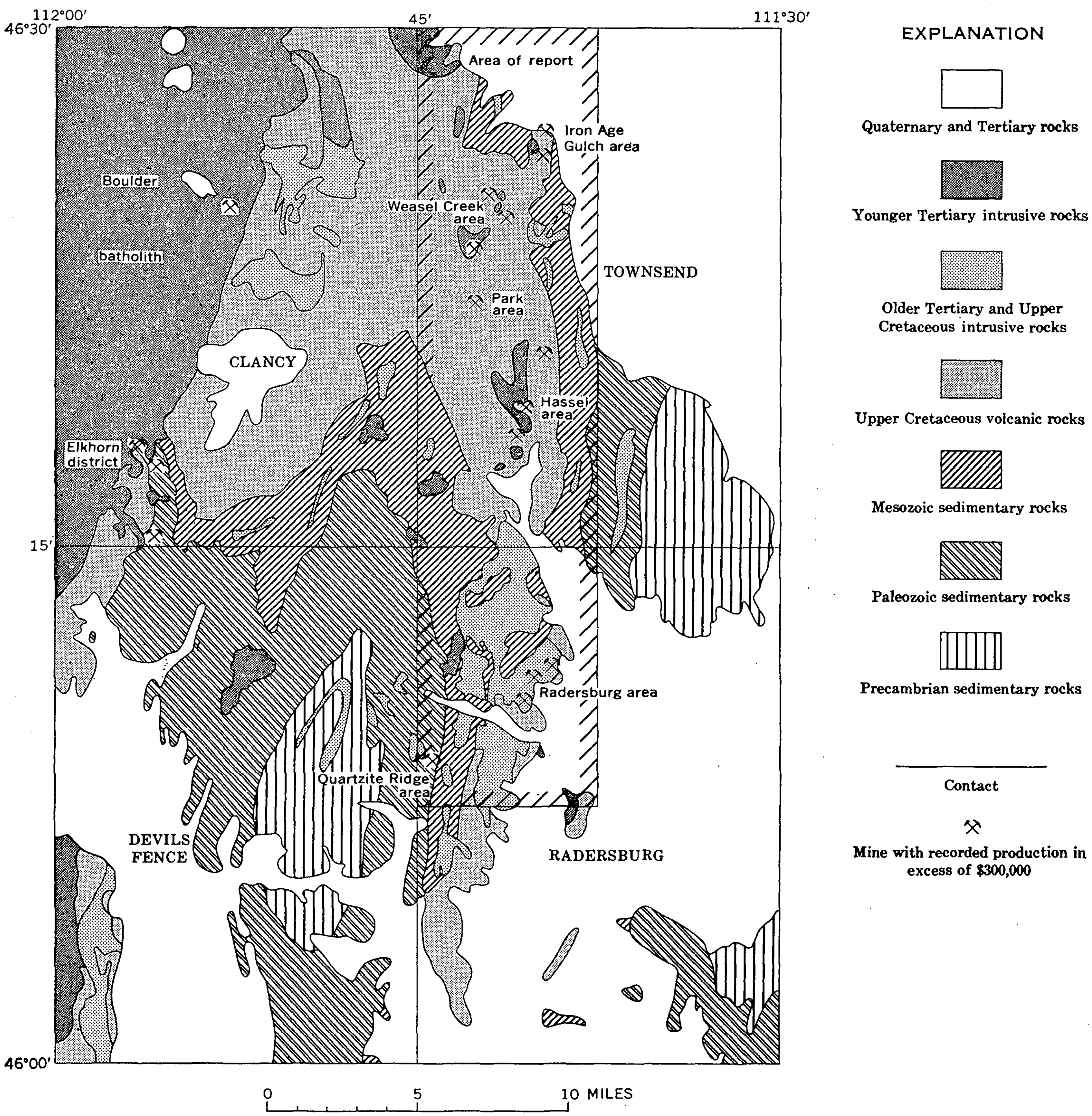

FIGURE 4.—Principal mines and mining areas in Clancy, Townsend, Devils Fence, and Radersburg quadrangles.

TABLE 2.—*Summary of mine production, east flank of Elkhorn Mountains*

[Data from Reed (1951), Stone (1911), Winchell (1914), Pardee and Schrader (1933), Corry (1933), Trauerman and Waldron (1940), Reyner and Trauerman (1950), U.S. Geol. Survey (1883–1923), and U.S. Bur. Mines (1924–31, 1932–53)]

District	Period	Gold (dollars)	Silver (ounces)	Lead (tons)	Zinc (tons)	Copper (tons)	Total value
Beaver Creek [1]	1864–1904	$1, 750, 000	730, 000	2, 050	0	0	$2, 500, 000
	1905–28	250, 000	175, 000	950	0	25	500, 000
	1929–56	750, 000	300, 000	2, 400	500	75	1, 500, 000
	Total	2, 750, 000	1, 205, 000	5, 400	500	100	4, 500, 000
Cedar Plains [2]	1864–1904	2, 200, 000	No data	70	0	140	2, 310, 000
	1905–28	3, 000, 000	180, 000	2, 530	0	1, 170	3, 820, 000
	1929–56	2, 700, 000	80, 000	650	250	50	3, 000, 000
	Total	7, 900, 000	260, 000	3, 250	250	1, 360	9, 130, 000
Park and Hassel [3]	1864–1904	850, 000	50, 000	0	0	0	900, 000
	1905–28	50, 000	25, 000	220	100	40	100, 000
	1929–56	1, 250, 000	175, 000	2, 000	1, 250	10	2, 200, 000
	Total	2, 150, 000	250, 000	2, 220	1, 350	50	3, 200, 000
	Grand total	12, 800, 000	1, 715, 000	10, 870	2, 100	1, 510	16, 830, 000

[1] Mainly mines in Iron Age Gulch and Weasel Creek areas.
[2] Mainly mines in Radersburg area and Quartzite Ridge area.
[3] Mainly mines in Park and Hassel areas.

primarily from the Keating mine. Mines in the Winston (Beaver Creek) district, principally those in Iron Age Gulch and Weasel Creek, contributed about 30 percent of the total value in gold, silver, lead, and subordinate amounts of zinc and copper. Most of the remaining 30 percent is accounted for by gold and, to a lesser extent, by silver and lead from mines in the Park and Hassel districts, by silver and lead from mines in the Quartzite Ridge area, and by byproduct copper from the Keating gold mine at Radersburg.

The initial mineral discoveries in the area were placer gold at Radersburg, Weasel Creek, and Indian Creek in 1866 and 1867. Intensive placer mining in these three areas during the next 10–15 years, intermittent small-scale operations thereafter, and mechanized operations along Indian Creek during the 1940's yielded gold worth at least $1 million and perhaps as much as $2 million. Some of the large lode deposits—the Keating, Diamond Hill, and East Pacific—were discovered shortly after the placers were found, and most of the more productive lode deposits were known before 1900.

The Keating mine west of Radersburg was long famous for its gold ores. Other principal gold mines along the east flank of the Elkhorn Mountains include the Ohio Keating and Black Friday near Radersburg, the Diamond Hill, Giant group, and Blacksmith in the Hassel district, the Custer-Iron Age-Hyantha group in Iron Age Gulch, and the Marietta in the Park district.

Some mines have yielded complex ore from which gold, silver, and lead, and small quantities of zinc and copper have been recovered. Perhaps the principal mine of this type is the East Pacific on Weasel Creek, from which ore valued at more than $2 million has been mined (Reed, 1951). Other mines that have produced noteworthy quantities of a similar type of ore are the January, Kleinschmidt (Little Olga), Stray Horse, and mines of the Custer-Iron Age-Hyantha group.

Some mines have produced ore valuable mainly for silver and lead. Important among these are the Jo Dandy, North Home, and Santa Anita, in the Quartzite Ridge area. The Ruby mine in the same area has yielded oxidized zinc-lead ore.

Different lode mines have been productive at different times since about 1870. The greater part of the production from the Beaver Creek district was before 1904, from the Custer-Iron Age-Hyantha group, the East Pacific mine, and the Kleinschmidt group; in recent years the January mine and the East Pacific mine dumps have yielded most of the ore reported from the district. Most of the production from the Park district before 1930 was gold from the Diamond Hill, Blacksmith, and Giant group mines; since 1930 the Marietta mine has been the largest and the most consistent producer. The Radersburg (Cedar Plains) district is noteworthy for gold from mines at Radersburg, particularly from the Keating mine which has accounted for more than half the output of gold from the district and for most of the copper. Mines in the Quartzite Ridge area, the Jo Dandy, North Home, Santa Anita, and Ruby, have yielded most of the lead and silver from the district. In recent years a deposit of titaniferous magnetite near Radersburg has been mined on a small scale.

TYPES OF METALLIC MINERAL DEPOSITS

The metallic mineral deposits of the area are assigned to the groups listed below:

- Auriferous pyrite veins (quartz-poor).
- Quartz veins with auriferous pyrite.
- Quartz veins with base and precious metals.
- Silver-lead-zinc replacements in carbonate rock.
- Skarn deposits.
- Titaniferous iron ore.
- Gold placers.

Most of the deposits (fig. 5) in the Radersburg and Hassel areas are auriferous pyrite veins with only minor quartz; the deposits in the Beaver Creek area are quartz veins with auriferous pyrite and quartz veins with base and precious metals. The silver-lead-zinc replacement deposits are mainly in the Quartzite Ridge area. Skarn deposits are small and scattered. Deposits of titaniferous iron deposits of economic interest are known only near Radersburg. Gold placers have been worked near Radersburg and along Indian and Weasel Creeks.

Most of the important veins trend near north or near east and are steep, but some veins in the Park and Iron Age Gulch areas dip gently. Recurrent movement took place along most veins during and after mineralization; some veins have been brecciated and then healed by two or more generations of quartz and sulfide minerals, and in some veins brecciated ore is incorporated in gouge.

Most of the vein deposits are clustered in the vicinity of bodies of younger intrusive rock, and some veins cut these intrusives. Accordingly, a genetic relationship between the intrusives and the veins is inferred. A further correlation between type of vein and type of intrusive rock is suggested. South of the Silver Wave and Diamond Hill stocks the younger intrusives are intermediate in composition, medium-grained equigranular, virtually lacking in phenocrysts, and are cut by almost no aplite and pegmatite dikes or quartz veinlets; in this area most of the veins consist of altered rock with auriferous pyrite and very little quartz and are enclosed by strongly altered rocks. North of the Silver Wave stock the intrusives tend to be more felsic and porphyritic, contain large K-feldspar phenocrysts, and are cut by many quartz veins and veinlets and by small aplite and pegmatite dikes; the mineralized veins in this area contain quartz as the principal gangue, and many contain galena, sphalerite, chalcopyrite, arsenopyrite, and tetrahedrite in addition to pyrite. Alteration halos adjacent to veins generally are narrower than they are to the south. Genetic relationship of vein type to intrusive rock type is most strongly suggested in the Hassel area where the Silver Wave stock and surrounding volcanic rocks are cut by abundant quartz-poor auriferous pyrite veins, whereas the nearby more felsic Diamond Hill stock is cut by quartz veins with auriferous pyrite and by quartz veins with base and precious metals, but it lacks quartz-poor auriferous pyrite veins.

AURIFEROUS PYRITE VEINS (QUARTZ POOR)

Steep veins that contain auriferous pyrite, sparse marcasite, very sparse chalcopyrite, and traces of pyrrhotite, galena, sphalerite, and chalcocite have been the principal source of gold in the Radersburg and Hassel areas. The veins are a few inches to several feet wide and a few hundred to at least 2,500 feet long. The Keating vein has been explored to a depth of about 1,200 feet. Simple veins consist of discontinuous bands of pyrite sheathed by altered rock along a single fracture. In more complex veins, stringers and pods of pyrite occur in a zone of sheared and strongly altered rock as much as 20 feet wide. Quartz and calcite, or other carbonate minerals, are sparse and erratically distributed as gangue. Rock within and adjacent to the veins is silicified, sericitized, kaloinized, and pyritized. Replacement has been more important than fracture filling. The veins are associated with younger intrusive bodies of nonporphyritic granodiorite and related rocks that contain few or no aplite dikes or quartz veins.

In the zone of oxidation, which in places is at least a few hundred feet deep, the pyrite is largely altered to iron oxides, and the veins are aggregates of varicolored iron oxides, locally with sparse manganese oxide and flecks or films of secondary copper minerals; the pyritized wallrocks are bleached almost white. In the Radersburg district, where veins are abundant and oxidation intense, most of the rock in an area a mile long by one-half a mile wide is altered and bleached (pl. 1).

Many veins were profitably mined in the oxidized or partly oxidized zone, but only a few veins, such as the Keating and Ohio Keating, were profitably worked beneath this zone. This strongly suggests that oxidation significantly improved the grade of ore, but available assay data are too few to support any quantitative estimate. In the Radersburg area, at least, much or most of the oxidation was pre-Oligocene, for Oligocene sedimentary rocks overlie the oxidized part of the Keating vein (Winchell, 1914, p. 182). This fact is of possible economic importance; for if similar veins exist beneath the relatively thin blanket of Tertiary sediments south of the Radersburg district, the chances are good that they are oxidized.

QUARTZ VEINS WITH AURIFEROUS PYRITE

Gold veins north of the Hassel area are distinctly different from those farther south. They consist mainly of quartz but contain auriferous pyrite, locally in

No.	*Mine*
1	Orphan Boy
2	Gold Bug
3	Custer
4	Edna No. 2
5	Hyantha
6	Iron Age
7	Maine
8	Sunshine
9	Monte Cristo
10	Freiburg
11	Silver Saddle
12	East Pacific
13	January
14	Sunrise
15	Stray Horse
16	Little Bonanza
17	Vosburg
18	Kleinschmidt (Little Olga)
19	Champion
20	Big Chief
21	Vulture
22	Marietta
23	Bullion King
24	Little Annie
25	Jawbone
26	Park-New Era-Venezuela
27	Parker
28	Shep
29	Buckeye
30	Phoenix
31	Iron Mask
32	John L
33	Lookout
34	Mammoth
35	St. Louis
36	Queen Bee
37	Silver Wave
38	Central
39	Spring Hill
40	Diamond Hill
41	Little Giant
42	Blacksmith
43	Bluebird
44	Monarch
45	Quartzite
46	Horn Silver
47	Rothfus
48	Iron Cross
49	Jebro
50	Rena
51	North Butte
52	Black Bear
53	Beauty
54	Surprise
55	Delome
56	Hidden Treasure
57	Greenhorn
58	Ohio-Keating
59	Keating
60	Etta
61	Hard Cash
62	Kahoka
63	North Home
64	Congress
65	Iron Age (Allen)
66	Black Friday
67	Bluebird
68	Gopher
69	Cyclone
70	Jo Jo
71	Jo Dandy
72	Gold Cross
73	Santa Anita
74	Ruby (Ruby Silver)
75	Monterey
76	Ralls

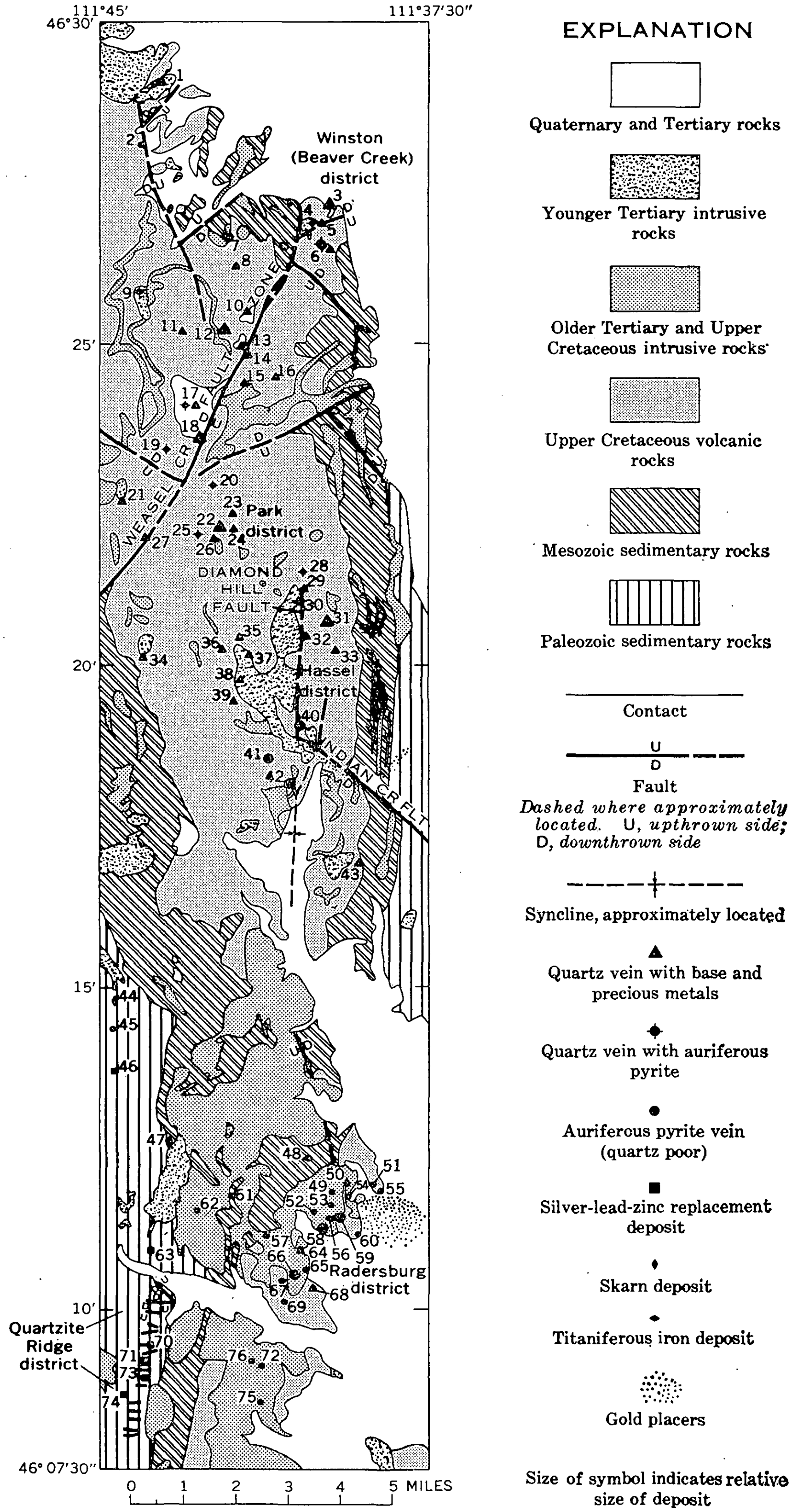

FIGURE 5.—Distribution of metallic mineral deposits along the east flank of the Elkhorn Mountains. Geology generalized from plate 1.

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abundance, and in places ankerite or another carbonate mineral. Some veins contain a little molybdenite and chalcopyrite, and a few contain sparse arsenopyrite, galena, and sphalerite. Veins of this type are mainly and perhaps entirely fissure fillings, and most of them are frozen to their walls. Many veins are less than a foot thick, but a few veins locally are as much as 4 feet thick. They occupy fractures of diverse trend, most of which dip less than 30°; none were observed to dip more steeply than 45°. In several places veins of this type are cut by steeply dipping base- and precious-metal veins; the reverse relationship has not been observed. Veins of this type have been important sources of gold in the Iron Age Gulch area and have yielded some gold in the Weasel Creek and Park mining areas; much of the gold has been from oxidized or partly oxidized parts of veins. Most of the veins of this type are associated with felsic intrusive rocks that are porphyritic and that are cut by numerous quartz veins and stringers.

QUARTZ VEINS WITH BASE AND PRECIOUS METALS

Many veins in volcanic and intrusive rocks north of Indian Creek and a few south of Indian Creek contain gold and silver and most or all of the following metallic minerals: pyrite, galena, sphalerite, arsenopyrite, chalcopyrite, and tetrahedrite. Such veins characteristically are associated with felsic intrusive rocks that are cut by aplite dikes and quartz veins and stringers. The amount and proportions of the minerals differ from vein to vein: for example, veins of this type at the Marietta mine are valuable mainly for gold; at the Iron Mask, for zinc and lead; at the Kleinschmidt, for silver, lead, and zinc; and at the January and East Pacific, for lead, silver, gold, and zinc. Quartz is the common gangue mineral and is abundant in some veins. Many veins contain small quantities of a carbonate mineral as well, most commonly probably ankerite, but in some veins it is siderite, in some veins, calcite, and in some veins, dolomite. The veins are mainly replacement deposits and partly banded fracture fillings in silicified, sericitized, argillized, and pyritized rock. Typically, they consist of broken altered rock laced with lenses and stringers of sulfides, gangue minerals, and gouge, but in places they are clean-cut fracture fillings accompanied by little or no gouge. Recurrent fracturing during and after mineralization has brecciated many of the veins.

Veins of this type are as much as several feet thick and a few thousand feet long; a few have been mined through a vertical distance of 600 or 700 feet. Most ore bodies were only a few feet thick and a few tens or a few hundred feet long, but in the East Pacific mine an ore body of this type was about 1,500 feet long and was mined to a depth of 700 feet (Reed, 1951, pl. 13). Some of the veins have been enriched by oxidation, but many have been profitably mined well beneath the zone of oxidation.

SILVER-LEAD-ZINC REPLACEMENTS IN CARBONATE ROCKS

Replacements in limestone and dolomite of the Quadrant Formation and Mission Canyon Limestone have been explored south of Johnny Gulch. The deposits are lenticular or pipelike aggregates of galena, sphalerite, and pyrite, or their oxidation productions, in a gangue of cryptocrystalline quartz (chalcedony and jasper) and calcite or dolomite. A few contain a little barite. Most of the deposits have been mined only in the zone of oxidation or partial oxidation where iron oxides, cerussite, smithsonite, and subordinate amounts of secondary minerals of lead and zinc (hemimorphite, anglesite, pyromorphite, wulfenite, and probably others) strongly predominate over sulfide minerals.

The deposits are localized along steep east-trending fractures. In the Quadrant Formation most of the deposits are steeply plunging pipelike bodies in dolomite beds. The few ore bodies in the Mission Conyon Limestone are irregularly shaped lenses in limestone beds or in premineral collapse breccias adjacent to or between steep fractures. Pipes or lenses are from a few square feet to a few hundred square feet in cross section and are as much as a few hundred feet in length.

A few small deposits (Nada, Buckhorn) in the Quadrant Formation are similar in habit and control to these replacement deposits, but the ore is porous iron oxide that contains free gold and little or no silver, lead, or zinc.

SKARN DEPOSITS

In a few places, particularly at the margin of the Keating Gulch stock, limestone and associated beds have been converted to masses of coarse-grained silicate minerals, mainly garnet, epidote, vesuvianite, quartz, and calcite. Some of these skarns contain magnetite, hematite, pyrite, pyrrhotite, chalcopyrite, and secondary iron and copper minerals. The largest known body of this type, at the Rothfus mine, yielded a few thousand tons of partly oxidized copper ore.

Volcanic rocks in the lower part of the Elkhorn Mountains Volcanics adjacent to the Silver Wave stock have been hornfelsed and locally replaced by coarser textured aggregates of epidote, chlorite, quartz, garnet, and pyrite that resemble skarn and locally contain gold and scheelite. Most of the coarse-textured silicate rock is along fractures in a zone of intensely fractured rock near the intrusive contact. The distribution of these silicate rocks and the intimate intergrowth of pyrite and scheelite with the silicate minerals suggest that they and the associated metallic minerals are genetically related to the Silver Wave stock. The silicate rock and the stock are cut by many pyritic gold veins, some of which contain scattered crystals of scheelite, and by a few small base- and precious-metal veins.

TITANIFEROUS IRON ORE

Lenticular beds of titaniferous magnetite are locally present in the middle of the Slim Sam Formation. These beds are thought to be lithified beach concentrations deposited as the Late Cretaceous sea withdrew, probably in Niobrara time. In the vicinity of Radersburg, ore has been mined from a slightly metamorphosed deposit of this type near the margin of the Rattlesnake intrusive body; these magnetite-bearing rocks are distinctly harder, tougher, and of higher grade than those at other localities. Though the magnetite grains appear to be detrital, some recrystallization and perhaps even some migration of iron probably took place during thermal metamorphism. Samples of the ore contained 43.1 and 44.1 percent Fe and 9.6 and 9.3 percent TiO_2. Most of the titanium is probably in solid solution in the magnetite (titanomagnetite), for neither exsolved ilmenite nor any other titanium minerals were recognized in the few polished and thin sections examined.

GOLD PLACERS

Gold placers have been mined at several places. South and west of Radersburg, a pediment of probable late Pliocene age is veneered by gravel and is cut by a network of shallow gravel-filled channels (pl. 1), many of which have yielded placer gold. The age of the gold-bearing gravel probably ranges from late Pliocene to Holocene. The source of the gold is the numerous oxidized veins that crop out in the low hills that border the placer area to the west.

The placer gold along Indian Creek, in the mapped area, is mainly in remnants of gravel terraces of probable late Pleistocene age that border the present channel of the creek, and partly in the present channel gravels. East of the area, gold is in gravel-filled channels on a pediment of probable late Pliocene age as well as in gravel terraces along the present stream. The source of the gold is veins in the Park and Hassel areas.

Placer gold also was recovered from postglacial gravel along the present stream channels of Weasel and Beaver Creeks.

OXIDATION AND ENRICHMENT

At least one-third and perhaps more than one-half of the total value of metal produced from the area has been from oxidized or partly oxidized ore; oxidized veins yielded most of the ore mined before 1900 and part of the ore mined since. In the Radersburg district only the Keating and Ohio Keating auriferous pyrite veins sustained profitable operations beneath the zone of oxidation. In the Park, Weasel Creek, and Iron Age Gulch areas the importance of oxidation on the quartz veins with auriferous pyrite and the base- and precious-metal veins was not so great, but nevertheless it seems certain that the most profitable mines (East Pacific, Custer-Hyantha-Iron Age groups, Kleinschmidt) were mostly in oxidized ore. Though unoxidized ore bodies or parts of ore bodies were profitably mined from these and other mines, most of them were relatively small and the grade of ore was generally lower than that in the oxidized zone.

Most deposits are oxidized or partly oxidized to a depth of at least 100 feet, and some are largely oxidized to depths of several hundred feet. Winchell (1914, p. 173) reported that the Keating vein was oxidized to a depth of 175 feet and partly oxidized for an additional 59 feet. The East Pacific vein is reported to be oxidized to a depth of about 300 feet (Pardee and Schrader, 1933, p. 219). The importance of oxidation was probably twofold: gold was liberated from the pyrite with which it was associated in primary ore, and thus recovery was facilitated; and the grade of ore was increased by removal of pyrite, sphalerite, and arsenopyrite. Furthermore, liberation of gold during oxidation was a necessary first step in the formation of placer deposits.

Much of the ore in the silver-lead-zinc replacement bodies in the Quartzite Ridge area also is oxidized. For example, the unusually rich ore from the Jo Dandy mine was mainly lead carbonate, and virtually the entire output of the Ruby mine has been secondary minerals of zinc and lead.

The history of oxidation in the area is complex and imperfectly known. In the Radersburg area, and perhaps elsewhere, the veins were oxidized in latest Cretaceous and early Tertiary time and subsequently covered, at least in part, by Oligocene (and Miocene?) sediments. This cover has been eroded from the productive part of the Radersburg area in relatively recent time (late Pliocene? to Holocene), but oxidized veins may lie beneath the Tertiary cover farther south. North of Indian Creek, some veins have probably been exposed to weathering and oxidation since latest Cretaceous or early Tertiary time.

DESCRIPTION OF DEPOSITS

IRON AGE GULCH AND WEASEL CREEK AREAS (WINSTON AND BEAVER CREEKS)

The Iron Age Gulch and Weasel Creek areas include most of the deposits that are referred to the Winston region or district (fig. 5) or the Beaver Creek district of earlier reports (Reed, 1951; Pardee and Schrader, 1933; Stone, 1911; U.S. Geol. Survey, 1883–1927; U.S. Bur. Mines, 1925–32, 1932–56; Earll, 1964; Schell, 1963). As the principal ore deposits in these two areas have been described by Pardee and Schrader (1933, p. 211–277), Earll (1964, p. 4–29), and Schell (1963), only a resumé of pertinent features is given here. Earll (1964, p. 30–43) also described the results of a geochemical survey of the Winston district.

Most of the deposits in both areas are fissure veins adjacent to or within stocks of quartz-rich felsic intrusive rocks. The mines in the Iron Age Gulch area cluster around the Edna stock and have yielded ore from steep base- and precious-metal veins and from gently dipping gold-bearing quartz veins with auriferous pyrite. In the Weasel Creek area the greater part of the ore has been from steep east-trending base-and precious-metal veins, but some ore has also been mined from quartz veins with auriferous pyrite; these mines are near several stocks, of which the Vosburg is the largest.

Mineralogy of the veins is fairly uniform. The gently dipping veins consist of limonite-stained quartz and a little pyrite at the surface and, where less affected by weathering, of clear glassy quartz with pyrite. The veins appear to heal fractures and contain little or no gouge. The steep veins contain pyrite, argentiferous galena, sphalerite, subordinate chalcopyrite and arsenopyrite, and sparse tetrahedrite in a gangue of quartz and locally carbonate minerals. Gold is present, probably mostly in pyrite. Much of the ore mined from these two areas was oxidized. Pardee and Schrader (1933, p. 214–215) reported that most of the oxidized ores were valuable mainly for gold and that in the unoxidized ores "gold appears to be carried mostly by pyrite, but its distribution is irregular" and that "silver is associated mainly with the galena."

These veins have been explored over a vertical distance of 3,400 feet, from an altitude of 4,250 feet at the bottom of the Custer mine (Reed, 1951, fig. 12) to an altitude of 7,650 feet along the outcrop of the Little Olga vein (Kleinschmidt mine); the deepest workings on a single vein, about 750 feet, are at the East Pacific mine. Most ore shoots do not exceed a few hundred feet in length and depth and a few feet in thickness; a few are much longer and deeper, but, except for small local bulges, none has exceeded 5 feet in thickness. An ore shoot in the East Pacific mine was almost completely stoped for a length of 1,200–1,500 feet through a vertical distance of 400 feet, mainly in the oxidized zone, and was partly stoped for 300 feet below this in the sulfide zone (Reed, 1951, fig. 13). Vein thickness in most places did not exceed 2 feet and in some places was a foot or less. A longitudinal section of the Custer mine (Reed, 1951, fig. 12) suggests that an ore shoot, or several closely spaced ore shoots, in the Custer vein was of comparable size.

Most of the mines are wholly or partly inaccessible, and consequently little information could be obtained on the characteristics of veins and ore shoots at depth except in the Kleinschmidt (Little Olga) mine. In this mine a long south-trending crosscut adit was driven to explore several east-trending steep veins at depth (Pardee and Schrader, 1933, pl. 31). The Little Olga vein, which yielded partly oxidized silver-lead-gold ore within 250 feet of the surface, was intersected at a depth of 500–750 feet below the outcrop. A level was driven 400 feet along the vein from the intersection, and a raise at least 180 feet long was driven on the vein. In these workings the vein was 2–4 feet thick and consisted of altered rock and gouge cut by stringers of pyrite, sphalerite, and galena. Only a few small pockets of ore were rich enough to be mined. Several other veins were intersected by the crosscut, but they were too narrow or of too low grade to be mined. None of them could be correlated with certainty with veins near the surface above the crosscut (Irish Syndicate, Cynosure, Harmony, and two unnamed veins shown on pl. 31 of Pardee and Schrader, 1933).

A map published by Reed (1951, fig. 13) suggests that the East Pacific ore shoot pinched and became discontinuous below the No. 4 adit (about 400 ft. below the outcrop and 100 ft. below the bottom of the oxidized zone as reported by Pardee and Schrader, 1933) and was less than 200 feet long on the bottom level of the mine, about 300 feet below the No. 4 adit.

CUSTER MINE (3)[2]

The largest mine in the Iron Age Gulch area, the Custer, explored a steep base- and precious-metal vein that trends N. 30° E. Ore was mined from a single shoot 2,400 feet in length (Mrs. Charles Muffly, oral commun.; see also Reed, 1951, fig. 12). Gold was the principal metal produced. The vein cuts the Edna stock and the Elkhorn Mountains Volcanics, but the ore shoot was confined to that part of the vein in the volcanic rocks. The mine was operated through two vertical shafts and an adit. It was largely inaccessible in 1952, and only a small part of the adit level was examined. Where seen, the vein comprises two splits striking about N. 30° E.; the east split is about vertical, and in a 12-inch width it contains chiefly pyrite and smaller amounts of galena, arsenopyrite, chalcopyrite, and sphalerite in brecciated quartz and a carbonate mineral (ankerite?). Gouge along the vein walls contains brecciated sulfides and

[2] The number in parentheses following each mine name is the number of that mine on plate 1 and in figure 5.

fragments of altered andesite. The west split dips 48°–65° NW. and consists of brecciated andesite, gouge, and, locally, of brecciated sulfides.

EDNA NO. 2 MINE (4)

Most of the shallow workings in the Iron Age Gulch area apparently explored gently dipping gold-bearing quartz veins that cut granite porphyry of the Edna stock. One of the workings on the Edna No. 2 claim (pl. 2) illustrates many of the features seen in the workings that were examined. In this adit, the continuity of any single gently dipping vein is difficult to prove because of the many steep faults. Displacements on the faults are small, but are enough to hinder systematic mining. Similar gently dipping veins somewhat less disrupted by faults were developed on the adjacent Edna claim. The veins typically are one-half to 8 inches thick, and the gold content reportedly ranges from a trace to a few ounces per ton.

HYANTHA MINE (5)

The Hyantha mine yielded lead, zinc, silver, and gold from a base- and precious-metal vein that trends N. 50°–70° E. and dips 60° N. to vertical. The vein cuts several gently dipping quartz veins with auriferous pyrite. The vein is explored by a 340-foot-deep vertical shaft and by two adits. At the shaft collar, the vein is as much as 4 feet wide, occupies a fault in the Elkhorn Mountains Volcanics, and consists of pyrite, galena, and sphalerite in brecciated quartz and abundant gouge. A short distance west of the shaft, the vein cuts into the Edna stock and probably continues as one or more of the barren northeast-trending, steeply dipping faults in the Edna No. 2 mine (pl. 2).

EAST PACIFIC MINE (12)

The East Pacific mine, the most productive mine in the Weasel Creek area, yielded ore having an estimated value of more than $2 million (Reed, 1951, p. 38, fig. 13). It was largely inaccessible in 1952. The mine exploited a vein that trends N. 65°–80° E., dips 65°–85° N., and cuts the Elkhorn Mountains Volcanics near the Freiburg stock of porphyritic quartz monzonite. The vein is a filled fracture that has banded structure and is accompanied by minor replacement in the adjacent wallrock. Vein width ranges from a few inches to several feet. The vein contained several shoots of base- and precious-metal ore, within which were narrow chimneys of high-grade gold ore. The principal ore minerals were argentiferous galena, auriferous pyrite, sphalerite, and smaller amounts of chalcopyrite and tetrahedrite in a gangue of quartz and one or more carbonate minerals.

JANUARY MINE (13)

The January mine exploited a base- and precious-metal vein for a length of 450 feet and over a vertical distance of about 400 feet. The vein trends N. 70°–90° W. and dips about 40°–70° N. (pl. 2). Ore has been mined from a discontinuous shoot that rakes to the east and is as much as 160 feet long. West of the ore shoot the January vein has not been identified with certainty, but a number of faults along the projected strike of the vein contain brecciated sulfides and altered rock. The ore ranges in thickness from a few inches to about 4 feet and typically is 12–18 inches thick in a vein that is 1–15 feet thick and consists of altered and broken rock laced with strands of gouge and with lenses and stringers of sulfide and gangue minerals. Postmineralization movement along the vein is indicated by brecciated sulfides and thick gouge. Sulfide minerals are pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, and arsenopyrite. The gangue is quartz and rhodochrosite. Minerals in the oxidized ore include limonite, cerussite, pyromophite, pyrolusite, and gold. Reed (1951, p. 39) reported the average metal content of the ore to be: copper, 0.11 percent; lead, 5.0 percent; zinc, 3.4 percent; silver, 5.3 oz (ounces) per ton; gold, 0.108 oz per ton.

A second vein, the Montana-Idaho, was explored for a short distance on the No. 1 level. This vein trends N. 70°–90° E., dips 60° N. to vertical, and appears to be offset by the January vein. It differs from the January vein in containing abundant arsenopyrite and pyrite and little galena or sphalerite. Both veins cross the contact between the Elkhorn Mountains Volcanics and the January stock, and the January vein contains ore on both sides of the contact.

KLEINSCHMIDT (LITTLE OLGA) MINE (18)

The Kleinschmidt (Little Olga) mine (pl. 2) (Pardee and Schrader, 1933, p. 31; Reed, 1951, p. 40) explores two sets of veins (Little Olga and Quartette) in the porphyritic quartz monzonite of the Vosburg stock. Most of the production has been from the Little Olga vein, a steep east-trending base- and precious-metal vein as much as several feet thick that contains pyrite, galena, sphalerite, chalcopyrite, stephanite, and tetrahedrite in a gangue of quartz, siderite, altered rock, and gouge; some ore was mined from other steeply dipping base- and precious-metal veins and from thin north-trending gently dipping quartz veins that contained pyrite and sparse arsenopyrite, molybdenite, and gold. The gently dipping veins are cut and slightly displaced by the steep veins. The steep veins contain considerable broken rock and gouge, and the country rock bordering them is sericitized, pyritized, and argillized. The gently dipping veins are largely fillings that heal the fractures; gouge and broken rock are uncommon along them and the adjacent altered zone is generally no more than a foot thick.

A crosscut was driven 3,300 feet southward from the head of Whitehorse Gulch to explore at a depth of about 500 feet beneath the Little Olga lower adit (pl. 2). In this crosscut the Quartette vein was not identified and the Little Olga vein consisted of altered broken rock and gouge cut by a few narrow stringers of sulfides. Only a few small pods of ore were mined above this crosscut and adjacent to a raise driven from it.

OTHER MINES

Several other mines near Weasel Creek yielded ore from veins similar to those described above. The Stray Horse (15) mine expored two parallel, east-trending, steep veins in the Elkhorn Mountains Volcanics, both typically a foot or less thick. The veins are displaced as much as 20 feet by steep north-trending faults. Mineralization is similar to that in the January vein. The Little Bonanza mine explored a small ore shoot on yielded small amounts of high-grade silver-lead ores. The Little Bonanza mine explored a small ore shoot on a vein trending N. 75° E. and dipping 65° NW. in the Elkhorn Mountains Volcanics. The Silver Saddle mine explores a mineralized fracture zone that trends northeast and dips 30°–45° SE. (pl. 2) in the Elkhorn Mountains Volcanics. A few small pods of ore containing argentiferous galena, pyrite, and sparse sphalerite in a quartz gangue were mined. Between ore pods the vein consists of gouge seams in bleached, slightly silicified, and pyritized volcanic rock.

PARK AREA

The Park area at the head of Indian Creek centers around the Marietta mine in and near sec. 15, T. 7 N., R. 1 W. It is underlain by rocks of the Elkhorn Mountains Volcanics, mainly tuff, and a few small bodies of intrusive rocks related to the volcanics. Most of the ore mined has been from gently dipping lenticular quartz veins with base and precious metals, valuable mainly for gold, but in places containing important quantities of lead and silver. In some veins arsenopyrite is relatively abundant. The veins are mostly 2–3 feet thick with local swells to as much as 5 feet. Some of them have been mined for several hundred feet along strike and vertically 250–300 feet. Most veins dip 35° or less and in places roll to almost horizontal. In some places rolls appear to localize thicker parts of veins. The veins commonly are frozen to the walls. They contain a few thin gouge seams and small horses of altered rock.

Granodiorite on the dump of a caved shaft at the Venezuela mine and thermally metamorphosed volcanic rocks in the vicinity suggest that a sizable body of younger intrusive rock lies at shallow depth.

MARIETTA MINE (22)

The Marietta mine (pl. 3; Reed, 1951, p. 48; Schell, 1963) explores several gently to moderately dipping north- and northeast-trending lenticular veins in the Elkhorn Mountains Volcanics and associated intrusives. Most of the ore has come from a north-trending zone that includes the Marietta and Blue veins (pl. 3). The veins contain pyrite, arsenopyrite, galena, sphalerite, and sparse chalcopyrite in a gangue of quartz and a manganiferous carbonate mineral. Limonite and manganese oxide stain are prevalent in oxidized and partly oxidized ore. The veins are a few inches to rarely as much as 6 feet thick, are in part banded, and are mainly fracture fillings. Adjacent to the veins the volcanic rocks are argillized, pyritized, and locally sericitized. The dip of the veins is variable but generally low, and some of the thicker ore bodies are localized by rolls. Most of the ore is valuable mainly for gold, which apparently is in auriferous pyrite and arsenopyrite in unoxidized ore. Lead and silver are important locally, for example in a flat part of the Marietta vein in the Gold Dust intermediate level (pl. 3). Zinc and copper are present only in minor quantities.

The north-trending vein zone is cut by faults or fault zones of several trends (pl. 3). Displacements along the faults are small and range from a few feet to rarely as much as 20 feet, even though in some places the rocks are intensely fractured in zones 10 feet or more across. Because of the fracturing and displacement of the veins and their lenticularity and variable dip, correlation of veins in the north-trending zone is uncertain. The most persistent fault trends N. 30° W. along the course of the intermediate level, dips steeply, and has an apparent offset of 12–16 feet, southwest side down. On the southwest side of the fault the Blue vein trends nearly parallel to the fault but dips very gently. This vein has been stoped for a length of 200 feet over a vertical distance of at least 150 feet. Northeast of the fault, the north-trending Marietta vein or vein zone has been mined intermittently for about 700 feet through a vertical distance of more than 250 feet.

OTHER MINES

Gently to moderately dipping veins of diverse trend similar to those in the Marietta mine have yielded gold ore with different amounts of lead and silver at the Park (26), New Era (26), and Venezuela (26) mines, a short distance southwest of Marietta, at the Little

Annie (24) mine about 1,000 feet east of the Marietta, and at the Vulture (21) mine at the head of Eureka Creek. Vuggy milky quartz characterizes the vein material at the Vulture mine. Massive and partly vuggy veins of white quartz and small amounts of a carbonate mineral, probably siderite, and pyrite yielded gold ore at the Champion (19) mine (NE¼SE¼ sec. 4, T. 7 N., R. 1 W.) and at the Big Chief (20) mine near the head of Whitehorse Creek. A northwest-trending steep vain on the Jawbone (25) claim (NW¼NW¼ sec. 17, T. 7 N., R. 1 W.) also yielded gold ore from the oxidized part of a pyritic vein that contained quartz, calcite, and ankerite or siderite. High-grade silver-lead ore is reported to have been mined from a nearly vertical pipe along a north-trending fault at the Bullion King (23) mine (Albert Dance, oral commun., 1952), about 1,000 feet northeast of the Marietta mine. At the Parker (27) mine in the valley of Eureka Creek, base- and precious-metal ore containing pyrite, galena, sphalerite, and arsenopyrite was mined from a pipelike body in a steep vein of N. 70° E. trend.

HASSEL AREA

Veins in the Hassel area are around and in the Silver Wave and Diamond Hill stocks. North of Diamond Hill most of the veins are of the base- and precious-metal type; the most productive, explored by the Iron Mask mine, yielded 23,000 tons of zinc-lead-silver ore (Reed, 1951, p. 46). South of Diamond Hill, the veins are mainly of the quartz-poor auriferous pyrite type, similar to those in the Radersburg area. Oxidized gold ore from auriferous pyrite veins at the Diamond Hill, Blacksmith, and Little Giant mines accounted for most of the production from the Hassel area. The Little Giant and Blacksmith mines explore the oxidized parts of narrow, vertical or steeply dipping east-trending veins. The Diamond Hill mine explored a north-trending belt of thermally metamorphosed and hydrothermally altered (pyritized) volcanic rock cut by lenticular pyritic veins and stringers of diverse trend; ore was mined from open pits and underground workings in the oxidized zone, and the mineralized rock beneath the zone of oxidation was explored by a long adit with appended short drifts.

The Diamond Hill stock is cut by many aplite dikes and by small quartz veins which contain pyrite and sparse chalcopyrite, and which are similar to the quartz veins with auriferous pyrite in the Beaver Creek and Iron Age Gulch areas. The stock is also cut by a few thin base- and precious-metal veins. Though quartz-poor auriferous pyrite veins are the principal vein type in the volcanic rocks nearby and in the Silver Wave stock, none has been recognized cutting the Diamond Hill stock.

IRON MASK MINE (31)

The Iron Mask mine explored a north-trending steeply east-dipping base- and precious-metal vein that cuts the lower member of the Elkhorn Mountains volcanics. The mine yielded about 23,000 tons of ore of the following average grades: 4 percent lead, 7.4 percent zinc, 0.2 percent copper, 4.9 oz. per ton silver, and 0.005 oz. per ton gold (Reed, 1951, p. 46). The mine is developed by three vertical shafts and a 2,300-foot-long crosscut adit at a depth of 570 feet beneath the outcrop (Reed, 1951, p. 46). In and above this adit the vein was explored and partly stoped for a length of about 600 feet.

The only exposure of the vein at the time of this study was in a sublevel 100 feet below the adit, where the thickness of the vein ranged from 3 to 8 feet, and averaged about 4 feet. In the north heading of this sublevel the vein consisted of a thin footwall gouge, 16 inches of altered fractured tuff with disseminated sphalerite, galena, pyrite, and quartz, a 4-inch-thick band of sphalerite and pyrite and some galena, 36 inches of fractured and altered tuff laced with stringers of a manganiferous carbonate mineral and sulfides, and a 1-foot-thick hanging-wall gouge containing sparse brecciated sulfides. Strands of gouge overlap and split within the vein zone. The ore shoot on this sublevel was about 90 feet long. The tuff adjacent to the vein is bleached and contains disseminated pyrite and sericite.

Unoxidized ore contains pyrite, sphalerite, and galena, and sparse chalcopyrite and tetrahedrite in a gangue of quartz, calcite, and a manganiferous carbonate mineral. Samples of oxidized ore on dumps of workings along the outcrop of the vein contain limonite, jarosite, psilomelane, pyrolusite, cerussite, smithsonite, and sparse galena and sphalerite.

A parallel vein, the Red Wing vein, is exposed in the crosscut adit and at the surface. This vein trends north, dips 80° E., is 3–4 feet thick, and contains abundant limonite and manganese oxide and sparse chalcopyrite in a gangue of quartz and two carbonate minerals.

DIAMOND HILL MINE (40)

The Diamond Hill mine is in a north-trending belt of metamorphosed tuff of the Elkhorn Mountains Volcanics adjacent to the Silver Wave stock (pl. 4). The mine explores one of the first lode deposits discovered on Indian Creek, and its workings include eight adits, six open pits, and numerous prospect pits and shafts. Reed (1951, p. 45) stated that these workings explore and develop the deposit for a horizontal distance of 2,700 feet and a vertical distance of 250 feet. The mine has yielded about $550,000 worth of ore valued chiefly for its gold content, but it also contains minor scheelite and base-metal sulfides.

Rocks in the north-trending metamorphosed zone are silicified and pyritized and locally contain epidote, chlorite, garnet, calcite, and sparse scheelite; in the zone of oxidation they are bleached. The zone is cut by erratically distributed but abundant seams and irregular stringers, pipelike shoots, and distinct veins of auriferous pyrite in a gangue of calcite, perhaps other carbonate minerals, and quartz. Lenses of massive auriferous pyrite are present in places. The pyrite veins and lenses contain native gold and sparse chalcopyrite and scheelite. Scheelite also is sparsely disseminated in epidote-chlorite-garnet rock with no particular concentration near pyrite veins and lenses and probably is older than the pyritic mineralization. A few quartz-pyrite veins that contain galena and sphalerite appear to be younger than the more widespread pyritic mineralization.

Rock alteration and metallization appears to have occurred in several episodes. During emplacement of the Silver Wave stock, the invaded andesitic tuffs were hornfelsed and, locally along fractures, epidote-chlorite-garnet rock was formed; pyrite and probably most of the sparse scheelite was deposited at this time. Somewhat later, probably during the final stages of consolidation of the Silver Wave stock, rocks in the fractured zone were hydrothermally altered, and stringers and lenses of pyritic gold ore were deposited, partly as fracture fillings and partly as replacements of altered volcanic and intrusive rocks. Following emplacement and consolidation of the Diamond Hill stock, a few quartz veins containing pyrite, galena, and sphalerite were formed. The final stage of mineralization in the area is marked by the filling of fractures by calcite.

LITTLE GIANT MINE (41)

At least 14 narrow, east-trending steep pyritic gold veins in hydrothermally altered volcanic rocks south of the Diamond Hill mine have been explored by the Little Giant and nearby mines. The veins are explored by several adits, three shafts, and many prospect pits and trenches, all in the oxidized zone. A typically east-trending vein of this group is shown on plate 4. The estimated value of the ore from these mines is about $300,000 (Reed, 1951, p. 47), nearly all of it mined before 1901. The veins occupy narrow but persistent fractures that range in thickness from 1 inch to rarely 5 feet, and in most places are less than 2 feet thick. The east-trending fractures are displaced a few feet by at least two steep faults that trend N. 25°–35° E.; locally these faults are weakly mineralized. The ore in the oxidized zone is native gold in a gangue of limonite and altered andesite with very little quartz. Below the zone of oxidation auriferous pyrite is the only sulfide present, and apparently the ore could not be profitably mined. The country rocks, lapilli tuff, tuff breccia, and crystal tuff of the Elkhorn Mountains Volcanics, are hydrothermally altered and contain abundant epidote, kaolinite, sericite, and finely disseminated pyrite. They are intensely fractured and cut by many quartz stringers. Weathered rocks are heavily seamed and stained by limonite.

BLACKSMITH MINE (42)

The Blacksmith mine (pl. 4), an adit with appended drifts, two shafts, and prospect pits southeast of the Little Giant mine, explores a series of narrow anastomosing north-trending steep veins that consist mainly of altered rock and limonite with a little quartz. The ore, mined for its gold content, was similar to that in the Little Giant veins, and as in the Little Giant mine it apparently was not profitable below the zone of oxidation. The mine reportedly yielded ore valued at about $250,000 (Reed, 1951, p. 44). The volcanic country rocks are bleached and limonite stained for several feet adjacent to the veins.

OTHER MINES

A number of mines and prospects in the Hassel area explore base- and precious-metal veins that contain pyrite, galena, sphalerite, and arsenopyrite in a gangue of quartz and ankerite or another carbonate mineral. In this group are the Central (38) and Queen Bee (36) mines, which yielded ore from steep N. 50° W.-trending veins; the St. Louis (35), Spring Hill (39), and the Mammoth (34) mines, which explore steep N. 80° W.-trending veins, and the Silver Wave mine (37), which developed an ore body on a N. 50° W.-trending vein at its intersection with a N. 70° E.-trending vein.

RADERSBURG AREA (CEDAR PLAINS)

Except for a deposit of titaniferous iron ore and a few narrow base- and precious-metal veins, the ore deposits of the Radersburg area are auriferous pyrite veins (Winchell, 1914; Corry, 1933) in a gangue of strongly altered wallrock and relatively sparse quartz, calcite, and an iron-bearing carbonate mineral. Most of these veins trend nearly north and dip 65° W. to vertical. They range in thickness from less than a foot to as much as 5 feet and in length from a few hundred feet to about 3,000 feet. The Keating vein has been explored to a depth of about 1,200 feet.

Most of the veins are clustered in an area of about 1 square mile in which the country rocks are intensely altered and include two gradational zones (pl. 1): an inner zone (heavy stipple on pl. 1), which is almost entirely in the Rattlesnake intrusive and contains most of the veins, and an outer zone (light stipple) in both intrusive and extrusive rocks. Rocks in the inner zone are highly fractured, pyritized, silicified, sericitized, and argillized. Most of the rock in this zone has been oxidized, bleached white or light gray, and is seamed and coated with limonite. The alteration is most intense adjacent to the major veins, but no distinct zonation related to specific veins was recognized. Rocks in the outer zone are green or greenish gray, and the effect of pervasive alteration seems to have been mainly the formation of epidote, chlorite, and locally pyrite; adjacent to individual veins in this zone, however, an envelope of wallrock is bleached and pyritized, and it resembles the strongly altered rock of the inner zone. The difference in intensity of alteration between the inner and outer zones appears to be related to abundance of fractures; part of the inferred difference between zones, however, may be more apparent than real because of differences in original rock type and degree of oxidation, which tend to emphasize effects of alteration. In places the rocks are so intensely altered that diagnostic features have been obliterated and the contact between intrusive and extrusive rocks cannot be located with confidence.

KEATING MINE (59)

The Keating mine has been the most productive in the area and was for years one of the foremost gold producers in Montana. During the period 1901–48 it yielded 412,471 short tons of ore from which were recovered 157,538 oz of gold, 43,557 oz of silver, and 1,064 tons of copper (Reed, 1951). The deposit was discovered in 1866 and was worked at intervals until 1947, when underground operations were suspended. Since then, small shipments have been made from the dumps. Total recorded production of gold is about $4 million (Trauermann and Waldron, 1940, p. 9), of which a small part may have come from nearby small mines. The mine was flooded and inaccessible in 1952. The average recovered metal content of the ore was 0.38 oz gold per ton, 0.25 percent copper (Reed, 1951), and a little silver.

The Keating mine is along one of the most persistent of a number of steep north-trending auriferous pyrite veins in a large area of intensely altered rock that is partly tuff of the Elkhorn Mountains Volcanics and is partly porphyritic rocks of the Rattlesnake intrusive.

The Keating vein has been explored by three shafts and 10 levels over a length of 2,200 feet and for a depth of 1,100 feet (Reed, 1951, p. 25). The vein trends north to N. 5° E., dips about 70° W., and is about 1–5 feet thick. Typically, it was about 20 inches thick south of the main inclined shaft, and it formed a stringer zone over a 1- to 2-foot width north of the shaft. According to Winchell (1941, p. 132), the vein was followed southward on the fourth level into "broken ground" consisting of unstratified boulders as much as 18 inches across of altered and oxidized rock of local origin. Winchell correctly considered this material to be part of Tertiary deposit. To the north, the vein narrows and was not followed to its termination. The vein is displaced as much as 25 feet by a few faults (Winchell, 1914, p. 179).

The ore is auriferous pyrite in altered pyritic rock with a little quartz and calcite, and sparse chalcopyrite, marcasite, pyrrhotite, galena, sphalerite, and chalcocite (Stone, 1911, p. 93). Quartz and calcite are more abundant in parts of the vein that do not constitute ore. Near the surface, the oxidized part of the vein contains abundant limonite, a little malachite, and gold. The ore was completely oxidized to a depth of 175 feet and partly oxidized for an additional 60 feet (Winchell, 1914, p. 173).

OHIO-KEATING MINE (58)

The Ohio-Keating mine, formerly the second most productive in the area, explored an auriferous pyrite vein in altered rock of the Rattlesnake intrusive parallel to and about half a mile west of the Keating vein. The mine, inaccessible in 1952, was opened by a 550-foot-deep inclined shaft with five levels. The Ohio vein yielded about 200,000 tons of ore with an average grade of 0.31 oz gold per ton (Reed, 1951, p. 27). The vein trends about N. 15° W. and dips about 80° W., it is about 1–5 feet wide and contains abundant auriferous pyrite and very sparse chalcopyrite and bornite. Quartz, calcite, and lenses of altered country rocks are conspicuous in parts of the vein that contain little or no ore (Winchell, 1914, p. 179). The vein is offset a few feet by two cross-faults (Winchell, 1914, p. 179).

OTHER DEPOSITS

Ore has been mined from a number of pyritic gold veins in the vicinity of the Keating and Ohio-Keating veins (fig. 2). Most of the veins trend nearly north and dip steeply. Perhaps the most productive has been the Black Friday (66), which trends about N. 5° W. and dips 70° W. The Cyclone (69) vein, which trends N. 15° E. and dips 60°–75° W., is 1–4 feet thick and may be a continuation of the Black Friday vein. A few veins in this vicinity contain base metals in addition to auriferous pyrite. Ore containing galena, cerussite, wulfenite, pyrolusite, quartz, limonite, and probably vanadinite (Winchell, 1914, p. 180), abundant pyrite and traces of calcite was mined from a vein trending

N. 68° W. and dipping 65° NE. at the Congress (64) mine, and lead-silver-gold ore was mined from a vein trending N. 60° W. and dipping 80° NE. at the Gopher mine (68).

IRON CROSS MINE (48)

At least two lenticular beds of titaniferous magnetite in sandstone and sandy crystal tuff in the Slim Sam Formation have been exploited at the Iron Cross mine. The ore beds are folded (fig. 6), and the principal ore bodies are along a fold crest and a fold trough. The magnetite accumulated as placer sands, but the massive appearance of the ore and the localization of the richest and thickest ore bodies along the crests and troughs of folds suggest that some of it was redistributed, perhaps by hydrothermal solutions.

Ore is mined from several small open pits and sold for use in a special type of cement made at Trident, Mont.

QUARTZITE RIDGE AREA

Pipelike and lenticular bodies of silver-lead-zinc ore have replaced favorable rocks adjacent to east-trending steep faults of slight displacement in the Quartzite Ridge area, south of Johnny Gulch and the Rattlesnake intrusive. Most of the bodies are in thin dolomite beds between quartzite beds in the Quadrant Formation. At least two ore bodies are in the Mission Canyon Limestone, where one of them is partly localized in a collapse breccia.

JO DANDY MINE (71)

The Jo Dandy mine, the most productive of the mines that explore silver-lead-zinc replacement deposits in carbonate rocks, since 1920 has yielded about 9,300 tons of ore with an average grade of 34 percent lead and 11.9 oz per ton silver. The deposit is opened by a 600 foot-deep vertical shaft with six levels. The mine was inactive in 1952.

The ore is in pipelike replacement bodies at intersections of east-trending nearly vertical fractures with some of the north-trending dolomite beds in the Quadrant Formation; the main host beds are immediately above and below the thick quartzite bed that forms the ridge crest in this vicinity. The largest ore body was beneath the thick quartzite and was mined from the surface to the 600-foot level. The cross-sectional dimensions of this ore pipe near the surface were 2–3 feet along the fracture and 10–15 feet along bedding; on the 300-foot level they were about 16 feet along the fracture and 4 feet along bedding (A. R. Berg, oral commun., 1950). The second largest ore pipe was along the same fracture at its intersection with the carbonate bed above the thick quartzite bed; this pipe is reported to have extended 1–3 feet along the fracture and 7–20 feet along bedding and to have had an average cross section of 2 by 12 feet. At least three smaller pipes were mined, two in these same dolomite beds along a fracture about 30 feet south of the main fracture, and the third in a higher dolomite bed along a fracture 35 feet north of the main fracture. The dolomite above the thick quartzite was explored for a length of 350 feet at about the level of the collar of the vertical shaft and for about 800 feet in a drift driven toward the Santa Anita mine (73), on the 500 level, but no other pipes were found.

Most of the ore was oxidized and consisted of cerussite, pyromorphite, limonite, and calcite along with galena, manganese oxides, and wulfenite. The galena content increased in depth, and ore from the bottom level of the shaft was a mixed sulfide-carbonate ore (Carl Trauerman, oral commun.).

SANTA ANITA MINE (73)

The Santa Anita mine, a short distance south of the Jo Dandy, consists of a 475-foot adit with connecting stopes and inclined shafts (pl. 4) and explores a mineralized fault that cuts the Quadrant Formation and the upper part of the Amsden Formation. The fault trends N. 75° to 85° W., dips from vertical to 65° S., and offsets the beds about 60 feet. The ore was similar to the lead-silver ore of the Jo Dandy but was mainly in lenticular tabular bodies along the fault; a few small ore bodies were in irregular replacements projecting from the fault into favorable dolomite beds. The oxidized ore was a mixture of limonite, cerussite, smithsonite, and manganese oxides with minor galena, sphalerite, and pyrite. The mine has yielded about 1,600 tons of ore since 1910 with an average of 23 percent lead, 5.7 oz. per ton silver, and 0.02 oz. per ton gold (Reed, 1951, p. 28). The rock in the upper part of the Amsden Formation and at the base of the Quadrant Formation at the west end of the adit is strongly brecciated and oxidized. This oxidized breccia zone is thought to have formed by leaching of carbonate rocks along the fault and subsequent collapse during an early Teritiary episode of weathering.

RUBY MINE (RUBY SILVER) (74)

The Ruby mine (pl. 4), southwest of the Santa Anita, explores a replacement deposit of zinc-silver-lead ore in the upper part of the Mission Canyon Limestone adjacent to two N. 75° W. vertical small faults. The mine includes two inclined shafts with interconnecting stopes. The workings extend about 75 feet along the strike and 300 feet down the dip of beds that trend about N. 15° E. and dip 40°–55° SE. About 4,000 tons of ore with a recoverable grade of 4.4 percent lead, 8.8 percent zinc,

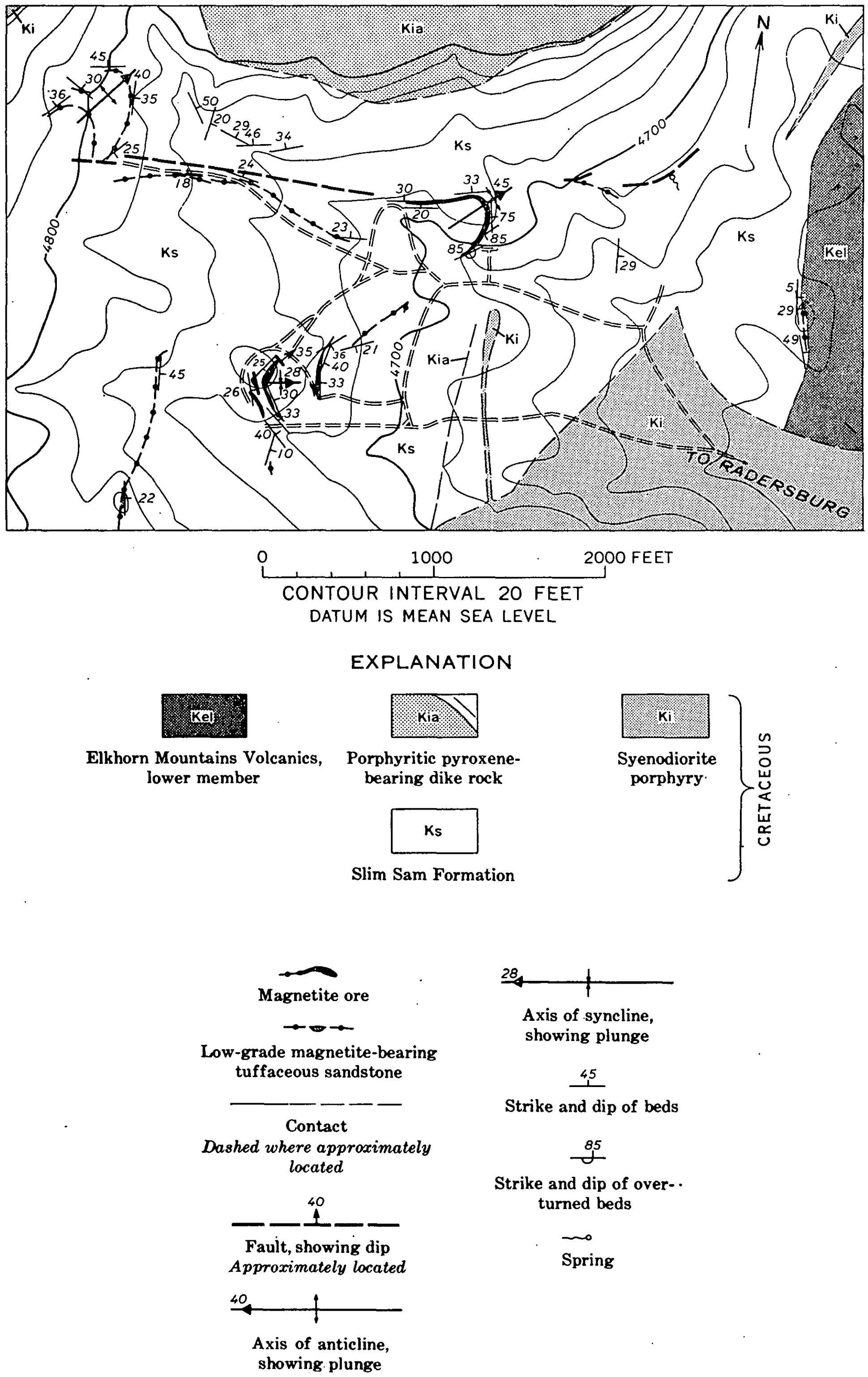

FIGURE 6.—Iron Cross magnetite mine, Broadwater County, Mont. Geology by V. L. Freeman and D. E. Brambilla, 1952.

and 5 oz. per ton silver has been mined (Reed, 1951, p. 27).

The limestone beds in which the ore occurs have a maximum thickness of 35 feet. Most of the ore near the surface was in two distinct zones, each several feet thick and 5–10 feet apart; in the lower workings only the upper zone was followed, and the ore in it thinned. In the upper zone, from which most of the ore was obtained, several feet of high-grade oxidized lead ore was underlain gradationally by several feet of high-grade oxidized zinc ore (A. R. Berg, oral commun., 1949). The ore bodies consisted of cerussite, smithsonite, hemimorphite, limonite, drusy quartz, calcite, dolomite, and jasper and were sheathed by partly silicified limestone. Galena, sphalerite, and pyrite were sparsely present near the bottom of the mine. A little fluorite was seen in a few specimens of ore.

NORTH HOME MINE (63)

The North Home mine, north of Johnny Gulch, also explored replacement silver-lead ore bodies in the upper part of the Mission Canyon Limestone. Between 1901 and 1950 it yielded about 4,000 tons of ore with an average grade of 2.3 percent lead, 17.4 oz. per ton silver, and 0.06 oz. per ton gold (Reed, 1951, p. 26).

The ore bodies were developed by steep shafts, both of which were inaccessible in 1952. The main ore body, in beds immediately beneath a thick collapse breccia, was followed to a depth of about 400 feet. The shapes and trends of open stopes suggest that the main ore body was a lens that raked 60°–70° N. in beds that trend N. 15° E., and dip 65° SE. It was 25 feet long and 4 feet thick at the surface and was about 70 feet long and as much as 5 feet thick at a depth of 40 feet. Below 40 feet the stope is filled. The other ore body in the basal part of the collapse breccia was pipelike and was followed to a depth of about 150 feet. Near the surface the cross section of the pipe was 10 by 6 feet.

The ore bodies are partly sheathed by silicified limestone and limestone breccia and appear to have formed partly by cavity filling and partly by replacement. Most of the ore that was mined was oxidized. It consisted of limonite, cerussite, smithsonite, cerargyrite, pyrmorphite, and traces of galena in a gangue of dolomite, barite, calcite, aragonite, manganese oxides, brown jasper, gray quartz, clear drusy quartz, and traces of fluorite. Ore deposition was preceded by silicification and perhaps by the formation of caverns in massive limestone and in earlier formed collapse breccia.

OTHER AREAS AND DEPOSITS

Elsewhere in the mapped area small mineral deposits occur in and near most of the younger intrusive bodies, but few of these have been productive. In and around the Antelope Creek, Monte Cristo, Vulture, and Mammoth intrusives are narrow veins that contained gold; some of them also contained silver and lead. Near the Slim Sam and Keating Gulch stocks are gold-bearing skarn (Monarch mine (44)), and gold (Quartzite mine (45)) and silver-lead (Horn Silver mine (46)) replacement bodies in carbonate rocks

NONMETALLIC MINERAL DEPOSITS

Potentially useful deposits of limestone, dolomite, and building stone are found in the different sedimentary formations, and abundant sand and gravel are present in the surficial deposits

Low-grade bentonite, potentially useful as a sealing agent for dams and canals, is present along Beaver Creek a few miles northeast of the mapped area (Mertie, Fischer, and Hobbs, 1951, p. 89–90). The bentonitic strata probably extend southward into the mapped area but are concealed beneath younger deposits. Bentonitic strata are also present in the Oligocene sedimentary rocks near Johnny Gulch, but the deposits are probably too small and too impure to be exploited. Similarly, beds of phosphate rock in the Phosphoria Formation are too thin and too low grade to be of commercial interest.

Lignitic shale near the top of the Morrison Formation has been prospected in the SW¼ sec. 32, T. 7 N., R. 1 E., a few hundred yards west of the Indian Creek road, but the deposit is to thin and too impure to be of economic interest.

POSSIBLE FUTURE DISCOVERY AND DEVELOPMENT OF MINERAL DEPOSITS

The area has long been readily accessible and has been explored and exploited for more than 100 years, so that veins and ore bodies that crop out almost certainly have been found. The possibilities for discovery and future development of ore in the area are of three kinds: (1) concealed deposits of the same kinds that have been mined in the past, (2) extensions of known deposits, and (3) development of low-grade deposits under more favorable economic conditions or through development of cheaper mining and recovery methods. Concealed deposits or extensions of known deposits may be discovered as a result of detailed geological studies and geochemical prospecting (for example, see Earll, 1964, p. 30–3). As technology improves, perhaps the low-grade gold deposits, such as those at the Diamond Hill and Keating mines, could be profitably mined. Parts of the area are judged worthy of more detailed geologic, geochemical, and perhaps geophysical study in the search for concealed deposits or extensions of known deposits.

AURIFEROUS PYRITE VEINS

Auriferous pyrite veins in the Radersburg and Hassel areas have accounted for most of the value of metal produced from the mapped area. The oxidized and enriched parts of the known veins have been largely or wholly mined. Large tonnages of unoxidized vein material remain but apparently have not been profitable to mine. For example, the Keating mine was reopened during 1947 and about 18,000 tons of ore was mined (U.S. Bur. Mines, 1947, p. 1449); if the total output of lode gold from the Cedar Plains district during that year (2,472 oz, U.S. Bur. Mines, 1947, p. 1446) was from this ore, the indicated recovery was 0.138 oz per ton ($4.83 per ton at $35). A 2,800-foot-long adit in unoxidized material at the Diamond Hill mine is reported to be in "ore assaying from 80 cents to $2.50 a ton" (Stone, 1911, p. 82) based on $20.67 per oz price for gold; the equivalent value is $1.35 to $4.25 per ton at $35 per oz price of gold. The tonnage of gold-bearing material that may be of about this grade is larger, probably at least several hundred thousand tons, of which a part might be amenable to open-pit mining. Some of this rock also contains small quantities of scheelite, but most of it almost certainly does not contain as much as 0.1 percent WO_3.

Undiscovered oxidized ore bodies in auriferous pyrite veins may exist beneath Cenozoic deposits south of the Keating and Ohio-Keating mines in the Radersburg area. The veins in this area were exposed to oxidation and enrichment in Tertiary time (p. 39), and the belt of mineralization west of Radersburg can reasonably be extended southward beneath the Cenozoic cover, which is not more than a few hundred feet thick. Oxidized pyritic gold veins also might be sought beneath the gravel-covered area in Cold Springs Gulch.

QUARTZ VEINS WITH BASE AND PRECIOUS-METALS AND QUARTZ VEINS WITH AURIFEROUS PYRITE

Small and intermittent production can be expected from quartz veins with base and precious metals and from quartz with auriferous pyrite veins. Almost without exception veins of both types are narrow, and few of the known ore shoots extend more than several hundred feet in length or depth. Furthermore, values beneath the oxidized zone tend to be erratic. From these considerations, it seems unlikely that new deposits or extensions of known deposits will be found that will yield more than several thousand tons of direct shipping ore or that would yield enough ore of lower grade to sustain a mill of capacity larger than about 50 tons per day.

REPLACEMENT BODIES IN CARBONATE ROCK

More intensive exploration in the Quartzite Ridge area might lead to the discovery of high-grade but relatively small replacement bodies of silver-lead-zinc ore. Geochemical prospecting in carbonate rocks known to be favorable host rocks would probably be a logical first step.

GOLD PLACERS

The gravel along Cold Springs Gulch (p. 14) was deposited by an ancestral Indian Creek that headed in the Park and Hassel areas, which are noted for their gold veins; these areas contributed the placer gold mined from younger gravels along the present channel of Indian Creek. The gravel along Cold Springs Gulch accordingly may contain placer concentrations of gold derived from the Park and Hassel areas.

Placer deposits of gold may also be buried beneath the Oligocene sedimentary tuff in the vicinity of Radersburg. The vein deposits in the Radersburg area were exposed to erosion before deposition of the tuff (p. 39), and gold eroded from the veins could have been deposited with gravels in now-buried stream channels, or concentrated in the lower part of the Oligocene sedimentary unit itself.

Neither the gravel in Cold Springs Gulch nor the base of Oligocene sedimentary tuff near Radersburg appears to have been prospected for placer gold, but both areas are considered promising.

MEASURED SECTIONS

SECTION 1.—*Morrison, Swift, Phosphoria (and related strata), Quadrant, and Amsden Formations near Indian Creek*

[Measured by M. R. Klepper, 1948, along and near road on northwest side of Indian Creek (pl. 1) NW¼ sec. 5, T. 6 N., R. 1 E., to approximate center sec. 32, T. 7 N., R. 1 E.]

Kootenai Formation:

Sandstone, "salt-and-pepper," gray; speckled with darker chert grains; light gray to medium light gray and medium coarse grained in lower 9 ft; greenish gray, finer grained, and less conspicuously speckled in upper 14.6 ft. Approximately 24 ft thick.

Disconformity.

Morrison Formation:	*Feet*
129. Concealed	11
128. Sandstone, gray, speckled, "glassy," relatively fine grained	1.5
127. Concealed	2
126. Limestone, olive-brown, very finely crystalline, sandy or silty; in beds 1 ft. thick; weathers brown	10
125. Mudstone, olive and gray, fissile; interbeds of silky dolomite; weathers yellowish brown	24
124. Siltstone, light-olive-gray to yellowish-orange, dolomitic, blocky	10
123. Dolomite, gray, dense, silty	3
122. Concealed	6
121. Sandstone, gray, silty; speckled with dark chert fragments	6

SECTION 1.—*Morrison, Swift, Phosphoria (and related strata), Quadrant, and Amsden Formations near Indian Creek*—Con.

	Feet
Morrison Formation—Continued	
120. Sandstone, salt-and-pepper, medium-gray with faint greenish tint; in beds about 0.5 ft. thick; lower 2 ft. silty and fine grained, upper 6 ft. medium coarse grained	8
119. Concealed; mostly if not wholly underlain by dark carbonaceous mudstone and one or more lignite layers	20.5
118. Concealed	10
117. Mudstone, yellowish-orange, punky, blocky; two lignite beds, one 0.5 ft. thick and one 0.7 ft. thick, in upper 2 ft of unit	6
116. Concealed; soil in part reddish	45.5
115. Shale, olive-gray and dark-greenish-gray, hackly to pencilly	16
114. Concealed	9.5
113. Mudstone, olive-gray and brownish-olive; in part calcareous	8
112. Concealed	8.5
111. Mudstone, olive-brown; in beds 0.1 ft thick	2.5
110. Concealed	4
109. Mudstone, olive and dark-gray	13
108. Limestone, siltstone, and sandstone; olive and olive-gray silty limestone, limy siltstone, and fine-grained sandstone in beds 0.25–0.5 ft thick; in part fissile; abundant dark-gray cherty fragments in the upper 6 ft of unit; weathers orange brown to drab brownish gray	27.5
107. Limestone, olive and gray, silty; weathers dark yellowish orange to moderate yellowish brown or lighter	15.5
106. Concealed	9
105. Sandstone, light-brownish-olive, speckled, fine-grained, calcareous; weathers to medium light gray	5
104. Quartzite, light-olive, dense, calcareous	1
103. Limestone, dolomite, and siltstone; brownish-olive-gray, pale-yellowish-brown, and yellowish-brown, silty and dense limestone and dolomite and limy or dolomitic siltstones with carbonate rocks predominant; siltstones commonly in beds less than 0.02 ft thick, carbonate rocks in beds as much as 0.7 ft thick; unit weathers dark yellowish orange, grayish orange, and light olive	31
102. Concealed	86
101. Siltstone, weathers orange brown	2
100. Siltstone, punky, calcareous, or dolomitic; in part very fine grained sandstone; unit weathers yellowish brown	3.5
99. Sandstone, pale-yellowish-brown, light-olive, and light-gray, speckled, fine-grained, somewhat crossbedded; in beds 0.2–1 ft thick; weathers pale yellowish brown	19.5
98. Siltstone, orange-brown, calcareous, fissile; upper half of unit mostly concealed	22.5
97. Siltstone, calcareous; weathers dull yellowish brown	11.5
96. Siltstone and limestone; hackly to fissile siltstone interlayered with thicker beds of silty limestone; weathers dark yellowish orange	15
95. Limestone, brownish-olive, silty; weathers brownish	0.5
94. Siltstone and limestone; similar to unit 96, but siltstone is calcareous	11.5
93. Concealed; underlain at least in part by brownish-gray, olive, and grayish-orange calcareous siltstone that weathers nearly dark yellowish orange	17
92. Siltstone, brownish-gray, olive, and grayish-orange, calcareous, fissile to thin-bedded; weathers nearly dark yellowish orange	16
91. Limestone, olive-gray, silty, indistinctly bedded; weathers gray to brown	4
Total thickness of the Morrison Formation	523
Swift Formation:	
90. Concealed	7
89. Sandstone, brownish-gray, speckled, fine-grained; consists of whitish to glassy subangular to subrounded quartz grains in fine-grained brown-stained sand matrix; unit weathers brownish gray	11
88. Sandstone, moderate-dusky-yellow, speckled, fine-grained, with subrounded grains, very calcareous, friable, locally pebbly	1
Total thickness of Swift Formation	19
Disconformity.	
Phosphoria Formation and related strata:	
87. Chert, dark-gray, mottled dull red, brown, and white	1
86. Quartzite, dark-gray, vitreous, very fine grained; contains opaque white-weathering ovoids (probably phosphatic material) as much as ¼ in. long, and near top a few pebbles of quartzite	16
85. Quartzite, light-grayish-brown, very fine grained, vitreous; one bed	3
84. Sandstone, dolomitic, light-brownish gray, fine-grained; in beds as much as 1 ft thick	10
83. Sandstone, silty, orange-brown, strongly limonitic, punky	1
82. Igneous rock; 3½ ft thick.	
81. Concealed	1
80. Chert and very fine-grained quartzite, light-gray and light-brownish-gray; weathers to yellowish orange, grayish orange, and yellowish gray rough surface; some beds are chert, some are quartzite, and some contain both chert and quartzite	15
Total thickness of Phosphoria Formation and related strata	47

SECTION 1.—*Morrison, Swift, Phosphoria (and related strata), Quadrant, and Amsden Formations near Indian Creek*—Con.

Quadrant Formation:	Feet
79. Quartzite, pinkish-gray to light-grayish-brown; in beds 1–2 ft thick	7
78. Concealed	5
77. Quartzite, similar to unit 79	11
76. Concealed	33
75. Dolomite, sandy; weathers light gray	3
74. Quartzite, pale-gray and brown, fine-grained vitreous; weathered surface is brown and rough	3
73. Dolomite, light-gray, thin-bedded, sandy to fine crystalline	2.5
72. Sandstone, dolomitic, honey-colored, very fine grained; weathered surface very rough	2
71. Dolomite, sandy, light-gray; contains irregular chert masses; 2 in. band of gray chert at top	2
70. Dolomite, dense; weathers very light gray; in beds as much as 2 ft thick; contains thin sandy layer near top	10
69. Quartzite, white very fine grained, thin-bedded	4
68. Dolomitie, cherty; weathers pale bluish gray; contains fossil fragments	1
67. Concealed	3
66. Quartzite, cherty matrix with quartz grains, yellowish-gray	1
65. Concealed	15
64. Quartzite, white, very fine grained	4
63. Concealed	6
62. Dolomite, dense; weathers light gray, contains 3 beds of quartzite each 1 in. thick near top	2
61. Quartzite, dolomitic, pale gray, dense; middle part weathers to pitted surface	4
60. Quartzite; similar to unit 61, but weathered surface is ribbed	4
59. Concealed	11
58. Dolomite, cherty, dense; weathers light gray; contains thin beds of quartzite in upper half	15
57. Quartzite, honey-colored; bedding thick and indistinct	18
56. Concealed	11
55. Sandstone, dolomitic, friable	1
54. Dolomitic, sandy; 1-in. layer of gray chert near top	4.5
53. Quartzite, dolomitic, honey-colored	1
52. Sandstone, calcareous, or limestone, sandy, almost white, punky	5.5
51. Dolomite, dense, light gray; contains chert laminae in lower half	11.5
50. Concealed	8
49. Sandstone, calcareous, or limestone, sandy, light-gray, friable	10.5
48. Quartzite, light-gray to light-yellowish-gray; weathers pale brown; upper 4 ft. vitreous; lower 1 ft calcareous and friable	5
47. Sandstone, yellowish-gray, calcareous, fine-grained	2
46. Dolomite, dense; weathers white	1
45. Dolomite, very finely crystalline, light-gray; weathers darker gray	1

SECTION 1.—*Morrison, Swift, Phosphoria (and related strata), Quadrant, and Amsden Formations near Indian Creek*—Con.

Quadrant Formation—Continued	Feet
44. Dolomite, dense gray; weathers white	1
43. Concealed	2
42. Dolomite, sandy, gray	5
41. Concealed	2
40. Sandstone, dolomitic, yellowish-gray and very light gray, fine-grained; upper part quartzitic	4
39. Dolomite, sandy; weathers very light gray	3
38. Dolomite, honey-colored, sandy	1
37. Quartzite, very light gray and yellowish-gray, fine-grained	1.5
36. Covered	
35. Sandstone, dolomitic, pale-yellowish-brown, thin-bedded	2
Total thickness of the Quadrant Formation	250

Contact between Quadrant Formation and Amsden Formation is gradational and is placed at bed above uppermost red or pink rocks.

Amsden Formation:	Feet
34. Quartzite, dolomitic, pale-red; weathers pale brownish gray	1
33. Siltstone and fine-grained sandstone, in part dolomitic; weathers light yellowish gray, pinkish gray, and white; thin bedded (⅛–¼ in.), in part crossbedded and very fine grained sandstone	10
32. Siltstone, red; in part slightly dolomitic	3
31. Conglomerate; weathers pale red; fragments are from underlying bed	1
30. Dolomite, silty, very pale gray, thin-bedded	0.5
29. Sandstone, pale-red, coarse and gritty, crossbedded	1
28. Sandstone, slightly dolomitic, very light gray, very fine grained	0.5
27. Sandstone, grayish-red, very fine grained, oolitic?	1
26. Concealed; float is grayish-red mudstone and very fine grained sandstone	10
25. Dolomite, silty, pale-red	1
24. Siltstone, dolomitic, pale-reddish-gray	0.5
23. Quartzite, dolomitic, pale-gray to pinkish-gray	2
22. Shale, papery, grayish-red	3
21. Dolomite, pinkish-gray and blue-gray, dense	0.5
20. Quartzite, light-gray, slightly dolomitic; weathers yellowish gray and brown; in beds about 3 in. thick	1.5
19. Concealed; float is red siltstone	7
18. Dolomite, pale-bluish-gray, dense	4
17. Concealed; float is red siltstone	5
16. Dolomite, reddish-gray to pinkish-gray, dense; in beds 6–8 in. thick	3
15. Concealed	7
14. Dolomite, gray, dense	1
13. Dolomite, dense, pale-olive-gray; weathers grayish orange	6

SECTION 1.—*Morrison, Swift, Phosphoria (and related strata), Quadrant, and Amsden Formations near Indian Creek*—Con.

	Feet
Amsden Formation—Continued	
12. Limestone, fine-grained, dark-gray; weathers bluish gray to yellowish gray; most beds in lower 10 ft are 4–10 in. thick and in upper 18 ft are 12–18 in. thick; chert present as nodules and thin layers; 3 ft above base is bed with abundant small horn corals overlain by 4-in. bed of black calcareous paper shale; dark-gray pencilly shale in beds as much as 1 in. thick present throughout; beds of fossiliferous, light-gray crystalline limestone 5.5–7.5 ft below top	34
11. Limestone, dolomitic, or dolomite, calcareous, dense, yellowish-gray; weathers light gray; in beds 8 in. to 2 ft. thick	15
10. Concealed	38
9. Dolomite, calcareous in lower half of unit, pale gray locally stained pink, dense	11
8. Concealed	12
7. Dolomite, dense, light-gray; weathers with brownish hue; in beds 6–8 inches thick; interbedded with dusky-red siltstone	3
6. Siltstone, grayish-red to dusky-red on fresh and weather surfaces	3.5
5. Concealed	5
4. Limestone, light-gray to almost white, fine-grained; contains chips of red siltstone	6
3. Concealed	7
2. Dolomite, light-gray partly stained pink; in beds 6 in. thick; contains a few thin interbeds of grayish-red siltstone	15
1. Concealed; float is red siltstone, quartzite and dolomite; interval mainly or wholy underlain by red siltstone	96
Total thickness of Amsden Formation	315

Mission Canyon Limestone:
Limestone, massive, cliff-forming; weathers light gray. not measured.

SECTION 2.—*Morrison and Swift Formations near Montana Silver Star mine*

[Measured, by M. R. Klepper, 1948, in SW¼ sec. 16, T. 4 N., R. 1 W., about 2,000 ft east of Montana Silver Star mine (2 miles south of southwest corner of mapped area)]

	Feet
Kootenai Formation (basal part only):	
46. Sandstone, salt-and-pepper, light-gray speckled with darker chert grains, coarse-grained in beds as much as 1 ft thick; partly cross-bedded; basal part gritty and locally pebbly	50
Disconformity	
Morrison Formation:	
45. Concealed; some brown-weathering mudstone in float	23
44. Sandstone, speckled, medium-grained, cross-bedded	1
43. Concealed	15
42. Siltstone and sandstone, fine-grained, yellowish-gray, thin-bedded, friable	4

SECTION 2.—*Morrison and Swift Formations near Montana Silver Star mine*—Continued

	Feet
Morrison Formation—Continued	
41. Mudstone, medium-gray, blocky weathering, contains a few thin beds of yellowish-gray siltstone and fine-grained sandstone	4
40. Sandstone, yellowish-gray, fine-grained, friable	1
39. Shale, dark-gray, fissile to papery	5
38. Concealed; mainly sandstone float	43
37. Sandstone, light-gray to light-brownish-gray, in part color laminated; speckled with dark chert grains; some beds very argillaceous; some contain abundant chips of black shale; thin to medium bedded, in part crossbedded	19
36. Concealed; lower half of interval covered by dark shale and mudstone float	52
35. Mudstone, dull-red and olive, slightly calcereous; weathers to small chips; alternates with dark-olive, very calcareous siltstone and fine-grained sandstone; unit weathers to plates and chunks averaging 1 in. on a side	19
34. Concealed; abundant hematite-stained light-gray sandstone float near middle of interval	30
33. Siltstone and very fine grained sandstones, olive-gray, calcareous; interval contains a few beds of dull-grayish-red silty limestone	15
32. Shale, alternating dull-red and green; interval partly covered	21
31. Concealed	27
30. Limestone, greenish-gray, dense, sublithographic	4
29. Concealed, red soil	21
28. Limestone; similar to unit 30	5
27. Concealed	2
26. Limestone, greenish-gray, dense	1
25. Concealed; lower part probably underlain by olive and brownish siltstone and fine-grained sandstone and upper half by red shale	20
24. Sandstone, calcareous, friable; alternating with sandy and silty limestone; most beds are olive or brownish yellow on fresh and weathered surfaces	11
23. Concealed	11
22. Limestone, impure; alternating with calcareous shale	5
21. Limestone, dolomitic, crystalline, pale-yellowish-brown	1.5
20. Shale, red and grayish-yellow, flaggy, calcareous	4
19. Mudstone and shale, mostly grayish-red, chippy to hackly; contains conspicuous pale-greenish-gray to grayish-red limy concretions	18
18. Shale, grayish-red; few thin interbeds of dense brownish-gray limestone	4.5
17. Siltstone, pale-yellow, calcareous; grades upward into thin-bedded dolomitic limestone	1
16. Shale, grayish-red, greenish-gray, and olive, partly mottled, very slightly calcareous, fissile to hackly; contains concretions and at least one 0.5-ft bed of dense greenish-gray limestone	14
15. Mudstone, greenish-gray, calcareous	1
14. Limestone, pale-greenish-gray, dense, argillaceous	0.5
13. Siltstone, greenish-gray	1

SECTION 2.—*Morrison and Swift Formations near Montana Silver Star mine*—Continued

Morrison Formation—Continued — *Feet*

12. Limestone, weathers light gray; blocky fracturing; contains a few small irregular cherty concretions — 0.5
11. Sandstone, greenish-gray, very fine grained — 0.5
10. Limestone, pinkish-gray, dense, silty; weathers greenish-gray — 0.5
9. Concealed — 1
8. Dolomite, grayish-orange, calcareous, fine-grained — 4
7. Concealed; pale-yellow clayey soil — 9
6. Siltstone, dusky-yellow; weathers into blocks about 1 in. on a side — 2
5. Concealed; float is mixed fine-grained sandstone, shale, and dense limestone — 16

Total thickness Morrison Formation — 438

Swift Formation:

4. Sandstone, grayish-orange, pale-yellowish-brown, and light-olive-gray, fine- to medium-grained, thin-bedded, locally crossbedded, friable; in part argillaceous and in part weakly calcareous — 18
3. Sandstone, gray, calcareous, friable; contains abundant fragments of pelecypod shells — 8.5
2. Concealed — 3.5

Total thickness Swift Formation — 30

Disconformity.

Phosphoria Formation:

1. Chert — Not measured

SECTION 3.—*Kootenai Formation and parts of the Colorado and Morrison Formations*

[Measured by E. T. Ruppel and M. R. Klepper, 1948, in SW¼ sec. 5, T. 6 N., R. 1 E.]

Colorado Formation (part of lower unit only): — *Feet*

67. Shale, medium-dark-gray, fissile, papery to thinly platy; in part contains very small flakes of mica — 41
66. Siltstone, dark-gray, hard, blocky; alternating beds of dark-gray and very dark gray, fissile, papery shale in lower 20.5 ft of unit; two moderately thick beds of similar shale in the upper 28.6 ft; weathers yellowish gray — 49
65. Concealed; probably underlain by olive and gray compact blocky siltstone — 27.5
64. Siltstone, dark-gray, compact, blocky — 6
63. Sandstone, light-olive-gray to yellowish-brown, clean, quartzitic; weathers pale yellowish brown — 2.5

Total measured thickness of Colorado Formation — 126

Kootenai Formation:

62. Siltstone, dark-gray, coarse-grained, compact, blocky; very calcareous in lower 2 ft — 5.5
61. Concealed; shale interval — 4
60. Limestone, dark-gray, dense to fine-grained, lumpy-weathering — 2
59. Concealed — 12

SECTION 3.—*Kootenai Formation and parts of the Colorado and Morrison Formation*—Continued

Kootenai Formation—Continued — *Feet*

58. Limestone, medium-dark-gray, irregularly bedded; weathers medium gray to medium light gray — 2.5
57. Siltstone, micaceous; contains 0.5-ft-thick platy gray limestone bed in middle of unit — 3
56. Limestone, gray, platy — 1
55. Sill of Late Cretaceous and Paleocene age, decomposed; contains abundant biotite phenocrysts; 2 ft thick.
54. Limestone, dark-gray, very fine grained; contains scattered pebbles and chips of limestone similar to that in unit 53; weathers light gray to light olive gray — 5
53. Limestone, medium-dark-gray, granular, fetid; fossil gastropods abundant; weathers medium gray to dark yellowish brown — 2.5
52. Limestone, medium-gray to medium-dark-gray, very fine to medium grained; contains a few gastropod-rich layers; weathers medium light gray — 5.5
51. Limestone, similar to unit 53, but only slightly fetid — 1.5
50. Concealed — 10.5
49. Shale, grayish-red to grayish-purple and greenish-gray to light-olive-gray; grayish red predominant in lower 48 ft, greenish gray predominant in upper 23.6 ft; fissile to thinly platy; contains irregular thin, lenticular, and ovoidal dense limestone concretions from 4.3 to 14 ft above base, and 0.2-ft-thick brown-weathering dense concretionary limestone bed 48 ft above base — 71.5
48. Shale, pale-red to grayish-red, and subordinate light-olive-gray to greenish-gray interbeds; fissile, chippy, and hackly; zone of irregular ovoidal to spherical brown-weathering limestone concretions from 12.1 to 13.3 ft above base — 17
47. Mudstone, light-olive-gray to olive-gray, and subordinate grayish-red interbeds, platy to fissile — 3
46. Limestone, pale-purple to pale-reddish-purple, locally with pale-green tint, very fine grained, subconchoidal fracture; weathers dark yellowish brown — 0.5
45. Mudstone, light-olive-gray to olive-gray, and grayish-red interbeds in upper 6 ft, platy to subfissile; thin zone of limestone concretions 20.6 ft above base is similar to those of unit 49 — 27.5
44. Concealed — 20
43. Mudstone, light-olive-gray, platy — 4
42. Limestone, dark-gray, dense; contains scattered small calcite crystals; very fossiliferous — 0.5
41. Shale, yellowish-gray to light-olive-gray, fissile to chippy — 3
40. Shale, dusky-blue to grayish-purple, fissile to chippy — 3
39. Concealed — 3
38. Limestone, pale-purple to grayish-red-purple, very fine grained; weathers dusky yellowish brown — 1

SECTION 3.—*Kootenai Formation and parts of the Colorado and Morrison Formation*—Continued

Kootenai Formation—Continued	*Feet*
37. Shale, grayish-red, and grayish-olive interbeds in lower 6 ft, fissile; abundant limestone concretions similar to those in unit 49 in upper 1 ft	16
36. Shale, grayish-olive, fissile, micaceous; contains thin, lenticular, and flattened grayish-olive dense limestone concretions in upper 4 ft	15
35. Mudstone, light-olive-gray to greenish-gray, fissile, pencilly, and chippy; contains sparsely disseminated light-gray dense limestone concretions up to 2 in. in diameter; upper 1 ft is principally medium-gray concretionary limestone that weathers to irregular rounded pieces up to 8 in. in diameter	16
34. Mudstone, light-greenish-gray, very thin and irregularly bedded; weathers very light gray	6
33. Mudstone, greenish-gray and yellowish-gray, fissile to blocky; pencilly in lower 5 ft; weathers yellowish orange	10
32. Shale, grayish-purple to very dusky purple, very fissile; conspicuous rounded sublithographic limestone concretions up to 5 in. in diameter in zones 2 ft thick near the top and bottom of unit	16
31. Concealed; red shale float	19
30. Siltstone, yellowish gray to grayish yellow in lower half and pale red to grayish red in upper half of unit; sparse limestone concretions throughout	9
29. Sandstone, white, clean, in beds 0.4 ft thick; a few interbeds of grayish-yellow mudstone, in part irregularly ripple marked	6
28. Sandstone, pale-yellowish-brown, limonitic; contains subordinate rounded black chert grains; medium-grained; in beds 0.4–1 ft thick	17
27. Sandstone, yellowish-gray, fine-grained, compact; in beds 0.5–0.7 ft thick; contains interbeds of yellowish-orange, grayish, and grayish-red, platy, fissile, irregularly lumpy sandstone	9
26. Concealed; float is red mudstone	8.5
25. Mudstone, pale-red to grayish-red, fissile to platy, and lumpy	2
24. Sandstone, medium-grained, limonitic	0.5
23. Mudstone, similar to unit 25	13.5
22. Mudstone, yellowish-orange, platy to chippy	1.5
21. Concealed	4
20. Conglomerate, fine-grained sandstone matrix and pebbles of yellowish siltstone and light-gray limestone	2
19. Concealed	6
18. Sandstone, pale-reddish-brown, very fine grained	2
17. Sandstone medium-gray, "salt-and-pepper" medium grained, compact, quartzitic; in beds 0.25–0.75 ft thick	10
16. Mudstone, interbedded pale-red and grayish-yellow, chippy to lumpy; 0.3-ft thick bed of reddish-brown fine-grained blocky sandstone at base of unit	13

SECTION 3.—*Kootenai Formation and parts of the Colorado and Morrison Formation*—Continued

Kootenai Formation—Continued	*Feet*
15. Sandstone, pale-reddish-brown, very fine grained, blocky; contains a few thin beds of grayish-yellow, fissile to lumpy mudstone	4
14. Conglomerate, subrounded gray limestone and orange siltstone fragments up to 0.25 in. in diameter in a matrix of sand and mud	2
13. Mudstone, interbedded yellowish-gray and pale-red, fissile to platy and lumpy	15
12. Concealed	2
11. Sandstone, pale-yellowish-brown, slightly calcareous, very fine grained; contains sparsely disseminated black chert pebbles	1
10. Concealed	7
9. Limestone, pale-yellowish-brown, dense, sublithographic, and yellowish-gray mudstone; edgewise pebble conglomerate zone in upper 0.5 ft	7
8. Mudstone, olive-gray, somewhat hackly; contains small limestone chips or flattened concretions	9
7. Concealed	9
6. Mudstone, similar to unit 8, but contains small concretions of light-olive-gray dense limestone in upper part	17
5. Mudstone, dark-gray, platy; weathers light gray	1
4. Concealed	8
3. Sandstone, pale-yellowish-brown to light-gray, salt-and-pepper medium-grained, homogeneous, quartzitic, very indistinctly bedded to massive; weathers to large irregular blocks up to 6 ft in diameter	36
Total thickness of the Kootenai Formation	529
Morrison Formation:	
2. Concealed	35
1. Sandstone, light-olive-gray, medium-fine- to medium-grained, limonitic, in beds less than 1 ft thick, which are crossbedded on a small scale	31

SECTION 4.—*Colorado Formation near south end of mapped area*

[Measured by M. R. Klepper, 1949, along shallow gully that approximately coincides with boundary between NE¼ and SE¼ sec. 4, T. 4 N., R. 1 W.]

Slim Sam Formation:	*Feet*
Measured section published in Klepper, Weeks, and Ruppel (1957, p 31).	
Basal unit is sandstone, light-olive-gray, thin-bedded, non-resistant; contains a few thin beds of siltstone in lower half. "*Mactra*" *arenaria* Meek, a pelecypod not known from rocks as young as the Montana Group was collected from beds about 300 ft (USGS Mesozoic loc. 23039) and 375 ft (USGS Mesozoic loc. 23040) above the base of the formation (W. A. Cobban, written commun. May 31, 1951)	55

Gradational contact.

SECTION 4.—*Colorado Formation near south end of mapped area*—Continued

	Feet
Colorado Formation:	
Upper black shale unit:	
66. Shale (80–90 percent), dark-gray to very dark-gray, chippy to fissile, and dark-gray very fine grained micaceous sandstone (10–20 percent); shale contains sporadic moderate-yellowish-brown-weathering limestone concretions up to 6 in. in diameter. Collection (USGS Mesozoic loc. 23032) near top of unit contains *Inoceramus* cf. *I. umbonatus* Meek and Hayden, *Scaphites ventricosus* Meek and Hayden, and *Scaphites* cf. *S. tetonensis* Cobban. Another collection (USGS Mesozoic loc. 23031) near middle of unit contains *Inoceramus umbonatus* Meek and Hayden, *Ostrea congesta* Conrad, and *Baculites asper* Morton. A collection (USGS Mesozoic loc. 23030) near the base of the unit contains *Inoceramus* cf. *I. umbonatus* Meek and Hayden, and *Ostrea congesta* Conrad. These collections are indicative of the next faunal zone above the zone of *Inoceramus deformis* of earliest Niobrara age (W. A. Cobban, written commun., May 31, 1951)	254
65. Concealed; probable duplication by faulting	97
64. Shale, very dark gray, and olive-gray; mudstone; contains conspicuous brown-weathering limestone concretions	30
Total thickness of upper black shale unit maximum [3]	381
minimum	284
Gradational contact.	
Middle siliceous mudstone and sandstone unit:	
63. Concealed; sandstone float	22
62. Sandstone, coarse-grained, crossbedded; speckled with chert and feldspar(?) grains	4
61. Concealed; 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
59. Concealed	45
58. Sandstone, quartzitic, medium-dark-gray	5
57. Sandstone, light-gray and olive, thin- to medium-bedded; in part speckled with chert and feldspar grains; contains a few interbeds of blocky mudstone	38
56. Concealed	56
55. Sandstone, light-gray, speckled, crossbedded; 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. Concealed	37

[3] About 100 ft. thicker than this unit at other localities: some beds are probably duplicated by a concealed fault or faults in interval 65; true thickness is greater than 284 ft. and probably less than 381 ft.

SECTION 4.—*Colorado Formation near south end of mapped area*—Continued

	Feet
Colorado Formation—Continued	
Middle siliceous mudstone and sandstone unit—Con.	
52. Mudstone, similar to unit 54	24
51. Mudstone, yellow, olive, and gray, siliceous; in layers 4 in. to 1 ft thick	19
50. Concealed	28
49. Mudstone, siliceous; similar to unit 51; contains 4-ft-thick bed of quartzite near top	22
48. Concealed	21
47. Mudstone, very light to dark gray and olive-gray, siliceous, blocky; contains a few thin layers of hard sandstone	18
46. Concealed	20
45. Mudstone, medium-gray, siliceous	2
44. Sandstone, light-olive-gray, medium-grained, speckled	3
43. Concealed; float is blocky siliceous mudstone	22
42. Mudstone, pale-greenish-yellow and medium-dark-gray, siliceous, blocky to subconchoidal fracture	10
41. Quartzite, very light gray with thin brown layers	10
40. Concealed	17
39. Mudstone, greenish-gray, siliceous, blocky	4
38. Concealed	12
37. Sandstone, very light gray, thin-bedded, crossbedded, speckled	8
36. Mudstone; alternation of units from 1 to 6 ft thick colored grayish olive, light gray, and medium gray; contains 1 thin layer of siliceous mudstone and several of light-gray standstone	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 gray 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. Concealed	10
29. Mudstone or shale, olive-gray, medium-gray, and medium-dark-gray, chippy to fissile	35
28. Sandstone, siltstone, shale, and a few limestone concretions, drab-colored	39
27. Mudstone and 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; speckled with chert and feldspar(?) grains	7
22. Concealed	6
21. Sandstone, similar to unit 19	8
20. Concealed; sandstone float	24

SECTION 4.—*Colorado Formation near south end of mapped area*—Continued

	Feet
Colorado Formation—Continued	
Middle siliceous mudstone and sandstone unit—Con.	
19. Sandstone, medium- to light-gray, very fine grained; contains a zone of roundish calcareous sandstone concretions near middle of unit. Collections (USGS Mesozoic loc. 23029 and 23498) from this unit contain: *Lingula* cf. *L. subspatula* Hall and Meek, "*Yoldia*" sp.; *Nemodon?* sp.; *Ostrea anomioides* Meek; *Volsella* n. sp.; *Anatimya* n. sp.; *Cymella* n. sp.; *Cardium* (Nemocardium) n. sp. aff. *C. kansasense* Meek; *Linearia* n. sp. aff. *L. cribelli* Stephenson; *Leptosolen* n. sp., *Mactra? aspenana* Reeside and Weymouth; "*Corbula*" sp.; *Protodonax* aff. *P. stantoni* Vokes; *Anchura?* sp.; "*Cyrena*" *inflexa* Meek. A number of the species are known at other localities only in the Mowry and Aspen Shales (W. A. Cobban, written commun., May 31, 1951, and Oct. 24, 1951)	11
18. Concealed; sandstone float	11
17. Sandstone, similar to unit 15	2
16. Concealed	12
15. Sandstone, medium-light-gray, crossbedded, speckled, cherty and feldspathic(?); in beds about ½ in. thick; calcareous sandstone concretions (2–3 in. 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 mudstone and sandstone unit	930
Gradational contact.	
Lower black shale unit:	
13. Concealed	17
12. Shale, very dark gray	9
11. Sandstone and siltstone, medium-gray; bedding is irregular and wavy. Collection (USGS Mesozoic loc. 23028) from middle part of unit contains *Inoceramus* cf. *I. bellvuensis* Reeside; this fossil indicates a probable correlation with the Skull Creek Shale of the Black Hills (W. A. Cobban, written commun., May 31, 1951)	37
10. Concealed; very dark gray shale float	34
9. Sandstone, similar to unit 7	2
Fine-grained diorite sill 40 ft thick	
8. Mostly covered; outcrops are sandstone similar to unit 7	47
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. Concealed; very dark gray and dark-gray shale float is predominant; sandstone float is subordinate	106

SECTION 4.—*Colorado Formation near south end of mapped area*—Continued

	Feet
Gradational contact—Continued	
Lower black shale unit—Continued	
5. Siltstone, dark-gray and olive, thin-bedded and almost fissile; contains irregular limonitic concretions in upper 4 ft	13
4. Shale, very dark gray; a few 2-in.-thick beds of rusty-weathering siltstone	19
3. Concealed; olive-gray siltstone float	10
2. Sandstone, very light gray, calcareous, very fine grained; in beds ½–3 in. thick	12
1. Sandstone, light-olive-gray, fine-grained	3
Total thickness of lower black shale unit	328
Total thickness of Colorado Formation:	
Maximum	1,639
Minimum	1,542

Kootenai Formation (Not measured)
Limestone near top contains the following prosobrachian gastropods: *Lioplacodes* cf. *L. convexiculus* Yen, *Lioplacodes* cf. *L. cretaceus* (Stanton), *Charydrobia* cf. *C. cretacea* Yen, and *? Reesidella* sp. undet. common species of the Kootenai Formation (T. C. Yen, written comm. Mar. 25, 1952).

SECTION 5.—*Colorado Formation along and near the Indian Creek road*

[Measured by M. R. Klepper and V. L. Freeman in secs. 5 and 6, T. 6 N., R. 1E.]

	Feet
Slim Sam Formation:	
Measured section published in Klepper, Weeks, and Ruppel (1957, p. 30–31). Basal part is sandstone, medium gray, argillaceous, feldspathic, thin bedded with few thin black shale interbeds, 14 ft thick	—
Total thickness of Slim Sam Formation	910
Colorado Formation:	
Upper black shale unit:	
29. Shale, very dark gray to black. Fossil collection (USGS Mesozoic loc. 23037) about 20 ft below top of unit contains: *Ostera congesta* Conrad; *Baculites asper* Morton; and *Scaphites ventricosus* Meek and Hayden. Fossil collection (USGS Mesozoic loc. 23034) near base of unit contains: *Pinna dolosoniensis* McLean; *Inoceramus umbonatus* Meek and Hayden; *Ostrea congesta* Conrad; *Volsella* n. sp.; *Pholadomya* aff. *P. papyracea* Meek and Hayden; *Lucina* sp.; *Legumen* cf. *L. ellipticum* Conrad; *Gyrodes conradi* Meek; *Baculites asper* Morton; *Baculites* cf. *B. codyensis* Reeside; *Scaphites tetonesis* Cobban. This collection is indicative of the next faunal zone above the zone of *Inoceramus deformis* of earliest Niobrara age (W. A. Cobban, written commun., May 31, 1951)	56

SECTION 5.—*Colorado Formation along and near the Indian Creek road*—Continued

Colorado Formation—Continued

Upper black shale unit—Continued — Feet

28. Shale, very dark gray to black; upper 36 ft mostly covered and may contain diorite porphyry sill about 5 ft thick — 72.5
27. Shale, very dark to black; mostly outcrop; some interbeds of very fine grained black sandstone. Fossil collection (USGS mesozoic loc. 23033) near middle of unit contains *Inoceramus umbonatus* Meek and Hayden; *Inoceramus* n. sp. *Ostrea congesta* Conrad; *Pholadomya* cf. *P. papyracea* Meek and Hayden; *Veniella goniophora* Meek; *Legumen* cf. *L. ellipticum* Conrad; *Baculites asper* Morton *Idiohamites?* sp. *Scaphites* sp. This collection is indicative of the next faunal zone above the zone of *Inoceramus deformis* of earlest Niobrara age (W. A. Cobban, written comm., May 31, 1951) — 95
26. Sandstone and subordinate, dark gray; foul-bottom type lithology and structure, with undulose bedding, ripple marks, and worm trails. Fossil collection (USGS Mesozoic loc. 23035) from top of unit contains *Inoceramus* cf. *I. deformis* Meek, indicative of earliest Niobrara age (W. A. Cobban, written commun., May 31, 1951). Another collection (58K4), possibly from the same bed but probably from another bed a few feet lower in the section, contains *Inoceramus* cf. *I. incertus* Jimbo, *Ostrea* sp., *Baculites* sp., and *Scaphites* sp. *Inoceramus* cf. *I. incertus* marks the very highest Carlile bed in the Western Interior region (W. A. Cobban, written comm., Sept. 15, 1958)

A collection (USGS Mesozoic loc. 24000) from 10–25 ft above base of the unit (25–40 ft below collections listed above) contains *Inoceramus deformis* Meek, *Inoceramus*, unnamed species resembling *I. labiatus* (Schlotheim), *Pholadomya papyracea* Meek and Hayden, and *Scaphites* sp. cf. *S. ventricosus* group and is indicative of the basal Niobrara zone (J. B. Reeside, Jr., written commun., Oct. 3, 1952). Another collection (58K3) from about the same bed contains *Inoceramus* sp. and *Cardium* cf. *C. pauperculum* Meek. (W. A. Cobban, written commun., Sept. 15, 1958).

The presence of rocks that are probably of highest Carlile age between rocks of earliest Niobrara age suggests that 10–20 ft of beds has been duplicated by an unrecognized fault within unit 26. In any event the contact between rocks of Carlile and Niobrara age is within this unit, for rocks at the top of the underlying unit are probable equivalents of the middle part of the Carlile and those in the overlying shale are equivalents of the lower part of the Niobrara (next faunal zone above zone of *Inoceramus deformis* of earliest Niobrara age) — 50

Total thickness of upper black shale unit — 273.5

Middle siliceous mudstone and sandstone unit:

25. Sandstone, tan, salt-and-pepper. Collection 58K2 (USGS Mesozoic loc. D1749) from top of unit contains: *Inoceramus* cf. *I. perplexus* Whitfield, *Mactra*, sp., and *Tellina* sp. The impressions of *Inoceramus* suggest the species *perplexus* of middle Carlile age (W. A. Cobban, written commun., Sept. 15, 1958) — 37
24. Sandstone, siltstone, and thin interbeds of grayish-black shale; sandstone is argillaceous foul-bottom lithology having scattered fossil fragments, undulose bedding, ripple marks and worm trails; poorly exposed. Collection 58K1 (USGS Mesozoic loc. D1748) from base of unit contains *Inoceramus?* sp., *Ostrea* sp., and preserved fragments of gastropods. The fragments of oysters suggest a small smooth species that is common in rocks of Greenhorn and early Carlile age (W. A. Cobban, written commun., Sept. 15, 1958) — 109
23. Sandstone, tan, salt-and-pepper, pebbly, thick-bedded — 37

Sill, diorite porphyry, not measured; section offset.

22. Concealed; diorite porphyry float obscures bedrock, but probably underlain by sandstone, siltstone, and mudstone; may include some thin sills — 92.5
21. Mudstone, siliceous, and some mudstone pebble conglomerate; poorly exposed, less than one-quarter of interval is outcrop — 21
20. Concealed; probably underlain by siliceous mudstone, mudstone, and siltstone — 118

Sill, diorite porphyry, 32 ft thick.

19. Sandstone, greenish-gray to pale-olive, medium-coarse-grained, feldspathic; interbedded with dark-gray shale — 70.5
18. Sandstone, greenish-gray to pale-olive, medium-coarse-grained, feldspathic — 12
17. Concealed; but probably underlain by sandstone similar to 18 — 14

Sill, diorite porphyry, 14.5 ft thick.

16. Concealed; probably underlain by sandstone similar to 18 — 43

SECTION 5.—*Colorado Formation along and near the Indian Creek road*—Continued

	Feet
Colorado Formation—Continued	
Middle siliceous mudstone and sandstone unit—Continued	
15. Sandstone, greenish-gray, medium-fine-grained, feldspathic, distinctly bedded and thin-bedded	4.5
14. Concealed; float similar to 15	19
13. Sandstone, greenish-gray, medium-fine-grained, feldspathic, slightly to moderately calcareous	4.5
12. Concealed; probably underlain by sandstone similar to that in unit 13. Sandstone float nearby from this unit or within 50 ft above it (USGS Mesozoic loc. 23413) contains *Lingula* cf. *L. subspatulata* Hall and Meek, *Ostrea anomioides* Meek, *Trigonia* sp., and *Mactra* sp.; fossils that indicate a correlation with the Mowry and Aspen formations (W. A. Cobban, written commun., May 31, 1951)	29
Total thickness of middle siliceous mudstone and sandstone unit	611
Lower black shale unit:	
11. Concealed	4
10. Sandstone, fine-grained, argillaceous, and dark-gray poorly exposed siltstone	33
9. Sandstone, very fine-grained, and siltstone, interbedded with dark-gray papery shale: all are rusty weathering, in part mottled and irregularly laminated in shades of medium and dark gray; three beds, each 6 in. thick, of light-gray coarse-grained salt-and-pepper sandstone in upper 13 ft	72.5
8. Shale, very dark gray to grayish-black, fissile	10.5
Sill, diorite porphyry 15.5 ft thick.	
7. Shale; similar to that in unit 8	62
Sill, diorite porphyry 11 ft thick.	
6. Shale; similar to that in unit 8	23.5
5. Siltstone, olive-gray, blocky, and brown-weathering, very fine grained sandstone; poorly exposed; top 1–2 ft of interval is fine- to medium-grained light-gray quartzite, similar to unit 4	35
4. Quartzite, light-gray to olive-gray, salt-and-pepper fine- to medium-grained, massive bedded	15
Total thickness of lower black shale unit	255.5
Total thickness of Colorado Formation	1,140
Kootenai Formation:	
3. Concealed	19
2. Mudstone, siltstone	11
1. Limstone, light-gray-weathering; contains fossil gastropods	Not measured

SECTION 6.—*Slim Sam Formation (part) and Colorado Formation near Iron Mask mine*

[Measured by M. R. Klepper and V. L. Freeman, 1952, near Iron Mask Mine in SE¼ sec. 30, T. 7 N., R. 1 W., and adjacent parts of secs. 29, 31, 32]

	Feet
Slim Sam Formation (lower part only):	
71. Sandstone, medium-gray to light-olive-gray, medium-grained, feldspathic and argillaceous; beds ¼–4 in. thick with a few ¼–1 in.-thick medium-dark-gray shaly interbeds; one 8-in. crystal tuff bed 44 ft above base	71
70. Sandstone, medium-gray, fine- to medium-grained, feldspathic, thin-bedded (¼–2 in.)	2
69. Concealed; except for 1 ft of sandstone similar to that in unit 70	15
68. Sandstone, medium-gray, slightly mottled, argillaceous	3
67. Concealed	6.5
66. Siltstone and very fine grained sandstone, medium-gray and olive; some interstitial clay and thin lenses of crystal tuff; thin-bedded	2
65. Concealed	13.5
64. Siltstone and very fine grained sandstone, like unit 66	28.5
63. Siltstone, interbedded olive and medium- to dark-gray, hackly to rubbly fracturing	3
Measured thickness of Slim Sam Formation	144.5
Colorado Formation:	
Upper black shale unit:	
62. Shale, grayish-black, fissile; local thin interbeds of siltstone and very fine grained sandstone form about 5 percent of interval; weathers with some limonite staining	57
61. Shale, dark-gray to grayish-black, fissile, and thin blocky siltstone beds; diorite dike 5–6 ft thick cuts middle part of unit; 1- to 3-in.-thick beds of dark-gray, very fine grained sandstone common 28–40 ft above base; large brown-weathering limestone concretions common in upper 11 ft of unit	45.5
60. Concealed	8.5
59. Sandstone, very fine grained; interbedded with siltstone; dark-gray and olive	3
Sill, diorite porphyry with conspicuous hornblende phenocrysts, approximately 40 ft thick.	
58. Shale, dark-gray, fissile; upper part contains about equal amounts of shale and olive fine-grained laminated sandstone in ½- to 3-in.-thick beds	19
57. Shale, grayish-black, fissile, and numerous very thin beds of dark-gray siltstone; limonite staining common	32.5
56. Concealed	30.5
55. Shale, dark-gray to grayish-black, fissile to finely chippy, few 1-in. thick beds of siltstone; in part limonite stained along fractures	11.5
54. Concealed	20

SECTION 6.—*Slim Sam Formation (part) and Colorado Formation near Iron Mask mine*—Continued

	Feet
Colorado Formation—Continued	
Upper black shale unit—Continued	
53. Sandstone, very fine grained, and siltstone, medium-dark-gray to dark-gray, micaceous, distinct bedding in 1- to 6-in.-thick beds; weathers blocky near base to hackly or crumbly in upper two-thirds of unit	24
52. Sandstone, dark-gray, fine grained; with one 3-ft-thick zone of olive siltstone; chippy weathering	13
51. Sandstone, medium- to dark-gray, fine-grained, argillaceous, laminated, in part light gray streaked; subordinate very dark gray shale interbeds	16.5
Total thickness of upper black shale unit	281
Middle siliceous mudstone and sandstone unit:	
50. Sandstone, medium-gray, coarse-grained salt-and-pepper; indistinctly bedded with irregular streaky laminae	7
Sill, diorite porphyry about 6 ft thick.	
49. Sandstone, similar to that in unit 50	3
48. Sandstone, pale-olive, medium-grained, thin- to medium-bedded; in part cross-laminated, slightly calcareous in part	24.5
47. Shale, olive and dark-gray, fissile; siltstone; a few thin beds of fine-grained olive sandstone	15
46. Sandstone, medium-gray to light-olive-gray and light-yellow-brown, limonite-stained, fine-grained; in beds 1–12 in. thick; subordinate dark-gray to very dark gray fissile shale in beds ¼–6 in. thick	36
45. Sandstone, mottled medium-gray and dark-gray, fine-grained, argillaceous; interbedded with dark-gray subfissile siltstone	12
44. Concealed	20
43. Sandstone, very fine grained, and siltstone, medium-dark-gray, blocky; some beds thinly laminated and cross-laminated; subordinate dark-gray shale	9
Sill, diorite porphyry, about 13 ft thick.	
42. Sandstone, medium-light-gray to medium-gray, salt-and-pepper; coarse-grained with pebble conglomerate near base and scattered pebbles above; medium bedded and distinctly bedded. Lower half is finer grained, less friable	19.5
41. Sandstone, light-olive-gray, fine- to medium-fine-grained, medium-bedded	18.5
Sill, diorite porphyry, 15 ft thick.	
40. Mudstone, greenish-gray to pale-olive, subfissile to rubbly or hackly weathering; a few thin blocky weathering siliceous mudstone beds	22
39. Sandstone, medium-light-gray, fine-grained, thin-bedded, calcareous	8.5

SECTION 6.—*Slim Sam Formation (part) and Colorado Formation near Iron Mask mine*—Continued

	Feet
Colorado Formation—Continued	
Middle siliceous mudstone and sandstone unit—Continued	
38. Mudstone, gray and olive, splintery and chippy	19
37. Sandstone, light-gray, fine-grained, thin-bedded, calcareous	2.5
36. Siltstone, medium-gray, light-gray, and olive, splintery- and rubbly-weathering; middle part calcareous	29
35. Mudstone, very light-gray, siliceous, blocky; weathers white, a few dark-gray siltstone interbedds	13
Sill, diorite porphyry, 7 ft thick.	
34. Siltstone, olive and dark-gray; interbedded siliceous and nonsiliceous beds and prominent beds of light-gray-weathering speckled coarse-grained sandstone 7–9 ft above base	31
Concealed; probably underlain by diorite sill or dike, 8 ft thick.	
33. Siltstone, light-olive and greenish-gray, splintery; medium- to dark-gray blocky siliceous mudstone	29
Sill, diorite porphyry 1.5 ft thick.	
32. Siltstone, olive, light-gray, and dark-gray, blocky fracturing, chippy to rubbly weathering; some beds are siliceous; diorite porphyry sill 2 ft thick cuts unit	22
31. Sandstone, light-gray, medium-grained; and olive siltstone	6.5
30. Mudstone, dark-gray, siliceous	5
29. Concealed	20
28. Siltstone, greenish-gray to pale-olive, splintery; subordinate olive to dark-gray siliceous mudstone and light-gray sandstone	22
Sill, diorite porphyry, 7 ft thick.	
27. Mudstone, dark-gray, siliceous, fissile to hackly	6
26. Siltstone, olive, hackly fracture	7
25. Concealed	12
24. Mudstone, olive and gray, siliceous, blocky fracture; interbedded with irregular-fracturing olive siltstone and very fine grained sandstone	22
23. Mudstone, siliceous, blocky fracture; interbedded with gray and olive hackly- to splintery-fracturing siltstone to very fine grained sandstone	10.5
22. Sandstone, speckled, medium- to coarse-grained	1
21. Siltstone, pale-olive, olive-gray, and greenish-gray; similar to unit 17; two conspicuous medium-grained sandstone beds, one 3 ft above base, other 22 ft above base; diorite porphyry sill 2.5 ft thick 14.5 ft above base (thickness not included)	27
Sill, diorite porphyry, 4.5 ft thick.	

SECTION 6.—*Slim Sam Formation (part) and Colorado Formation near Iron Mask mine*—Continued

	Feet
Colorado Formation—Continued	
Middle siliceous mudstone and sandstone unit—Continued	
20. Sandstone, medium-gray, fine-grained, calcareous, thin-bedded and irregularly bedded; weathers greenish-gray	5
19. Siltstone, similar to unit 17	22.5
Sill, diorite porphyry, 3–4 ft thick. Section offset on top of sill.	
18. Siltstone, olive-gray, sandy, subhackly fracture	12
17. Siltstone, pale-olive, olive-gray, and greenish-gray; a few dusky-yellow blocky to chippy fracturing beds, and common dark-gray chippy to hackly or pencilly fracturing beds; a few beds 6–12 in. thick of medium-grained argillaceous sandstone; most of the coarser grained beds are calcareous	53.5
16. Concealed	5
15. Sandstone, olive-gray, medium- and fine-grained, and subordinate siltstone; cut by a 3- to 4-ft-thick diorite sill (thickness not included)	25
14. Sandstone, medium-gray to medium-dark-gray and some olive-gray beds, fine-grained, thin- to very thin-bedded (1/8-1 in. beds); weathers olive gray; medium-gray to dark-gray platy siltstone	29
13. Concealed	29
12. Sandstone, medium- to greenish-gray, medium-fine-grained, well-bedded; in beds 1 in. thick with one 3-ft-thick bed near middle of unit; argillaceous and slightly calcareous	30
Sill, pyroxene andesite, about 10 ft thick. Section offset.	
Total thickness of middle siliceous mudstone and sandstone unit	690.5
Lower black shale unit:	
11. Concealed; probably underlain by gray sandstone and dark-gray siltstone	11.5
10. Sandstone, dark-gray, and dark-gray siltstone	3
Sill, diorite porphyry, 14 ft thick.	
9. Sandstone, dark-gray, and dark-gray siltstone	12.5
8. Sandstone, light olive-gray, speckled, medium-grained	2.5
7. Mostly covered; underlain by gray mottled argillaceous sandstone and dark-gray pencilly fracturing siltstone	85
6. Mostly concealed; underlain by black to very dark gray papery shale	54.5
5. Concealed	26
4. Argillite, drab and olive, and some blocky siltstone and fine-grained sandstone; irregular lumpy bedding, some ripple marks and worm trails on bedding planes	29

SECTION 6.—*Slim Sam Formation (part) and Colorado Formation near Iron Mask mine*—Continued

	Feet
Colorado Formation—Continued	
Lower black shale unit—Continued	
3. Quartzite, yellowish-gray to light olive-gray, fine-grained	16
Total thickness lower black shale unit	240
Total thickness Colorado Formation	1,211.5
Kootenai Formation:	
2. Claystone and siltstone	36
1. Limestone; contains abundant fossil gastropods	Not measured

SECTION 7.—*Lower part of middle member of the Elkhorn Mountains Volcanics*

[Measured by M. R. Klepper, H. W. Smedes, and R. A. Weeks, starting at road at line between secs. 15 and 16, T. 8 N., R. 1 W., extending along spur through the NW¼NE¼ sec. 21, and ending along the line between secs. 17 and 20]

	Feet
Top of measured section:	
63. Welded ash-flow tuff, dark-gray; weathers to medium gray or medium light gray; contains abundant flattened pumice ribbons, many of which are more than 18 in. long, and sparse rock fragments	>100
62. Covered	17
61. Crystal tuff and crystal lithic tuff, poorly bedded; contains sparse to abundant fragments up to 8 in. in diameter; matrix is dominantly silt-size crystal tuff; lithic fragments resemble fragments in unit 58	33
60. Crystal tuff and crystal lithic tuff, indistinctly to distinctly bedded; most layers are fine grained, a few are coarse grained, and a few are lapilli tuff	12
59. Covered	10
58. Tuff breccia; lithic fragments, which average less than 4 in. in diameter but are as much as 10 in., from half to two-thirds of the unit; most fragments are of same apparent composition as the crystal tuff matrix; some fragments are sharply bounded, others are vaguely outlined. Vague bedding at 60 ft above base and sparsely throughout upper 50 ft indicates that transporting agent was able to accomplish some sorting; probably of hot mudflow origin	160
Probable erosional surface of slight relief.	
57. Crystal and crystal lithic tuff, poorly bedded; contains sparse lapilli throughout; number of lapilli increases upward	35
56. Covered; probably underlain by rocks similar to those in unit above	16
55. Tuff breccia, similar to unit 58; largest fragment observed was 3 in. across	2
54. Crystal tuff, dark-gray to dark-greenish-gray, massive to well-bedded, dominantly fine-grained; sparse ¼- to ½-inch lapilli in beds near middle of unit	65
53. Ash flow tuff, poorly welded	3
52. Crystal tuff, well-bedded; contains a few mudstone laminae and one thin mudstone dike	2

SECTION 7.—*Lower part of middle member of the Elkhorn Mountains Volcanics*—Continued

	Feet
51. Tuff breccia, medium-gray with a greenish cast; weathers light olive gray, grayish orange, and greenish gray; forms blocky to rubbly cliffs; slightly rounded fragments are ¼-9 in. across and average about 3 in.; all are of the same lithology and strongly resemble the crystal tuff matrix. On fresh surface, rock is apparently homogeneous, but on weathering the breccia fragments become apparent. Massive, except for indistinct layering and one thin irregular fine-grained crystal tuff lens at 70 ft above base. Probably of hot mudflow origin	125
50. Ash-flow tuff, welded to partly welded, medium-dark-gray to dark-greenish-gray; weathers medium gray to light greenish gray; top few feet is of unwelded lapilli tuff, grades down to strongly welded tuff containing flattened pumice ribbons several inches long and abundant lithic fragments up to 3 in. in diameter, which in turn grades into lower 50-ft-thick unit containing sparse flattened pumice about 1 in. in maximum diameter and relatively abundant lithic fragments less than ½-inch across. The strongly welded part is grayish black and dense; the rest of the unit is somewhat lighter colored and less dense	100
49. Crystal tuff, dark-greenish-gray, indistinctly bedded, medium-to coarse-grained; weathers greenish gray	80
48. Vein zone, with limonite-stained crystal tuff and quartz	10
47. Crystal tuff, dark-gray, and medium-gray to grayish-green; mostly massive, but a few thin zones are well bedded; particles dominantly fine grained; a few beds are crystal-lithic tuff; upper half of unit contains common long hornblende prisms	120
46. Concealed; probably underlain by crystal tuff similar to unit 47	33
Sill, dark-greenish-gray; weathers olive gray to brownish gray; contains abundant plagioclase phenocrysts in a fine-grained matrix; 9 ft. thick.	
45. Crystal tuff; comprises interbedded relatively massive siliceous volcanic mudstone and distinctly bedded units of sand-sized grains	150
44. Crystal tuff; relatively massive siliceous mudstone	20
43. Crystal tuff, well-bedded, fine- to medium-grained	15
42. Crystal tuff; relatively massive siliceous mudstones	30
41. Concealed; some welded tuff float	5
40. Crystal tuff, medium- to greenish-gray; weathers grayish orange, very light gray, and yellowish gray; mostly fine grained; local thin layers and lenses of coarser crystals and as much as ¼ in. thick	46

SECTION 7.—*Lower part of middle member of the Elkhorn Mountains Volcanics*—Continued

	Feet
39. Ash-flow tuff, welded, dark-gray, very dense; contains abundant collapsed pumice ribbons up to 6 in. long and abundant lithic fragments up to 3 in. in diameter	24
38. Crystal tuff, grayish-black to dark-gray; weathers pale yellowish green; poorly bedded; fine grained	76
37. Crystal tuff, well-bedded, fine-grained	22
36. Ash-flow tuff, welded, medium-gray; weathers yellowish green, pinkish gray, and yellow gray; contains abundant flattened pumice ribbons and wisps as much as 3 in. long and ¼ in. thick and abundant lithic fragments. Basal 7 ft. contains smaller collapsed pumice fragments about 1 in. in maximum length	30
35. Crystal tuff, poorly bedded to massive, fine-grained	42
34. Crystal tuff, medium-dark-gray; weathers light olive gray and greenish gray; distinctly bedded to finely laminated with alternate layers of coarse to fine sand, silt- and clay-sized particles; characterized by layers and lenses of white plagioclase crystals; locally has small channel deposits. Thin layers of siliceous mudstone weather out as ribs. Almost certainly a water-laid deposit. Unit forms coarse blocky to thin slabby debris	153
Sill, dark-greenish-gray pyroxene-bearing porphyry with abundant smaller plagioclase phenocrysts, small reddish altered phenocrysts (hematite?), and abundant epidote-quartz-filled amygdules; about 300 ft thick; concealed zone from 45 to 75 ft above base that probably contains a fault of relatively small displacement.	
33. Crystal tuff, dark-purplish-gray to medium-gray; upper 26 ft is distinctly bedded and coarse grained with many layers composed chiefly of mafic minerals; next 14 ft is dominantly fine grained; lower 32 ft is indistinctly bedded and fine grained at base, grading upward to more distinctly bedded and coarser grained tuff	72
32. Ash-flow tuff, welded, black to dark-gray, dense; contains a moderate amount of small collapsed pumice fragments and small lithic fragments generally less than ¼ in. across	27
31. Crystal tuff, distinctly thick-bedded, medium-coarse-grained	7
30. Crystal tuff, distinctly thin-bedded, fine- to medium-grained	25
29. Crystal tuff, distinctly thin-bedded, medium-grained	9
28. Crystal tuff, distinctly thin-bedded; fine grained with common layers of coarser grained white plagioclase crystals and a few thin clastic dikes of fine-grained material	43
27. Crystal tuff, mostly massive; dominantly fine grained but some granule beds are present; some epidote-rich layers 35 ft above base	100
26. Crystal tuff, dark-gray; mostly mudstone but contains contorted crystal-bearing layers	6

SECTION 7.—*Lower part of middle member of the Elkhorn Mountains Volcanics*—Continued

	Feet
25. Crystal tuff, medium-grained	43
24. Crystal tuff, dark- to medium-gray; mostly mudstone with coarser grained plagioclase crystals; some layers are contorted and brecciated; resembles welded tuff, but is probably a contemporaneously deformed mudflow deposit	6
23. Crystal tuff, particles of sand and silt size in distinct beds	23
22. Crystal tuff, dark-gray; weathers olive gray; some layers contorted and locally brecciated; similar to unit 24	5
21. Crystal tuff, distinctly bedded, coarse-grained; some channeling and some clastic dikes	60
20. Crystal tuff, obscurely bedded, fine-grained	25
19. Crystal tuff, distinctly bedded, fine-grained; broad shallow channels on some bedding planes	37
18. Crystal tuff, medium-gray; weathers medium light gray to light brownish gray; monthly massive mudstone with laminae, layers, and lenses of coarser grained particles; predominantly coarse grained in upper part	50
17. Ash-flow tuff, partly welded; top few feet contains abundant fragments as much as 3 in. across, lower and middle parts contain abundant slightly collapsed pumice fragments	34
16. Crystal tuff, bedded, medium-grained	5
15. Ash-flow tuff, welded, blackish-gray, dense; collapsed pumice abundant	13
14. Crystal tuff, dark-greenish-gray to medium-gray; dominantly massive with some thinly bedded layers, dominantly fine grained; locally contains sparse pyrite crystals	18
13. Ash-flow tuff, welded to poorly welded; contains abundant partly collapsed pumice fragments and very abundant small lithic fragments	62
12. Ash-flow tuff, welded; contains strongly collapsed pumice fragments and a few large accessory lithic fragments as much as 9 in. across	30
11. Crystal tuff, thinly bedded, medium-grained, lenticular	1
10. Ash-flow tuff, welded; contains strongly collapsed pumice fragments, some with altered halos	31
9. Crystal tuff, medium- to medium-dark-gray; weathers olive gray; well bedded, fine and medium grained with lenticular layers of coarser crystals at top	9
8. Ash-flow tuff, welded	23
7. Concealed, probably underlain by same welded tuff as units 6 and 8	26
6. Ash-flow tuff, welded	6
5. Concealed; a few outcrops and all float suggest interval is underlain by welded tuff like units above and below	37
4. Ash-flow tuff, welded; strongly collapsed pumice fragments many with alteration halos of epidote and cores of epidote and chlorite	30
3. Crystal tuff, dark-gray, to medium-greenish-gray, fine-grained, massive; forms blocky debris	6
2. Ash flow tuff, welded, grayish-black; weathers medium light gray; contains abundant flattened pumice fragments, many of which are altered, some with a bleached halo and some entirely bleached	49
1. Concealed; float is welded tuff	29
Total thickness of measured section	2,483

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