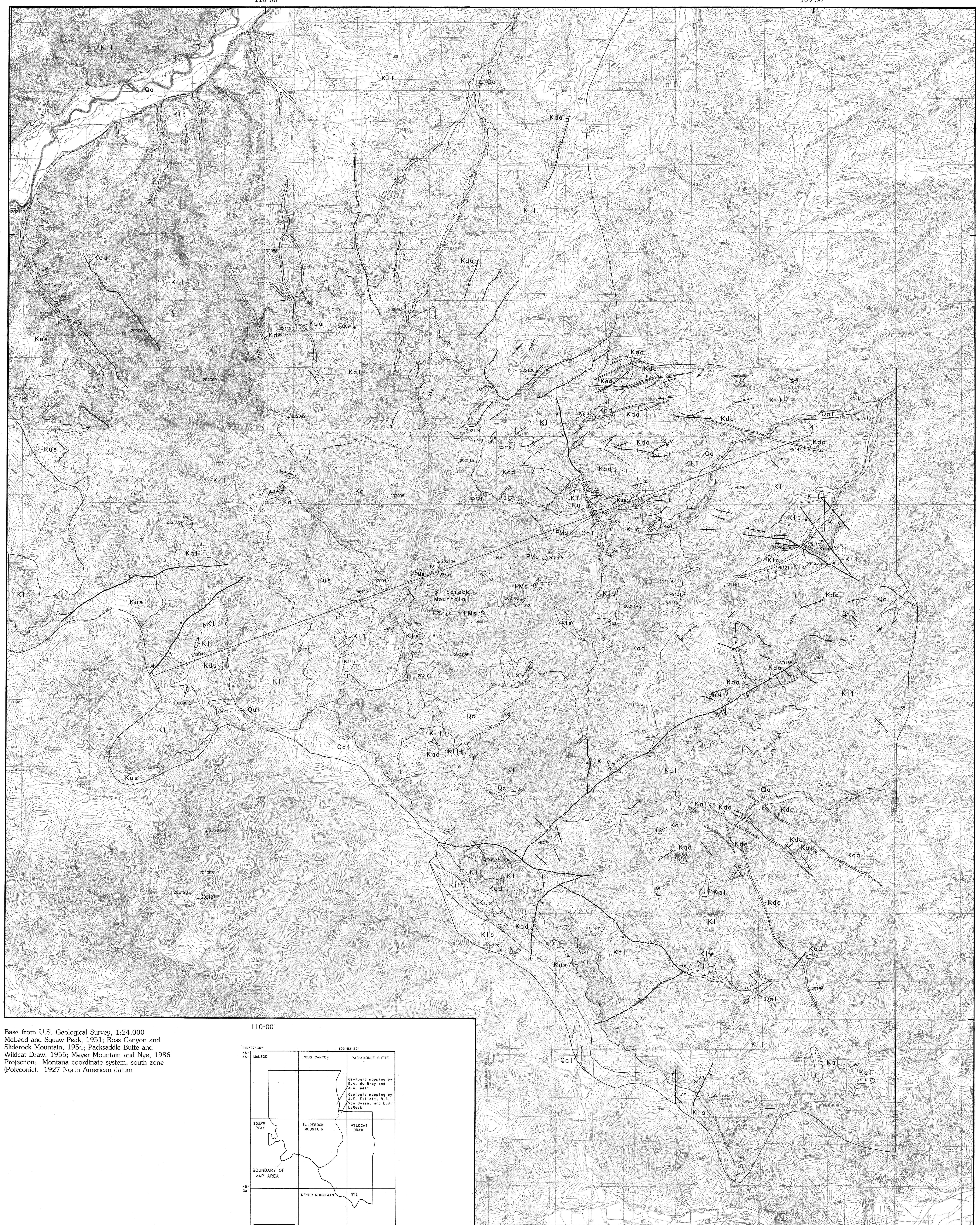
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF–2259



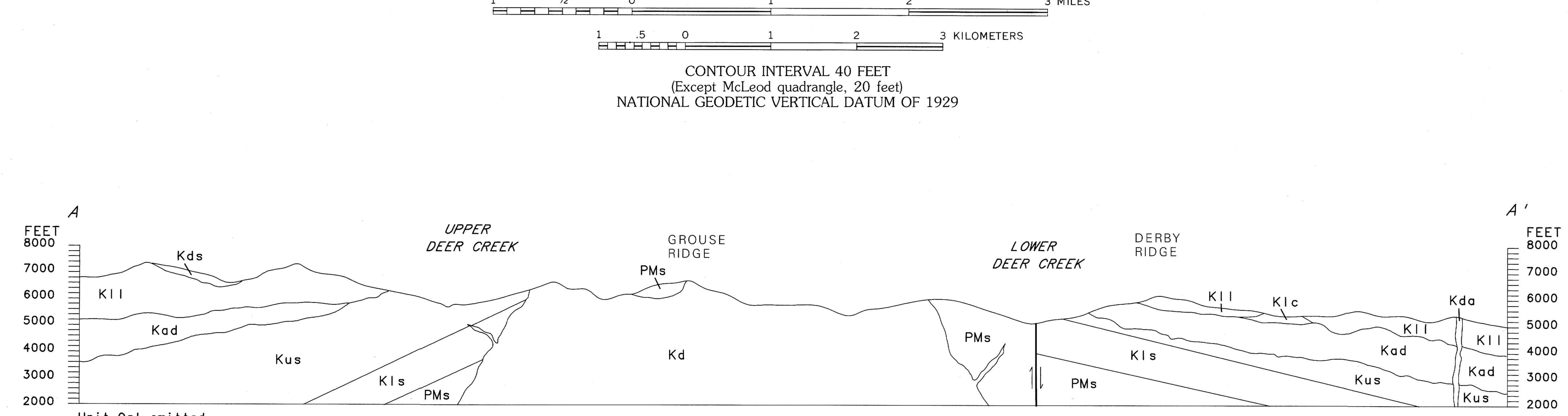
Base from U.S. Geological Survey, 1:24,000 McLeod and Squaw Peak, 1951; Ross Canyon and Sliderock Mountain, 1954; Packsaddle Butte and Wildcat Draw, 1955; Meyer Mountain and Nye, 1986
Projection: Montana coordinate system, south zone (Polyconic). 1927 North American datum

Geology mapped in 1991

Manuscript approved for publication January 5, 1994

SCALE 1:50 000

CONTOUR INTERVAL 40 FEET
(Except McLeod quadrangle, 20 feet)
NATIONAL GEODETIC VERTICAL DATUM OF 1929



CORRELATION OF MAP UNITS

Units		
Qal, Qc	Holocene and Pleistocene	QUATERNARY
Kda, Kd, Kal, Kds, Ki, Kll, Klw, Klc, Kad, Kus	Upper Cretaceous	CRETACEOUS
Kls, Ku	Lower Cretaceous	CRETACEOUS
PMs		PERMIAN, PENNSYLVANIAN, AND MISSISSIPPIAN

DESCRIPTION OF MAP UNITS

[Plutonic and volcanic names are in accord with the IUGS system (Streckeisen, 1973; Le Bas and others, 1986), except the subalkaline-alkaline division of Irvine and Baragar (1971) is used. Phenocryst assemblages are listed in order of decreasing abundances. Indicated phenocryst sizes are approximate averages for their maximum dimensions. The term trace, where referring to mineral abundances, indicates <0.1 percent by volume. SiO_2 ranges are derived from means and standard deviations calculated from unpublished data (E.A. du Bray)]

Qal **Alluvium (Holocene and Pleistocene)**—Unconsolidated to poorly consolidated silt, sand, gravel, and peaty material in valley bottoms; hummocky topography 3.5 km southwest of Sliderock Mountain may be mantled by glacial moraine

Qc **Colluvium (Holocene and Pleistocene)**—Poorly sorted, silt- to boulder-size material on slopes and in steep valleys. Locally includes small alluvial fans, talus, and landslide deposits

Kda **Basaltic trachyandesite to trachyte dikes (Late Cretaceous)**—Porphyritic, light-gray basaltic trachyandesite to trachyte dikes (51–60 percent SiO_2) that form prominent linear ridges, especially north of Sliderock Mountain. Contain 15–30 percent phenocrysts, including euhedral to subhedral laths of strongly zoned, albite-twinned, clay-altered plagioclase (1 mm) and subequal amounts of anhedral to subhedral pale-green clinopyroxene (0.5 mm) and subhedral to euhedral olive-green hornblende (1 mm); apatite is a trace mineral. Groundmass is turbid, devitrified intergrowth of plagioclase and opaque oxide minerals. Secondary zeolite minerals common. Most dikes are 1.5–5 km long and 1–10 m thick. Preliminary $^{40}Ar/^{39}Ar$ plateau age (hornblende) is 74.1±0.2 Ma (du Bray and Harlan, 1993)

Ki **Porphyritic andesite and diorite sills, dikes, and plug (Late Cretaceous)**—Three small intrusive masses; two sills in upper Lodgepole Creek in southwestern part of map area and a plug and associated dikes in Blind Bridger Creek in eastern part of map area. Intrusions along Lodgepole Creek are weakly altered, light-gray, porphyritic andesite; contain 25–40 percent phenocrysts of plagioclase, hornblende, and biotite. Calcite and zeolite minerals are secondary. Intrusion along Blind Bridger Creek is light-gray, porphyritic diorite; contains about 60 percent plagioclase, hornblende, and augite phenocrysts in a fine-grained groundmass. Zeolite minerals are abundant in the groundmass and replace plagioclase

Kd **Diorite to granodiorite stock of Sliderock Mountain (Late Cretaceous)**—Very light gray to medium-gray, hypidiomorphic granular diorite to granodiorite (54–66 percent SiO_2). Subhedral to euhedral laths of zoned and albite-twinned plagioclase (0.8 mm) form most crystals; moderately to strongly sericitized in many places. Hornblende (0.8 mm) is the principal mafic mineral and forms straw-yellow to olive-green subhedral laths. About 5 percent of the crystals in the stock are anhedral grains of opaque oxide minerals (0.2 mm). Quartz (anhedral, very fine grained, and interstitial), biotite, or clinopyroxene present in some samples; apatite is a ubiquitous trace phase. Stock texturally nonhomogeneous and characterized by pronounced grain size variation; fine grained in most places, locally medium grained. Some samples include a turbid groundmass composed of a very fine grained intergrowth of plagioclase, chlorite, calcite, and opaque oxide minerals. Moderately to pervasively altered between Gold Hill and Fire Ridge. Around Evergreen Mountain, map unit includes either a finer-grained border phase or basaltic andesitic lava flows similar to those of the basaltic andesite of Derby Ridge (Kad); poor exposure and the altered nature of these rocks preclude definitive identification. Preliminary $^{40}Ar/^{39}Ar$ isochron age (hornblende) is 77.0±1.0 Ma (du Bray and Harlan, 1993)

Kal **Basaltic andesite lava flows (Upper Cretaceous)**—Porphyritic, light- to dark-gray basaltic andesite (54–56 percent SiO_2) lava flows. Crystal content highly variable; phenocrysts are subhedral to euhedral laths of albite-twinned and zoned plagioclase (0.6 mm), subhedral clinopyroxene (0.5 mm), and anhedral opaque oxide minerals (0.2 mm). Groundmass is a devitrified intergrowth of fine-grained plagioclase and opaque oxide minerals. Lava flows characterized by an intersertal texture; trachytic layering present locally. Approximately 300 m thick

Kds **Diorite sill (Late Cretaceous)**—Very light gray to medium-gray diorite sill (62 percent SiO_2). Contains about 20 percent phenocrysts in a very fine grained groundmass composed of plagioclase, Fe-Ti oxides, and clinopyroxene. Phenocrysts are anhedral to subhedral laths of zoned and albite-twinned plagioclase (0.5 mm) altered to calcite and clay minerals, laths of straw-yellow to orange-brown oxyhornblende (0.4 mm), and anhedral grains of opaque oxide minerals (0.1 mm); pale-green clinopyroxene is a trace phase. Approximately 200 m thick

Livingston Group lahars (Upper Cretaceous)

Kll **Lahars**—Clast-supported lahar deposits composed of poorly sorted, bouldery mudflows (Parsons, 1942). Individual mudflows are massive and tens of meters thick; bedding absent or poorly developed in most places. Forms prominent rubbly cliffs. Clasts, predominantly composed of disaggregated basaltic andesite lava, are 0.05–3 m in diameter and subangular to angular; clasts in basal part of unit may be derived from the Lodgepole laccolith of Brozdowski (1983). Matrix is composed of ash and finely comminuted, altered andesite lava. A few thin basaltic andesite lava flows are enclosed by lahars. Unit contains thin interbeds of moderately well sorted epiclastic volcanic sandstone, siltstone, and shale that contain carbonized plant remains; may also contain minor pyroclastic flow deposits. Correlated with sedimentary rocks of the Livingston Group. Unconformably overlies basaltic andesite lava flows of Derby Ridge (Kad) and Upper Cretaceous arkosic sandstones (Kus) and, north of map area, is unconformably overlain by conglomerate, shale, sandstone of Paleocene Fort Union Formation (Parsons, 1942; Roberts, 1972). At least 300 m thick

Klw **Pyroclastic flow deposits**—Light-gray to brownish-gray, flaggy, poorly sorted and moderately welded pyroclastic flow deposits; limited to a single exposure in southern part of map area. Contains partially flattened pumice blocks as much as 3 cm long, lithic fragments of porphyritic andesite as much as 15 cm in diameter, and crystal fragments in a devitrified matrix. Rock is very crystal rich; phenocrysts are principally hornblende and plagioclase with minor quartz, potassium feldspar, biotite, and magnetite. Base of unit is reworked pyroclastic flow deposit composed of moderately well sorted, medium- to coarse-grained green sandstone. Base not exposed, at least 50 m thick

Klc **Clastic rocks**—Texturally and compositionally immature volcaniclastic sedimentary rocks. Unit consists of pale-olive, interbedded sandstone, siltstone, and shale. Probably forms the base of the Livingston Group rocks in this area. Angular to subangular plagioclase grains (0.3 mm) compose the majority of detrital clasts, although opaque oxide minerals are also present; matrix is clay rich. Base not exposed; at least 50 m thick

Kad **Basaltic andesite lava flows of Derby Ridge (Upper Cretaceous)**—Light-gray to light-olive gray, intersertal basaltic andesite (54–58 percent SiO_2) lava flows; weak trachytic layering developed in some places. Greatly varied crystal abundance. Phenocrysts are subhedral to euhedral laths of zoned and albite-twinned plagioclase (0.6 mm) altered to clay, subhedral grains of pale-green clinopyroxene (0.5 mm), and anhedral grains of opaque oxide minerals (0.2 mm); trace phases include apatite and hornblende. Groundmass, partly altered to calcite in some places, is composed of a very fine grained, turbid intergrowth of plagioclase and opaque oxide minerals; locally contains incipiently devitrified glass. Unconformably deposited on Cretaceous sedimentary rocks. Includes minor pyroclastic flows, block and ash flows, and interbedded lahar. At least 400 m thick

Kus **Sandstone and shale (Upper Cretaceous)**—Includes the Eagle Sandstone, Telegraph Creek Formation, Cody Shale, and Frontier Formation. Eagle Sandstone is light-gray, fine- to coarse-grained, crossbedded sandstone, with some thin coal beds in upper part. Telegraph Creek Formation composed of thin interbeds of pale-yellowish-orange to gray sandstone and siltstone; ripple marks common. Cody Shale is mainly dark-gray mudstone and thin interbeds of medium- to dark-gray sandstone. Lower and upper parts of the Frontier Formation are mainly light-gray, fine- to medium-grained sandstone; medial strata are dark-gray mudstone that contain minor thin interbeds of sandstone. Exposed thickness 120–850 m

Kls **Shale and sandstone (Lower Cretaceous)**—Includes Mowry and Thermopolis Shales and Kootenai Formation. Mowry Shale is poorly exposed dark-gray to olive-green mudstone, sandstone, and bentonitic mudstone. Upper part of Thermopolis Shale is olive-gray, fine- to coarse-grained sandstone; middle part is dark-gray fissile shale; lower part is thin interbeds of quartz-rich sandstone, with abundant ripple marks, and gray siltstone and shale. Upper part of Kootenai Formation contains light-gray gastropod-bearing limestone; medial part is red mudstone; lower part is ledge-forming, medium- to coarse-grained quartzose sandstone that contains abundant dark-gray chert pebbles and locally is a conglomerate. Exposed thickness about 430 m

Ku **Sedimentary rocks, undivided (Cretaceous)**—Very poorly exposed arkosic sandstone and black shale along Fire Ridge. Exposed thickness about 200 m

PMs **Sedimentary rocks, undivided (Permian, Pennsylvanian, and Mississippian)**—Forms many small xenoliths or roof pendants associated with diorite to granodiorite of Sliderock Mountain (Kd). Locally intruded by many diorite to granodiorite dikes, and metamorphosed to an assemblage of calc-silicate minerals. Recessive weathering character and metamorphism combine to preclude explicit identification of Paleozoic units except limestone of the Madison Group. Locally hosts magnetite-garnet-epidote skarn. Exposed thickness about 200 m

Contact—Approximately located

High-angle fault—Approximately located; dashed where inferred; dotted where concealed. Ball and bar on downthrown side

Strike and dip of bedding
Inclined

Sample locality, showing sample number—Samples collected for geochemical determinations (E.A. du Bray, unpublished data) and (or) petrographic study

Site of geologic observation

SUMMARY

The remains of a deeply eroded Late Cretaceous stratovolcano centered near Sliderock Mountain dominate the map area. The volcano consists mostly of lahars, although basaltic andesite lava flows are also present. An extensively eroded, weakly mineralized hypabyssal intrusive complex, inferred to represent the volcano's solidified magma chamber, intrudes previously erupted lava flows and associated lahars. Cretaceous sandstone and shale and Paleozoic sedimentary rocks, principally limestone of the Madison Group, host the stratovolcano; remnants of these rocks are preserved as large xenoliths and roof pendants.

GEOLOGY OF THE SLIDEROCK MOUNTAIN AREA

The oldest rocks exposed in the Sliderock Mountain area are Paleozoic strata (PMs) that form isolated roof pendants, large xenoliths, or host rocks to the intrusive phase of the Sliderock Mountain stratovolcano. The stratigraphy and lithology of the Paleozoic strata, all marine rocks, are better exposed in nearby areas, and were described by Richards (1957). In the Sliderock Mountain area the Paleozoic sedimentary rocks are poorly exposed and are weakly metamorphosed, precluding explicit identification of Paleozoic formations except limestone of the Mississippian Madison Group. Triassic and Jurassic rocks are not exposed in the area.

Lower Cretaceous rocks (Kls) are well exposed in Lower Deer Creek, where they host the stock of Sliderock Mountain, and are composed of the Kootenai Formation and the Thermopolis and Mowry Shales. These units include massive to thin-bedded black shale and siltstone containing intervals of fine-grained micaceous or quartzose sandstone. The lower part of the Kootenai Formation contains thin interbeds of chert-pebble conglomerate and sandstone. Upper Cretaceous sedimentary rocks (Kus) are present along the southwestern, western, and northwestern parts of the map area and in Upper Deer Creek. Units present are the Frontier Formation, Cody Shale, Telegraph Creek Formation, and Eagle Sandstone, which consist of well-bedded to massive, well-indurated, very light gray to yellowish-gray, parallel-bedded to crossbedded arkosic sandstone and dark-gray micaceous shale. These rocks contain carbonaceous siltstone and shale, and tuffaceous siltstone, and in the Eagle, discontinuous coal beds. Continuous sections of Lower and Upper Cretaceous rocks are present only in the southern part of the map area near Lodgepole Creek.

The earliest manifestation of volcanic activity associated with the Sliderock stratovolcano is represented by the Upper Cretaceous basaltic andesite lava flows of Derby Ridge (Kad). These rocks are interpreted as a section of lava flows at least 400 m thick, which includes minor pyroclastic flows, block and ash flows, welded tuff, and interbedded lahars, erupted from the Sliderock Mountain stratovolcano and unconformably deposited on Mesozoic sedimentary rocks. The basaltic andesite lava flows are light gray to light olive gray and characterized by greatly varied crystal abundance, and contain phenocrysts of plagioclase (clay-altered laths), clinopyroxene, and opaque oxide minerals. A subparallel arrangement of plagioclase laths defines a trachytoid texture in many places.

The basaltic andesite lava flows of Derby Ridge (Kad) are overlain by texturally and compositionally immature volcaniclastic strata (Klc) that are well exposed about 3 km northwest of Black Butte in the northwestern part of the Sliderock Mountain map area, in West Bridger Creek north of Derby Mountain, and in Derby Gulch. This unit, approximately 50 m thick, consists of pale-olive, interbedded sandstone, siltstone, and shale and probably forms the base of the Livingston Group in this area.

A small volume of pyroclastic flow rocks (Klw) are exposed beneath lahars in the southern part of the map area. Along Bad Canyon Creek, lahar deposits are underlain by at least 50 m of poorly sorted, moderately welded pyroclastic flow deposits whose base is not exposed. These deposits may be interbedded with lahars of the Sliderock Mountain stratovolcano and may be more extensive than is presently known.

The immature sedimentary rocks described above are overlain by at least 300 m of clast-supported lahar deposits (Kll) composed of poorly sorted, bouldery mudflows (Parsons, 1942). The lahars are correlative with sedimentary rocks of the Livingston Group (Parsons, 1942; p. 1177) and unconformably overlie basaltic andesite of Derby Ridge (Kad) and Upper Cretaceous arkosic sandstones (Kus). The minimum age of the lahars, and therefore of this part of the Livingston Group, is 77±1 Ma (du Bray and Harlan, 1993) as indicated by the age of the diorite to granodiorite stock of Sliderock Mountain.

The lahars are inferred to be derived by disaggregation of lavas erupted from the Sliderock Mountain stratovolcano. Individual mudflows form prominent rubbly cliffs and are massive and tens of meters thick; bedding is absent or poorly developed in most places. Clasts are 0.05- to 3-m-diameter, subangular to angular blocks composed predominantly of brecciated basaltic andesite and porphyritic andesite; granodiorite clasts in the basal part of the unit may be derived from the Lodgepole laccolith of Brozdowski (1983), which crops out in the Clover Basin area about 8 km south of Ellis Mountain. A few thin andesite lava flows are enclosed within the lahar sequence. This unit contains thin interbeds of more well sorted epiclastic volcanic sandstone, siltstone, and shale that contain carbonized plant remains and may also contain minor pyroclastic flow deposits.

Four rock units, including the diorite to granodiorite stock of Sliderock Mountain (Kd), a sequence of basaltic andesite lava flows (Kal), a diorite sill (Kds), and porphyritic andesite and diorite sills, dikes, and a plug (Ki) are demonstrably younger than the lahar deposits, but relative age relations among these units are indeterminate.

The intrusive phase (Kd) of the Sliderock Mountain stratovolcano is a very light gray to medium-gray plagioclase-hornblende diorite to granodiorite that intrudes the basaltic andesite lava flows of Derby Ridge (Kad) and the lahar deposits (Kll). Between Gold Hill and Fire Ridge the stock is moderately to pervasively altered. The diorite to granodiorite is texturally inhomogeneous and characterized by pronounced grain size variation; it may represent multiple intrusive phases that coalesced to form an intrusive complex. The intrusive complex is inferred to represent the inferred stratovolcano's solidified, residual magma chamber.

Porphyritic, light- to dark-gray plagioclase-clinopyroxene basaltic andesite lava flows (Kal) form three large masses, about 300 m thick, located (1) around the Red Mountain area, (2) atop the ridge that extends east northeast from Hicks Mountain, and (3) atop the ridge that extends southeast from Sugarloaf Mountain, as well as numerous, small erosional outliers. The relationship of these lava flows to the inferred Sliderock Mountain stratovolcano is unknown although they may represent a terminal phase of eruptive activity.

A very light gray to medium-gray, 200-m-thick plagioclase oxyhornblende diorite sill (Kds) crops out about 5 km west of Sliderock Mountain. The sill is petrographically similar and possibly genetically related to a sill exposed nearby at Enos Mountain (just west of the map area) and to the Lodgepole laccolith (Brozdowski, 1983).

Porphyritic, light-gray plagioclase-clinopyroxene-hornblende basaltic trachyandesite to trachyte dikes (Kda), 1.5–5 km long and 1–10 m thick, form prominent, linear ridges, especially north of Sliderock Mountain. Components of the Sliderock Mountain stratovolcano are intruded by the dikes, which form a crudely radial pattern around the volcano. These rocks are compositionally and petrographically similar to other igneous rocks of the Sliderock Mountain area and probably represent the terminal phase of igneous activity associated with an inferred stratovolcano. Other intrusive rocks, possibly contemporaneous with and genetically related to the dikes, include sills of light-gray porphyritic andesite (Ki) along Lodgepole Creek in the southern part of the map area, and a plug of light-gray porphyritic diorite (Ki) along Blind Bridger Creek in the eastern part of the map area.

Evolution of the Sliderock Mountain stratovolcano occurred between about 77 and 74 Ma (du Bray and Harlan, 1993). Consequently, strata associated with the volcano, although undeformed, were deposited prior to the middle to late Paleocene (Harlan and others, 1988) Laramide deformation that affected rocks less than 100 km to the northwest in the Crazy Mountains Basin. The lack of deformation in strata associated with the Sliderock Mountain stratovolcano corroborates that the leading (eastern) edge of Laramide deformation was west of the map area (Woodward, 1981).

ECONOMIC GEOLOGY

Paleozoic sedimentary rocks that host the Sliderock Mountain stratovolcano are intruded by many diorite to granodiorite dikes and irregularly shaped bodies, and are metamorphosed to an assemblage of calc-silicate minerals including garnet and epidote. Where metamorphism of these rocks was most intense, small bodies of weakly mineralized magnetite-garnet-epidote skarn are present. These skarns contain some sulfide minerals, especially chalcopyrite, and contain anomalous abundances of metals such as Au, Mo, Pb, Ag, Cu, and Sb.

Numerous gold-bearing quartz veins are present in the area around Gold Hill (Crow, Gold Hill, Silver King, and Sulphide mines). The diorite to granodiorite of Sliderock Mountain is sercitized and contains disseminated pyrite near these veins. The extent and intensity of mineralized rock in this area is limited. Gold placer deposits of limited size may be present in the drainages near these gold-bearing veins. $^{40}Ar/^{39}Ar$ plateau ages for two samples of sericite separated from hydrothemally altered diorite are 74.6±0.2 and 74.3±0.3 Ma, respectively (du Bray and Harlan, 1993). Consequently, mineral deposits spatially related to the diorite to granodiorite of Sliderock Mountain are also temporally and probably, therefore, genetically related to the stock.

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REFERENCES CITED

Brozdowski, R.A., 1983, Geologic setting and xenoliths of the Lodgepole intrusive area—Implications for the northern extent of the Stillwater Complex, Montana: Philadelphia, Pa., Temple University, Ph.D. thesis 322 p.
du Bray, E.A., and Harlan, S.S., 1993, Geology and preliminary $^{40}Ar/^{39}Ar$ geochronology of the Sliderock Mountain volcano, south-central Montana: Geological Society of America Abstracts with Programs, v. 25, no. 5, p. 32.
Harlan, S.S., Geissman, J.M., Lageson, D.R., and Snee, L.W., 1988, Paleomagnetic and isotopic dating of thrust-belt deformation along the eastern edge of the Helena salient, northern Crazy Mountains Basin, Montana: Geological Society of America Bulletin, v. 100, p. 492–499.
Irvine, T.N., and Baragar, W.R., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523–548.
Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks using the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750.
Parsons, W.H., 1942, Origin and structure of the Livingston igneous rocks, Montana: Geological Society of America Bulletin, v. 53, p. 1175–1186.
Richards, P.W., 1957, Geology of the area east and southeast of Livingston, Park County, Montana: U.S. Geological Survey Bulletin 1021–L, p. 385–438.
Roberts, A.E., 1972, Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, Montana: U.S. Geological Survey Professional Paper 526–C, p. C1–C120.
Streckeisen, A.L., 1973, Plutonic rocks, classification and nomenclature recommended by the IUGS subcommission on the systematics of igneous rocks: Geotimes, v. 18, no. 10, p. 26–30.
Woodward, L.A., 1981, Tectonic framework of the Disturbed Belt of west-central Montana: American Association of Petroleum Geologists Bulletin, v. 65, p. 291–302.

RECONNAISSANCE GEOLOGIC MAP OF THE SLIDEROCK MOUNTAIN AREA, SWEET GRASS AND STILLWATER COUNTIES, MONTANA

By
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