GEOLOGIC MAP OF THE LIMA 30' x 60' QUADRANGLE, SOUTHWEST MONTANA

by

Jeffrey D. Lonn, Betty Skipp, Edward T. Ruppel, Susanne U. Janecke, William J. Perry Jr., James W. Sears, Mervin J. Bartholomew, Michael C. Stickney, William J. Fritz, Hugh A. Hurlow, and Robert C. Thomas

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Revised

1/05 Correlation Chart symbols; Text, Part A, unit symbols

1/06 Map: faults with Quaternary movement; added Holocene faults in Centennial Valley north of Lima Reservoir; revised location and type of other faults; Text and Correlation Chart units

This report has had preliminary reviews for conformity with Montana Bureau of Mines and Geology's technical and editorial standards.

Partial support has been provided by the STATEMAP component of the National Cooperative Geologic Mapping Program of the U. S. Geological Survey under Contract Number 99-HQ-AG-0130.

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Introduction

This geologic map represents a compilation of mostly previously unpublished maps by numerous authors. The map is divided into three areas of responsibility: 1) the Tendoy Mountains and western Centennial Mountains, mapped and compiled by Betty Skipp, Susanne Janecke, and Bill Perry (Part A); 2) the Snowcrest Range, mapped by Edward T. Ruppel (Part B), and 3) the remainder of the area, including the Sage Creek basin, the Red Rock Hills, the Blacktail Range, and the Upper Blacktail Deer Creek valley, compiled and mapped by Jeff Lonn and Jim Sears, with data also contributed by Bill Fritz, Hugh Hurlow, and Rob Thomas (Part C). Figure 1 shows mapping responsibilities.

The geologic map (Plate 1) is accompanied by this text pamphlet describing map units for each of the three areas. The same lithologic distinctions among units and the same unit labels were used where possible, usually where formal stratigraphic nomenclature existed, but each area has its own informal Tertiary and Quaternary stratigraphy. References are also given separately in each section. However, correlation diagrams for each of the three areas are shown in a single Correlation Chart for the whole quadrangle (Figure 2).

Plate 2, at the same scale, is provided in order to show more readily the names being applied to specific faults and folds, particularly in the Tendoy Mountains and western Centennial Mountains.

Sources of Geologic Map Data for the Lima Quadrangle (see Figure 1)

1) Bartholomew, M.J., 1989, unpublished mapping

2) Haley, J.C., and Perry, W.J., The Red Butte Conglomerate – A thrust-belt-derived conglomerate of the Beaverhead Group, southwestern Montana: U.S. Geological Survey Bulletin 1945, 19 p., map scale 1:32,000.

3) Hurlow, H.A., 1999, unpublished mapping

4) Lonn, J.D., 1999, unpublished mapping

5) Pecora, W.C., 1987, Geologic map of the frontal fold and thrust zone in the Blacktail Mountains, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 87-0079, scale 1:24,000.

6) Perry, W.J., Jr., 1999, unpublished mapping

7) Ruppel, E.T., 1999, unpublished mapping

8) Sears, J.W., Fritz, W.J., Harlow, H.A., and Thomas, R.C., 1999, unpublished mapping

9) Skipp, B.A., Janecke, S.U., Perry, W.J., Jr., and Kellogg, K.S., 2000, unpublished mapping

10) Stickney, M.C., Haller, K.M., and Machette, M.N., 2000, Quaternary faults and seismicity in western Montana: Montana Bureau of Mines and Geology Special Publication 114.

11) Tysdal, R.G., 1988, Geologic map of the northeast flank of the Blacktail Mountains, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2041, scale 1:24,000.

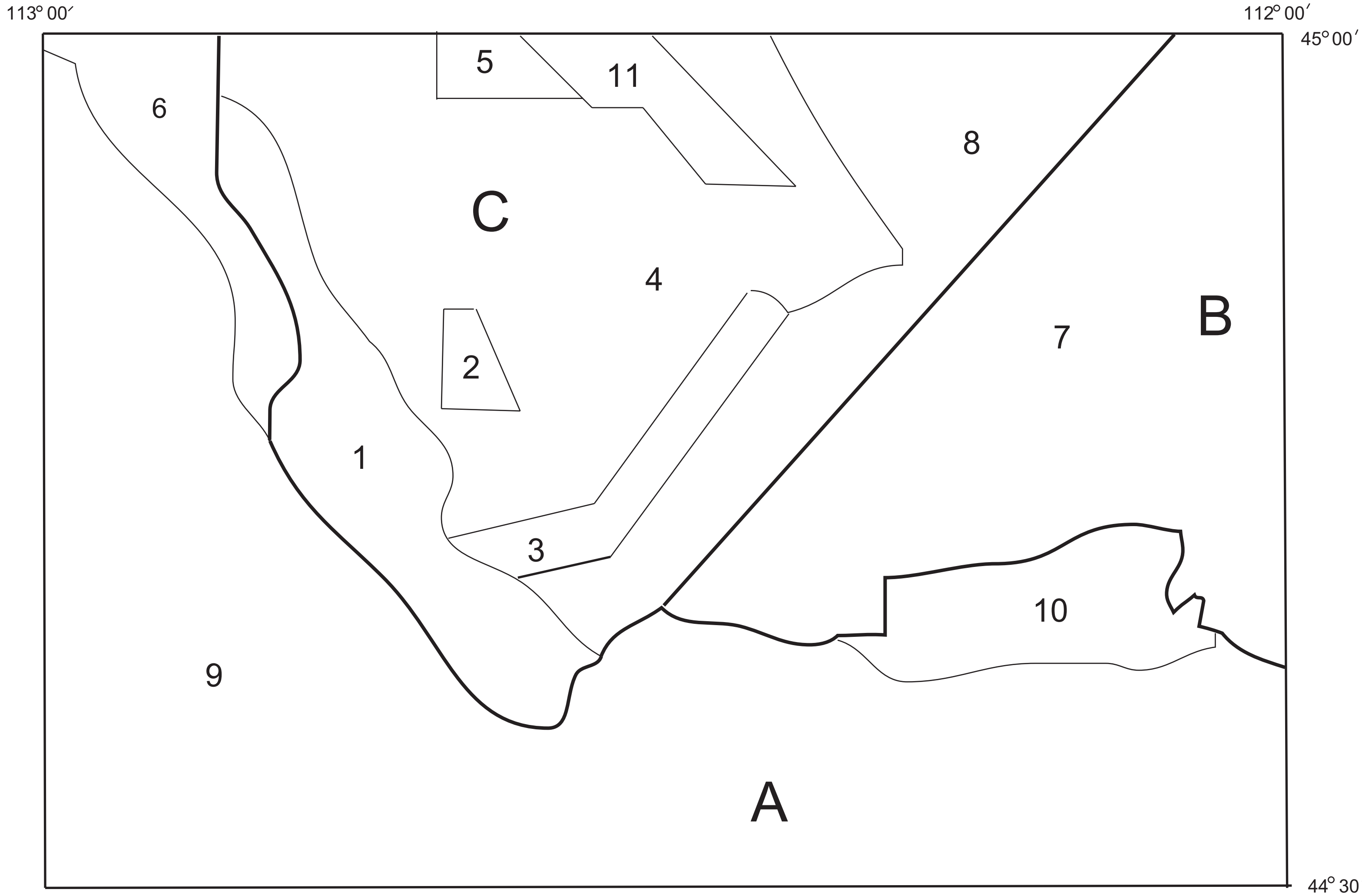


Figure 1. Areas of geologic mapping responsibility. Bold lines delineate parts A, B, and C of this report. Numbers indicate sources of geologic map data. Minor modifications were made by senior author at area boundaries to establish map-wide continuity of stratigraphic units.

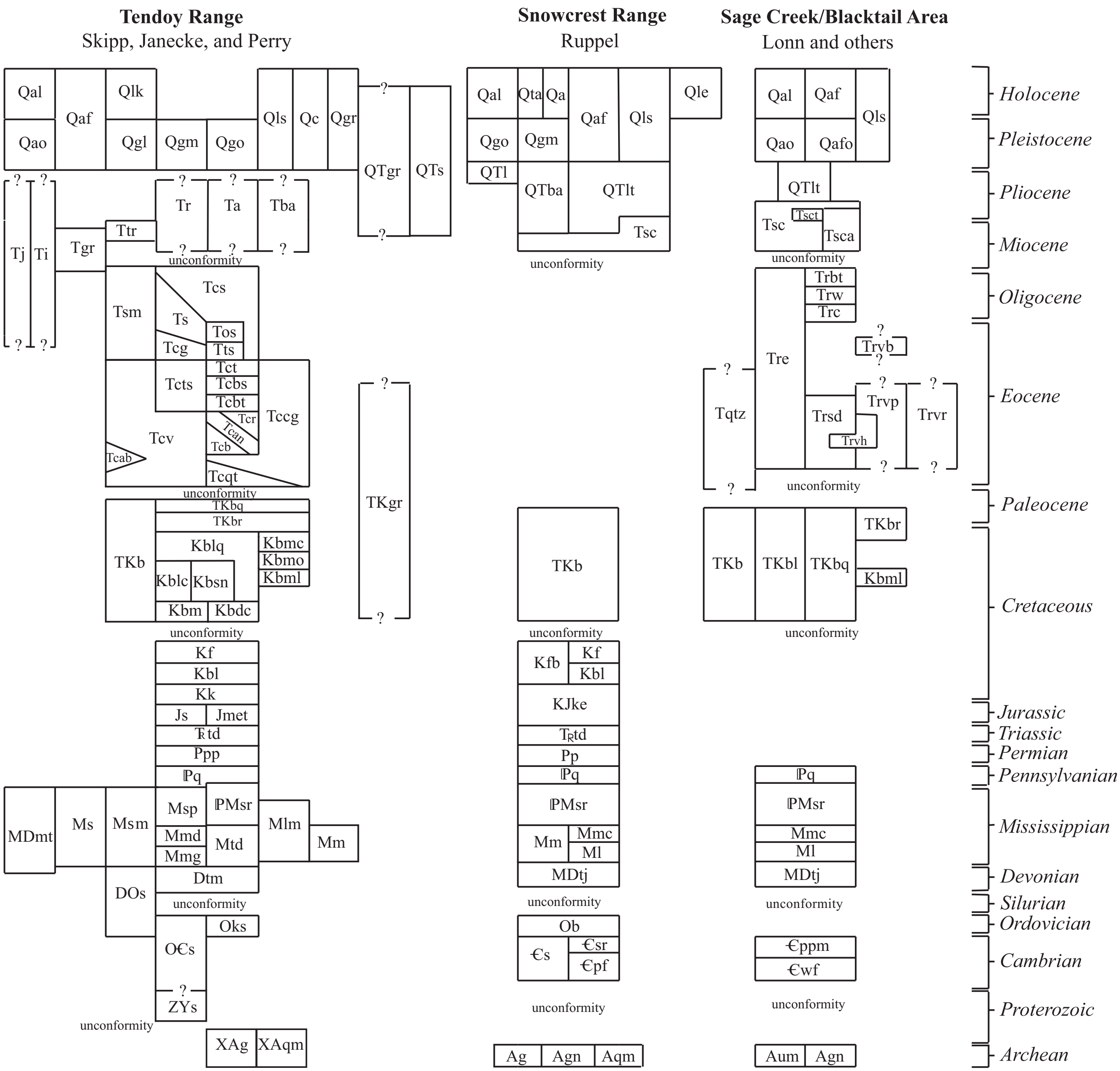


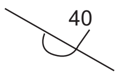
Figure 2. Age correlation of map units on the Lima 30’ x 60’ quadrangle.

Map Symbols

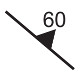
Strike and dip of bedding where measured

Horizontal bedding

Vertical bedding



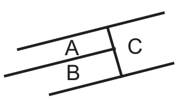
Overturned bedding



Attitude of foliation in metamorphic rocks

Contact; dashed where approximate; dotted where concealed

Facies change in sediments or sedimentary rocks



Contact between divided and undivided units of the same stratigraphic interval

Fault with unknown sense of movement; dashed where approximate; dotted where concealed

Normal fault; ball and bar on downthrown side; dashed where approximate; dotted where concealed

Thrust or reverse fault; teeth on upthrown side; dashed where approximate; dotted where concealed

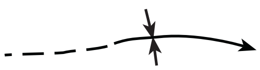
Detachment fault; symbols on downthrown side; dashed where approximate; dotted where concealed

Thrust fault with reactivated normal movement; symbols on hanging wall; dashed where approximate; dotted where concealed

 Strike-slip fault; dashed where approximate; dotted where concealed

 Axial trace of anticline showing plunge; dashed where approximate

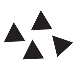
 Axial trace of overturned anticline showing plunge; dashed where approximate

 Axial trace of syncline showing plunge; dashed where approximate

 Axial trace of overturned syncline showing plunge; dashed where approximate

 Ring fracture system (see Part B for an explanation)

 Fault scarp

 Breccia

PRELIMINARY GEOLOGIC MAP OF THE LIMA 30' x 60' QUADRANGLE, SOUTHWEST MONTANA

Part A:

PRELIMINARY GEOLOGIC MAP OF THE TENDOY MOUNTAINS AREA

by

Betty Skipp, Susanne U. Janecke, and William J. Perry, Jr.

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DESCRIPTION OF MAP UNITS

Tendoy Mountains Area
Lima 30' x 60' Quadrangle

Quaternary

Qal ALLUVIUM (HOLOCENE) — Unconsolidated, poorly sorted deposit of mud, silt, sand, and gravel in modern streams and channels.

Qaf ALLUVIAL FAN DEPOSIT (HOLOCENE) –- Fan-shaped deposit of unconsolidated gravel, sand, and silt.

Qlk LAKE DEPOSIT (HOLOCENE) — Fine-grained, paludal sediments of Lima Reservoir area.

Qc COLLUVIUM (HOLOCENE AND PLEISTOCENE) — Unconsolidated slope wash, talus, and rock fall; locally includes alluvium.

Qls LANDSLIDE DEPOSIT (HOLOCENE AND PLEISTOCENE) — Unconsolidated deposits of locally derived, chiefly angular, unsorted debris.

Qgr GRAVEL DEPOSIT (HOLOCENE AND PLEISTOCENE) — Unconsolidated to poorly consolidated gravel deposits of mixed or uncertain origins.

Qao OLDER ALLUVIUM (PLEISTOCENE) — Mainly unconsolidated, locally dissected deposits of mud, silt, sand, and gravel.

Qafo OLDER ALLUVIAL FAN DEPOSIT (PLEISTOCENE) — Chiefly fan-shaped deposits of unconsolidated mud, silt, sand, and gravel; locally dissected.

Qgl GLACIAL LAKE DEPOSIT (PLEISTOCENE) — Unconsolidated mud and silt at head of Middle Fork of Little Sheep Creek; SE Sec. 20 and SW Sec. 21, T. 15 S., R. 8 W.

Qgm GLACIAL MORAINE (PLEISTOCENE) — Loosely consolidated to unconsolidated, unsorted pebble to boulder gravel in a matrix of silt, sand, and clay in cirques of Lima Peaks and along upper Dutch Hollow.

Qgo GLACIAL OUTWASH DEPOSIT (PLEISTOCENE) — Unconsolidated, poorly sorted pebble to boulder gravel on sloping surfaces north of Lima Peaks and isolated patches along creeks.

Quaternary and Tertiary

QTgr GRAVEL (HOLOCENE THROUGH MIOCENE) — Unconsolidated to poorly consolidated gravels of uncertain affinity.

QTs SEDIMENTS, UNDIVIDED

Tertiary

Tj JASPEROID (PLIOCENE? TO EOCENE?) — Light gray to black silicified limestone and other sedimentary rocks.

Ti INTRUSIVE ROCKS (PLIOCENE? TO EOCENE?) –- Rhyolitic to basaltic dikes and small intrusive bodies.

Tr RHYOLITE (PLIOCENE AND/OR MIOCENE)

Ta ANDESITE (PLIOCENE AND/OR MIOCENE)

Tba BASALT (PLIOCENE AND/OR MIOCENE) — Dark colored; locally scoriaceous. Fills paleovalleys and overlies fluvial gravel deposits in the Tendoy Mountains.

Tgr GRAVEL (MIOCENE TO LOWER PLIOCENE(?)) — Chiefly unconsolidated, locally cemented, rounded to sub-rounded, quartzite boulder gravel.

Ttr TRAVERTINE (MIOCENE) — Freshwater limestone; light gray and white, thick-bedded, vuggy; locally quarried for decorative stone. Round Timber limestone of Sadler (1980). Gravel at base thickens to northeast where it is correlative with unit Tgr.

Tsm SEDIMENTARY ROCKS OF MEDICINE LODGE BEDS, UNDIVIDED (OLIGOCENE(?) TO EOCENE)—Laterally equivalent units mapped in the Muddy Creek basin and in the Nicholia basin.

Nicholia basin:

Ts SEDIMENTARY ROCKS, UNDIVIDED (OLIGOCENE? TO EOCENE) — Conglomerate, sandstone, limestone, mudstone, and locally gypsum in Nicholia and Medicine Lodge Creek basins. Upper part laterally equivalent to unit Tcs. Includes thin Quaternary cover in places.

Tcg CONGLOMERATE (OLIGOCENE(?) AND EOCENE) – Well-rounded to subangular pebble to cobble conglomerate composed of volcanic and subordinate sedimentary and plutonic clasts east of Nicholia Creek; subordinate sandstone (see also Skipp and Janecke, 2004).

Muddy Creek basin:

Tcs CONGLOMERATE AND SANDSTONE (OLIGOCENE? TO EOCENE) — Coarse-grained clastics of Muddy Creek Basin (Janecke and others, 1999). Upper part laterally equivalent to unit Ts.

Tos ORGANIC-RICH SHALEY MUDSTONE (EOCENE) — Contains conglomerate lenses and limestone clasts; restricted to Muddy Creek basin (Janecke and others, 1999)

Tts TUFFACEOUS SHALE (EOCENE) — Contains limestone lenses; restricted to Muddy Creek basin (Janecke and others, 1999)

Tcv CHALLIS VOLCANICS GROUP, UNDIVIDED (EOCENE) — Units mapped in Muddy Creek Basin by Janecke and others (1999).

Tcts TUFF AND MINOR SANDSTONE, UNDIVIDED

Tccg CONGLOMERATE AND SANDSTONE – Chiefly greenish-gray volcanic conglomerate containing petrified wood in upper part. Basal beds contain nonvolcanic detritus derived from Paleozoic sedimentary and igneous rocks including Ordovician Kinnikinic Quartzite and Beaverhead Mountains pluton, and some Middle Proterozoic sandstone. Locally contains vuggy, slightly cherty limestone beds associated with rare mudstone and sandstone.

Tct TUFF, CHIEFLY QUARTZ- AND SANIDINE-BEARING

Tcbs BIOTITE-BEARING SANDSTONE

Tcbt BIOTITE-BEARING TUFF

Tcr RHYOLITE

Tcan ANDESITE — Locally includes basalt.

Tcb BASALT

Tcab BRECCIA (LANDSLIDE DEPOSIT) (EOCENE) — Blocks of Archean rocks interbedded in lower part of Challis Volcanics Group in northern Muddy Creek Basin.

Tcqt QUARTZITE-BEARING TUFF

Tertiary and Cretaceous

TKgr GRAVEL AND CONGLOMERATE OF UNCERTAIN AFFINITIES (EOCENE TO UPPER CRETACEOUS)

TKb BEAVERHEAD GROUP UNDIVIDED (PALEOCENE AND UPPER CRETACEOUS) — Conglomerate, sandstone, mudstone, and limestone

TKbq QUARTZITE CLAST CONGLOMERATE – Unit overlies the Red Butte Conglomerate in the Chute Canyon area. Clasts may be recycled from the Little Sheep Quartzite Conglomerate (Kblq).

TKbr RED BUTTE CONGLOMERATE (PALEOCENE AND UPPER CRETACEOUS) — Limestone conglomerate contains clasts of recycled limestone conglomerate and well-rounded quartzite (Haley & Perry, 1991).

Cretaceous

Kblq LITTLE SHEEP QUARTZITE CONGLOMERATE (UPPER CRETACEOUS) — Quartzite roundstone conglomerate; Contains large limestone blocks of Madison Group limestone (Mm) chiefly carried along thrust faults (Perry and others, 1988)

Kblc LIMA CONGLOMERATE (UPPER CRETACEOUS) — Limestone pebble to cobble conglomerate derived from erosion of Blacktail-Snowcrest uplift (Nichols and others, 1985).

Kbsn SNOWLINE SANDSTONE (UPPER CRETACEOUS) — Calcareous salt and pepper sandstone; contains limestone fragments (Ryder and Scholten, 1973).

Kbm MONIDA SANDSTONE (UPPER CRETACEOUS) — Clean, calcareous quartz sandstone (Wilson, 1970; Ryder and Scholten, 1973).

Kbdc DIVIDE CREEK CONGLOMERATE (UPPER CRETACEOUS) — Limestone and quartzite conglomerates derived respectively from Triassic and Jurassic rocks and Belt Supergroup rocks (Ryder and Scholten, 1973).

Kbmc UPPER LIMESTONE CONGLOMERATE UNIT IN MCKNIGHT CANYON AREA (UPPER CRETACEOUS) –- (Haley and Perry, 1991)

Kbmo ONCOID LIMESTONE UNIT IN MCKNIGHT CANYON AREA (UPPER CRETACEOUS) — (Haley and Perry, 1991).

Kbml LOWER LIMESTONE CONGLOMERATE UNIT IN MCKNIGHT CANYON AREA (UPPER CRETACEOUS) — (Haley and Perry, 1991).

Kf FRONTIER FORMATION (UPPER CRETACEOUS) — Greenish-gray siltstone and mudstone, interbedded with brown-weathering salt-and-pepper sandstone. Upper part locally contains limestone and quartzite conglomerate. (Dyman and others, 1997).

Kbl BLACKLEAF FORMATION (UPPER AND LOWER CRETACEOUS) — Volcaniclastic mudstone, bentonite, porcellanite, and siltstone (pastel beds) in upper part. Ledge-forming quartz and chert sandstone and minor mudstone in lower part. (Dyman and Nichols, 1988)

Kk KOOTENAI FORMATION (LOWER CRETACEOUS) — Mollusc-bearing fresh-water limestone in upper part; sandstone and mudstone, locally red, in middle part; and ledge-forming conglomerate at base (DeCelles, 1986; Moritz, 1951).

Jurassic

Js SEDIMENTARY ROCKS, UNDIVIDED (JURASSIC)

Jmet MORRISON FORMATION, ELLIS GROUP, AND TWIN CREEK(?) FORMATION, UNDIVIDED (JURASSIC); LOCALLY MAY INCLUDE ANKAREH FORMATION (TRIASSIC) — Poorly exposed upper interval of gray and grayish-green calcareous mudstone and argillaceous limestone, containing a ledge-forming oolitic limestone near the base. Lower part is reddish-brown mudstone, siltstone, and sandstone; may include Triassic Ankareh Formation locally. (Sadler, 1980; Perry, 1986; Moritz, 1951)

Triassic

TRtd THAYNES, WOODSIDE, AND DINWOODY FORMATIONS, UNDIVIDED (TRIASSIC) –- Light gray to brownish gray interbedded limestone, silty limestone, and calcareous siltstone in upper part; recessive red mudstone in middle part; and chocolate-brown, thin-bedded limestone and silty limestone in lower part (Sadler, 1980; Moritz, 1951).

Permian

Ppp PHOSPHORIA AND PARK CITY FORMATIONS, UNDIVIDED (PERMIAN) — Interbedded gray dolostone, gray to black chert, brown phosphatic mudstone, phosphorite, minor limestone, olive-gray siltstone, and and salt-and-pepper sandstone (Cressman and Swanson, 1964).

Pennsylvanian

IPq QUADRANT FORMATION (PENNSYLVANIAN) — Sandstone and minor dolostone or limestone. Upper part pale orange to light gray, medium- to fine-grained quartzose sandstone, some calcareous, with minor thick beds of dolostone or limestone; forms cliffs or ledges. Lower part is dolostone and dolomitic sandstone. (Saperstone, 1986; Sloss and Moritz, 1951)

Mississippian and Pennsylvanian

IPMsr SNOWCREST RANGE GROUP (PENNSYLVANIAN? AND UPPER MISSISSIPPIAN) — Includes Conover Ranch and Lombard Formations. Dark gray, black, and reddish-brown limestone, calcareous mudstone, sandstone, siltstone, and minor gypsum (Wardlaw and Pecora, 1985).

Mississippian

Ms SEDIMENTARY ROCKS, UNDIVIDED (MISSISSIPPIAN) — Mainly limestone and minor sandstone.

Msm SCOTT PEAK THROUGH MCGOWAN CREEK FORMATIONS, UNDIVIDED (MISSISSIPPIAN)

Msp SCOTT PEAK FORMATION (UPPER MISSISSIPPIAN) — Medium gray, thick bedded, cliff-forming, sandy limestone; locally includes some thin Surrett Canyon and South Creek Formations.

Mmd MIDDLE CANYON FORMATION (UPPER AND LOWER MISSISSIPPIAN)—- Medium to dark gray, thin-bedded limestone and black ribbon chert (up to 60%).

Mmg MCGOWAN CREEK FORMATION (LOWER MISSISSIPPIAN) — Grayish-black mudstone and sandstone; medium to dark gray limestone at base. Locally includes Devonian rocks of Three Forks Formation

Mtd TENDOY GROUP (LOWER MISSISSIPPIAN) — Includes, in descending order, McKenzie Canyon, Kibbey (?), Mission Canyon, Middle Canyon, and Paine Formations. Chiefly medium to dark gray limestone, thin- to thick-bedded, with locally abundant ribbon chert and minor sandstone (Sando and others, 1985).

Mlm LOMBARD AND KIBBEY FORMATIONS AND MADISON GROUP, UNDIVIDED (UPPER AND LOWER MISSISSIPPIAN) — Chiefly medium to dark gray, medium- to thick-bedded limestone and calcareous mudstone and siltstone in upper part. Lower part is medium gray, thick-bedded, cliff-forming limestone.

Mm MADISON GROUP (MIDDLE AND LOWER MISSISSIPPIAN) – Limestone and dolomitic limestone of Mission Canyon and Lodgepole Formations.

Mississippian and Devonian

MDmt MCGOWAN CREEK AND THREE FORKS FORMATIONS, UNDIVIDED (MISSISSIPPIAN AND DEVONIAN) — Chiefly black shaly mudstone and interbedded limestone and sandstone.

Devonian, Ordovician, and Cambrian

Dtm SEDIMENTARY ROCKS, UNDIVIDED (DEVONIAN) — Includes Three Forks, Jefferson, and Maywood? Formations. Medium gray, sheared limestone and dolomite; and red and yellow sandstone and siltstone

DOs SEDIMENTARY ROCKS, UNDIVIDED (DEVONIAN AND ORDOVICIAN) — Sandstone, dolomite, quartzite, and siltstone

Oks KINNIKINNIC AND SUMMERHOUSE FORMATIONS, UNDIVIDED (ORDOVICIAN) — White to light gray quartzite and dolomite.

O€s SEDIMENTARY ROCKS, UNDIVIDED (ORDOVICIAN AND CAMBRIAN?) — Quartzite, sandstone, conglomeratic sandstone, and dolomite (Dubois, 1983).

Proterozoic

ZYs WILBERT(?) FORMATION AND LEMHI GROUP ROCKS, UNDIVIDED (UPPER? AND MIDDLE PROTEROZOIC) — Chiefly reddish-brown feldspathic sandstone.

Proterozic and Archean

XAg GRANITIC GNEISS AND SCHIST (EARLY PROTEROZOIC? AND ARCHEAN)

XAqm QUARTZITE AND MARBLE (ARCHEAN)

Contributors to each 7.5' Quadrangle Map

1. Garfield Canyon 7.5' quadrangle
   W.J. Perry, Jr., S.U. Janecke, and J.W. M'Gonigle, unpublished mapping; D.P. Dubois (1981, 1982); W.R. Lowell (1965).

2. Red Rock 7.5' quadrangle
   W.J. Perry, Jr., unpublished mapping; W.R. Lowell (1965).

3. Deer Canyon 7.5' quadrangle
   S.U. Janecke, W.J. Perry, Jr., and B. Skipp, unpublished mapping; D.P. Dubois (1881, 1982).

4. Kidd 7.5' quadrangle
   R.J. McDowell (1992, 1997, 1998); W.J. Perry, Jr., and S.U. Janecke, unpublished mapping; N.S. Williams (1984); N.S. Williams and J.M. Bartley, (1988).

5. Graphite Mountain 7.5' quadrangle
   C.A. Landis, Jr. (1963); D.G. Dunlop (1982); K.S. Kellogg, S.U. Janecke, and B. Skipp, unpublished mapping.

6. Dixon Mountain 7.5' quadrangle
   S.U. Janecke, W. McIntosh, and S. Good (1999); M.J. Bartholomew (1989 and unpublished mapping); R.A. Klecker (1981); D.G. Dunlop (1982); J.D. Ponton (1983); S.U. Janecke, unpublished mapping; H.I. Saperstone (1986).

7. Dell 7.5' quadrangle
   M.J. Bartholomew (1989 and unpublished mapping); S.U. Janecke and B. Skipp, unpublished mapping; A.J. Crone and K.M. Haller (1991).

8. Island Butte 7.5' quadrangle
   S.U. Janecke and B. Skipp, unpublished mapping; B. Skipp and others (1988); B. Skipp (1988).

9. Caboose Canyon 7.5' quadrangle
   S.U. Janecke, W.J. Perry, Jr., W.J. Sando, and B. Skipp, unpublished mapping; D.G. Dunlop (1982); H.C. Witte (1965); W.J. Perry, Jr., and W.J. Sando (1982); R.K. Sadler (1980); B. Skipp (1988).

10. Gallagher Gulch 7.5' quadrangle
    R.K. Sadler (1980); R.J. McDowell (1992, 1997, 1998); B. Skipp, W.J. Perry, Jr., and S.U. Janecke, unpublished mapping; P.M. Hammons (1981).

11. Lima Peaks 7.5' quadrangle
    W.J. Perry, Jr., B. Skipp, and S.U. Janecke, unpublished mapping; R.J. McDowell (1992, 1997, 1998); P.M. Hammons (1981).

12. Snowline 7.5' quadrangle
    B. Skipp, W.J. Perry, Jr., S.U. Janecke, and T.S. Dyman, unpublished mapping; M.D. Wilson (1970); T.S. Dyman, J.C. Haley and W.J. Perry, Jr. (1995).

13. Monida 7.5' quadrangle
M.D. Wilson (1970); S.U. Janecke, D.L. Schleicher, B. Skipp, H.J. Prostka, M. Stickney, and M.J. Bartholomew, unpublished mapping.

14. Corral Creek 7.5' quadrangle
D.L. Schleicher, B. Skipp, H.J. Prostka, M.H. Hait, Jr., T.S. Dyman, M. Stickney, and M.J. Bartholomew, unpublished mapping.

15. Big Table Mountain 7.5' quadrangle
H.J. Prostka, B. Skipp, D.L. Schleicher, M.H. Hait, Jr., M. Stickney, M.J. Bartholomew, T.S. Dyman, and R.G. Tysdal, unpublished mapping.

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PRELIMINARY GEOLOGIC MAP OF THE LIMA 30' x 60' QUADRANGLE, SOUTHWEST MONTANA

Part B:

PRELIMINARY GEOLOGIC MAP OF THE SNOWCREST RANGE, MADISON AND BEAVERHEAD COUNTIES, MONTANA

by

Edward T. Ruppel

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DESCRIPTION OF MAP UNITS

Qal ALLUVIUM (HOLOCENE) — Silt, sand, and gravel in channels and flood plains of major rivers and streams. May be partly of Pleistocene age.

Qa AVALANCHE DEPOSIT (HOLOCENE) — Accumulations of unsorted, angular rock fragments in and at the toe of snow avalanche chutes, commonly littered with broken and shattered trees. Common on steep, east-facing slopes in the Snowcrest Range.

Qls LANDSLIDE DEPOSIT (HOLOCENE AND PLEISTOCENE) — Angular fragments of bedrock mixed with soil. Characterized by irregular, hummocky topography. Many landslides are marked by torn sod, tilted or uprooted trees, and steep, unvegetated slopes that indicate very recent continuing movement. Most of the landslides mapped in the Snowcrest Range have moved on underlying beds of shale, especially in the Lombard, Blackleaf, and Frontier Formations, and in the Beaverhead Group.

Qle LAKE DEPOSITS AND OVERLYING EOLIAN DEPOSITS (HOLOCENE AND PLEISTOCENE?) — Active sand dunes in the Centennial Basin; carried by prevailing winds from the southwest. Dunes are underlain by lake deposits of pale yellowish-brown to light brown, unconsolidated sand, silt, and clay that locally contain small pebbles about 3 mm in diameter.

Qaf ALLUVIAL FAN DEPOSIT (HOLOCENE AND PLEISTOCENE) — Poorly sorted, silty sand and gravel deposits in broad alluvial fans along valley margins and in valleys of streams tributary to the Ruby and Red Rock Rivers.

Qgm GLACIAL VALLEY AND CIRQUE MORAINE DEPOSIT (PLEISTOCENE) — Till containing unsorted boulders, cobbles, and pebbles in a matrix of sand and clay. Unit includes deposits of two major episodes of glaciation; youngest deposits are nearly unweathered in moraine that is not significantly dissected; older till is deeply weathered, in moraines that are rounded and dissected.

Qgo GLACIAL OUTWASH GRAVEL (PLEISTOCENE) — Poorly sorted bouldery gravel and sand deposited by glacial meltwater; compositionally similar to glacial moraines, and with similar weathering characteristics. Deposits typically include large angular boulders of Quadrant and younger sandstones as much as 15 ft in diameter that in older outwash are rounded, exfoliated, and deeply weathered and pitted by solution and wind.

QTl LEDFORD PASS SOIL (PLEISTOCENE AND LATE PLIOCENE?) — Mature soil zone preserved on upland surfaces in Ledford Pass and on Beaver Bench in the central part of the Snowcrest Range; surface has been deeply dissected by Ledford Creek and by the West Fork of the Ruby River and its tributaries. Overlain by till of the Hogback Mountain glaciers, and is clearly pre-glacial in age.

QTba BASALTIC VOLCANIC ROCKS (QUATERNARY AND TERTIARY) — Dark gray, fine grained, vesicular; in thin flows overlying boulder gravels in the south part of the Snowcrest Range. May include lavas related to the Tertiary Sage Creek and Blacktail Deer Creek flows (Scholten and others, 1955), and younger flows contemporaneous with Snake River Plain volcanics 3 to 4 M.Y. old (Fields and others, 1985).

QTlt LIMESTONE AND CALCAREOUS TUFA (EARLY PLEISTOCENE TO UPPER MIOCENE?) — Light yellowish-gray to light gray very fine-grained to fine-grained, vuggy, partly thinly laminated, beds 0.3 to 5 ft thick or massive and cliff-forming; locally tuffaceous or silty. Widespread along west flank of Snowcrest Range from Lone Rock Creek south to Steamboat Rock; in most places 100 ft or more thick, but thins north of Lone Rock Creek. Overlain by as much as 400 ft of quartzite cobble conglomerate cemented by travertine.

Unit deposited in a lake fed by thermal springs, some of which are still active, along the Snowcrest frontal fault zone. Calcium carbonate was leached from rocks in and adjacent to the fault zone, including (a) limestones in the Madison Group, which now is solution breccia heavily veined with calcite and well exposed in the canyon of the West Fork of Blacktail Creek; (b) Quadrant sandstone, which in places is reduced to loose, fine grains of white sand; and (c) limestone in the Lombard Formation of the Snowcrest Range Group, which is bleached, solution-pitted, and brecciated. Gypsum and calcareous rocks in the underlying Kibbey Formation typically have been completely dissolved and the formation in places has been almost totally removed. Large sinkholes in the SW ¼ Sec. 4, T.12 N., R.5 W. show that solution and removal of the formation is continuing today, with accompanying extensive brecciation and solution in the underlying Madison limestone and the overlying Lombard Formation (see Anderson and Diehl, 1999). The original extent of the limestone and of the lake in which it was deposited are unknown, but the present outcrops of the limestone indicate that at least as much as a cubic mile of calcium carbonate was leached from the rocks in and adjacent to the frontal fault zone in the Snowcrest Range.

The source of the hydrothermal fluids is uncertain, but some evidence suggests a heat source near Basin and Little Basin Creeks and near Vinegar Hill in T.12 and 13 S., R.7 W. The curving courses of the creeks define a nearly perfect semi-circle that forms the south edges of a basin filled with coarse gravel in a compound alluvial fan, suggesting rapid collapse along a ring structure. The rocks of the frontal fault zone are thermally metamorphosed near the possible ring structure, and a large hot-spring tufa deposit is adjacent to the fault zone in Sec.16, T.13 S., R.7 W. Tufa is vuggy, fine grained algal limestone and travertine cemeting angular fragments 1 to 3 inches in diameter of bleached and hydrothermally altered rocks. Locally abundant seams and veinlets of chalcedony and in places cristobalite (Zeigler, 1954). Archean and Mississippian rocks near the hot spring deposit are bleached, brecciated, and indicate extreme and widespread hydrothermal alteration.

Other possible ring fractures are present north of Vinegar Hill, and near Little Sage Creek where a curving fault has been recognized by J. W. Sears (written communication, 1999). In all, these features seem to outline a ring fracture zone about 7 miles in diameter, or possibly as much as 10 miles in diameter, that encloses a collapsed area. At depth, the fracture zone also may have been the source of the abundant basaltic volcanic rocks in the area.

The age of the limestone is only approximately known. It overlies rocks included in the upper Miocene Sixmile Creek Formation, and rhyolitic volcanic rocks that probably are Huckleberry Tuff (Brasher, 1950). It probably is mainly or entirely of Pliocene age (Fields and others, 1985; Zeigler, 1954; Ripley, 1995), but may include Upper Miocene rocks as well.

Tsc SIXMILE CREEK FORMATION (MIOCENE) — Sandstone, siltstone, and conglomerate commonly correlated with the Sixmile Creek Formation (Fields and others, 1985; Monroe, 1976; Robinson, 1963).

Sandstone and siltstone – Light gray and olive-gray to yellowish-gray, pale brownish-gray and grayish-orange, fine- to medium-grained, calcareous, cross-laminated, partly tuffaceous sandstone and siltstone; in beds 1 to 5 ft thick interbedded with 10- to 50-ft thick units of thicker and more massive, yellowish-gray, partly tuffaceous fine-grained sandstone and siltstone and sandy or silty tuff, and light gray fine- to medium-grained, calcareous crystal tuff in beds 1 to 3 ft thick. Many beds contain isolated small well rounded pebbles of basalt, quartzitic sandstone, and chert, and thin beds, lenses, and channel fills of pebble conglomerate or conglomeratic sandstone 0.5 to 3 feet thick; many beds thinly laminated or cross-laminated, and some characterized by large, festoon cross laminations.

Conglomerate – Cobbles and pebbles, well rounded, mainly of locally derived quartzitic sandstone, chert, limestone, and dolomite, and rare quartzofeldspathic gneiss, but including basalt, vesicular basalt, and a small percentage of Belt Supergroup pebbles and cobbles derived from the Gravelly Range gravel (Gutmann and others, 1989; Ruppel 1993); commonly well sorted, with cobbles, and rare boulders of vesicular basalt as much as one ft in diameter floating in a pebble-sand matrix; beds 10 to 20 ft thick. And interbedded light gray to pale yellowish-gray calcareous, partly tuffaceous siltstone and very fine-grained sandstone in beds 0.5 to 2 ft thick.

TKb BEAVERHEAD GROUP (LOWER TERTIARY AND UPPER CRETACEOUS) — (Lowell and Klepper, 1953; Nichols and others, 1985; Perry and others, 1988). Interbedded sandstone, siltstone, mudstone, and conglomerate.

Sandstone – Typically yellowish-gray, light olive-gray to light gray, fine-grained to medium-grained, rarely coarse-grained, commonly moderately to well rounded and well sorted; and locally containing abundant grains of dark gray chert, locally calcareous, commonly cross-bedded, locally contains scattered pebbles and pebbly zones of yellowish-gray to dark gray chert; in places contains abundant fragments of partly fossilized wood, charcoal, lignite, and leaf imprints. Beds 0.5 to 6 ft thick in interbedded units 10 to 30 ft thick.

Siltstone and mudstone: – Yellowish-gray to olive-gray or dark gray, partly calcareous, locally bentonitic, in interbeds 1 to 4 ft thick, and interbedded units 10 to 60 ft thick.

Conglomerate – Medium gray to yellowish-gray, thin- (0.5 ft) to thick-bedded (upt to 40 ft), containing well rounded pebbles or subangular to subrounded chips of medium gray to dark gray or yellowish-gray chert, and less abundant quartzite in a matrix of medium to very coarse sand. Includes limestone conglomerate composed of well rounded cobbles 0.5 to 0.8 ft in diameter and boulders of Madison Group limestone 1 to 2 ft in diameter, thick-bedded to massive, in a matrix of limestone sand and pebbles.

<u>Facies distribution</u> – Chert-pebble conglomerate interbeds are most common in the headwaters area of the Ruby River, where they form about one-third of the basal Beaverhead Group. Between Antone Peak and the Ruby River outcrops, the Beaverhead Group is mainly sandstone that is pebbly and includes relatively sparse interbeds of chert-pebble conglomerate, with some interbeds of mudstone and siltstone and a few thin beds of olive-gray, platy limestone. In the Clover Creek and Little Basin Creek area, south of Antone Peak, Zeigler (1954) mapped a lower member of chert-pebble conglomerate interbeds and lenses in cherty salt-and-pepper sandstone. The

unit ranges from about 750 ft to 3,000 or 4,000 ft thick, thickening eastward from Little Basin Creek. The cherty unit is overlain by and intertongues with a limestone cobble and boulder conglomerate of uncertain but great thickness. Zeigler (1954) measured more than 1000 ft in an incomplete section. Haley (1986) and Nichols and others (1985) include the Beaverhead Group rocks of the Snowcrest Range in the Lima Conglomerate and Clover Creek Sandstone units of the Group. The Beaverhead rocks overlie tightly folded and overturned rocks of the Frontier Formation and older formations with profound angular unconformity. The unconformity is best exposed near Stonehouse Mountain and farther south near Little Basin Creek (Zeigler, 1954; Gealy, 1953).

Kfb FRONTIER AND BLACKLEAF FORMATIONS, UNDIVIDED (UPPER AND LOWER CRETACEOUS)

Kf FRONTIER FORMATION (UPPER CRETACEOUS) – Interbedded sandstone, siltstone, mudstone, and limestone. Sandstone ranges from light gray to dark gray, but most commonly is medium light gray to yellowish- or greenish-gray or olive-gray, very fine- to medium-grained, but coarse-grained in places, with subrounded or subangular grains of quartz, dark gray chert, feldspar, and biotite; commonly calcareous, with some beds nearly sandy limestone; laminated or cross-laminated, and thinly platy. Sandstone is pebbly or conglomeratic in places, containing well rounded pebbles 0.1 to 0.2 ft in diameter of quartzite and chert. Sandstone beds 0.5 to 1 ft thick in single beds or in intervals as much as 20 ft thick, interbedded with siltstone and mudstone, make up most of the formation. Basal sandstone of formation is medium gray to medium-light gray, fine- to medium-grained with abundant chert grains and is 10 to 20 ft thick. Siltstone and mudstone are olive-gray to medium gray or medium-dark gray, partly bentonitic, partly porcellanitic, chippy, and typically concealed. Limestone is medium gray to olive-gray, fine-grained, thinly platy, in thin and irregular beds, nodules and concretions.

A faulted and incomplete measured section is about 2,900 ft thick, northeast of the Snowcrest Range (Tysdal and others, 1990). Near the south end of the Snowcrest Range, the formation is about 7,000 ft thick (Dyman and Nichols, 1988). The Frontier Formation overlies the porcellanitic upper Vaughn Member of the Blackleaf Formation with apparent conformity. It is overlain with angular unconformity by the Beaverhead Group.

Kbl BLACKLEAF FORMATION (UPPER AND LOWER CRETACEOUS) – Includes four lithofacies units (Dyman, 1985a, 1985b, 1985c; Dyman and Nichols 1988; Dyman and Tysdal, 1990; Tysdal and others 1989a, 1989b) not mapped separately in the Snowcrest Range. Thickness ranges from as much as 400 ft to about 1,500 ft and most commonly is 800 to 1,000 ft; the wide range in thickness is a result of tectonic thinning of shale units on the overturned limbs of tight chevron folds, and of concomitant thickening from the upright limbs.

Vaughn Member – Interbedded sandstone, siltstone and mudstone. Sandstone is light olive-gray to medium-light gray, fine- to medium-grained, partly calcareous, poorly to well sorted, subangular to subrounded quartz and locally abundant feldspar. Pebbly or conglomeratic with well-rounded pebbles and cobbles, as much as 0.2 ft in diameter, of mudstone, shale, siltstone, quartzite and chert; thin- to medium-bedded and partly thinly laminated. Siltstone and mudstone are predominant and are medium-dark gray to light brown or pale yellowish-brown and pale red, chippy to blocky, and commonly porcellanitic in upper part of unit; partly calcareous, locally bentonitic. Limestone is rare and is medium gray to grayish-brown, very fine-grained, in platy beds 0.1 to 1 ft thick. Stratigraphically equivalent to part of the Mowry Shale. Thickness as much as 260 ft.

Lower three lithofacies units are included in Flood Member of Blackleaf Formation (Tysdal and others, 1989):

Upper Sandstone unit – Medium-light gray and pale red to yellowish-gray and dusky-yellow, fine- to medium-grained, calcareous, subrounded to subangular grains or quartz and sparse chert, locally cross-laminated, beds 0.3 to 1 ft thick, and interbedded medium gray to olive-gray, fissile to chippy shales and mudstone. Basal sandstone of unit is thin-bedded to massive and about 10 to 30 ft thick, most commonly 10 to 20 ft thick. Thickness of unit as much as 50 ft. Stratigraphically equivalent to Muddy Sandstone.

Middle Shale unit – Dark gray to medium dark gray, fissile to chippy, light olive-gray and brownish-gray to grayish-brown, calcareous, chippy mudstone and silty or muddy limestone; interbedded with sparse beds 0.3- to 1-ft thick of yellowish-gray, fine-grained sandstone. Thickness of unit less than 50 ft to as much as 300 ft Stratigraphically equivalent to Thermopolis (or Skull Creek) Shale.

Lower Sandstone unit – Sandstone and interbedded sandstone, mudstone, and shale. Sandstone is medium-light gray and light olive-gray and dusky-yellow or pale yellowish-brown, and weathers to distinctive rusty color; very fine- to medium-grained with subrounded to subangular grains; calcareous; partly thinly laminated or cross-laminated and pebbly or conglomeratic in places. Interbedded siltstone, mudstone and shale are medium-light gray and light olive-gray to medium-dark gray, calcareous, partly fissile to chippy. Interbedded limestone is medium gray to grayish-brown, very fine-grained, in platy beds 0.1 to 1 ft thick. Basal sandstone typically is olive-gray or yellowish-gray to pale red, fine-grained with well rounded to subangular grains of quartz and sparse chert, calcareous, in beds 0.3 to 4 ft thick; as much as 25 to 35 ft thick, but absent in places. Thickness of unit about 45 to 50 ft. Stratigraphically equivalent to Fall River Formation.

KJke KOOTENAI FORMATION, MORRISON FORMATION, AND ELLIS GROUP, UNDIVIDED (LOWER CRETACEOUS AND UPPER JURASSIC)

Kootenai Formation (Lower Cretaceous) – Sandstone and conglomerate, siltstone, mudstone, shale, and limestone. Thickness of formation 350 to 500 ft. From top to base of formation:

Limestone – Limestone and thin interbeds and partings of dark gray, fissile shale. Limestone is medium-light gray to medium gray, very fine- to coarse-grained, typically partly bioclastic, in places sandy in lower and upper beds; fossiliferous containing abundant gastropods and fossil fragments in some beds; beds 1 to 3 ft thick. Gastropod limestone unit is 35 to 150 ft thick and most commonly is about 40 to 80 ft thick.

Upper shale and mudstone – Shale, mudstone, and subordinate sandstone; typically mostly concealed. Shale and mudstone are fissile, yellowish-gray to olive -gray, rarely pale red; interbedded quartz sandstone is yellowish-gray to olive-gray, fine- to medium-grained, very calcareous, in beds 0.4 to 1 ft thick. Approximately 50 to 110 ft thick.

Middle sandstone – Salt and pepper sandstone unit of pale yellowish-gray to medium gray, fine- to medium-grained with well rounded to subrounded quartz and chert grains, very calcareous, and cross-laminated. Beds are 0.4 to 1.2 ft thick, separated by medium gray to medium-light gray fissile shale partings and beds as much as 1 ft thick. Unit is10 to 30 ft thick

Lower mudstone, shale, and sandstone unit – Pale red mudstone, shale, and fine-grained sandstone, 25 to 35 ft thick, which is in turn underlain by 30 to 50 ft of interbedded shale, mudstone, and sandstone like that in the upper shale unit.

Basal Kootenai sandstone – Salt and pepper sandstone and chert pebble conglomerate, 30 to 100 ft thick. Sandstone is medium gray to light brown and dark yellowish-orange, medium- to coarse grained, with subangular grains of quartz and abundant dark gray chert, in beds 1 to 2 ft thick to massive; interbedded with chert-pebble conglomerate and pebbly sandstone, with subrounded to well rounded pebbles commonly 0.1 ft or less in diameter of yellowish-gray to dark gray or grayish-red chert. In lenses and beds 1 to 5 ft thick.

Morrison Formation (Upper Jurassic) – Olive-gray, greenish-gray, dusky-yellow and pale red to light brownish-gray and medium-dark gray, fissile to blocky mudstone and shale; includes nodules as much as 3 ft long and thin interbeds of medium gray to medium-light gray to blackish-red, very fine-grained, conchoidal limestone. Includes thin interbeds of olive-gray, rusty weathering fine-grained, dirty sandstone. As much as 40 ft thick, but absent in places.

Ellis Group rocks (Middle and Upper Jurassic) –Present in the southern Snowcrest Range and in the canyon of the West Fork of Blacktail Creek (Gealy, 1953). Medium light gray, fine-grained, locally oolitic, partly conglomeratic limestone and grayish green glauconitic siltstone and shale; about 50 ft thick.

TRtd THAYNES, WOODSIDE, AND DINWOODY FORMATIONS, UNDIVIDED (TRIASSIC)

Thaynes Formation (Lower Triassic) – Interbedded sandstone, siltstone, and limestone. Sandstone is predominant and is yellowish-gray and grayish-orange to light gray and medium-light gray, very fine-grained to fine-grained, rarely medium-grained, with well sorted and rounded quartz grains; calcareous, grading into sandy limestone in places; thinly platy and typically in thin (0.2 to 1.0 ft) and irregular beds. Siltstone resembles and is gradational into very fine-grained sandstone. Limestone is yellowish-gray and light gray to pale yellowish-brown, very fine- to medium-grained, commonly sandy, locally dolomitic, in beds 0.5 to 2 ft thick. Abundantly fossiliferous in some beds. Uppermost limestone beds in the central and south parts of the Snowcrest Range contain abundant dark gray to medium-light gray chert in nodules 0.2 to 0.5 ft thick and as much as 2 ft, long, in irregular beds up to 0.5 ft thick.

The Thaynes Formation is exposed most completely on Hogback Mountain and Sunset Peak in the central part of the Snowcrest Range. The middle of the formation there includes two zones of grayish-red to moderate reddish-orange siltstone, each about 10 to 15 ft thick separated by about 15 ft of pale yellowish-gray, very fine-grained sandstone. The formation is about 600 ft thick on Hogback Mountain (Gealy, 1953), and the lower contact is gradational through a thickness of about 20 ft from the underlying Woodside Formation. Farther north in the Snowcrest Range the cherty limestones are not present at the top of the formation, probably because of pre-Jurassic erosion, and the lower part of the formation, including the red siltstones and sandstone, apparently was not deposited. The formation thins to about 400 to 450 ft on the west side of Sliderock Mountain, and to about 50 ft at the north end of the Snowcrest Range. It is not present in the Greenhorn Range farther north (Hadley, 1980).

Woodside Formation (Lower Triassic) – Interbedded mudstone, siltstone, and subordinate very fine-grained, sandstone, all reddish-brown, reddish-purple and grayish-red to yellowish-brown, calcareous; in beds 0.3 to 1 ft thick. Prominently exposed on the east face of Hogback Mountain, where the formation is about 600 ft thick (Kummel, 1954); also about 600 ft thick near Devils Hole and 450 to 500 ft on Sliderock Mountain. Formation thins to about 180 ft north of Sliderock Mountain but thickens to about 500 feet farther north near Badger Creek; thins to 50 to 100 ft at the north end of the Snowcrest Range; absent farther north. Thickness changes from Hogback Mountain to Badger Creek result from tectonic thinning and thickening; the northward regional thinning is a result of non-deposition (Moritz, 1951).

Dinwoody Formation (Lower Triassic) – Interbedded limestone and sandstone with mudstone and shale principally in bedding partings and thin interbeds. Predominantly limestone that is pale yellowish-brown, olive-gray and brownish-gray to light gray, and medium gray and typically weathers pale brown to moderate brown; fine- to medium-grained, partly sandy or silty, abundantly fossiliferous, in places a fish bone coquina, partly dolomitic; in platy and irregular beds 0.5 to 1 ft thick, many of which are thinly laminated. Sandstone is moderate yellowish-brown and light brownish-gray to light olive-gray and medium to medium-light gray and typically weathers yellowish-gray and brownish-gray to pale brown; very fine- to medium-grained, with well rounded and well sorted quartz grains; calcareous, grading into sandy or silty limestone in thin and platy beds 0.3 to 2 ft thick but with beds as much as 5 ft thick in basal part of formation. Thickness ranges from 500 to 600 ft at the south end of the Snowcrest Range (Gealy, 1953; Kummel, 1954) to about 550 ft near Ledford Creek and Hogback Mountain and to about 500 ft at the north end of the Snowcrest Range.

Pp PHOSPHORIA FORMATION (PERMIAN) — Dolomite, chert, quartzitic sandstone, mudstone, and shale; partly phosphatic, including thin beds of oolitic phosphate rock.

Lithology and thickness differ from place to place, but generally include, from top to bottom: (a) medium-light gray to olive-gray, fine-grained, thick bedded (0.5 to 1 ft), partly phosphatic and quartzitic, cherty sandstone and interbedded dark gray, phosphatic mudstone and shale, as much as 110 ft thick, but absent in places; (b) light gray to medium gray, thin (0.3 to 1 ft) and irregularly bedded chert, with locally interbedded light gray dolomite, and including light gray, quartzitic sandstone and interbedded phosphatic mudstone and phosphate rock near base of unit; as much as 110 ft thick; (c) light gray to light olive-gray, very fine-grained, dolomite in beds 1 to 5 ft thick or massive, locally very cherty including abundant nodules up to 0.5 ft long and irregular interbeds up to 0.5 ft thick of medium gray chert; locally includes mammillary clusters of quartz crystals; includes about 15 ft of dark gray shale and mudstone in middle of unit; thickness as much as 125 ft; (d) medium gray to yellowish-gray, irregularly bedded (0.5 to 4 ft), partly nodular chert; about 100 to 130 ft thick including a middle unit of yellowish-gray, fine-grained, dolomitic sandstone about 30 ft thick; (e) yellowish-gray, fine-grained sandstone underlain by about 6 ft of phosphatic mudstone and shale and phosphate rock, in all about 40 ft thick; (f) light gray to very light gray, very fine-grained dolomite in beds 0.5 to 2 ft thick, with interbedded thin beds and nodules of medium-light gray chert, and sandy dolomite near base of unit; 75 to 150 ft thick; (g) basal medium-light gray to yellowish-brown and light brown, fine-grained sandstone in beds 0.1 to 0.3 ft thick, with interbedded chert and cherty light gray dolomite; as much as 25 ft thick, but locally absent.

Total thickness of Phosphoria Formation ranges from about 420 ft in the northern Snowcrest Range to more than 900 ft on Olson Peak, and about 600 ft at Wadhams Spring near the south end of the range (Gealy, 1953; Klepper, 1950; Klepper and others, 1953; Cressman, 1955; Swanson, 1970). Thickness variations result from erosion of upper beds, northward thinning by non-deposition of some lower beds, and tectonic thinning.

IPq QUADRANT FORMATION (PENNSYLVANIAN) — Sandstone, dolomite, and dolomitic limestone. Upper two-thirds of formation is predominantly yellowish-gray to pale olive-gray to pale yellowish-brown and grayish-orange, fine-grained to medium-grained, well sorted and well rounded, commonly cross-bedded, partly calcareous, quartzitic sandstone in beds 1 to 4 ft thick or massive. Locally includes thin interbeds of light gray to medium gray, sandy limestone or dolomite. Lower one-third of formation is interbedded light gray to medium-dark gray, fine-grained, locally cherty dolomite in beds 0.5 to 5 ft thick, and yellowish-gray to brownish-gray, fine-grained, well sorted and rounded, quartzitic, calcareous sandstone in 1- to 3-ft beds. Basal sandstone of formation, which may be as much as 50 ft thick, is light gray to pale yellowish-gray, fine- to medium-grained, well rounded and sorted, and thin-bedded (0.2 to 1 ft). Thickness of formation ranges from 600 to about 350 ft, thinning northward (Saperstone and Ethridge, 1984; Saperstone, 1986; Gealy, 1953).

IPMsr SNOWCREST RANGE GROUP (UPPER MISSISSIPPIAN AND LOWER PENNSYLVANIAN) — Formerly mapped as Amsden Formation and/or Big Snowy Group in this region, but now included in the Snowcrest Range Group which includes the Conover Ranch Formation, Lombard Limestone, and Kibbey Formation (Wardlaw and Pecora, 1985; Pecora, 1987; Key, 1986; Byrne, 1985).

Conover Ranch Formation – Interbedded sandstone, limestone, and shale. Upper half of formation includes relatively abundant interbeds of limestone that typically is medium-light gray to yellowish-brown, very fine-grained, and fossiliferous; gradational into overlying Quadrant Formation. Lower half of formation is predominately olive-gray and yellowish-gray to yellowish-brown, fine- to medium-grained, well sorted and well rounded, thin-bedded, calcareous sandstone with thin interbeds of similarly colored shale, siltstone, and sparse limestone. Estimated thickness about 750 to 800 ft, thinning northward; formation present only southwest of Little Basin Creek at south end of Snowcrest Range.

Lombard Limestone – Includes three units, an upper limestone, a middle sandstone and shale, and a lower limestone:

Upper limestone – Medium-dark gray to medium gray and less commonly medium-light gray to pale brown and light olive-gray, very fine-grained to fine-grained, partly cherty with medium-light gray to dark gray chert in irregular nodules and lenses 0.1 to 0.5 ft thick and up to 5 ft long; fossiliferous, commonly bioclastic, including crinoid coquinas; in beds 0.1 to 6 ft thick separated by thin beds of platy to shaly dark gray limestone or calcareous mudstone and shale. Unit is predominantly thin-bedded, but includes more thick (2 to 6 ft) beds than lower Lombard Limestone. Top of formation commonly is medium-dark gray, very fine-grained to fine-grained, shaly to platy, mud-cracked, thin-bedded limestone as much as 40 ft thick, with yellowish-gray, silty partings on bedding planes; gradational into overlying Quadrant Formation where Conover Ranch Formation is not present in central and northern Snowcrest Range. Thickness of unit ranges from about 200 to 370 ft (Key, 1986; Gealy, 1953).

Middle sandstone and shale – Predominantly dark gray, fissile shale separated by a middle unit, typically 10 to 30 ft thick, of sandstone and conglomerate. The sandstone is yellowish-orange and olive-gray to yellowish-gray and light brown, fine- to medium-grained, calcareous, partly well sorted and rounded, partly poorly sorted with subrounded to subangular quartz grains grading into conglomerate with mostly well rounded pebbles and cobbles of limestone and chert, probably from the Madison limestone, and with siltstone and rip-up clasts of limestone and mudstone. Dark gray to medium-dark gray, fissile shale above sandstone is as much as 100 ft thick, but most commonly is 30 to 50 ft thick, and is gradational both from the sandstone below and into the overlying upper limestone. Shale below sandstone is similar, and also is gradational into the overlying sandstone and into the underlying lower limestone. Middle sandstone and shale unit typically is 30 to 50 ft thick, but may be as much as 100 ft thick.

Lower limestone – Medium-dark gray to medium-light gray and pale olive-gray, fine-grained to very fine-grained or sublithographic, locally abundantly fossiliferous and bioclastic, thinly platy to thin-bedded (0.1 to 0.5 ft), but rarely as much as 3 ft thick; partly cherty with medium-dark gray chert in irregular nodules as much as 0.3 ft thick and up to 5 ft long; partly thinly laminated; bedding partings and thin interbeds of dark gray, fissile shale increase in abundance upward in unit; commonly weathers into splintered pencil-like fragments. Thickness of lower limestone about 175 to 200 ft (Byrne, 1985).

Kibbey Formation – Interbedded limestone, sandstone, siltstone, and mudstone, partly gypsiferous. Limestone is medium-dark gray to bluish-gray and yellowish-brown, fine-grained, silty to sandy, thinly laminated, thin- to medium-bedded. Sandstone is yellowish-gray and grayish-red to pale reddish-brown, fine- to medium-grained, very calcareous, limonite-speckled and stained. Siltstone and mudstone are pale red to moderate reddish-brown and pale reddish-brown, very calcareous, in interbeds up to 0.5 ft thick. Includes dark gray fissile shale in upper part of formation. Formation partly brecciated from solution of gypsum, particularly in lower half. Thickness ranges from about 100 to 200 ft, but in places is tectonically thinned to a few tens of feet, or is absent. Age is late middle Meramecian to early late Meramecian (Byrne, 1985).

Mm MADISON GROUP, UNDIVIDED (MIDDLE AND LOWER MISSISSIPPIAN) — Limestone, dolomitic limestone, and shale included in Mission Canyon and Lodgepole Formations.

Mmc MISSION CANYON FORMATION – Medium-light gray and medium gray to brownish-gray, generally fine- to medium-grained but coarse-grained in places, medium- and thick-bedded to massive limestone. Locally with nodules and lenses of pale yellowish-brown to light olive-gray chert 0.2 to 0.3 ft thick and 3 to 4 ft long. Occurs only on the west side of Snowcrest Range in fault-bounded and locally solution-brecciated outcrops.

Ml LODGEPOLE FORMATION – Medium gray to medium-dark gray, fine- to medium-grained limestone in beds from 0.5 to 2 ft thick, rarely as thick as 4 ft, partly thinly laminated, argillaceous, with thin interbeds and bedding partings of dark gray, calcareous shale. Occurs only on west side of Snowcrest Range in fault-bounded and locally solution-brecciated outcrops.

MDtj THREE FORKS AND JEFFERSON FORMATIONS, UNDIVIDED (LOWER MISSISSIPPIAN? TO MIDDLE DEVONIAN)

Three Forks Formation (Lower Mississippian? and Upper Devonian) -Medium gray and dark gray to dark olive-gray siltstone and very fissile shale with sparse concretions up to 1.5 ft in diameter of dark gray, very fine-grained limestone; subordinate interbedded light brownish-gray to grayish-brown, fine- to medium-grained, poorly sorted, glauconitic, fossiliferous sandstone in beds 0.1 to 2 ft thick, and rare beds of limestone-pebble conglomerate. Thickness ranges from 320-440 ft (Gealy, 1953).

Jefferson Formation (Upper and Middle Devonian) – Medium-gray to medium-dark-gray to yellowish-gray, fine- to medium-grained, fetid, splendant dolomite; thin- to medium-bedded (0.2 to 3 ft) to massive. About 150-300 feet thick (Gealy, 1953).

Ob BIGHORN DOLOMITE (MIDDLE AND LATE ORDOVICIAN) — Light gray and yellowish-gray to very pale-brownish-gray, fine-grained, massive dolomite. Present only near Basin Creek and Little Basin Creek in southern part of Snowcrest Range, the westernmost outcrops of the formation. About 20 to 50 ft thick where present.

Ꞓs SEDIMENTARY ROCKS, UNDIVIDED (UPPER AND MIDDLE CAMBRIAN)

Ꞓsr SNOWY RANGE FORMATION (UPPER CAMBRIAN)

Sage Dolomite Member: Medium-light gray, fine-grained, thin-bedded dolomite with crinkled and irregular laminae; locally contains thinly laminated algal beds. About 40 to 200 ft thick. Exposed mainly near Little Basin Creek in south part of Snowcrest Range.

Dry Creek Shale Member: Pale red to grayish-red, very fine-grained to medium-grained dolomite and calcareous sandstone, with interbedded yellowish-brown to yellowish-gray, dolomitic and calcareous siltstone, mudstone, and shale. About 10 to 30 ft thick.

Ꞓpf PILGRIM THROUGH FLATHEAD FORMATIONS, UNDIVIDED (UPPER AND MIDDLE CAMBRIAN) — Includes Pilgrim, Park, Meagher, Wolsey, and Flathead Formations.

Pilgrim Formation (Upper Cambrian) – Medium-light gray and yellowish-gray to light brownish-gray, fine grained dolomite in beds 0.5 to 6 ft thick, mostly 0.5 to 4 ft Upper part of formation is sandy, particularly on laminae and cross laminae, and includes interbeds of very fine- to medium-grained, well sorted and rounded, dolomitic sandstone. Sandy zone is 40 to 60 ft thick. Uppermost 20 to 40 ft of formation commonly not sandy. Beds beneath sandy zone are irregularly “ribboned” wavy-laminated, yellowish-gray, fine-grained, dolomite and dolomitic limestone about 50 to 100 ft thick, underlain by non-ribboned dolomite. Thickness of formation about 300 to 350 ft.

Park Shale (Middle-Cambrian) – Pale olive and grayish-green, micaceous, fissile shale and minor thin interbeds of grayish-red and yellowish-brown to yellowish-gray siltstone and mudstone. About 40 to 100 ft thick.

Meagher Formation (Middle Cambrian) – Medium gray and light olive-gray to yellowish-brown, fine- to medium-grained dolomite and dolomitic limestone in beds 1 to 3 ft thick. Partly irregularly mottled light or medium gray, yellowish-gray, or pale red. Thickness about 300 to 350 ft

Wolsey Shale (Middle Cambrian) – Olive-green to grayish-red or reddish-brown, micaceous, calcareous, glauconitic, very fine-grained sandstone and siltstone, and olive-green, fissile, micaceous shale. Thickness about 50 to 75 ft.

Flathead Sandstone (Middle Cambrian) – Yellowish-gray and yellowish-brown to pale red and grayish-red, fine- to medium-grained, but locally coarse-grained sandstone. Partly thinly laminated; beds commonly 0.5 to 3 ft thick or massive; partly glauconitic, particularly in lower part of formation about 3 ft above base, and in uppermost beds gradational into overlying Wolsey Shale. Basal beds, 1 to 3 ft thick, are locally coarse-grained and conglomeratic, containing well rounded white quartz pebbles up to 0.1 ft in diameter. Thickness of formation 0 to 50 ft.

Agn CRYSTALLINE METAMORPHIC ROCKS (ARCHEAN) — Metamorphic rocks about 2.75 to 3 b.y. old (Zell E. Peterman, written communication, 1982); includes quartzofeldspathic gneiss, complexly interlayered granitic, tonalitic quartz-feldspar-biotite, and hornblende-plagioclase gneiss.

Ag GRANITIC GNEISS (ARCHEAN) — Light-colored, quartz-feldspar-biotite gneiss and associated foliated granitic pegmatite.

Aqm QUARTZITE AND MARBLE (ARCHEAN) — Mainly medium gray to dark brown coarsely crystalline marble composed of calcite and dolomite with subordinate amounts of quartz, diopside, tremolite, forsterite, and talc.

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PRELIMINARY GEOLOGIC MAP OF THE LIMA 30' x 60' QUADRANGLE, SOUTHWEST MONTANA

Part C:

PRELIMINARY GEOLOGIC MAP OF THE RED ROCK HILLS, SAGE CREEK BASIN, AND UPPER BLACKTAIL REGION, MONTANA

by

Jeffrey D. Lonn, James W. Sears, William J. Fritz, Hugh A. Hurlow, and Robert C. Thomas

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Geologic Discussion of the Red Rock Hills, Sage Creek Basin, Blacktail Range, and Upper Blacktail Deer Creek Area, Southwest Montana

Because Tertiary rocks crop out over much of this part of the Lima quadrangle, some elaboration on Tertiary stratigraphy and Cenozoic tectonism is warranted. Tertiary rocks in southwestern Montana have traditionally been divided into two formations, the late Miocene to Pliocene Sixmile Creek Formation and the Eocene to mid-Miocene Renova Formation (Kuenzi and Fields, 1971; Fields and others, 1985), plus volcanic rocks that have usually been considered separately. Volcanic and volcaniclastic rocks just north of the Lima quadrangle, the so-called Dillon volcanics, were dated at 49.5-16.9 Ma (McDowell and Fritz, 1995). These dates span the range of vertebrate fossil dates for the Renova Formation (50-21 Ma; Fields and others, 1985) for the Sage Creek-Upper Blacktail Deer Creek area. It appears, then, that volcanic rocks interfinger with and grade laterally into the sedimentary and volcaniclastic rocks of the Renova Formation, and actually form a volcanic facies of the Renova Formation. In this region of the Lima quadrangle, the volcanic units are treated as an informal member of the Renova Formation, as suggested by McDowell and Fritz (1995).

Hanneman and Wideman (1991) proposed revising the Tertiary stratigraphy of southwestern Montana into four unconformity-bounded sequences. However, sequences 1-3, equivalent to the Renova Formation, are difficult to distinguish on the basis of field characteristics alone, so we have retained the traditional nomenclature.

Most workers (Fields and others, 1985) have believed that the Renova and Sixmile Creek Formations were deposited in partially isolated basins defined by topography that was similar to that of today. However, careful mapping on parts of the Lima quadrangle caused Fritz and Sears (1993), Janecke (1994), Sears and others (1995), Thomas (1995), and, to a lesser extent, Ruppel (1993) to challenge this traditional view of Tertiary geography. They postulated that the Renova basin was an area of low relief extending eastward from about the present position of the Tendoy Range, and that Renova sediments accumulated in broad shallow valleys peppered with volcanic centers, one of which was the Dillon volcanic center. These nearby volcanoes provided much of the source material for the tuffaceous units that make up most of the Renova Formation (Fritz and others, 1989).

A regional mid-Miocene unconformity marks the contact between the Renova Formation and the overlying Sixmile Creek Formation (Fields and others, 1985). Sears and others (1995) attributed the unconformity to the onset of extension, although Ruppel (1993) thought that extension had begun in the middle Oligocene. Extension first formed northeast-striking valleys, including a southeast-tilting half graben on the northwest flank of the Snowcrest Range called the Ruby graben. This northeast-trending valley filled with Sixmile Creek sediment, mostly well-sorted, rounded, fluvial gravel in the valley axis with debris-flow and fan deposits along the margins. Occasionally, ash from eruptions along the track of the Yellowstone hotspot overwhelmed the river system, and the thick fluvial tephra beds of the Anderson Ranch Member were deposited (Sears and others, 1995). About six million years ago, the Timber Hill Basalt flowed down at least 50 km of the valley. After 6 Ma, the nature of the extension changed, and northwest-striking normal faults became active. The similarity of the Sixmile Creek gravels makes it difficult to document offsets, but the Timber Hill Basalt flow is a useful marker and shows that the region is now broken into tilted blocks. The northwest-striking faults cut the northeast-trending Ruby graben into segments and disrupted the drainage system. The lacustrine limestone that caps the Sixmile Creek Formation probably formed in this disrupted drainage system (Jim Sears, personal communication, 1999). The late Cenozoic faults created the mountain ranges present today – the Tendoy Range, the Red Rock Hills, and the Blacktail Range – and are still active.

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New mapping supports some of these new concepts on Tertiary tectonism. Figure C1 is a cross section sketched from the northern Red Rock Hills southeast to the upper Blacktail Deer Creek Valley and Snowcrest Range. Note that Renova Formation beds are gently tilted into the Miocene-Pliocene? Snowcrest Fault Zone. The youngest Renova beds (Trbt) are preserved in the deepest part of the half-graben. The oldest beds (Trvp) form a dip slope on the northern end of the Sage Creek basin.

Ruppel (1993) interprets most movement on the Snowcrest Fault Zone to be right-lateral strike-slip and the fault zone to be vertical.

Figure C2 is a sketch of a cross section across the northern Red Rock Hills. The hills are capped by Sixmile Creek gravels. A striking pediment surface on the northwest end is actually an exhumed Eocene? erosional surface now thinly veneered with Quaternary gravel and tilted southwest into the Red Rock Fault. Remnants of Eocene volcanics and Sixmile gravel are perched on the surface.

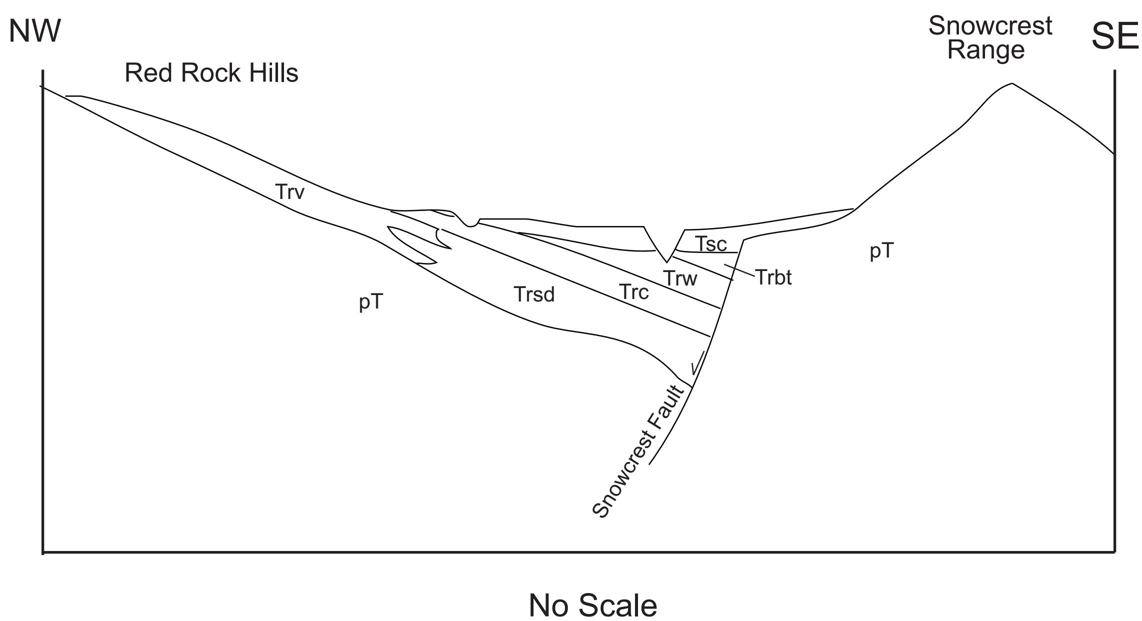

Figure C1. Simplified cross-section sketched from the northeastern Red Rock Hills southeast across the upper Sage Creek Basin to the upper Blacktail Valley and Snowcrest Range based on Sears and others' (1995) interpretation. Renova Formation units are gently tilted into the Miocene-Pliocene? Snowcrest Fault zone. Tsc--Sixmile Creek Fm; Trbt--Blacktail Member Renova Formation; Trw--White Hills Member; Trc--Cook Ranch Member; Trsd--Sage Creek and Dell members; Trv-- Dillon Volcanics Member; pT--pre-Tertiary rocks.

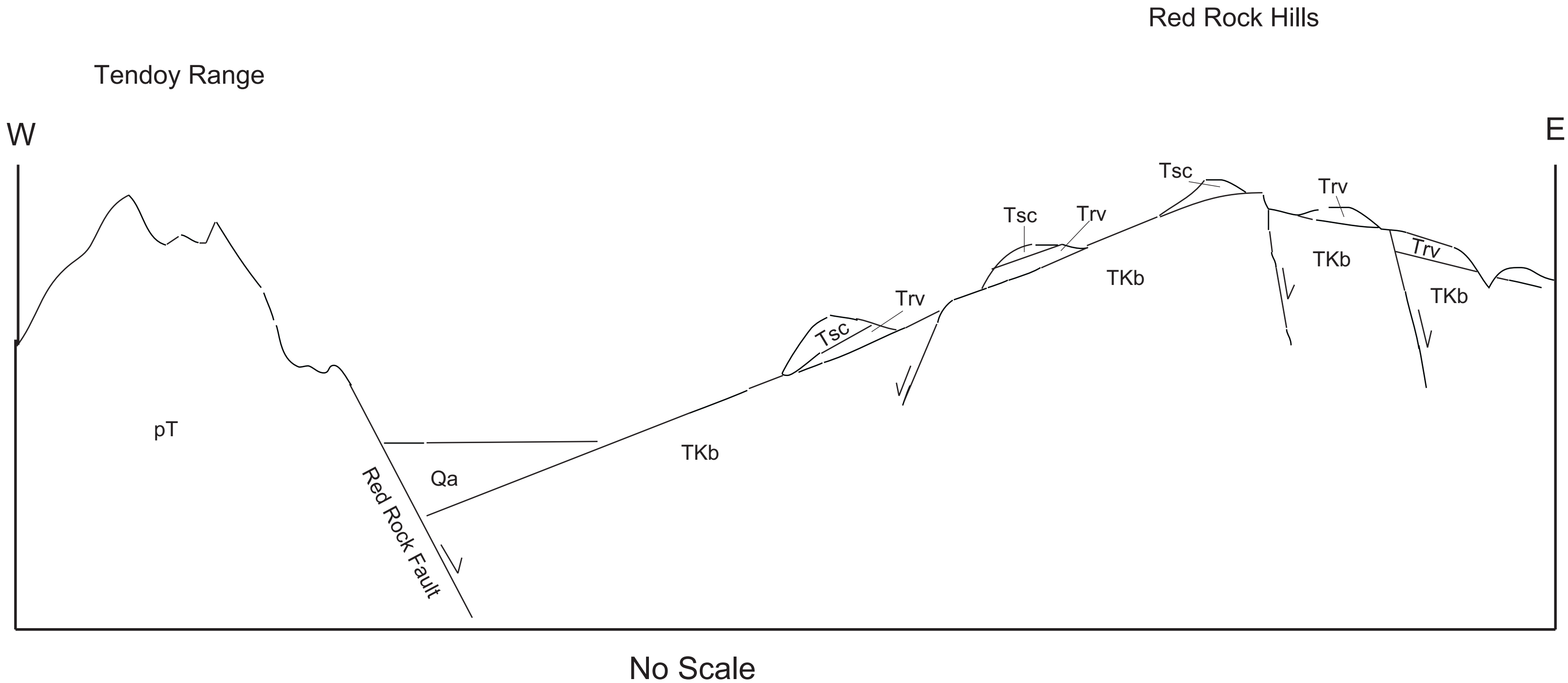

Figure C2. Simplified cross section sketched across the northern Red Rock Valley. The Red Rock Hills are capped by Sixmile Creek gravel.
The apparent pediment is really an exhumed Eocene? erosional surface, now tilted to the west against the Red Rock Fault. Note the remnants of volcanics and gravel perched on the tilted surface. Qa--alluvium; Tsc--Sixmile Creek Formation; Trv--volcanic rocks; TKb--Beaverhead Group; pT--pre-Tertiary rocks.

Description of Map Units

Qal ALLUVIUM (HOLOCENE) – Well rounded, well sorted cobble gravel deposited in active stream channels and floodplains.

Qaf ALLUVIAL FAN DEPOSITS (HOLOCENE) – Poorly to moderately sorted deposits of locally-derived, sub-angular to sub-rounded, silt- to boulder-sized clasts deposited in debris flow and fluvial environments along valley margins and in tributary valleys.

Qls LANDSLIDE DEPOSITS (HOLOCENE AND PLEISTOCENE) – Unsorted and unstratified mixtures of angular material that have been moved down slope by gravity. Characterized by irregular hummocky topography. Many are still active. Most landslides in this area are developed on underlying Renova Formation, especially on Trev that contains abundant bentonite developed as an alteration product..

Qao OLDER ALLUVIUM (PLEISTOCENE) – Well sorted, well rounded boulders, cobbles, gravel, sand, and silt deposited by streams, later incised by modern streams and now stranded up to15 m above the present watercourses. Includes both terrace deposits along rivers and outwash fan deposits emerging from the mountains.

Qafo OLDER ALLUVIAL FAN DEPOSITS (PLEISTOCENE) – Poorly to moderately sorted deposits of locally-derived, sub-angular to sub-rounded, silt- to boulder-sized clasts deposited in debris flow and fluvial environments along valley margins and in tributary valleys. Includes glacial outwash deposits.

QTlt LIMESTONE AND CALCAREOUS TUFA (PLIOCENE?) – Light yellowish-gray to light gray, very fine-grained to fine-grained, vuggy, partly thinly banded, beds 0.3-5 feet thick or massive and cliff-forming. Locally tuffaceous or silty. Ranges from 5 to 200 feet thick; averages 100 feet thick. See Ruppel's discussion on its deposition in this paper (Part B). Probably deposited in a lake formed by the break-up of the late Miocene-early Pliocene Ruby graben (Jim Sears, personal communication, 1999).

Tsc SIXMILE CREEK FORMATION, UNDIVIDED (PLIOCENE TO MIDDLE MIOCENE) – Mostly conglomerate with sand to cobble sized clasts of mainly quartzite, although basalt, limestone, and Belt argillite clasts are also common. Much is reworked Beaverhead Formation. The presence of volcanic clasts distinguishes it from Beaverhead Formation (Jim Sears, personal communication, 1999). Mostly unconsolidated. Age dates from tephra beds (Fritz and Sears, 1993) are consistent with vertebrate fossil ages (Monroe, 1976) and range from 3.7 to 16 Ma. Four members have been described by Fritz and Sears (1993) and Sears and others (1995), but only two were mapped as separate units in this study . Undivided unit Tsc is mostly Bighole River and Sweetwater Creek members, although some Anderson Ranch Member (Tsca) is included.

BIGHOLE RIVER MEMBER, INFORMAL – Well-sorted, well-rounded conglomerate with sand- to bouder-sized clasts of predominantly quartzite, but also including volcanic, limestone, and Belt argillite clasts. Deposited in fluvial environments. Unit recognized but included in undivided Tsc.

SWEETWATER CREEK MEMBER, INFORMAL – Moderate to poorly sorted conglomerate with silt to subrounded boulder clasts up to 2 m in diameter. Deposited in debris flow and alluvial fan environments. Laterally gradational with the Bighole River and Anderson Ranch members. Unit recognized but included in undivided unit Tsc.

Tsca ANDERSON RANCH MEMBER, INFORMAL (PLIOCENE TO MIDDLE MIOCENE) – White, fluvial tephra interbedded with light brown silt, sand, and gravel. Distinguished from tephra-rich members of the Renova Formation by clean appearance and lack of bentonitic clay.

Tsct TIMBER HILL BASALT MEMBER, INFORMAL (PLIOCENE) – A single olivine basalt flow that Sears and others (1995) traced for 50 km along the ancestral northeast-trending Ruby graben. Age is 6 Ma (Kreps and others, 1992). Found with gravels of the Big Hole River member or unconformable overlying Archean to Miocene rocks.

Tre RENOVA FORMATION, UNDIVIDED (LOWER MIOCENE TO EOCENE)

Trbt BLACKTAIL DEER MEMBER, INFORMAL (EARLY MIOCENE) – Gritty sandstone, tuffaceous mudstone commonly with abundant bentonite, and thin brown limestone. Sandstone contains angular clasts of quartz, volcanic rock fragments, and black chert. Late Arikareean vertebrate fossil assemblages have been found (Fields and others, 1985).

Trw WHITE HILLS MEMBER, INFORMAL (LATE OLIGOCENE) – Light gray tuffaceous mudstone containing abundant bentonitic clay. Yielded Whitneyan vertebrate fossils (Fields and others, 1985).

Trc COOK RANCH MEMBER, INFORMAL (OLIGOCENE) – Very light brown tuffaceous mudstones with lesser amounts of conglomeratic sandstone and volcanic ash. Abundant calcareous nodular horizons. Includes only the Cook Ranch Member of Tabrum (1996).

Trvb BASALT CAP, DILLON VOLCANIC MEMBER, INFORMAL (EOCENE?) – Black, dense olivine basalt forms a cap on the Trev unit in the north-central part of the map. Tentatively correlated with basalts to the north in Grasshopper Canyon that yielded age dates of 40.5 to 47.1 Ma (Leeth, 2000).

Trvh HALL SPRING BASALT AND OTHER OLDER BASALT, DILLON VOLCANIC MEMBER, INFORMAL (EOCENE) – Altered and weathered vesicular and amydaloidal basalt flows, breccias, and agglomerates. Rests unconformably on Beaverhead Group rocks, but Tabrum (1996) found it separating Sage Creek and Dell beds, making it about 48 Ma. This is the Sage Creek basalt of Scholten and others.(1955).

Trsd SAGE CREEK AND DELL BED MEMBERS, INFORMAL (EOCENE) – Poorly sorted tuffaceous mudstone, pebbly to cobbly tuffaceous mudstone, sandstone, and conglomerate. Brightly colored cobbles and pebbles of rhyolitic tuff containing sanidine phenocrysts are diagnostic (Tabrum, 1996). Bridgerian Sage Creek sediments unconformably underlie Uintan Dell Beds (Tabrum, 1996), but the distinction is hard to make, and Sage Creek Member is exposed over only a small area.

Trvp RHYOLITIC PYROCLASTIC ROCKS, DILLON VOLCANIC MEMBER, INFORMAL (EOCENE?) – Air fall and pyroclastic flow tuff, and tuffaceous mudstone. Light gray to light brown. Commonly altered to bentonitic clays. Includes some interbedded basalt flows, sometimes distinguished as Trvh. Tentatively correlated with the 40.5-47.1 Ma tuffs (Leeth, 2000) north of the map area in Grasshopper Canyon and with the 41-43 Ma tuffs (Fritz and others, 1989) of Frying Pan Basin. Unit may also be correlative with the Sage Creek and Dell beds in the Renova Formation (Fields and others, 1985; Tabrum, 1996) to the south. Unit is the same as Cook Ranch Volcanics of Pecora (1981, 1987). Landslides commonly develop in this unit.

Trvr RHYOLITIC FLOWS, DILLON VOLCANIC MEMBER, INFORMAL (EOCENE?) – Brick-red to maroon rhyolite lava flows with an aphanitic groundmass and tiny phenocrysts of quartz and plagioclase (after Tysdal, 1988). Found on the southeast flank of the Blacktail Range, far from the postulated Dillon volcanic center.

Tqtz QUARTZ (EOCENE?) – Gray, tan, or white dense masses of quartz and locally jasperoid; commonly vuggy, fractured, and layered. Replaces gneiss and fills open spaces on the northeast flank of the Blacktail Range, and appears to be associated with the Jake Canyon Reverse Fault. (After Tysdal, 1988).

TKb BEAVERHEAD GROUP, UNDIVIDED (PALEOCENE TO UPPER CRETACEOUS) Synorogenic conglomerate with interbedded sandstone, siltstone, mudstone, and conglomerate. Clasts are primarily composed of Precambrian and Paleozoic quartzite and limestone that were shed from advancing thrust sheets. Mostly lithified. In this area, rocks of the Beaverhead Group have been folded and thrust faulted. (See Lowell and Klepper, 1953; Nichols and others, 1985; Perry and others, 1988; and Haley and Perry, 1991.)

TKbl LIMESTONE CONGLOMERATES OF THE BEAVERHEAD GROUP – Conglomerates containing mainly clasts of Paleozoic limestone.

TKbq QUARTZITE CONGLOMERATES OF THE BEAVERHEAD GROUP – Conglomerates containing mainly clasts of quartzite.

TKbr RED BUTTE CONGLOMERATE OF THE BEAVERHEAD GROUP – Boulder and cobble conglomerate characterized by clasts of dominantly limestone of Mississippian through Triassic age, but with as much as 25% rounded cobbles of Precambrian Belt quartzite (after Haley and Perry, 1991).

Kbml LOWER LIMESTONE CONGLOMERATE OF THE BEAVERHEAD GROUP IN MCKNIGHT CANYON AND ASHBOUGH CANYON (UPPER CRETACEOUS)

IPq QUADRANT FORMATION (PENNSYLVANIAN) – Light gray to white and tan, fine- to medium-grained, medium- to thick-bedded, well-sorted quartz sandstone. Trough crossbeds are common. Lower contact is conformable. Commonly forms liffs and talus slopes. Thickness 680 to 725 feet. (After Pecora, 1981; Tysdal, 1988)

IPMsr SNOWCREST RANGE GROUP (LOWER PENNSYLVANIAN AND UPPER MISSISSIPPIAN) – Conover Ranch, Lombard, and Kibbey Formations, undivided.

CONOVER RANCH FORMATION (LOWER PENNSYLVANNIAN AND UPPER MISSISSIPPIAN) – Brick-red shale and mudstone, siltstone, and sandstone, with minor green shale and gray limestone; 0-100 feet thick; basal unit is limestone pebble conglomerate; conformable with underlying Lombard Limestone. (After Pecora, 1981; Tysdal, 1988)

LOMBARD LIMESTONE (UPPER MISSISSIPPIAN) – Tectonically deformed; consists of an upper sequence of 300 feet of pale-brown to gray, thick-bedded, crinoidal limestone and dark gray limey shale; a 220-580-foot-thick middle sequence of thin- to thick-bedded limestone with interbeds of siltstone and claystone and a 1-foot-thick discontinuous coal seam; and a 125-foot-thick lower sequence of olive-gray to pale-red-purple, thin- to thick-bedded, ostracod-rich limestone. Lower contact is conformable. (After Pecora, 1981; Tysdal, 1988)

KIBBEY SANDSTONE (UPPER MISSISSIPPIAN) – Pale yellow and reddish brown, thin-bedded, argillaceous, fine-grained, quartz sandstone. Limestone and evaporite solution breccia in the middle of the formation. Lower contact is conformable. Thickness 100 to160 feet.(After Pecora, 1981; Tysdal, 1988)

Mmc MISSION CANYON FORMATION (UPPER TO LOWER MISSISSIPPIAN) – Light gray, medium- to thick-bedded to massive limestone, oolitic limestone, and dolomitic limestone. Dark gray chert stringers in lower part and zones of evaporite-solution breccia in the upper and middle parts. Forms cliffs. Thickness 800 to1000 feet. (After Pecora, 1981; Tysdal, 1988)

Ml LODGEPOLE FORMATION (LOWER MISSISSIPPIAN) – Upper third is thin- to medium-bedded limestone, limey mudstone, and red calcareous siltstone. Lower two thirds is light gray, finely laminated, thin-bedded, limestone with partings of silty mudstone or calcareous siltstone. Thickness 1000 feet. (After Pecora, 1981; Tysdal, 1988).

MDtj THREE FORKS AND JEFFERSON FORMATIONS, UNDIVIDED (LOWER MISSISSIPPIAN AND UPPER DEVONIAN) – Three Forks Formations is grayish-orange siltsone, silty limestone, and evaporite solution breccia, about 60 feet thick. Unconformable contact with the underlying Jefferson Formation, which is grayish black, thick-bedded, fetid dolomite, yellowish-brown, sugary dolomite, and thin beds of yellowish brown calcareous siltstone. Thickness 100-120 feet. (After Pecora, 1981; Tysdal, 1988).

Ꞓppm PILGRIM, PARK, AND MEAGHER FORMATIONS, UNDIVIDED (CAMBRIAN) – Pilgrim dolomite is gray to pinkish-gray medium- and thick-bedded sugary dolomite, 100-140 feet thick. Lower contact with Park is conformable. Park Shale is olive-green fissile chippy clay shale with thin limestone beds in the middle part, 150-200 feet thick. Conformable with underlying Meagher limestone, which is yellowish-brown to gray, mottled, medium- to thick-bedded dolomite, and a cliff former. Thickness 575 feet (After Pecora, 1981; Tysdal, 1988).

Ꞓwf WOLSEY AND FLATHEAD FORMATIONS, UNDIVIDED (CAMBRIAN) – Wolsey shale is olive-green, finely micaceous, clay shale with thin layers of brown glauconitic quartzose siltstone. From 50 to100 feet thick. The underlying Flathead sandstone is light-gray, tan, and maroon, medium- to coarse-grained, medium-bedded quartz sandstone. Cross-bedded, and contains some quartz pebbles; thickness 30-120 feet (After Pecora, 1981; Tysdal, 1988).

Aum ULTRAMAFIC ROCKS (ARCHEAN) – Greenish-black, fine- to medium-grained biotite-plagioclase-clinopyroxene metamorphic rock, commonly serpentinized.

Agn GNEISS (ARCHEAN) – Mostly pink to pale orange, medium- to coarse-grained, quartz-microcline granitic gneiss, with light gray, banded, medium- to coarse-grained biotite-plagioclase-quartz gneiss also common. Hornblende gneiss layers a few tens of feet thick also present (After Tysdal, 1988).

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