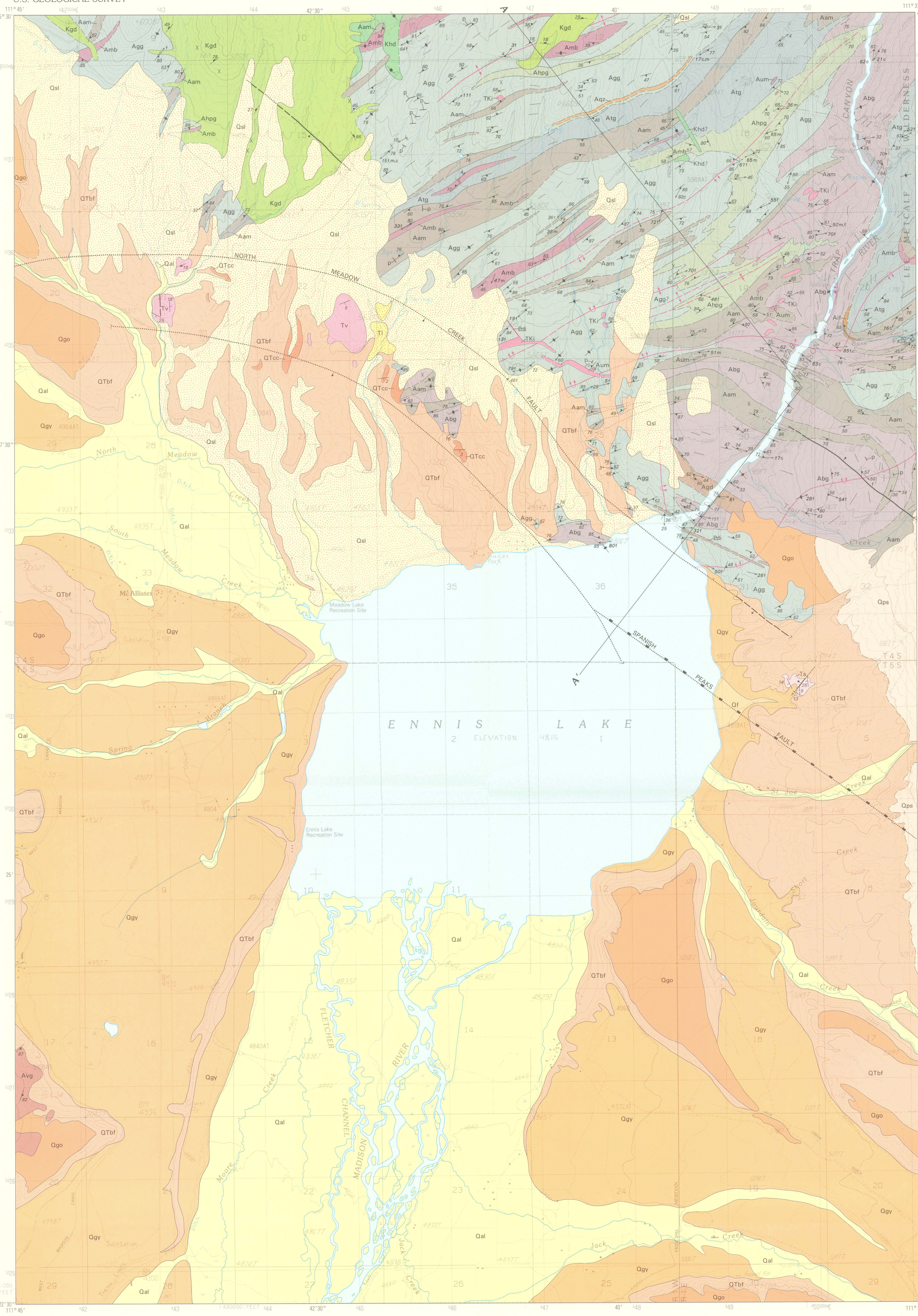


Base from U.S. Geological Survey, 1988
1000-meter Universal Transverse Mercator, zone 12
10,000-foot State grid ticks, Montana, south zone
Projection is Lambert Conformal Conic
Horizontal datum is 1927 North American datum
Provision edition

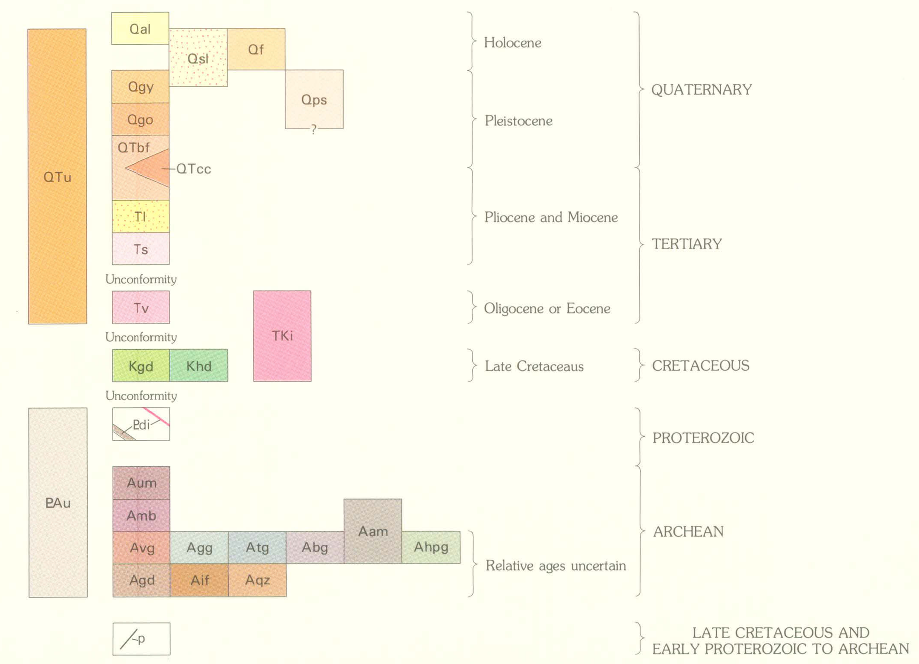
Geology mapped in 1989–90; assisted by Brian G. Lund, 1990.
Color and graphic design by Virginia G. Scott
Cartography by Henry Williams
Manuscript approved for publication, May 12, 1992

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

PHANEROZOIC SEDIMENTS AND ROCKS

Qal **Alluvium (Holocene)**—Silt- to boulder-size, moderately rounded to well-rounded, moderately sorted to well-sorted alluvial sediments. Includes deposits in the floodplain and in low terraces as much as about 5 m above modern stream. Maximum thickness greater than 10 m

QTu **Alluvial, lacustrine, and volcanic basin-fill deposits of Madison Valley (Holocene to Eocene?)**—Silt, sand, gravel, lacustrine limestone, and volcanic deposits downfaulted along north end of Madison Valley. Thickness in northern part of Madison River valley, along southern boundary of quadrangle, is as great as about 2,500 m (Young, 1985); maximum thickness in Madison River valley, about 25 km south of quadrangle, is 4,500 m (Rasmussen and Fields, 1983). Unit includes basin-fill deposits (unit QTbf) and limestone and volcanic sandstone (unit Ts). Shown only on cross section

Ql **Loess and sheetwash deposits (Holocene and late Pleistocene)**—Mostly massive, poorly indurated, light-tan very fine sand, silt, and minor clay that mantles sloping surfaces (many of which are underlain by older terrace-gravel (unit Qgo) or piedmont-slope (unit Qps) deposits) in northern part of quadrangle. Sheetwash deposits locally contain pebbly layers and lenses of colluvium. Thin loess and sheetwash deposits locally mantle, but are not shown on, mapped older terrace-gravel deposits in southern part of quadrangle. Maximum thickness greater than 10 m

Qf **Fan deposits (Holocene)**—Sand and pebble- to boulder-size gravel in small fan in sec. 6, T. 5 S., R. 1 E. Clasts moderately to well rounded and predominantly Archean gneiss. Thin loess cover. Drainage pattern visible on aerial photograph. Maximum thickness not known

Qps **Piedmont-slope deposits (late? Pleistocene)**—Very poorly sorted, unstratified gravel at base of mountain front (Madison Range is just east of map area) that contains angular to subrounded boulders as large as 2 m in diameter. Probably coalesced alluvial-fan deposits that lack fan morphology and braided stream pattern, which are typical of younger alluvial fans. Maximum thickness greater than 10 m

Qgy **Younger terrace-gravel deposits (late Pleistocene)**—Moderately sorted, moderately rounded to well-rounded, poorly bedded sand and gravel. Underlie lowest two prominent terraces, separated by as much as 20 m, west of Madison River; underlie lowest terrace east of Madison River; occur as much as 40 m above river. Along Jack Creek, deposits underlie lowest eight terraces below about 40 m above Jack Creek (Bearzi, 1987). Some deposits probably are outwash of Pinedale glaciation. As interpreted for Jack Creek by Bearzi (1987), age is late Pinedale to early post-Pinedale (about 15–10 ka), although upper terrace deposits of unit are suspected to be Bull Lake in age (about 140–100 ka) (M.C. Reheis, written commun., 1991). Correlates with younger terrace and pediment gravel deposits as mapped in Cherry Lake quadrangle (Kellogg, 1993). Mostly less than 10 m thick

Qgo **Older terrace-gravel deposits (Pleistocene)**—Moderately sorted, moderately rounded to well-rounded, poorly bedded sand and gravel underlying topographically highest (and oldest) three terraces in quadrangle. Deposits are about 40–60 m above Jack Creek, where they predate Pinedale glaciation (greater than about 20 ka) (Bearzi, 1987). Some deposits of Qgo may be outwash from Bull Lake glaciation. Deposits are mantled by less than 2 m of loess at most places. Geomorphic surface defined by this unit east of Madison River projects slightly below terrace gravel of Cameron bench, which crops out 0.1 km south of quadrangle (Kellogg, 1992). Cameron bench is older than Bull Lake glaciation (Schneider and Ritter, 1987). Geomorphic surface defined by this unit west of Madison River, as well as prominent surface north of Ennis Lake that is mantled by loess and sheetwash deposits (Ql), are speculatively correlated with Cameron surface by de la Montagne and others (1960). Correlates, in part, with older terrace-gravel deposits as mapped in Cherry Lake quadrangle (Kellogg, 1993). Mostly less than 10 m thick

QTbf **Basin-fill deposits (Pleistocene and Pliocene?)**—Interbedded, moderately sorted silt, sand, and gravel deposits that are exposed in slopes adjacent to and below terrace surfaces; underlie older and younger terrace-gravel deposits, topographically above present level of Madison River. Mostly unconsolidated. Gravel contains well-rounded clasts as large as cobbles. Bedding massive to lensoidal. Exposed basin-fill deposits are presumed to be no older than Pliocene, although they overlie tightly buried basin-fill deposits (included in unit QTu) that may be as old as Eocene (Rasmussen and Fields, 1983). Clasts in gravel beds commonly are amphibolite. Forms ledges at approximately constant stratigraphic level within upper part of basin-fill deposits north of Ennis Lake. May represent lacustrine deposit (near-shore or beach facies) or thick carbonate-cemented paleosol. Thickness at least 20 m

QTcc **Carbonate-cemented sandstone (Pleistocene or Pliocene)**—Light-tan to white, moderately well indurated, carbonate-cemented pebbly sandstone and sandy, pebbly limestone. Matrix-supported clasts as large as 4 cm make up as much as 30 percent of the rock and consist of subrounded to moderately well rounded quartz and Archean gneiss; largest clasts commonly are amphibolite. Forms ledges at approximately constant stratigraphic level within upper part of basin-fill deposits north of Ennis Lake. May represent lacustrine deposit (near-shore or beach facies) or thick carbonate-cemented paleosol. Thickness at least 20 m

Tl **Landslide deposit (Pliocene or Miocene)**—Chaotically oriented angular blocks of Archean gneiss and rhyodacite flow rocks that are as large as 30 m. Ancient post-landslide hydrothermal activity suggested by blocks that contain hematite and jasperitic vein fillings as wide as 2 cm and by argillic alteration and bleaching of gneiss. Occurs in and near SW¼ sec. 23, T. 4 S., R. 1 W. Total thickness unknown

Ts **Limestone and volcanic sandstone (Miocene?)**—Interbedded light-gray to light-brownish-gray, poorly indurated to well-indurated, locally vuggy limestone, sandy limestone, and limy siltstone and sandstone. Sandstone is composed mostly of volcanic ash and lapilli; crossbedding and channels indicate fluvial or deltaic origin. Beds are mostly 5 cm to 5 m thick; locally massive. Cobbles and pebbles of Archean rock common in siltstone and sandstone. Limestone deposits interpreted as lacustrine; limy siltstone and sandstone are probably near-shore lacustrine, deposited during, or immediately subsequent to, rhyolitic volcanic eruption of unknown source. Stratigraphic section measured by Young (1985). Crops out as small cliffs and ledges mostly in NE¼ sec. 6, T. 5 S., R. 1 E. Exposed thickness about 40 m

Tv **Rhyodacite flow (Oligocene or Eocene)**—Gray, siliceous, aphanitic rhyodacite lava flow, containing very sparse, small (less than 0.1 mm in diameter), rounded phenocrysts of quartz and feldspar. Matrix is a finely felted mass of aligned feldspar grains and subordinate green hornblende. Weathers grayish tan; platy; plates typically 1–3 cm thick, mostly aligned parallel with bedding. Cracks between plates filled with drusy, pink- and white-mottled, probably epigenetic intergrowth of quartz, epidote, and hematite. Interbedded with tuffaceous, clastic sedimentary rocks about 2 km west of quadrangle boundary (Vitaliano and Cordua, 1979). Correlated with middle Eocene to lower Oligocene volcanic rocks near Virginia City, 20 km southwest, which crop out extensively about 9 km southeast of quadrangle (Vitaliano and Cordua, 1979). One analysis of sample from north end of large rhyodacite outcrop in SE¼ sec. 22, T. 4 S., R. 1 W., gave following oxide percentages, by weight: 67.6 SiO_2, 16.3 Al_2O_3, 2.89 CaO, 4.36 Na_2O, 3.37 K_2O, 2.74 Fe_2O_3, 0.10 FeO, 0.39 MgO, 0.36 TiO_2, 0.17 P_2O_5, 0.82 H_2O^+, and 0.30 H_2O^-. Individual flows as thick as 5 m. Thickness of unit greater than 50 m

TKi **Felsite intrusive (early Tertiary or Late Cretaceous)**—Greenish-gray, sparsely to moderately porphyritic, massive siliceous dacite or rhyolite. Phenocrysts consist of as much as 15 percent white (in hand sample), strongly saussuritized plagioclase as long as 3 mm and 3 percent chloritized hornblende in an aphanitic groundmass containing a trace of fine-grained opaque minerals. Rock is commonly stained black by manganese oxides. Occurs mainly as sills, dikes, and irregularly shaped pods that intrude Archean rocks. Unit undated, but compositional and textural similarities to both Eocene rhyodacitic and rhyolitic intrusive rocks within 10 km north and northeast of quadrangle (Chadwick, 1980) and Late Cretaceous dacite porphyry of Fan Mountain (Tysdal and others, 1986; Kellogg, 1992) suggest it may be either early Tertiary or Late Cretaceous in age

Rocks of Tobacco Root batholith (Late Cretaceous)—
Two facies mapped: volumetrically predominant granodiorite facies (unit Kgd) and subordinate hornblende diorite border facies (unit Khd). Margin of batholith and country rocks within several hundred meters of contact intruded by numerous aplite and pegmatite dikes. K-Ar age of batholith is 70–77.4 Ma (Vitaliano and Cordua, 1979)

Kgd **Granodiorite**—Gray, coarse-grained, inequigranular to porphyritic, massive, hypidiomorphic hornblende-biotite granodiorite, monzogranite, and monzodiorite (classification of Streckeisen, 1976); weathers gray, in rounded tors or grussy outcrops. Typically contains 50 percent normally zoned oligoclase (An_{20}–An_{30}), 15–25 percent green hornblende, 15–20 percent microcline, commonly as phenocrysts as large as 3 cm (slight development of Rapakivi texture), 10–20 percent quartz, 5 percent biotite, 0–1 percent clinopyroxene cores in hornblende, trace to 2 percent magnetite, and traces of conspicuous sphene, zircon, and apatite

Khd **Hornblende diorite**—Dark-gray, fine- to medium-grained, equigranular to inequigranular, granoblastic, well-indurated hornblende diorite and hornblende monzo-diorite (Streckeisen, 1976). Weathers into dark-gray, rounded blocks. Typically contains 50–60 percent normally zoned plagioclase (oligoclase rim and andesine core), 20–25 percent green hornblende, 0–20 percent homogeneous potassium feldspar, 0–10 percent quartz, 0–8 percent biotite, 2–3 percent magnetite, and traces of zircon and apatite. Restricted to margin directly adjacent to mafic and ultramafic metamorphic rocks (Vitaliano and Cordua, 1979) and to numerous satellite stocks east of main batholith

PRECAMBRIAN ROCKS

BAu **Proterozoic and Archean rocks, undivided**—Shown only on cross section

Bd **Diabase dikes (Proterozoic)**—Black to dark-greenish-gray, fine- to medium-grained, equigranular diabase and gabbro in steeply dipping, northwest-striking dikes as wide as 30 m (most are considerably thinner); where less than about 10 m wide, shown by single line. Large gabbro dike at mouth of Bear Trap Canyon (N½ sec. 31, T. 4 S., R. 1 E.) contains about 65 percent augite, 30 percent calcic labradorite (An_{60}), 2 percent quartz, 2 percent reddish-brown biotite, 1 percent opaque minerals, and about 1 percent epidote. Elsewhere, diabase dikes contain about 30–50 percent euhedral labradorite, 30–60 percent augite, 0–30 percent hornblende (rarely cored by augite), 0–10 percent potassium feldspar, 5–8 percent opaque minerals, 1–3 percent apatite, 0–5 percent biotite, 0–3 percent quartz, and trace to 1 percent epidote. Diabase dikes in Tobacco Root Mountains, within 30 km west of quadrangle, are of three geochemically distinct groups (A, B, and C) injected during two periods of extension (Koehler, 1976; Wooden and others, 1978). Group A comprises low-potassium (K) tholeiitic dikes emplaced about 1,455 Ma, as determined on the basis of rubidium-strontium (Rb-Sr) whole-rock isochrons; groups B (ferrobasalt or ferrogabbro) and C (flow in iron, high in alkali and silica) comprise both high-K, quartz-normative dikes reported by Wooden and others (1978) to be injected about 1,130 Ma, as determined on the basis of Rb-Sr whole-rock isochrons; however, subsequent $^{40}Ar/^{39}Ar$ geochronology and paleomagnetic analysis of dikes in groups B and C suggest that their ages are about 750–780 Ma (Harlan and others, 1990)

Probable meta-igneous rocks (Archean)

Aum **Meta-ultramafic rocks**—Black to dark greenish-gray, fine- to medium-grained, well-foliated to massive, variably serpentinized ultramafic rocks of wide-ranging composition; unserpentinized rocks include olivine websterite, lherzolite, and olivine clinopyroxenite. Accessory minerals include olive-green spinel, magnetite, and apatite. Commonly contains secondary amphibole (anthophyllite, actinolite, or rarely, cummingtonite), serpentine, talc, dolomite, magnesite, and (or) mica. Occurs in lenses, pods, and small irregularly shaped masses, generally less than 10 m across; smaller masses not shown. In SE¼ sec. 19, T. 4 S., R. 1 E., unit is surrounded by felsite intrusive rock; the origin of this association is unknown

Amb **Metabasite intrusive**—Black (commonly speckled with white feldspar and pink garnet), fine-grained, equigranular, granoblastic, weakly foliated to massive hornblende-augite-almandine metagabbro and metadiorite. Composition variable; contains 15–45 percent plagioclase (mostly andesine), 10–60 percent yellowish green to brown hornblende, 2–30 percent augite, 0–20 percent almandine, 0–10 percent reddish-brown biotite, 0–8 percent quartz, 0–5 percent potassium feldspar, 1–5 percent opaque minerals, and trace apatite. In some places relict porphyritic texture is preserved as white clusters of fine-grained plagioclase as long as 1 cm. Occurs as sills as wide as about 40 m that are concordant to regional foliation; in some places shows pinch-and-swell structure and boudinage, producing circular or oval outcrops as wide as about 30 m. Commonly enveloped in medium-grained amphibolite margin as wide as 10 m (indicating post-emplacement metasomatism at amphibolite grade?). Equivalent to orthoamphibolite of Vitaliano and Cordua (1979) in Tobacco Root Mountains, within about 40 km west and northwest of quadrangle

Mostly felsic gneiss of unknown origin

[Following four units correspond to "quartzofeldspathic gneiss" of Vitaliano and Cordua (1979), some of which was interpreted to be of sedimentary origin on the basis of zircon morphology (Hess, 1967). Igneous rock names follow Streckeisen (1976) but do not necessarily imply igneous origin]

Avg **Granite gneiss of Valley Garden Ranch**—Light orange-tan to pinkish-tan, medium-grained, xenomorphic to hypidiomorphic, equigranular, weakly foliated to massive, leucocratic, quartz-rich magnetite monzogranite or syenogranite. Contains about 40 percent microcline, 40 percent quartz having undulatory extinction, 10–20 percent oligoclase, 2–5 percent magnetite (the only mafic phase visible in hand specimen), 1–2 percent garnet, and traces of epidote, zircon, and apatite. Weathers typically in rounded, orange-tan outcrops. Nearly massive character and similarity to granite of Red Knob, as mapped in Cherry Lake quadrangle immediately to east (Kellogg, 1993), suggest that unit also may be meta-igneous

Agg **Plagioclase-microcline-quartz-biotite ("granitic") gneiss**—Light-gray to light-pinkish-gray, generally tan weathering, medium-grained, hypidiomorphic to xenomorphic, equigranular, moderately foliated gneiss of variable composition ranging from granodiorite to syenogranite; typically contains 10–60 percent plagioclase (oligoclase or andesine), 10–50 percent microcline, 3–40 percent quartz, trace to 15 percent yellowish-brown biotite, 0–5 percent yellow to greenish-brown hornblende, 0–5 percent almandine, 0–2 percent augite, 0–2 percent muscovite, and traces of zircon, epidote, allanite, and opaque minerals. Commonly migmatitic. Locally has a blastomylonitic texture. Hess (1967) considered origin of "microcline-rich paragneiss," which is approximately equivalent to this unit, to be sedimentary on basis of contained rounded zircon grains. Most areally extensive map unit; may include minor amounts of all other Archean units

Atg **Plagioclase-quartz-biotite ("tonalitic") gneiss**—Gray, medium-grained, inequigranular, weakly to moderately foliated gneiss of approximately tonalitic composition; includes some trondhjemitic and granodioritic gneiss; typically contains 30–50 percent plagioclase, 20–30 percent quartz, 10–15 percent biotite, trace to 10 percent potassium feldspar, 10–15 percent biotite, 0–5 percent hornblende, and traces of zircon, rutile, garnet, and opaque minerals. Commonly migmatitic. May include minor amounts of all other Archean units

Abg **Banded biotite gneiss**—White, light-gray, dark-gray, and black, medium-grained, well-foliated, inequigranular gneiss, ranging from tonalite to quartz monzonite in composition. Commonly migmatitic. Leucosomes contain plagioclase, quartz, ± potassium feldspar, ± garnet, and traces of biotite and opaque minerals. Melasomes contain biotite, plagioclase, quartz, ± garnet, ± hornblende, and traces of zircon, rutile, garnet, and opaque minerals. Contains rare quartzite layers and sillimanite-muscovite-bearing gneiss, and may include minor amounts of all other Archean units. Gradational contact with plagioclase-microcline-quartz-biotite gneiss (unit Agg) and plagioclase-quartz-biotite gneiss (unit Atg); position of contact is subjective, but is placed approximately where strong compositional layering, on 1- to 10-cm scale, characterizes at least 50 percent of outcrop

Mafic to intermediate gneiss of unknown protolith (Archean)

Aam **Hornblende-plagioclase gneiss and amphibolite**—Gray to black, medium-grained, hypidiomorphic equigranular, moderately foliated to well-foliated hornblende-plagioclase gneiss and amphibolite; contains as much as 5 percent quartz and traces of zircon, opaque minerals, and apatite; locally garnetiferous. The range of plagioclase composition is about An_{30}–An_{60} (typically An_{40}); plagioclase weathers white. Unit commonly contains white, migmatitic leucosomes of plagioclase leucogneiss as thick as 10 cm. Similar unit in Tobacco Root Mountains interpreted to be of either sedimentary (clay-rich dolomite) or mafic volcanic origin (Vitaliano and Cordua, 1979). Enveloping relationship with metabasite suggests that at least some amphibolite may be metamorphosed sills. Unit may include minor amounts of other Archean units

Ahpg **Hornblende-plagioclase gneiss**—Gray, medium-grained, hypidiomorphic equigranular, moderately foliated to well-foliated hornblende plagioclase gneiss. Typically contains about 50 percent plagioclase, 30 percent green hornblende, 0–10 percent quartz, 0–5 percent microcline, 0–5 percent clinopyroxene, 1 percent opaque minerals, and traces of zircon, epidote, and apatite. Contains no amphibolite, though is otherwise similar to hornblende-plagioclase gneiss portion of hornblende-plagioclase gneiss and amphibolite unit (unit Aam)

Metasedimentary rocks (Archean)

Agd **Gedrite gneiss association**—Brown to grayish-brown, moderately well foliated, medium-grained gedrite-bearing gneiss interlayered with massive, reddish-brown garnet-quartz rock and white plagioclase-gneiss. Unit grades laterally into and includes banded biotite gneiss. Gedrite-bearing gneiss is grayish brown, moderately well foliated, and medium grained, and it contains about 40–50 percent clove-brown gedrite, 30–35 percent quartz, 5–10 percent plagioclase, 3–10 percent biotite, 0–10 percent cordierite, 2–5 percent magnetite, and 0–3 percent kyanite. One band mapped mostly in SW¼ sec. 30, T. 4 S., R. 1 E.

Aif **Iron-formation**—Consists of interlayered magnetite-bearing gneiss, garnet-quartz rock, and sillimanite-kyanite-bearing gneiss. Magnetite-bearing gneiss is black, massive, and inequigranular; one thin section contained approximately 30 percent large (to 1 cm long) poikilitic hornblende, 25 percent magnetite, 25 percent garnet, 15 percent plagioclase, 5 percent fine-grained quartz, and trace of pyrite partially altered to goethite. Layer of magnetite-bearing gneiss is as wide as 5 m and grades into dark-brownish-gray, slightly foliated, equigranular, garnetiferous gneiss containing (in one thin section) about 30 percent almandine, 25 percent biotite, 20 percent quartz, 20 percent microcline, 5 percent sillimanite, 2 percent plagioclase, and traces of kyanite and opaque minerals. Banded iron-formation (magnetite and quartzite in millimeter- to centimeter-scale layers) not observed, as in Archean iron deposits of the Tobacco Root Mountains (James, 1981). Occurs as thin (as wide as 30 m) lens at hinge of overturned antiform in Barn Creek (SW¼ sec. 20, T. 4 S., R. 1 E.)

Aqz **Quartzite**—White, gray, and brown, medium- to coarse-grained, inequigranular, moderately foliated to massive quartzite. Internal bedding structures not preserved. Occurs in one layer less than 40 m wide in and near N½ sec. 13, T. 4 S., R. 1 W.

ROCKS OF BOTH CRETACEOUS AND PRECAMBRIAN AGE

p **Pegmatite (Late Cretaceous and Early Proterozoic to Archean)**—Concordant and discordant, white to pink, coarse-grained to very coarse grained, massive and foliated dikes and sills composed mostly of potassium feldspar, quartz, plagioclase, and muscovite. In some places pegmatite grades to white quartz veins. Number of pegmatites increases toward margin of Tobacco Root batholith, indicating that many pegmatites are Late Cretaceous in age. Suspected Late Cretaceous pegmatites also associated with aplite, unlike Precambrian pegmatites. Presence of pegmatite cobbles in basal conglomerate of Middle Proterozoic Belt Supergroup, approximately 40 km northwest of quadrangle, clearly establishes some pegmatites as Precambrian in age (Vitaliano and Cordua, 1979). All foliated pegmatites probably are Archean in age. Although common, these bodies are generally less than about 10 m across and most are not shown on map

60 **Contact**—Showing dip. Dashed where approximately located; dotted where concealed

Fault—Predominantly normal movement. Dashed where approximately located; dotted where concealed; queried where extent unknown. Bar and ball on downthrown side where known

Concealed reverse fault—Teeth on upper plate. Dip greater than 45° (as determined where exposed 3 km east of quadrangle; Kellogg, 1993)

Antiform—Showing trace of axial surface; dashed where approximately located. Arrows show dip directions of limbs

Overturned antiform—Showing trace of axial surface; dashed where approximately located. Arrows show dip directions of limbs

Synform—Showing trace of axial surface; dashed where approximately located. Arrows show dip directions of limbs

Overturned synform—Showing trace of axial surface; dashed where approximately located. Arrows show dip directions of limbs

14 **Strike and dip of inclined beds**

Strike and dip of foliation

75 **Inclined**

Vertical

70 **Approximate strike and dip of foliation**

50m,f **Bearing and plunge of lineation**—Mineral lineation (m), fold axis (f), mullion or rodding (r), crenulation axis (c), undefined (no symbol); lineation may be defined by several symbols

57 50f **Strike and dip of foliation combined with bearing and plunge of lineation**

Strike and dip of jointing

27 **Inclined**

Vertical

Linear feature observed on aerial photograph—Mostly parallel to strike of metamorphic foliation

X **Prospect pit**

EXPLANATORY NOTES

PREVIOUS MAPPING

The Precambrian geology of the Bear Trap Canyon area was mapped and discussed by McThenia (1960) and Pinckney and others (1980). The northwestern part of the quadrangle was mapped by Hess (1967) and included on a geologic map of the Tobacco Root Mountains (Vitaliano and Cordua, 1979). A simplified geologic map of the northern Madison Range (Spencer and Kozok, 1975) covers most of the area of Precambrian outcrop in the quadrangle. Young (1985) mapped part of the quadrangle north and east of Ennis Lake; this mapping also was published in Garihan and others (1983).

THE SPANISH PEAKS FAULT AND ITS RELATIONSHIP TO TERTIARY FORMATION OF THE MADISON RIVER VALLEY

The Spanish Peaks fault, a high-angle, northeast-dipping to vertical, reverse fault having a minimum of 4,100 m of vertical offset (Garahan and others, 1983), does not crop out in the quadrangle, but its projection under the Madison River valley from the Cherry Lake quadrangle to the east (Kellogg, 1993) is shown. The Spanish Peaks fault is thought to be a continuation of the Bismark fault in the Tobacco Root Mountains (Garahan and others, 1983).

Tertiary extension began in southwestern Montana during the middle Eocene, and early development of the present intermontane basins, like the Madison River valley, may date from this time, but rapid valley formation, producing coarse-grained basin fill, did not begin until late early Miocene (Hemingfordian) time (Fields and others, 1985). As shown by extensive Quaternary fault scarps along the eastern side of the Madison River valley south of the quadrangle (Pardee, 1950; Tysdal, 1986), the valley is a half graben, faulted down along the eastern side. About 15 km south of the quadrangle, the Madison River valley is filled with as much as about 4,500 m of Tertiary and Quaternary sediments (Rasmussen and Fields, 1983).

The North Meadow Creek fault (Garahan and others, 1983) is a poorly exposed, down-to-the-southwest, Tertiary normal fault that forms a major structural boundary for the north end of the Madison Valley. The fault is reported to be exposed in SE¼ sec. 31, T. 4 S., R. 1 E. (Shelden, 1960; Young, 1985). Exposures of the fault were not found at this locality during present mapping, although several small ridges that are truncated along a linear northwest trend and are underlain by strongly altered and fractured Archean gneiss suggest proximity to a major fault.

Outcrop patterns of Archean and Tertiary rocks indicate that the North Meadow Creek fault and at least one parallel normal fault (shown as a concealed fault about 1 km south of the North Meadow Creek fault) are arcuate and formed by eroding the Archean "lip" or buried escarpment formed by Late Cretaceous (and early Tertiary?) movement along the Spanish Peaks fault. The Spanish Peaks fault, therefore, governs the northern structural boundary of the Madison River valley because it constrains the location and extent of subsequent Tertiary normal faulting.

Tertiary beds within the downdropped blocks mostly dip gently (5°–26°) toward the valley axis, but two outcrops of Tertiary volcanic rocks in sec. 21, T. 4 S., R. 4 W. are strongly deformed. Post-early Oligocene landslide deposits (unit Tl), probably associated with valley formation, are exposed in and near the SW¼ sec. 23, T. 4 S., R. 1 W.

AGES OF PRECAMBRIAN GNEISSIC ROCKS

Uranium-lead zircon ages for "quartzofeldspathic gneiss" from the Spanish Peaks, about 10 km east of the quadrangle, in the Willow Swamp quadrangle, are 3.3–3.2 Ga (Mogk and others, 1989). Magmatic injection of voluminous, mostly trondhjemitic and tonalitic melts occurred in the Spanish Peaks area 3.2–3.1 Ga, which is the suggested age of peak metamorphism (Mogk and others, 1989); late granitic melts were injected as late as 2.6 Ga (Mogk and others, 1988). A rubidium-strontium isochron age of 2.7 Ga, determined from a suite of samples collected over a large part of southwestern Montana (James and Hedge, 1980), probably represents an approximate metamorphic and magmatic age for the region. A 1.6-Ga metamorphic event, determined from rubidium-strontium and potassium-argon geochronology, is recognized in the Tobacco Root Mountains, west and northwest of the map area, and may be related to a period of pegmatite intrusion (Giletti, 1966; Vitaliano and Cordua, 1976).

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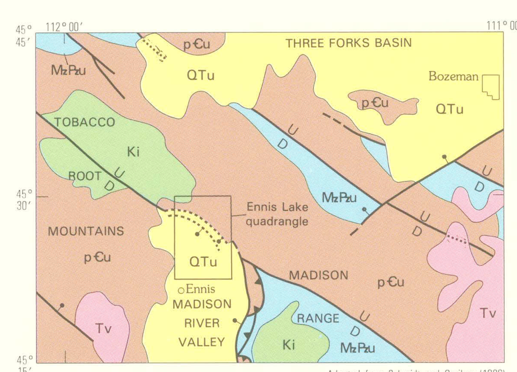


Adapted from Schmidt and Garihan (1986)

EXPLANATION

QTu Quaternary and Tertiary basin-fill deposits

Tv Tertiary volcanic rocks

Ki Late Cretaceous intrusive rocks

MzPzu Mesozoic and Paleozoic rocks, undivided

p€u Precambrian (mostly Archean) rocks, undivided

Normal fault—Bar and ball on downthrown side; dotted where concealed

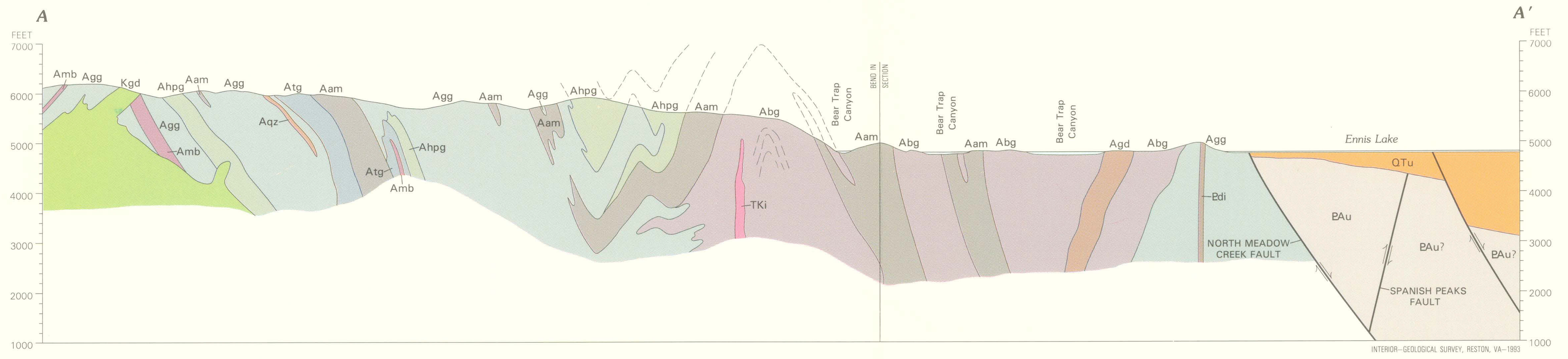
Reverse fault—U, upthrown side; D, downthrown side; dotted where concealed

Thrust fault—Sawteeth on upper plate

REGIONAL STRUCTURE MAP

CONVERSION FACTORS

Multiply	By	To obtain
centimeters (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)



GEOLOGIC MAP OF THE ENNIS LAKE QUADRANGLE, MADISON COUNTY, MONTANA

By
Karl S. Kellogg
1993

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1993