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GEOLOGIC MAP OF THE SEDAN QUADRANGLE, GALLATIN AND PARK COUNTIES, MONTANA

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DESCRIPTION OF MAP UNITS
SURFICIAL DEPOSITS

Alluvium (Holocene to Upper Pleistocene)—Upper part consists of silt, sand, clay, and minor angular to round gravel; locally humic, nonbedded to parallel bedded. Lower part consists of pebble and cobble gravel; parallel bedding and both large- and small-scale crossbedding. Maximum exposed thickness about 8 m

Alluvial-fan deposits (Holocene to Upper Pleistocene)—Fan-shaped deposits of silt, sand, clay, and angular to round gravel mapped near head of Ross Creek on western margin, and in School Gulch at southern margin of quadrangle

Lake deposits (Holocene to Upper Pleistocene)—Coarse-grained gravel on shore grading into clay and marl in center. Thickness 0.3–3 m

Rock talus (Holocene to Upper Pleistocene)—Accumulations of locally derived boulder- to pebble-sized angular detritus at heads of drainages on both sides of crest of Bridger Range

Landslide deposits (Holocene to Middle Pleistocene)—Pebble to boulder gravel; commonly silty sand to silty clay matrix; also includes largely intact slide blocks of bedrock; nonsorted to poorly sorted; clasts chiefly angular to subangular; nonbedded to crudely bedded. Includes deposits of avalanches, slumps, earth flows, debris flows, and mudflows. Locally includes colluvium in the larger deposits of east flank of Bridger Range. Characterized by hummocky topography. Thickness 0 to about 10 m

Colluvium (Holocene and Pleistocene)—Coarse- to fine-grained deposits derived from nearby bedrock. Includes (1) poorly bedded, coarse, angular to subrounded, gravel-size clasts containing variable amounts of fine-grained matrix material composing alluvial fans and cones in rugged terrain; and (2) sand, silt, and minor fine gravel containing variable amounts of fine-grained matrix forming slope-wash deposits chiefly on volcanic rocks in gentle terrain. Thickness generally 1–3 m

Glacial deposits (Pleistocene)—Boulder to pebble gravel; extremely coarse, irregular blocks as much as 10 m in diameter; unsorted; contains variable amounts of silty sand matrix; combination of morainal, outwash, and avalanche debris. Thickness as much as 80 m

Older Alluvium (Pleistocene)—Chiefly boulder to pebble gravel containing variable amounts of silty sand matrix; includes glacial outwash gravels along east flank of Bridger Range, the North Fork of Carrol Creek, and along Cache Creek, and pediment gravels on northwest flank of Battle Ridge; locally subdivided into three members along Bridger Creek as described below

Older alluvium—Terrace gravels along Bridger Creek less than 45 m above present stream levels

Older alluvium—Terrace gravels along Bridger Creek 45–60 m above present stream levels

Older alluvium—Terrace gravels along Bridger Creek 60–90 m above present stream levels

IGNEOUS ROCKS

Mafic dike (Eocene?)—A composite, mainly basic, dike injected along the plane of the Pass thrust fault and along a fault south of Pine Creek; principally porphyritic, panidiomorphic

olivine-augite-biotite diorite containing small segregations of biotite-augite syenite; thickness generally less than 90 m, but as much as 150 m in places

Composite sill (Eocene? or Paleocene?)—Sill confined to Middle Cambrian strata north and south of Cross Range fault; in places consists of upper chilled layer of biotite-augite microdiorite 30–60 cm thick, middle thin layer of syenodiorite, and lower thick layer of biotite-augite diorite; entire sill is 24–60 m thick. Offset by minor thrust. May be as young as earliest Eocene (Harlan and others, 1988)

SEDIMENTARY ROCKS

Fort Union Formation (Paleocene and Upper Cretaceous)

Conglomerate lens at Nixon Peak (Paleocene)—Interbedded brown and olive-gray sandstone and conglomerate (25 percent or more). Sandstone is medium to coarse grained, epiclastic, slightly calcareous, thin to medium bedded, and crossbedded; weathers into conspicuous vertical columns on Nixon Peak. Conglomerate and conglomeratic sandstone are medium to thick bedded, as much as 3 m thick; clasts include subangular to subrounded cobbles and boulders as large as 30 cm in diameter of Middle Proterozoic Spokane Formation and Greyson Shale (Belt Supergroup), Paleozoic limestone and quartzite, Proterozoic gabbro and diabase, and Cretaceous granodiorite derived from Big Belt Mountains to the northwest, mixed with other volcanic, sedimentary, igneous, and rare metamorphic rock fragments. Contacts are gradational with unit Tfu. Thickness 0–914 m

Upper conglomeratic and middle sandy members, undivided (Paleocene)—Dusky-yellow-green and olive-gray sandstone, conglomerate, and minor siltstone and mudstone. Sandstone is slightly calcareous, fine grained to conglomeratic; composed of lithic volcanic, limestone, and quartzite grains. The thin- to medium-bedded (beds as much as 60 cm thick) sandstone is crossbedded and locally displays soft-sediment folds and slumps indicating western and northwestern sources; wood and leaf impressions are common; clay pebbles and limestone nodules are common in upper fine-grained sandstones that also contain rare freshwater gastropods and pelecypods. Conglomerate is composed of cobbles of subangular to subrounded multilithologic clasts of volcanic and igneous rocks, sandstone, chert, fetid limestone, and rare gneiss and schist in southeastward-thinning tongues (Piombino, 1979; Roberts, 1972; this paper); boulders as much as 60 cm in diameter are present in upper part. Siltstone is dusky yellow green and chiefly thin bedded; weathers to grayish yellow green. Mudstone is olive gray and chiefly massive; weathers light olive gray. Basal 60–90 m of unit may contain beds of latest Cretaceous age. Unit has gradational contacts with over and underlying units; thickness more than 2,130 m

Basal conglomerate member (Paleocene? and Upper Cretaceous)—Interbedded dusky-yellow-green and olive-gray sandstone, lenses of conglomerate, and minor siltstone and mudstone. Sandstone is medium grained to conglomeratic, calcareous, thin bedded and crossbedded; contains soft-sediment folds and slumps, and weathers dark yellowish brown. Conglomerate is gray and brown, medium bedded and crossbedded; clasts include pebbles, cobbles, and some boulders as much as 30 cm in diameter of intermediate volcanic rocks, basalt, chert, quartzite, limestone, minor coarse-grained intrusive rocks, and a few gneiss pebbles derived from Archean through Cretaceous terranes; no fragments of unequivocal Belt Supergroup origin were noted; western and northwestern sources are indicated by crossbedding. Siltstone is dusky yellow green and thin bedded; weathers grayish yellow green. Mudstone is olive gray and chiefly massive; weathers light olive gray. Unit forms ridge composed of Battle Ridge and Grassy Mountain (or Bangtails) and weathers to gravel-strewn slopes; contact with Hoppers

Formation is abrupt and is placed at base of lowest cobble conglomerate; gradational upper contact with unit Tfu; unit thins to northeast; about 304 m thick in quadrangle; 228 m measured in sec. 35, T. 3 N., R. 8 E., 3.2 km east of quadrangle (Skipp and McGrew, 1972)

Livingston Group (Upper Cretaceous)

Hoppers Formation—Light-greenish-gray, light-olive-gray, and minor gray and grayish-purple conglomerate, sandstone, siltstone, and mudstone. Unit chiefly is fine grained, volcaniclastic, and calcareous. Locally, coarse-grained and crossbedded sandstone and siltstone are exposed as thin friable beds that weather olive gray and yellowish brown and that contain imprints and carbonacous films of plants and woody material. Interlayered grayish-purple, green, and gray mudstone commonly is calcareous and locally bentonitic. Conglomerate is present as minor ridge-forming thin beds and lenses composed of granules and pebbles of mainly western-derived Paleozoic and Mesozoic sedimentary rocks and a few well-rounded gneiss pebbles as much as 20 cm in diameter (Skipp and McGrew, 1972). Formation contains limestone nodules throughout, though they are more common in lower part; rare ironstone nodules are found in upper part. Unit forms a steep slope below basal conglomerate member of Fort Union Formation (unit Tkfc). Contact with Billman Creek Formation (unit Kbc) is gradational and is placed at base of lowest thick (about 7.5 m) sandstone bed. Thickness ranges from 450 to 730 m; 730 m measured in secs. 26 and 35, T. 3 N., R. 8 E., 3.2 km east of Sedan quadrangle (Skipp and McGrew, 1972)

Billman Creek Formation—Grayish-red, grayish-green and gray, volcaniclastic mudstone and siltstone interbedded with minor volcanic sandstone and conglomerate and vitric tuff. Unit is chiefly volcaniclastic mudstone and siltstone that are gray and green in lower 213 m and grayish red above; calcareous, containing common carbonaceous material and common yellowish-brown-weathering calcareous concretions; locally rich in magnetite and zeolites. Interlayered lenses of fine-grained to conglomeratic volcaniclastic sandstone are calcareous, containing “cannonball” structures, are thin bedded to massive, and are locally crossbedded. Conglomerate lenses contain subangular to subrounded pebbles and cobbles of intermediate volcanic rocks and accessory Paleozoic limestone and quartzite. Conglomerate and sandstone lenses are common in upper beds in southern part of quadrangle and in lower beds in northern part. Freshwater mollusks and Hadrosaurian dinosaur bones are common in lower mudstone beds (Skipp and McGrew, 1972). Unit forms valleys. Contact with Lennep Sandstone Member of Sedan Formation (unit Ksle) is gradational and is placed at top of highest ridge-forming sandstone in that member. Estimated thickness 760–914 m

Sedan Formation—Chiefly western-derived volcaniclastic sandstone and mudstone, and minor ash-flow tuffs; divided into the following five members; unit used only on cross sections

Lennep Sandstone Member—Ridge-forming , olive-gray, greenish-gray, and light-gray, volcaniclastic sandstone, conglomerate, and minor mudstone and devitrified vitric tuff.

Fine-grained to conglomeratic sandstone is calcareous, is poorly bedded to crossbedded, has local magnetite concentrations along bedding planes, contains reddish-brown-weathering "cannonball" concretions and abundant carbonaceous material, and weathers yellowish brown. Iron staining and zeolitic alteration locally are common. Lenses of volcaniclastic pebble and cobble conglomerate contain cobbles as much as 15 cm in diameter of intermediate volcanic rocks and a few pebbles of Paleozoic quartzite and limestone. Minor siliceous mudstone is brown and massive. Thin beds of light-green and light-gray, zeolitized (laumontite) vitric tuff are present in lower part of member. Unit contains rare dinosaur bone fragments, freshwater and brackish-water mollusks, and, in northern part of quadrangle, Ophiomorpha, a marine crustacean. Gradational lower contact of unit is placed at base of lowest prominent sandstone ledge. Thickness is about 106–152 m (Skipp and McGrew, 1977)

Mudstone member—Greenish-gray and brownish-gray, volcaniclastic mudstone, siltstone, sandstone, and minor interbedded conglomerate and altered vitric tuff. Siliceous mudstone is sandy, silty, locally bentonitic, massive, and veined with calcite; contains abundant orange zeolite (clinoptilolite); mudstone may be chiefly altered vitric lithic tuff. Fine-grained to conglomeratic, volcaniclastic sandstone and siltstone are locally calcareous and zeolitic, crossbedded, and graded. Yellowish-gray bentonite and light-gray-weathering, altered vitric tuff are common in upper beds. Rare lenses of volcanic pebble and cobble conglomerate containing a few boulders as much as 0.9 m in diameter of coarsely porphyritic augite andesite that resemble Member H of Maudlow Formation are present in middle beds in northern part of quadrangle (Skipp and McGrew, 1977). Unit contains freshwater mollusks, wood, and dinosaur bones, including one femur identified as Gorgosaurus sp. (Nicholas Hotton III, written commun., 1971). Member forms valleys and low barren hills, and has a gradational contact with Middle sandstone member (unit Ksms) below. Thickness ranges from 274 to 304 m

Middle sandstone member—Olive-green, olive-gray, and dark-greenish-gray, volcaniclastic sandstone, conglomerate, mudflow conglomerate, and minor siltstone and mudstone. Fine-grained to conglomeratic, but mainly medium- to coarse-grained sandstone is calcareous, locally mottled, and crossbedded; weathers brown; contains carbonaceous material and zeolites. Lenses of volcanic conglomerate and mudflow conglomerate in upper part contain fragments of intermediate volcanic rocks as much as 30 cm in diameter that resemble lava flows of Member F of Maudlow Formation of Livingston Group in Maudlow Basin, 12 km to the northwest (Skipp and McGrew, 1972; 1977); a K-Ar radiometric age on hornblende from Member F of Maudlow Formation is 76.61 Ma (Marvin and others, 1989). A light-gray, calcareous, biotitic quartzose sandstone present at base of unit in northern part of area is correlated with upper part of Parkman Sandstone Member in northern parts of western Crazy Mountains Basin (Skipp and McGrew, 1977). Unit forms series of ridges and disconformably overlies ash-flow tuff member (unit Ksa); contact is placed at top of highest ash-flow tuff or ash-flow tuff conglomerate. Thickness is about 304–436 m

Ash-flow tuff member—Pale-yellowish-green, light-greenish-gray, grayish-red, and pale-yellowish- brown, welded to nonwelded tuff and ash-flow tuff conglomerate, interbedded with volcaniclastic conglomerate, sandstone, mudstone, and porcelanite. Tuff is dacitic and fine grained, containing locally abundant phenocrysts of golden-weathering biotite and minor andesine, augite, hypersthene, and altered cognate inclusions; glass is mostly devitrified, but thin (90- to 150-cm-thick) zones of perlitic glass are present in northwestern part of quadrangle. Conglomerate composed of ash-flow tuff pebbles marks base and top of unit in some places. Welded tuff is composed of a maximum of three composite cooling units, each 0–91 m thick, separated by intervals of greenish-gray to light-gray, volcaniclastic sedimentary rocks including greenish-gray, olive-green, and brown porcelanite. Wood is present in volcaniclastic beds. Unit forms resistant knobs and ridges and disconformably overlies lower sandstone member (unit Ksl). Thickness about 60–152 m. Tuffs thicken to northwest (Skipp and Peterson, 1965; Skipp and Hepp, 1968). Unit equivalent to Welded tuff member of Skipp and McGrew (1977)

Lower sandstone member—Dark-olive-gray, greenish-gray, and yellowish-gray, volcaniclastic sandstone, siltstone, mudstone, altered crystal lithic tuff, minor volcaniclastic granule and pebble conglomerate, minor grayish-red-purple hornblende dacite, and minor lignitic coal. Volcaniclastic sedimentary rocks, chiefly sandstone, are fine grained to conglomeratic and calcareous, containing common calcareous concretions and carbonacous plant material, including leaf, needle, twig, and cone imprints; medium bedded and locally crossbedded. Magnetite-rich zones in the sandstone beds and ironstone nodules are common in lower part, and, locally, dark-brown lignitic coal is found at the base. A lens of dacite in upper part of member that was identified about 1 km southwest of northwest corner of quadrangle is correlated with Member B of Maudlow Formation of Livingston Group about 12 km to the northwest (Skipp and McGrew, 1977); a K-Ar age on hornblende from dacite of Member B is 80.81 Ma (Marvin and others, 1989). Unit forms a low ridge and has an abrupt contact with underlying Eagle Sandstone (unit Ket) throughout most of area, but units are gradational just south of quadrangle (Roberts, 1963, 1964a,b, 1972). Thickness is 152–304 m

Eagle Sandstone, Telegraph Creek Formation, Cody Shale, Frontier Formation, Mowry Shale, Thermopolis Shale, Kootenai Formation, Morrison Formation, and Ellis Group, undivided (Cretaceous and Jurassic)—Mudstone, sandstone, minor limestone, conglomerate, and porcelanite; includes Cross Range fault zone rubble comprising Morrison Formation, Ellis Group, and Kootenai Formation about 1.5 km east of Fairy Lake. Shown undivided primarily on cross sections

Eagle Sandstone and Upper Part of Telegraph Creek Formation, undivided (Upper Cretaceous)—Eagle Sandstone in upper part is light-olive-gray, yellowish-gray and medium-gray sandstone, minor gray shale, and thin black coal seams. Very fine grained to medium-grained sandstone is quartzose, feldspathic, biotitic, and chiefly calcareous, containing brown-weathering "cannonball" concretions; crossbedded and weathers yellowish gray. Basal Virgelle Sandstone Member consists of dark-greenish-gray and greenish-gray, volcaniclastic sandstone that is magnetite-rich and forms a ledge. Upper part of Telegraph Creek Formation is medium-gray and light-olive-gray sandstone, siltstone, and minor mudstone. Fine-grained sandstone is quartzose, micaceous, biotitic, and calcareous, containing large "cannonball" concretions; thin-bedded; contains fossils—mollusks, rare ammonites, and wood impressions; forms slopes and has a gradational lower contact. Thickness of map unit is 61–152 m ; thicker in southern part of quadrangle

Lower part of Telegraph Creek Formation (Upper Cretaceous)—Medium-dark- to dark-gray mudstone and light-gray sandstone, siltstone, and minor bentonite. Silty and sandy mudstone and very fine grained sandstone are biotitic, micaceous, calcareous, containing limestone nodules, and carbonacous; thin bedded and fossiliferous, containing mollusks and ammonites. Unit forms valleys or gentle slopes and is poorly exposed throughout area. Formation has gradational basal contact with Cody Formation (unit Kc). Thickness about 61–122 m

Cody Shale (Upper Cretaceous)—Gray shale and mudstone interbedded with grayish-green and olive-gray sandstone and siltstone and minor brown-weathering nodular limestone and yellowish-gray bentonite. Mudstone and shale are both calcareous and noncalcareous, locally biotitic, silty and sandy; contain limestone nodules, ironstone nodules, and cone-in-cone structures. Fine-grained sandstone is quartzose but contains abundant detrital rock fragments, is calcareous, argillaceous, and thin bedded. Mudstone and shale form slopes in lower and upper parts of interval. Eldridge Creek Sandstone Member near center of interval consists of ridge-forming sandstone that is greenish gray and olive gray, fine grained, thin bedded, crossbedded, and ripple marked; locally contains abundant glauconite. Member is about 30 m thick. Entire formation is locally fossiliferous and contains fish scales, starfish, mollusks, and ammonites. Unit is poorly exposed in quadrangle; sandstone ledges of Eldridge Creek Sandstone Member crop out locally. Basal contact is conformable. Thickness is about 304 m

Frontier Formation (Upper Cretaceous)—Ledges of light- to medium-gray, olive-gray, and dark-greenish-gray sandstone separated by mudstone and siltstone intervals that contain minor chert-pebble conglomerate, bentonite, and siliceous limestone. Fine- to coarse-grained sandstone is quartzose, feldspathic, lithic, calcareous, argillaceous, thin to medium bedded, and locally crossbedded; contains heavy-mineral concentrations on bedding planes; sandstone weathers brown and olive gray and forms prominent ledges. Distinctive sandstone at top of unit is light gray to light olive gray, friable, calcareous, and crossbedded. East of Ross Peak sandstones contain calc-silicate minerals that give them a mottled appearance. Dark-gray and greenish-gray mudstone and siltstone intervals as much as 30 m thick are siliceous and thin bedded, containing a few friable, fine-grained, calcareous sandstone beds. Marker beds in the upper mudstone intervals include thin, black chert-pebble conglomerate composed of well-rounded pebbles less than 2.5 cm in diameter, grayish-green siliceous limestone lenses, and thin beds of bentonite and fossil oyster (mollusk) banks. Basal contact is conformable. Thickness is about 152 m

Mowry Shale, Muddy Sandstone, Skull Creek Shale, and Fall River Sandstone, undivided (Lower Cretaceous)—Medium-dark-gray and greenish-gray mudstone, sandstone, porcelanite, and minor coal. Formations are described in descending order. Mowry Shale is medium-dark-gray and greenish-gray mudstone, sandstone, and porcelanite.

Muddy Sandstone is light-olive-gray to greenish-gray sandstone that is fine grained to conglomeratic; contains much volcanic detritus; is chiefly noncalcareous, thin bedded, and crossbedded, containing a thin, small pebble conglomerate bed near base. Muddy Sandstone forms a ledge about 12 m thick. Skull Creek Shale is grayish-green interbedded mudstone, siltstone, and fine-grained sandstone that is rich in volcanic detritus; laminated to thin bedded, crossbedded, and locally calcareous; contains minor thin coal beds. Fall River Sandstone is ridge-forming sandstone that is greenish gray to grayish orange, medium grained, quartzose and quartzitic, crossbedded, laminated, and ripple-marked; weathers yellowish brown; ledge is about 11 m thick. Unit is poorly exposed in quadrangle and has a disconformable basal contact. Thickness is about 182 m

Kootenai Formation (Lower Cretaceous)—Red, gray, and purple mudstone, interbedded with yellowish-gray and grayish-purple sandstone and minor conglomerate and medium-light-gray freshwater nodular limestone. Medium- to coarse-grained sandstone in upper part is quartzose, impure, and commonly hematitic. Medium-light-gray limestone in nodular layers is common in upper beds about 30 m below the top and just above the basal sandstone and conglomerate; commonly contains freshwater gastropods. Basal ledge-forming, coarse-grained sandstone and conglomerate are slightly argillaceous and are composed of salt-and-pepper chert and quartz grains as large as pebble size. Basal ledge is about 20 m thick. Formation is poorly exposed except for fragments of the basal sandstone and conglomerate. Unit disconformably overlies Morrison Formation (unit Jm). Thickness ranges from 111 to 121 m

Morrison Formation and Ellis Group, undivided (Middle and Upper Jurassic)—Poorly exposed, varicolored mudstone containing minor sandstone and limestone; mapped only along gully northeast of Fairy Lake

Morrison Formation (Upper Jurassic)—Red, green, and purple mudstone and hackly shale intercalated with light-gray, yellowish-brown, and yellowish-orange siltstone and sandstone. Upper 15–23 m includes light- to dark-gray carbonaceous shale and mudstone; locally, lower part contains irregularly bedded impure limestone and limestone nodules. Formation is poorly exposed and has a conformable basal contact. Thickness is 91–133 m

Ellis Group (Upper and Middle Jurassic)—Consists in descending order of Swift Sandstone, Rierdon Formation, and Sawtooth Formation. Swift Sandstone is yellowish brown to grayish brown, medium to coarse grained, quartzose, very calcareous, and glauconitic, containing scattered chert pebbles; is crossbedded and fossiliferous (mollusks). Rierdon Formation consists of an upper yellowish-gray calcareous shale and impure limestone and a lower gray-weathering, medium- to thick-bedded, ledge-forming oolitic limestone. Sawtooth Formation includes an upper red and yellow calcareous mudstone and shale, a middle gray-weathering, dense, platy limestone and interbedded calcareous shale, and a basal sandy to pebbly limestone or conglomeratic calcareous sandstone. Unit thins northward and unconformably overlies Phosphoria or Quadrant Formation (unit PMpa). Thickness varies from about 36 to 91 m

Phosphoria and Quadrant Formations; Amsden, Snowcrest Range and Madison Groups; and Three Forks Formation, Jefferson Dolomite, Maywood Formation, Snowy Range Formation, Pilgrim Limestone, Park Shale, Meagher Limestone, Wolsey Shale, and Flathead Sandstone, undivided (Permian, Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian)—Limestone, dolostone, mudstone, and sandstone; shown undivided only on cross sections

Phosphoria and Quadrant Formations and Amsden and Snowcrest Range Groups, undivided (Permian, Pennsylvanian, and Mississippian—Poorly exposed mudstone, locally stained red, containing fragments of sandstone, dolostone, and limestone. See units PMpa and Msr. Mapped on eastern flank of southern part of Bridger Range; interval about 50–130 m thick

Phosphoria and Quadrant Formations and Amsden Group, undivided (Permian, Pennsylvanian, and Mississippian)—Yellow, greenish-yellow, pale-gray-brown sandstone, white to yellowish-brown dolostone and limestone, red to purple dolomitic mudstone and shale, and minor green, nodular chert beds. Formations are described in descending order. Phosphoria Formation (Permian) is yellow to greenish-yellow sandstone containing scattered chert nodules; nodular chert beds with interstitial sand; soft, green, noncalcareous, nonphosphatic shale; and chert breccia or conglomerate. Thickness is 0–12 m; formation is absent north of Fairy Lake. Quadrant Formation (Pennsylvanian) is pale-gray-brown to white, fine-grained to very fine grained, medium-bedded to massive, crossbedded quartzose sandstone that contains some white to pale-yellow-gray, dense granular dolostone beds intercalated in lower part. Thickness is about 15–43.5 m. Amsden Group (Pennsylvanian and Mississippian) includes an upper pale-yellow-brown to white, dense, medium-granular, medium-bedded dolostone, containing a few thin beds of pale-gray-brown, fine-grained quartzose sandstone (probably the Devil's Pocket Formation) that unconformably overlies a lower red to purple dolomitic mudstone and shale interbedded with impure silty or argillaceous dolostone and limestone (probably Tyler Formation). Thickness of Amsden Group about 32–103 m. Unit unconformably overlies Snowcrest Range Group and is mapped separately in northern part of Bridger Range. Thickness of entire interval is 47–158 m

Snowcrest Range Group (Upper Mississippian)—Gray and gray-brown limestone and dolostone; red, pink, and yellow-orange sandstone; red and pink siltstone; red to purple shale; and a red-stained breccia. Group is divisible into three formations, described in descending order: The Conover Ranch Formation consists of ledge-forming, medium-bedded, gray to gray-brown, chert-nodule-bearing limestone and dolostone. Lower contact is gradational with Lombard Limestone, which consists of dark-gray to purplish-gray and black, fossiliferous shale or shaly limestone. Thickness of combined Conover Ranch Formation and Lombard Limestone varies from zero to about 61 m. Lombard Limestone unconformably overlies Kibbey Formation, which consists of three parts: upper part is red, pink, and pale-yellow-orange, platy to massive sandstone, sandy siltstone, and sandy dolostone, containing intercalated red siltstone; middle part is red and pink, blocky-fracturing dolomitic siltstone, and red to purple, hackly shale containing some thin pale-gray or cream-colored, purple-mottled, fine-grained dolostone; lower part is cream- and lavender-mottled, irregularly bedded, fine-grained dolostone or a red-stained breccia of limestone and dolostone fragments (McMannis, 1955). Thickness of Kibbey Formation varies from 11 to 71 m. Thickness of group varies from 11 to 122 m

Madison Group, Three Forks Formation, Jefferson Dolomite, and Maywood Formation, undivided (Mississippian and Devonian)—Fault zone breccia consisting of limestone and dolostone fragments derived from these formations in a structural horse just north of southern border of quadrangle, southwest of Baldy Mountain

Madison Group (Upper and Lower Mississippian)—Limestone and dolostone divided into an upper thick-bedded formation, the Mission Canyon Limestone, and a lower thin-bedded formation, the Lodgepole Limestone

Mission Canyon Limestone (Upper and Lower Mississippian)—Pale-yellow-brown, massive, poorly bedded limestone and dolostone that weather light gray and form cliffs and castellated ridges. Chert and limestone nodules are common in middle and upper beds. Several conspicuous solution-collapse breccias occupy persistent stratigraphic positions. Unit has a gradational lower contact with Lodgepole Limestone (unit Mlp) and ranges in thickness from about 220 to 290 m; it is thickest near Sacagawea Peak

Lodgepole Limestone (Lower Mississippian)—Gray and brown limestone and minor dark-brown to black silty shale. Formation is divisible into three members: Upper Woodhurst Limestone Member consists of pale-yellow-brown, orange-brown, gray-brown, red-stained, thin-bedded, and fine-grained limestone, and intercalated medium- to thick-bedded, lighter colored, massive, cliff-forming, crinoidal, very fossiliferous (corals, brachiopods) limestone. Woodhurst Limestone Member is 134–146 m thick. Middle Paine Shale Member includes dark-gray-brown, mainly thin-bedded and platy, fine-grained, brittle, sparsely fossiliferous limestone, intercalated with yellow-weathering shaly limestone, and local Waulsortian bioherms (Stone, 1972; Smith, 1982). “W” indicates positions of Waulsortian bioherms on map. Member is 94–99 m thick. Basal Cottonwood Canyon Member is dark-brown to black silty shale and siltstone. Member is 0.6–0.9 m thick. Formation unconformably overlies Sappington Member of Three Forks Formation (unit Dtm) Total thickness is 228–246 m

Three Forks Formation, Jefferson Dolomite, and Maywood Formation, undivided (Upper Devonian)—Light- and dark-brown dolostone; gray and gray-green, nodular limestone; yellowish-brown sandstone; pink and gray siltstone; black and green shale; and minor dolostone breccia. Unit comprises, in descending order, three formations and their members. The Three Forks Formation is divisible into three members: Sappington Member at top consists of yellowish-brown, very fine grained, calcareous sandstone that grades downward to gray and gray-green silty shale and silty to sandy, nodular, oncolith-bearing limestone and a thin basal conodont-bearing, black shale. Sappington Member disconformably overlies middle Trident Member, which consists of gray, nodular limestone in upper part and green shale intercalated with some dolomitic siltstone in main part. Underlying basal Logan Gulch Member includes an upper ledge-forming, brecciated limestone underlain by evaporite-solution breccia and red to orange, nodular, limonitic shale; conformable lower contact. Three Forks Formation is conformable above Jefferson Dolomite and is 61–70 m thick. Jefferson Dolomite consists of light- and dark-brown, mainly medium- to thick-bedded, fine- to medium-grained, saccharoidal dolostone; dolomitic limestone; and limestone having a few intercalated yellow and pale-pink dolomitic siltstone and green dolomitic shale beds and associated dolostone breccia lenses. Lower contact is gradational with Maywood Formation. Jefferson Dolomite is about 152–188 m thick. Maywood Formation in southern outcrops consists mainly of alternating thin beds of yellow to gray siltstone, dolomitic siltstone, and dolostone totaling about 12 m in thickness; northern outcrops include about 27 m of mainly reddish-orange to pale-yellow-gray, thin-bedded, platy siltstone and mudstone, and, at the top, 1 m or so of gray-brown, platy, fine-grained limestone. Unit disconformably overlies Upper Cambrian beds. Entire interval is 225–286 m thick

Snowy Range Formation and Pilgrim Limestone, undivided (Lower Ordovician and Upper Cambrian)—Dark- and light-gray mottled and grayish-brown limestone, limestone-pebble conglomerate, and grayish-green shale. Snowy Range Formation is divided into two parts: Upper part, the Sage Pebble Conglomerate Member, consists of gray-brown, fine-grained, thin-bedded limestone; limestone-pebble conglomerate; and interbedded green shale conformably underlain by a thin, columnar algal limestone. Upper part has a conformable contact with lower part. Lower part, the Dry Creek Shale Member, is mainly gray-green fissile shale that contains a few intercalated yellow, calcareous siltstone or very fine grained sandstone beds. Basal contact of formation is conformable. Snowy Range Formation is about 51–84 m thick. Upper part of Pilgrim Limestone consists of dark- and light-gray mottled, medium- to thick-bedded, partly dolomitized, medium-grained, oolitic, locally crossbedded limestone and a few intercalated beds of flat-pebble conglomerate. Uppermost 3–4.5 m is dense, mottled limestone similar to that of Meagher Limestone. Upper part is 70–74 m thick. Lower part consists mainly of gray and yellow-brown, thin- to medium-bedded, dense to bioclastic limestone, limestone-pebble conglomerate, and edgewise conglomerate; includes interbedded gray-green, fissile, calcareous shale, and a 2.4- to 3-m-thick, gray-brown, massive, oolitic, vaguely mottled limestone at base. Lower part is 39–57 m thick. At Bridger Peak, a massive, pale-greenish-brown, vaguely mottled, fine-grained, reefoid, partly columnar (algal) limestone is between the upper and lower parts. Basal contact is gradational. Pilgrim Limestone is 110–131 m thick. Entire interval is about 161–215 m thick

Park Shale, Meagher Limestone, Wolsey Shale, and Flathead Sandstone, undivided (Middle Cambrian)—Green and maroon, micaceous shale; dark-gray and yellow mottled limestone; and red, pale-orange, and white sandstone. Unit comprises, in descending order, four formations. Park Shale includes green and maroon, very finely micaceous, fissile shale intercalated with thin-bedded limestone at top and local beds of arkosic limestone and arkose; is locally glauconitic in lower part. In northern Bridger Range, the lower 30 m consists of interbedded arkosic sandstone, siltstone, and shale (Fryxell and Smith, 1986). Formation has a conformable lower contact. Park Shale is about 66 m thick. Meagher Limestone consists of three parts: Upper part is thin-bedded, dark-gray, dense limestone and interbedded green shale. Main middle ledge-forming part is massive, dark-gray and yellow mottled, dense limestone. Lower part includes thin-bedded, dark-gray, dense limestone and interbedded green and yellow, silty shale. Lower contact is conformable. Meagher Limestone is about 112 m thick. Wolsey Shale consists of green and maroon, micaceous shale interbedded with micaceous sandstone and siltstone; in places it contains conglomeratic arkosic limestone and arkose. Lower contact is conformable. Wolsey Shale is about 45–65 m thick. Flathead Sandstone contains red, pale-orange, and white sandstone, locally quartzitic, and some glauconitic beds. Flathead locally contains feldspathic sandstone and arkose beds, conglomeratic in places. Sandstone is about 36–42 m thick. Unit unconformably overlies arkose of Belt Supergroup (unit Yl) in northern part of area and on Archean metamorphic rocks in southern part. Entire interval is 259–285 m thick

La Hood Formation of Belt Supergroup (Middle Proterozoic)—Dark-gray-green, reddish-weathering, coarse, massive, poorly bedded arkose and conglomeratic arkose. Formation contains very coarse gneiss boulder conglomerate in which boulders are as much as 2.4 m in diameter in southwestern exposures. Intercalated dark-gray argillite and siliceous limestone beds are common in upper part in northern exposures. Base is not exposed. Minimum thickness ranges from about 2,134 m to more than 3,048 m. Unit is in fault contact with Archean metamorphic rocks (McMannis, 1955, 1963)

Metamorphic rocks (Archean)—Intermediate to felsic gneiss, amphibolite, schist, metaquartzite, marble, and numerous small pegmatite dikes and veinlets (McMannis, 1955; Lageson, 1989). Thickness is unknown

INTRODUCTION

The southwest corner of the Sedan Quadrangle is just 6.4 km northeast of the town of Bozeman, and urban sprawl from that community extends up the scenic Bridger Valley into the southern part of the quadrangle. Most of the high country is part of the Gallatin National Forest, and the Bridger Bowl ski area is located in the upper reaches of Maynard Creek within the Forest. Much of the area is densely forested and supports abundant wildlife, including bear, moose, elk, deer, and numerous smaller mammals. The northern rolling hills are used chiefly for grazing. Fairy Lake, beneath Sacagawea Peak in the Bridger Range, is a favorite destination for hikers and fishermen.

STRUCTURAL AND TECTONIC DISCUSSION

TECTONIC OVERVIEW

The Sedan quadrangle overlaps the crest and eastern flank of the north-south-trending Bridger Range and the western margin of the Crazy Mountains Basin. This region occupies the transition between the Northern Rocky Mountains and Great Plains physiographic provinces (Fenneman, 1946; Raisz, 1957; Locke and Lageson, 1989) and overlaps five major tectono-magmatic provinces (Lageson, 1989): (1) the south margin of the Middle Proterozoic Belt Basin (Helena embayment); (2) the Sevier fold and thrust belt, which mimics the shape of the Belt Basin through structural inversion; (3) the Laramide foreland province of basement-involved contractional deformation; (4) the easternmost Basin and Range Province; and (5) an area peripheral to zones of seismicity and active faulting associated with passage of the Yellowstone hot-spot (Anders and others, 1989; Pierce and Morgan, 1992). These provinces span the major tectonic events of the Northern Rocky Mountains, from rifting and passive-margin shelf sedimentation in the Proterozoic and Paleozoic, through the culmination of contractional mountain building in early Tertiary time, to the present phase of crustal extension and hot-spot-related deformation and volcanism. In a broad sense, the Bridger Range and Sedan quadrangle record a mega-Wilson cycle of continental margin evolution. As a result of having so many different styles of deformation superimposed in one area, the Sedan quadrangle contains reactivated fault zones, folded thrust sheets, and overlapping structural families.

STRUCTURAL DOMAINS

The Sedan quadrangle may be subdivided into six structural domains on the basis of structural style and structural attitude; marginal overlap in domains I through IV is indicated by a color break on the tectonic map.

Domain I: North-Central Area

The north-central part of the quadrangle consists of a large triangular area between the Bridger Range and Battle Ridge of outcropping Livingston Group rocks. These rocks were shortened along the south margin of the Helena salient of the fold and thrust belt. The southwest flank of domain I is defined largely by the Ksl detachment fault in the Lower Sandstone Member of the Sedan Formation (unit Ksl), whereas the southeast flank is an oblique-slip thrust fault within the Battle Ridge shear zone. The Ksl detachment is the bedding plane above which the upper part of the Sedan Formation has been detached and crumpled in the apex of the triangle zone. To the north in the Hatfield Mountain (Skipp and Hepp, 1968) and Wallrock quadrangles (Skipp, 1977) several large fault-propagation and kink-detachment folds plunge south into the north-central Sedan quadrangle, including the Ringling anticline, Wallrock syncline, Elkhorn anticline (Boyer, 1986), and Middle Fork syncline. Southeast-dipping strata on the flank of the Ringling anticline are shown on the left (northwest) side of cross section A–A'.

Domain II: Cross Range Thrust Sheet

Strata making up the hangingwall of the Cross Range fault dip steeply northeast or are overturned to the southwest. This Sevier thrust zone has been rotated about 90˚ from its original position (Skipp and McGrew, 1968). Kinematic indicators suggest original transport on the thrust was from west to east with a component of southeast slip along a high-angle lateral ramp (Lageson, 1989). At present, the Cross Range thrust fault slices diagonally across the northern Bridger Range for 15 km from the western range front, dipping 60˚–80˚ NE (McMannis, 1955). The northeast side of the fault is down. The surface trace of the fault is stair-stepped and ramps up-section in both footwall and hangingwall through the Lahood Formation and Paleozoic-Jurassic strata to a flat in the

Cretaceous Colorado shales, where it appears to merge with an unnamed lower thrust and stratigraphic offset virtually disappears.

Domain III: Northern Bridger Range

The rocks of domain III make up the hangingwall of the Pass thrust and range in age from Middle Proterozoic to Upper Cretaceous. The Pass thrust is the most prominent of several faults that form the "Ross Pass fault zone" (McMannis, 1955; Craiglow, 1986), and, like the Cross Range fault, it has been rotated 90˚ from its original position to a northeast-dipping, right-reverse, oblique-slip thrust fault having a stair-stepped geometry. The Pass fault is the most southerly and stratigraphically lowest "thin-skinned" fault of the Sevier fold and thrust belt in this region, and it probably forms the regional basal décollement at depth to the northeast. The Pass fault in the Sedan quadrangle places Middle Proterozoic LaHood Formation over Cambrian strata. Just west of the quadrangle, the fault displaces the Lahood Formation over older Archean basement rocks to produce an anomalous younger-over-older thrust relationship (McMannis, 1955). This younger-over-older relationship is the result of structural inversion and reactivation of a Middle Proterozoic east-west-trending ramp that formed the southern margin of the Middle Proterozoic Belt basin, the Helena embayment (McMannis, 1963; Lageson, 1989). The Pass fault is the lowest thrust fault that formed along the southern, probably fault-controlled, margin of the Belt basin. Both the Pass fault and the Cross Range thrust system lose throw and die out in the projected position of this Precambrian feature referred to variously as the "Perry line" (Winston, 1986b), "Willow Creek fault zone" (Robinson, 1963; Harrison and others, 1974), "Central Park fault"(Hackett and others, 1960), and the "southwest Montana transverse zone" (Schmidt and O'Neill, 1982). The Perry line extends east-northeast of the Bridger Range in the general position of the Battle Ridge "monocline" (Garrett, 1972).

Domain IV: Southern Bridger Range

The southern Bridger Range (southwest corner of the Sedan quadrangle) is structurally coupled with the northern Bridger Range to form a Laramide-style uplift. Archean basement rocks were uplifted in the southern part of the range (C–C') in concert with Middle Proterozoic rocks north of the Pass fault (B–B') by the "sub-Bridger thrust zone" (Lageson, 1989) to form a continuous, north-trending, east-verging, asymmetric Laramide anticlinorium. This anticlinorium spanned the southern boundary of the Belt Basin and deformed the fold-and-thrust belt to the north, thus rotating the Pass and Cross Range thrust faults into their present nearly vertical positions and deflecting the axial traces of folds in domain I (Skipp and McGrew, 1968). Late-stage motion on the sub-Bridger thrust zone interacted with a back-thrust within the Billman Creek Formation to uplift the western margin of the Crazy Mountains Basin to form Battle Ridge and the "Bangtails" (informal name used on U.S. Forest Service maps of Gallatin National Forest). The back-thrust is marked by duplication of the Billman Creek Formation down the middle of the southern Sedan quadrangle.

Domain V: Battle Ridge and the Bangtails

Battle Ridge and the Bangtails are topographically supported by resistant sandstones and basal conglomerates of the Upper Cretaceous Hoppers Formation (unit Kh) and the Upper Cretaceous–Paleocene Fort Union Formation (units TKfc and Tfu). Dips along the northeast-trending crest of Battle Ridge range from 60˚ to 80˚ overturned northwest, but rotate southeastward to 5˚–10˚ upright southeast. Along the north-south-trending Bangtails, dip angles rotate from 70˚ E. to 10˚ E. over a short distance. Therefore, domain V has the overall geometry of a large northeast-plunging, asymmetric, overturned syncline. Five lines of evidence point to a large back-thrust as the cause of this syncline: (1) the presence of a southeast-dipping thrust fault along the northwest base of Battle Ridge (cross section A–A'); (2) southward continuation of the above-mentioned thrust fault into a zone of duplicated Billman Creek Formation along Bridger Creek; (3) rapid eastward flattening of dips in domain V, indicative of a shallow detachment (back-thrust); (4) indications of a back-thrust on seismic reflection lines east of the Bridger Range in the approximate position of cross section A–A' (Garrett, 1972); and (5) the up-dip termination of the sub-Bridger thrust zone that coincides with steeply dipping, competent beds in the lower Fort Union at the surface, indicating that the sub-Bridger thrust zone is structurally "wedged" into the subjacent Livingston Group along the weak mudstones of the Billman Creek Formation. In other words, the up-dip termination of the sub-Bridger thrust zone into a back-thrust has delaminated the Livingston Group at the level of the Billman Creek Formation. A back-thrust geometry is required to distribute the slip on the sub-Bridger thrust zone beneath the Fort Union Formation because the thrust zone does not cut up-section to the surface. Although back-thrusts are well documented in the Canadian and Wyoming segments of the Cordilleran fold and thrust belts (Price and Fermor, 1984; Hunter, 1987), examples of back-thrusting along oblique ramps and Laramide-style uplifts are less well known in Montana but are not unrecognized (Tysdal, 1986; Kellogg, 1995).

Battle Ridge has been interpreted to reflect the continuation of the Perry line northeast of the Bridger Range (Garrett, 1972; Woodward, 1982). Battle Ridge also lies along the south margin of the Helena salient of the fold and thrust belt, having functioned as a broad shear zone of distributed right-reverse, oblique slip. This lateral ramp, herein called the Battle Ridge shear zone, is clearly defined by an array of right-stepping, en echelon folds in the Billman Creek Formation immediately northwest of Battle Ridge in domain I. Back-thrusting was induced along this segment of Battle Ridge by oblique impingement of rocks in the Helena salient, resulting in overturning of the Fort Union Formation and underlying Hoppers Formation. In the Bangtails the up-dip termination of the sub-Bridger thrust zone into the Livingston Group was the main cause of back-thrusting, resulting in gentle folding of the Fort Union in the upper plate of the back-thrust.

Domain VI: Conglomerate of Nixon Peak

Domain VI is bounded by a subsidiary back-thrust in the hanging wall of the Battle Ridge back-thrust. This domain is underlain lithologically by the conglomerate lens of Nixon Peak and subjacent rocks of the Fort Union Formation. The subsidiary back-thrust has offset a synclinal hinge line that passes through Nixon Peak. The back-thrust is also indicated by multiple reversals in dip directions and angles. It is believed that this back-thrust formed late in the history of contractional deformation in response to overturning of strata above the Battle Ridge back-thrust.

KINEMATIC HISTORY

Discussions of aspects of the tectonic evolution of southwestern Montana are to be found in Harlan and others (1988), Lageson (1989), McMannis (1965), O'Neill and others (1986), Schmidt and O'Neill (1982), Schmidt and Garihan (1983, 1986), and Schmidt and others (1988). The Sedan quadrangle records a complex sequence of deformational events spanning the last 1.4 billion years. Following is a summary of the Precambrian history of the region and a discussion of the main Quaternary and Tertiary tectonic events evident in the rocks and structures of the Sedan quadrangle. The Cenozoic events are labeled D1 to D3 from oldest to youngest, and they all postdate formation of the Cordilleran plate margin.

In the southern Bridger Range, Archean basement rocks are similar in degree of metamorphism and deformation to those in the cores of other Laramide uplifts across southwestern Montana and Wyoming. Isotopic dates for these rocks generally fall in the range of 3.2–2.7 Ga. (James and Hedge, 1980; Mueller and others, 1985; Mogk and Henry, 1988; Wooden and others, 1988; Mogk and others, 1992), although zircons have been dated as old as 3.96 Ga from quartzites in the Beartooth Mountains (Mueller and others, 1992). The metamorphic fabric of these basement rocks has in some cases exerted a strong control on the geometry of subsequent Proterozoic and Phanerozoic structures, particularly Laramide folds (Miller and Lageson, 1993). The important variable is the attitude of basement foliation with respect to the basement-cover nonconformity; where foliation is subparallel to the nonconformity and overlying stratigraphy, then the basement is folded concordantly with cover rocks; where foliation is sub-perpendicular to the nonconformity, then passive-slip mechanisms of basement deformation prevail in the cores of Laramide folds as exemplified in the southern Bridger Range (Miller and Lageson, 1993; cross section C–C').

Middle Proterozoic rocks in the central Bridger Range correlate with lower units of the Belt Supergroup to the northwest (Winston, 1986a) and are known to be older than 1,449 Ma and younger than 1,468 Ma (Aleinikoff and others, 1996). McMannis (1963) was the first to understand that the juxtaposition of Middle Proterozoic conglomerates containing Archean clasts and Archean rocks along the Pass fault marks the vicinity of the southern margin of the Belt basin. As early as 1894, however, Iddings and Weed (Iddings and Weed, 1894) had mapped the general distribution of Belt and pre-Belt rocks in the Bridger Range.

D1: Sevier Folding and Thrusting

The youngest synorogenic rocks in the Sedan area, the Nixon Peak Conglomerate Lens of the Late Cretaceous to Middle Paleocene Fort Union Formation (Roberts, 1972), were already in place before local Sevier fold-thrust deformation began, probably in late Paleocene time (Skipp and McGrew, 1968; Harlan and others, 1988). An Eocene(?) mafic dike intrudes the updip termination of the rotated Pass thrust fault (McMannis, 1955; this paper). Paleomagnetic and isotopic dating of alkalic dikes and sills of compositions similar to this dike in the Crazy Mountains Basin about 50 km to the northeast yielded post-deformational dates of 52–48 Ma, early middle Eocene (Harlan and others, 1988). Thus, fold-thrust deformation in the Sedan area is bracketed as post-Middle Paleocene and pre-Middle Eocene. The Cross Range and Pass thrust faults were active at this time, as was initial back-thrusting along the Battle Ridge shear zone. Laramide uplift of the ancestral Bridger Range closely followed fold-thrust deformation.

D2: Laramide Deformation

A second phase of contractional deformation involved uplift of the ancestral Bridger Range anticlinorium, a basement-cored Laramide-style uplift (McMannis, 1955; Skipp and McGrew, 1968; Lageson, 1989). There is approximately 7,600 m of structural relief on the Archean basement at the south end of the Bridger Range. No major thrust faults crop out along the eastern flank of the Bridger Range to account for this relief. However, Sohio Oil Company seismic and drilling data (Lageson, 1989) confirmed the existence of a west-dipping zone of thrust faults (sub-Bridger thrust zone of Lageson, 1989) that bounds the east flank of the Bridger Range, producing a Laramide-style "basement-overhang." As the sub-Bridger thrust zone translated up-section into the Livingston Group, it delaminated the Sedan Formation from superjacent strata to produce the Battle Ridge–Bangtail back-thrust and folded the Fort Union and Hoppers Formations in the process. As the ancestral Bridger Range uplift rose, the Pass and Cross Range fault zones were rotated into their present orientations and severe crowding developed between the sub-Bridger thrust zone and the southwest end of Battle Ridge, producing a detachment fault in the lower sandstone member of the Sedan Formation (the Ksl detachment) and disharmonic box folds north of Battle Ridge. The timing of Laramide uplift is bracketed by the following: (1) The youngest rock deformed by uplift of the ancestral Bridger Range is the Late Cretaceous to Middle Paleocene Fort Union Formation (Roberts, 1972); (2) directly south of the Bridger Range , the Absaroka-Gallatin volcanic field blankets Laramide structures in the Gallatin Range with pronounced angular unconformity. Volcanism began around 53 Ma and continued to about 43 Ma, clearly postdating Laramide deformation (Chadwick, 1972). Thus, Laramide uplift in the area is also bracketed as late Paleocene to Eocene. Structural relationships show, however, that Laramide uplift deformed Sevier folds and thrusts, so that within the late Paleocene to Eocene time period, late Paleocene Sevier deformation was closely followed by probable early Eocene Laramide thrusting and uplift of the Bridger Range. Late-stage motion on the Battle Ridge–Bangtail back-thrust took place during the waning stages of the Laramide event.

D3: Crustal Extension

McMannis (1955) mapped a range-front normal fault at the break in slope along the western base of the Bridger Range. This fault is shown south of Ross Pass on the Sedan quadrangle, but it extends the full length of the range beyond the western edge of the map area. The range-front normal fault has down-dropped the Gallatin River valley along its segmented trace, but overall it appears that the valley collapsed along the axial surface of the ancestral Bridger Range anticlinal uplift, leaving the east-dipping limb as a “perched basement wedge” (Lageson, 1989). Regionally, the range-front normal fault is parallel to Winston’s (1986b) “Townsend line,” suggesting reactivation of a deeper, Middle Proterozoic zone of weakness. Tertiary sedimentary rocks within the eastern Gallatin River valley dip 2∞–35∞ E. toward the normal fault, suggesting that the Gallatin River valley block has rotated clockwise (looking northward) during deformation. On the basis of preliminary gravity modeling, Lageson (1989) reported that the Gallatin River valley is an asymmetric half-graben having a maximum sediment thickness of about 2 km, with 2,200 m of throw on the adjacent range-front fault. The gravity model casts strong doubt on the existence of pre-Tertiary Phanerozoic rocks of any significant thickness at the bottom of the valley.

The onset of post-Laramide crustal extension in southwestern Montana has historically been based on the textural differences of the Eocene-Oligocene Renova and Miocene Sixmile Creek Formations, constituting the “Bozeman Group” (Kuenzi and Fields, 1971; Fields and others, 1985). These two units are separated by the “mid-Tertiary unconformity,” widely recognized throughout the region. The change from predominantly fine-grained fluvial and lacustrine sediments (Renova) to predominantly coarse-grained volcaniclastic sandstone and conglomerate (Sixmile Creek) is often cited as heralding the onset of modern Basin and Range extension in the Three Forks Basin (Lageson, 1989). However, Thompson and others (1982) called upon four major changes in climate during the Tertiary to account for the differences in sediment texture. Hanneman and Wideman (1991) used calcic paleosol zones to delimit five sequence stratigraphic units within the Bozeman Group and correlated sequence 4 (Sixmile Creek) with “partially filled extensional basins.” In the Paradise Valley, Burbank and Barnosky (1990) reported that extension began at 17 Ma, immediately following the mid-Tertiary unconformity. However, the presence of gently tilted Eocene through Miocene sedimentary rocks on the surface in the Three Forks and other basins in southwestern Montana, coupled with prograding alluvial fans, entrenched meandering rivers, and contemporary seismicity, suggests that this is an ongoing process that has become increasingly active in the last 5 million years. Pierce and Morgan (1992) discussed the seismic belts that define the parabolic “bow wave” of the Yellowstone hot spot; the Bridger Range lies within Belt I, characterized by “new, small escarpments and reactivated faults” that are in the waxing stage of activity. As the Yellowstone hot spot migrates farther northeast, it may be expected that the Bridger range-front normal fault will have renewed and significant displacement.

REFERENCES CITED

Aleinikoff, J. M., Evans, K.V., Fanning, C.M., Obradovich, J.D., Ruppel, E.T., Zieg, J.A., and Steinmetz, J.C., 1996, SHRIMP U-Pb ages of felsic igneous rocks, Belt Supergroup, western Montana: Geological Society of America Abstracts with Programs, 1996 Annual Meeting, p. A–376.

Anders, A.M., Geissman, J.W., Piety, L.A., and Sullivan, J.T., 1989, Parabolic distribution of circum-eastern Snake River Plain seismicity and latest Quaternary faulting—Migratory pattern and association with the Yellowstone hot spot: Journal of Geophysical Research, v. 94, p. 1589–1621.

Boyer, S.E., 1986, Styles of folding within thrust sheets—Examples from the Appalachians and Rocky Mountains of the U.S.A. and Canada: Journal of Structural Geology, v. 8, p. 325–339.

Burbank, D.W., and Barnosky, A.D., 1990, The magnetochronology of Barstovian mammals in southwestern Montana and implications for the initiation of Neogene crustal extension in the northern Rocky Mountains: Geological Society of America Bulletin, v. 102, p. 1093–1104.

Chadwick, R.A., 1972, Volcanism in Montana: Northwest Geology, v. 1, p. 1–20.

Craiglow, C.J., 1986, Tectonic significance of the Pass fault, central Bridger Range, Montana: Bozeman, Montana State University, M.S. thesis, 40 p.

Fenneman, N.M., 1946, Physical divisions of the United States: Washington, D.C., U.S. Geological Survey map, scale 1:7,000,000.

Fields, R.W., Rasmussen, D.L., Tabrum, A.R., and Nichols, R., 1985, Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho—A summary, in Flores, R.M., and Kaplan, S.S., eds., Cenozoic paleogeography of the west-central United States: Denver, Colo., Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 9–36.

Fryxell, J.C., and Smith, D.L., 1986, Paleotectonic implications of arkose beds in Park Shale (Middle Cambrian), Bridger Range, south-central Montana, in Peterson, J.A., ed., Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists Memoir 41, pt. II, p. 159–172.

Garrett, H.L., 1972, Structural geology of the Crazy Mountains Basin, in Lynn, John, Balster, C., and Warne, J., eds., Crazy Mountains Basin: Montana Geological Society Guidebook, 21st Annual Field Conference, 1972, p. 113–118.

Hackett, O.M., Visher, F.N., McMurtrey, R.G., and Steinhilber, W.L., 1960, Geology and ground-water resources of the Gallatin Valley, Gallatin County, Montana: U.S. Geological Survey Water-Supply Paper 1842, 282 p.

Hanneman, D.L., and Wideman, C.J., 1991, Sequence stratigraphy of Cenozoic continental rocks, southwestern Montana: Geological Society of America Bulletin, v. 103, p. 1335–1345.

Harlan, S.S., Geissman, J.W., Lageson, D.R., and Snee, L.W., 1988, Paleomagnetic and isotopic dating of thrust-belt deformation along the eastern edge of the Helena salient, northern Crazy Mountains Basin, Montana: Geological Society of America Bulletin, v. 100, p. 492–499.

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt Basin and their influence on post-Belt structures: U.S. Geological Survey Professional Paper 866, 15 p.

Hunter, R.B., 1987, Timing and structural relations between the Gros Ventre foreland uplift, the Prospect thrust system, and the Granite Creek thrust, Hoback Basin, Wyoming, in Miller, W.R., ed., The thrust belt revisited: Wyoming Geological Association Guidebook, 38th Field Conference, 1987, p. 109–131.

Iddings, J.P., and Weed, W.H., 1894, Geologic atlas of the United States, Livingston Folio, Montana: U.S. Geological Survey Folio 1, scale 1:250,000.

James, H.L., and Hedge, C.E., 1980, Age of the basement rocks of southwest Montana: Geological Society of America Bulletin, v. 91, p. 11–15.

Kellogg, K.S., Schmidt, C.J., and Young, S.W., 1995, Basement and cover-rock deformation during Laramide contraction in the northern Madison Range (Montana) and its influence on Cenozoic Basin Formation: American Association of Petroleum Geologists Bulletin, v. 79, no. 8, p. 1117–1137.

Kuenzi, W.D., and Fields, R.W., 1971, Tertiary stratigraphy, structure and geologic history, Jefferson Basin, Montana: Geological Society of America Bulletin, v. 82, p. 3373–3394.

Lageson, D.R., 1989, Reactivation of a Proterozoic continental margin, Bridger Range, southwestern Montana, in French, D.E., and Grabb, R.F., eds., Geologic resources of Montana: Montana Geological Society Field Conference Guidebook—Montana Centennial Edition, v. I, p. 279–298.

Locke, W.W., and Lageson, D.R., 1989, Geology and geomorphology of the Rocky Mountains/Great Plains transition, in French, D.E., and Grabb, R.F., eds., Geologic resources of Montana: Montana Geological Society Field Conference Guidebook—Montana Centennial Edition, v. II, p. 462–476.

Marvin, R.F., Mehnert, H.H., Naeser, C.W., and Zartman, R.E., 1989, U.S. Geological Survey radiometric ages—Compilation "C," Part five—Colorado, Montana, Utah, and Wyoming: Isochron West, no. 53, p. 14–19.

McMannis, W.J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, v. 66, p. 1385–1430.

———1963, LaHood Formation—A coarse facies of the Belt Series in southwestern Montana: Geological Society of America Bulletin, v. 74, p. 407–436.

———1965, Resume of depositional and structural history of western Montana: American Association of Petroleum Geologists Bulletin, v. 49, p. 1801–1823.

Miller, E.W., and Lageson, D.R., 1993, Influence of basement foliation attitude on geometry of Laramide basement deformation, southern Bridger Range and northern Gallatin Range, Montana, in Schmidt, C.J., Chase, R.B., and Erslev, E.A., eds., Laramide basement deformation in the Rocky Mountain foreland of the Western United States: Geological Society of America Special Paper 280, p. 73–88.

Mogk, D.M., and Henry, D.J., 1988, Metamorphic petrology of the northern Archean Wyoming province, southwestern Montana—Evidence for Archean collisional tectonics, in Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States [Rubey Volume VII]: Englewood Cliffs, N.J., Prentice Hall, Inc., p. 362–381.

Mogk, D.M., Mueller, P.A., and Wooden, J.L., 1992, The nature of Archean boundaries—An example from the northern Wyoming Province: Precambrian Research, v. 55, p. 155–168.

Mueller, P.A., Wooden, J.L., Henry, D.J., and Bowes, D.R., 1985, Archean crustal evolution of the eastern Beartooth Mountains, Montana and Wyoming, in Czamanske, G.K., and Zientek, M.L., eds., The Stillwater Complex, Montana—Geology and guide: Montana Bureau of Mines and Geology Special Publication 92, p. 9–20.

Mueller, P.A., Wooden, J.L., and Nutman, A.P., 1992, 3.96 Ga zircons from an Archean quartzite, Beartooth Mountains, Montana: Geological Society of America Bulletin, v. 20, p. 327–330.

O'Neill, J.M., Schmidt, C.J., Ferris, D.C., and Hanneman, D.L., 1986, Recurrent movement along northwest-trending faults at the southern margin of the Belt Basin, Highland Mountains, southwestern Montana, in Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 209–216.

Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot—Volcanism, faulting, and uplift, in Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1–53.

Piombino, Joseph, 1979, Depositional environments and petrology of the Fort Union Formation near Livingston, Montana—An evaluation as a host for sandstone type uranium mineralization: Missoula, University of Montana, M.S. thesis, 84 p.

Price, R.A., and Fermor, P.R., 1984, Structure section of the Cordilleran foreland thrust and fold belt west of Calgary, Alberta: Geological Survey of Canada Paper 84–14, scale 1:250,000.

Raisz, Erwin, 1957, Landforms of the United States: Melrose, Mass., Raisz Landform Maps, Sixth Revised Edition.

Roberts, A.E., 1963, The Livingston Group of south-central Montana, in Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 475–B, p. B86–B91.

———1964a, Geologic map of the Fort Ellis quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–397, scale 1:24,000.

———1964b, Geologic map of the Bozeman Pass quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–399, scale 1:24,000.

———1972, Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional paper 526–C, 120 p.

Robinson, G.D., 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geological Survey Professional Paper 370, 143 p.

Schmidt, C.J., and Garihan, J.M., 1983, Laramide tectonic development of the Rocky Mountain foreland of southwestern Montana, in Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Denver, Colo., Rocky Mountain Association of Geologists, p. 271–294.

———1986, Middle Proterozoic and Laramide tectonic activity along the southern margin of the Belt Basin, in Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 217–235.

Schmidt, C.J., and O'Neill, J.M., 1982, Structural evolution of the southwest Montana transverse zone, in Powers, R.B., ed., Geological studies of the Cordilleran thrust belt, volume I: Denver, Colo., Rocky Mountain Association of Geologists, p. 193–218.

Schmidt, C.J., O'Neill, J.M., and Brandon, W.C., 1988, Influence of Rocky Mountain foreland uplifts on the development of the frontal fold and thrust belt, southwestern

Montana, in Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain foreland and the Cordilleran thrust belt: Geological Society of America Memoir 171, p. 171–201.

Skipp, Betty, 1977, Geologic map and cross section of the Wallrock quadrangle, Gallatin and Park Counties, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ–1402, scale 1:24,000.

Skipp, Betty, and Hepp, M.M., 1968, Geologic map of the Hatfield Mountain quadrangle, Gallatin County, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ–729, scale 1:24,000.

Skipp, Betty, and McGrew, L.W., 1968, Tertiary structure of the west edge of the Crazy Mountains basin, Montana: Geological Society of America Special Paper 121, p. 637–638

Skipp, Betty, and McGrew, L.W., 1972, The Upper Cretaceous Livingston Group of the western Crazy Mountains Basin, Montana: Montana Geological Society Guidebook, 21st Annual Field Conference, 1972, p. 99–106.

———1977, The Maudlow and Sedan Formations of the Upper Cretaceous Livingston Group on the west edge of the Crazy Mountains Basin, Montana: U.S. Geological Survey Bulletin 1422–B, p. B1–B68.

Skipp, Betty, and Peterson, A.D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–452, scale 1:24,000.

Smith, D.L., 1982, Waulsortian bioherms in the Paine Member of the Lodgepole Limestone (Kinderhookian) of Montana, U.S.A., in Bolton, Keith, Lane, H.R., and Lemone, D.V., eds., Symposium on the paleo-environmental setting and distribution of Waulsortian facies: El Paso, Texas, and Alamagordo, N. Mex., El Paso Geological Society and the University of Texas at El Paso, p. 51-64.

Stone, R.A., 1972, Waulsortian type bioherms of Mississippian age, central Bridger Range, Montana: Montana Geological Society Guidebook, 21st Annual Field Conference, 1972, p. 36–55.

Thompson, G.R., Fields, R.W., and Alt, David, 1982, Land-based evidence for Tertiary climatic variations—Northern Rockies: Geology, v. 10, p. 413–417.

Tysdal, R.G., 1986, Thrust faults and back thrusts in Madison Range of southwestern Montana foreland: American Association of Petroleum Geologists Bulletin, v. 70, p. 360–376.

Winston, Don, 1986a, Stratigraphic correlation and nomenclature of the Middle Proterozoic Belt Supergroup, Montana, Idaho and Washington, in Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 69–84.

———1986b, Middle Proterozoic tectonics of the Belt Basin, western Montana and northern Idaho, in Roberts, S.M., ed., Belt Supergroup—A guide to Proterozoic rocks of western Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 94, p. 245–257.

Wooden, J.L., Mogk, D.W., and Mueller, P.A., 1988, A review of the geochemistry and geochronology of the Archean rocks of the northern part of the Wyoming Province, in Ernst, W.G., ed., Metamorphism and crustal evolution of the Western United States [Rubey Volume VII]: Englewood Cliffs, N.J., Prentice Hall, Inc., p. 383–410.

Woodward, L.A., 1982, Tectonic map of the fold and thrust belt and adjacent areas, west-central Montana: Montana Bureau of Mines and Geology Geologic Map 30, scale 1:250,000.

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