Geologic Map of the Bachelor Mountain 7.5' Quadrangle Beaverhead County, Montana

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Geologic Summary

The Bachelor Mountain quadrangle is located in the Horse Prairie Creek drainage basin of southwest Montana and contains exposures of Middle Proterozoic metasedimentary rocks and eighteen map units of Eocene to Oligocene basin-fill deposits assigned to the Medicine Lodge beds. Locally, overlying upper Oligocene to lower Miocene(?) Everson Creek beds and late early to early late Miocene Bannack Pass beds are also preserved as basin-fill deposits. The Medicine Lodge beds were deposited in an early basin, the Grant protobasin (Fig. 1a), during slip on the Muddy-Grasshopper detachment fault. This fault is listric, flattens at ~1.5 km depth, has a regional extent, and has 5-10 km of slip. The Muddy-Grasshopper detachment fault lies east of the map area and formed the eastern margin of the Grant protobasin (Fig. 1a). The Grant protobasin began to break up internally shortly after valley-filling 27.5 to 27.8 Ma basalts were deposited at the top of the Medicine Lodge beds. The Everson Creek beds were deposited during this later breakup of the hanging wall of the Muddy-Grasshopper detachment fault (VanDenburg and others, 1998; Janecke and others, 1999; Matoush, 2002) in an event that formed the present-day Medicine Lodge, Horse Prairie, and Grasshopper structural subbasins (Fig. 1b, c). The Barstovian Bannack Pass beds reflect infilling of remnant lows in these structural subbasins after basin-bounding normal faults had stopped slipping (VanDenburg and others, 1998). The quadrangle lies within the Grasshopper structural subbasin, in a major north-trending rift zone of Paleogene age (Janecke, 1994) (Fig. 1c), and contains more synrift Medicine Lodge and Everson Creek beds than post-rift Bannack Pass deposits.

The Grant protobasin (Beaverhead basin of Kickham, 2002, and Matoush, 2002) is the original sedimentary basin that formed in the hanging wall of the Muddy-Grasshopper fault (Fig. 1a). Sedimentary rocks of the former Grant protobasin are now preserved in the younger Medicine Lodge, Horse Prairie, and Grasshopper structural subbasins that segmented it. The Grant protobasin once extended across parts of the adjacent mountain ranges (M'Gonigle and Dalrymple, 1993). The Maiden Peak spur, parts of the Bloody Dick Creek divide area, and the Beaverhead Range west of upper Horse Prairie Creek were once covered by sedimentary rocks of this protobasin (M'Gonigle and Dalrymple, 1993, 1996; VanDenburg, 1997; Kickham, 2002; Matoush, 2002). Late Oligocene normal faulting in the hanging wall of the Muddy-Grasshopper detachment fault dropped the Medicine Lodge beds into the Grasshopper, Medicine Lodge, and Horse Prairie structural subbasins (Fig. 1b). These three structural subbasins are essentially east-tilted half grabens but the Grasshopper structural subbasin is more complex because of basin-scale extensional folds, a large east-dipping normal fault on its western margin, and several smaller west-dipping normal faults that duplicate strata on the east limb of the Bachelor Mountain anticline (Fig. 1c). Bachelor Mountain quadrangle lies near the boundaries of these three structural subbasins, in the southwest part of the present-day Grasshopper geographic basin (Fig. 1c).

Quaternary alluvial, fluvial, and hillslope deposits cover large portions of the quadrangle and obscure the older rocks. Pediment gravel deposits form the most laterally extensive Quaternary deposits and were laid down by streams draining into Horse Prairie. Multiple levels of pediment gravel show that the regional base level dropped progressively during the Quaternary.

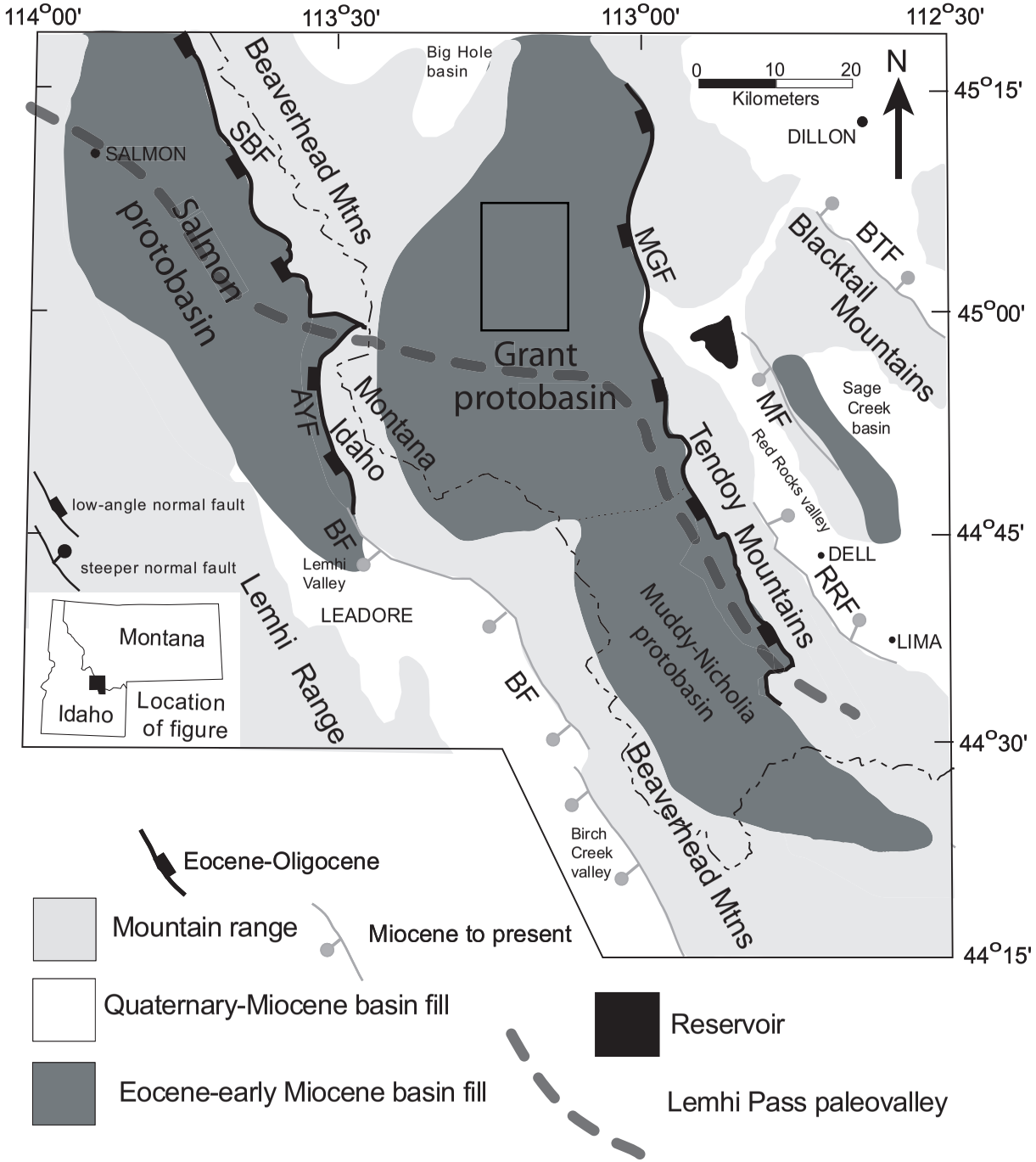


Figure 1 a. Index map showing the location of the Grant protobasin in which the Medicine Lodge beds were deposited. This rift basin is called a supradetachment basin because it formed in the hanging wall of the Muddy-Grasshopper detachment fault. Locations of two other protobasins are also shown. The northern Grant protobasin may once have been continuous with the Nicholia-Muddy protobasin to the south, because both contain Medicine Lodge beds and formed above the same detachment fault. Tendoy beds were deposited in the Salmon protobasin above the Salmon Basin detachment fault (Janecke and Blankenau, 2003). Bachelor Mountain quadrangle is show for reference, as are some selected structures and younger geographic features. See figure 1b for abbreviations.

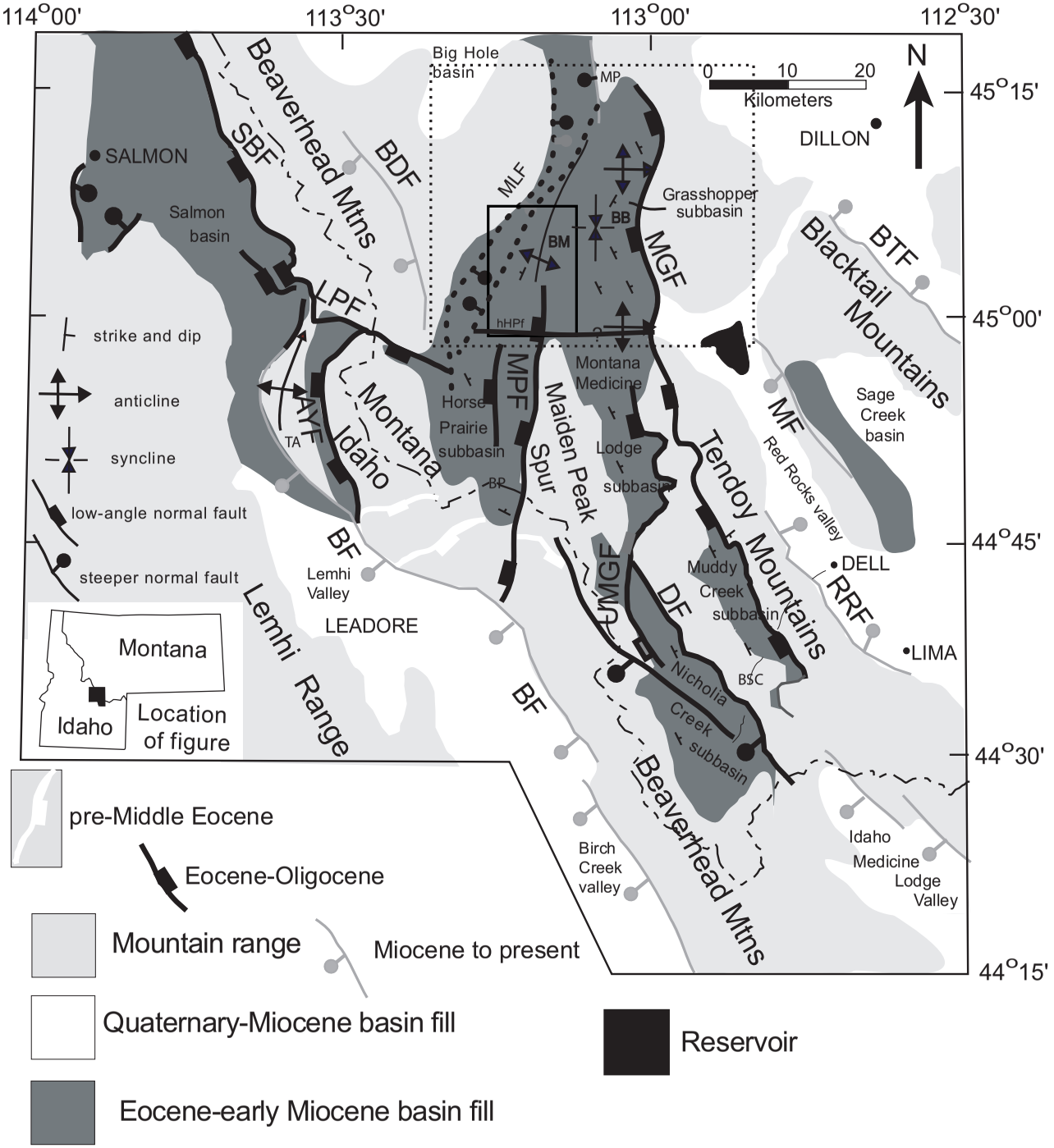


Figure 1b. Locations of secondary extensional subbasins that formed during the late Oligocene to early Miocene during breakup of the former protobasins shown figure 1a. The Everson Creek beds were deposited in the Horse Prairie and Grasshopper subbasins during this phase of extension. The Bannack Pass beds filled residual lows in these two subbasins after slip had stopped on the Maiden Peak and Muddy-Grasshopper faults. Modern drainage basins and valleys of the same name coincide with most of there older subbasins except in Grasshopper basin which is drained by both lower Horse Prairie Creek and Grasshopper Creek. Located in southwest Montana and eastern Idaho, and shows the Bachelor Mountain quadrangle. AYF=Agency-Yearian fault; BB=Bannack Bench syncline; BDF=Bloody Dick Creek fault; BF=Beaverhead fault; BM=Bachelor Mountain anticline; BP=Bannack Pass; BSC=Big Sheep Creek; BTF=Blacktail fault; DF=Deadman fault; hHpf=hypothesized Horse Prairie fault (which was disproven in this study); LPF=Lemhi Pass fault; MF=Monument Hills fault; MGF=Muddy-Grasshopper detachment fault; MLF=Meriwether Lewis fault; MP=Mill Point; MPF=Maiden Peak fault; RRF=Red Rock fault; SBF=Salmon basin detachment fault,; TA=Tendoy anticline; UMGF=upper detachment fault of Muddy-Grasshopper fault system; Figure 1c is an enlargement of the area in the dashed line. Small areas of Eocene basin fill in the Idaho Medicine Lodge basin are not shown.

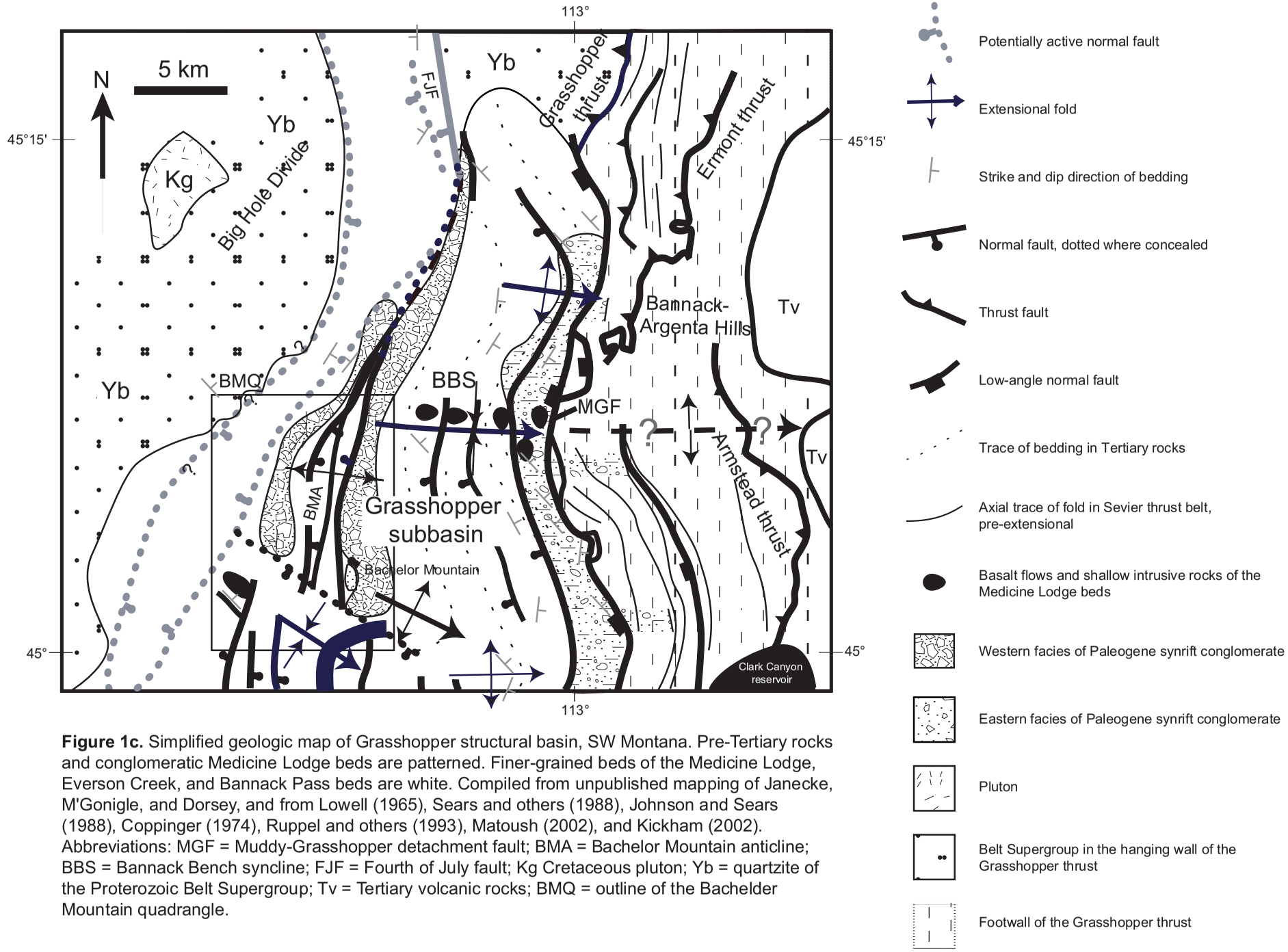


Figure 1c. Simplified geologic map of Grasshopper structural basin, SW Montana. Pre-Tertiary rocks and conglomeratic Medicine Lodge beds are patterned. Finer-grained beds of the Medicine Lodge, Everson Creek, and Bannack Pass beds are white. Compiled from unpublished mapping of Janecke, M'Gonigle, and Dorsey, and from Lowell (1965), Sears and others (1988), Johnson and Sears (1988), Coppinger (1974), Ruppel and others (1993), Matoush (2002), and Kickham (2002). Abbreviations: MGF = Muddy-Grasshopper detachment fault; BMA = Bachelor Mountain anticline; BBS = Bannack Bench syncline; FJF = Fourth of July fault; Kg Cretaceous pluton; Yb = quartzite of the Proterozoic Belt Supergroup; Tv = Tertiary volcanic rocks; BMQ = outline of the Bachelder Mountain quadrangle.

Lithologic Units

The oldest rocks in the Bachelor Mountain quadrangle are maroon, red, purple**,** and whitish weathering, feldspathic quartzite of the Proterozoic Belt Supergroup exposed in the northwest corner of the map. These rocks dip uniformly to the northeast and are part of the Missoula Group (Coppinger, 1974). Smaller exposures of Missoula Group(?) rocks were displaced in large intact slide blocks farther east in the quadrangle. Red Butte is composed of maroon and red quartzite of the Mount Shields Formation(?) (Don Winston, oral comm., 2004), whereas the northwest flank of Bachelor Mountain exposes coarser-grained, whitish Belt rocks that resemble the Wallace Formation(?) of Coppinger (1974) in exposures southwest of the Bachelor Mountain quadrangle, and may also correlate with the Mount Shields Formation of the Missoula Group (Don Winston, oral comm., 2004). The off-white Belt rocks exposed in the Bloody Dick Creek Divide area probably correlate with the base of the Missoula Group (Ruppel and others, 1993) but detailed study is needed to assess the identity of these rocks because they may lie above a tectonized disconformity north of early Proterozoic metamorphic and crystalline rocks at the mouth of Bloody Dick Creek.

The Challis Volcanic Group rocks were deposited on top of Belt Supergroup rocks during middle Eocene time south of the Bachelor Mountain quadrangle (Staatz, 1979; M'Gonigle and Dalrymple, 1993 and 1996; VanDenburg and others, 1998; VanDenburg, 1997). A paleovalley filled with Challis Volcanic Group rocks marks the northern limit of the Challis volcanic field near the southern edge of the Bachelor Mountain quadrangle and is called the Lemhi Pass paleovalley for a key area of exposure to the southwest of the quadrangle (VanDenburg, 1997; Janecke and others, 2000). To the southwest, in the Beaverhead Range, Challis volcanics rest in angular unconformity on Belt rocks. Challis volcanism in this region occurred during a short period between about 49.5 and 45.5 Ma (M'Gonigle and Dalrymple, 1993, 1997; VanDenburg, 1997; VanDenburg and others, 1998; M'Gonigle and others, 1991; M'Gonigle and Hait, 1997), following the end of Cordilleran thrusting.

Exposures of Challis Volcanic Group rocks in the Bachelor Mountain quadrangle are all within paleolandslide deposits (rockslide and rock avalanche) interbedded with the Eocene-Oligocene Medicine Lodge beds. These paleolandslide deposits all appear to have had a source area west of the basin. An exposure of an-ash flow tuff on the northeast flank of Red Butte appears to represent a displaced part of the northern margin of the middle Eocene Lemhi Pass paleovalley. The authors correlate this ash-flow tuff with the tuff of Curtis Ranch, the penultimate ash flow tuff that overlies a 2–km-thick succession of Challis lavas and lesser tuffs east of Lemhi Pass in the axis of the paleovalley (Staatz, 1979; VanDenburg and others, 1998; Janecke and others, 2000). The correlation is based on the tuff's distinctive biotite-rich lithology and prominent pumice lapilli. At Red Butte the tuff of Curtis Ranch was deposited directly on Belt rocks across the northern margin of the middle Eocene paleovalley. The contact at the base of the tuff appears to be depositional and the >2-km-thick Challis rocks in the axis of the paleovalley (Janecke and others, 2000) pinch out laterally beneath the tuff. The tuff at Red Butte thus was deposited onto the Belt rocks in middle Eocene time. Then, in late Eocene to Oligocene time, the Belt rocks and overlying volcanic rocks were emplaced eastward into the Grant protobasin as part of a large rock-slide deposit.

Andesitic lava flows comprise the northern end of a large Paleogene rockslide (Tsbv) on Bachelor Mountain and form parts of two smaller breccia masses (Tbmv) that are exposed southeast of Red Butte. Much larger masses of brecciated lava flows crop out immediately south of the Bachelor Mountain quadrangle, where they were originally mapped as having intruded the Medicine Lodge beds (M'Gonigle and Hait, 1997). $^{40}Ar/^{39}Ar$ age determinations from masses of brecciated volcanic rocks enclosed in Medicine Lodge beds in the south-adjacent Jeff Davis Peak quadrangle reveal overlap with the short, intense period of Challis volcanism. The volcanic rocks are too old to be intrusions into the Medicine Lodge beds because they are older than underlying dated units. All

the breccia bodies are here reinterpreted as paleolandslide deposits based on their intensely brecciated character and their age.

Most of the Tertiary sedimentary rocks in the Bachelor Mountain quadrangle are Eocene-Oligocene. Lateral equivalents of these rocks have been variously assigned to the Medicine Lodge beds (Scholten and others, 1955; Coppinger, 1974; Field and others, 1985; M'Gonigle and Hait, 1997; Matoush, 2002; Kickham, 2002), the Cretaceous Beaverhead Group (Coppinger, 1974; Ruppel and others, 1993), Quaternary colluvium (Coppinger, 1974), and the Renova Formation (Thomas, 1995). In accordance with precedence (Scholten and others, 1955), and common usage (Coppinger, 1974; Fields and others, 1985; M'Gonigle and Hait, 1997; Matoush, 2002; Kickham, 2002) a Medicine Lodge beds assignment is used in this study for most of the Eocene-Oligocene sedimentary rocks in the area.

Medicine Lodge Beds

Medicine Lodge beds in Grasshopper structural subbasin are Paleogene sandstone, conglomerate, shale, and paleolandslide deposits that filled the Grant protobasin, the first rift basin to form in the area (Figs. 1a, 2). Scholten and others (1955) applied the Medicine Lodge name to Tertiary sedimentary rocks in the Nicholia Creek Basin between the Tendoy Mountains and the Beaverhead Range, and to exposures in the Idaho Medicine Lodge Valley. This nomenclature is even more confusing because these authors also named Tertiary basin-fill deposits in the Montana Medicine Lodge Valley, more than 40 km farther north, the Medicine Lodge beds. Their reference section was in the Nicholia Creek Basin along Big Sheep Creek. They inferred a Miocene(?) age based on an erroneous lithologic correlation to the Miocene vertebrate-bearing Bannack Pass beds at the southern end of the Horse Prairie Basin. Further confusion about the stratigraphy and age of the Medicine Lodge beds arose from those authors misinterpreting the stratigraphic position of the Eocene Challis volcanics (called the Medicine Lodge Volcanics in Scholten and others, 1955) in the Muddy Creek Basin (Janecke and others, 1999). The Challis volcanic rocks underlie the Muddy Creek beds in the Muddy Creek Basin but were mapped as lying in angular unconformity on top of the sedimentary section (Scholten and others., 1955; Dunlap, 1982). The Medicine Lodge name was applied to all tuffaceous sedimentary rocks, conglomerates, and travertine deposits in the Idaho Medicine Lodge Valley (Skipp and others, 1979).

Age of Medicine Lodge Beds in Idaho

$^{40}Ar/^{39}Ar$ dating shows that the Idaho Medicine Lodge Valley contains two successions of sedimentary rocks: older tuffaceous Medicine Lodge beds of Eocene-Oligocene age and a younger succession of mostly volcanic rocks with a prominent travertine and conglomerate unit of Miocene age (Hodges and others, 2004a, b). Based on past usage, it is simplest to retain the name Medicine Lodge for the Paleogene part of the section and to use a new name for the Neogene deposits (Hodges and others, 2004a, b). The sedimentary rocks in the type area in the Nicholia Creek Basin are still undated but they overlie dated middle Eocene Challis volcanics, and their lithology resembles Paleogene basin-fill deposits in the region. A close association with basalt flows and rhyolite ash flow tuffs usually distinguishes the Miocene sedimentary rocks from the older Medicine Lodge beds. Retention of the name Medicine Lodge for most of the Paleogene synrift deposits west of the Muddy-Grasshopper detachment fault may cause some confusion because the name Medicine Lodge has been applied to distinctly younger Miocene and Pliocene sedimentary rocks in the Birch Creek and Medicine Lodge Valleys of Idaho (e.g., Skipp, and others, 1979; Rodgers and Anders, 1990; Hodges, and others, 2004a, b).

Nomenclature and Correlation of Medicine Lodge Beds

Cenozoic sedimentary rocks in the present-day Grasshopper, Horse Prairie, and Montana Medicine Lodge Basins are clearly correlative with the Medicine Lodge beds and with one another, but different names have been applied in some of the basins. In a regional compilation, Fields and others (1985) referred to all of these units as the

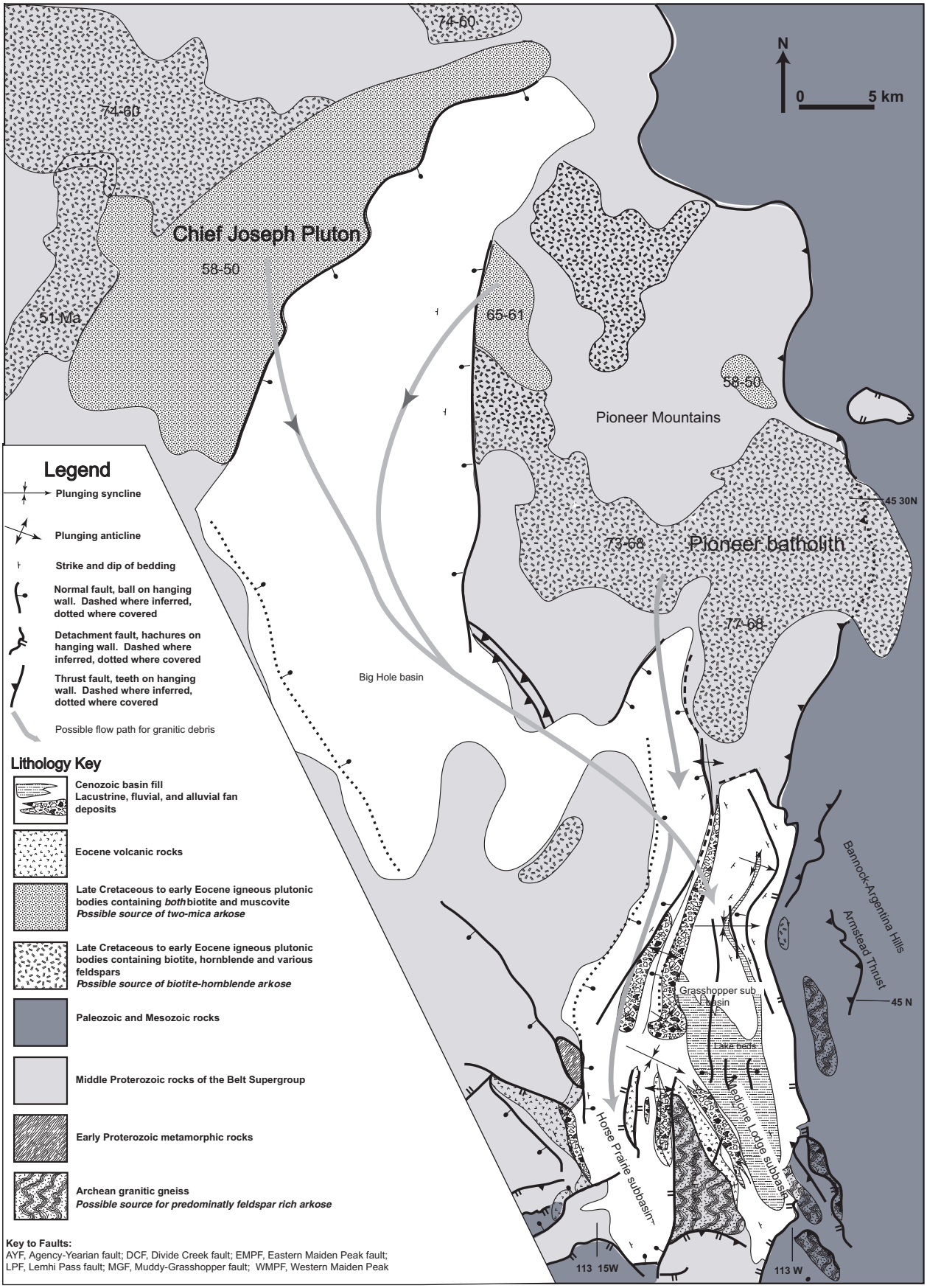


Figure 2. Paleogeographic map showing the present-day distribution of lake beds and conglomerate of the Medicine Lodge beds in the Grasshopper, Medicing Lodge and Horse Prairie structural subbasins of the Grant protobasin. Rivers flowing from the north, with a source in the Chief Joseph pluton, were the source of the feldspathic sandstone in the northern half of the basin complex. Geology compiled from Ruppel and others, 1993; M'Gonigle and Dalrymple, 1996; Janecke unpublished mapping; VanDenburg and others, 1998; Lonn and others, 2000; Janecke and others, 2004; Janecke, 2004.

Medicine Lodge beds. M'Gonigle used informal names for Cenozoic sedimentary rocks in the Montana Medicine Lodge Basin (M'Gonigle and others, 1991; M'Gonigle 1993, 1994) but ultimately retained the Medicine Lodge name for the Eocene-Oligocene deposits in the Montana Medicine Lodge Basin and the upper Horse Prairie Basin (M'Gonigle and Hait, 1997). VanDenburg (1997) and VanDenburg and others (1998) used a local name, Bear Creek beds, for correlative sequences in the western part of the Horse Prairie Basin. In Grasshopper structural subbasin, Matoush (2002) and Kickham (2002) followed M'Gonigle and Hait (1997) and Scholten and others (1955) and applied the Medicine Lodge name to along-strike correlative strata farther to the north.

For all these reasons, the present authors suggest that the nomenclature follow the original usage of Scholten and others (1955) for most of the basin-fill deposits. Thus, the name Medicine Lodge beds refers to the oldest sequence of sedimentary rocks in the Grant protobasin that overlies the Challis volcanics. The younger Everson Creek beds and Bannack Pass beds are separated from the Medicine Lodge beds by an angular unconformity along the hinged western margin of the structural subbasins (VanDenburg, 1997; VanDenburg and others, 1998) and are therefore separated from the Medicine Lodge beds. Vertebrate biostratigraphy, argon geochronology, and field studies show that these are distinct stratigraphic successions (VanDenburg and others, 1998; M'Gonigle, 1994; M'Gonigle and Hait, 1977; Nicholes and others, 2001; this study).

Application of the Renova name to Paleogene units in the Grant protobasin (Thomas, 1995; Sears and Fritz, 1998; Sears and Ryan, 2003) is not advocated, but the age-equivalence of the Medicine Lodge and Renova deposits of the Ruby and Beaverhead Basins is clear (Fields and others, 1985; Nichols and others, 2001). The Medicine Lodge beds and Renova Formation were deposited in different tectonic and structural settings according to some interpretations (Janecke, 1994; Sears and Fritz, 1998; Janecke and Blankenau, 2003).

Lithology of Medicine Lodge beds (Tml)

Lithology varies greatly within the Medicine Lodge beds, in part because there are lateral changes in depositional environment and composition of the units. Fluctuating lake levels resulted in repetition of lithofacies in different stratigraphic levels of the Medicine Lodge beds. In general, the Medicine Lodge beds consist of five main types of deposits: (1) conglomerate (Tcg), sandstone and conglomerate (Tscg), and quartzose sandstone (Tsq), that were deposited in braided alluvial fan and marginal lacustrine settings; (2) shale and quartzose sandstone (Tshsq), and tuffaceous shale, organic-rich shale and mudstone, and sandstone (Tsht) that were deposited in a perennial lake; (3) feldspathic sandstone and interbedded mudstone and shale (Tfs) that were deposited by south-southeast-flowing meandering and anastamosing streams and deltas that flowed along the axis of the Grant protobasin toward a lake basin in the south-central part of the basin; (4) interbedded conglomerate and mudstone (conglomeratic mudstone unit), with minor sandstone, that represent debris flows, fluvial deposits, and possible lake muds along the active eastern margin of the basin; and (5) brecciated masses (Tmbq, Tmbv) and slide blocks (Tsbq, Tsbv) of quartzite and volcanic rocks that were emplaced into the protobasin as paleolandslide deposits from both sides of the basin. The first four types of deposits are most common in the western, south-central, north-central, and eastern part of the Grant protobasin (Fig. 2) and have very different compositions because they were derived from distinct source areas. Conglomerate (Tcg), conglomerate and sandstone (Tscg), and quartzose sandstone (Tsq) in the western half of the basin are derived from quartzose units in the middle Proterozoic Belt Supergroup and had a source in the highlands that were in the hanging wall of the protobasin at the time. Lake beds in the axial part of the protobasin contain relatively little coarse sediment. Lake beds contain ash, and white paper shale is common. Subordinate sandstone interbeds preserve sediment from different source areas on all sides of the basin. Feldspathic sandstone (Tfs) is composed of feldspar, quartz, muscovite, biotite, and some granitoid rock fragments of granitoid rock, and thus differs from all the other rocks types in the protobasin except for some feldspathic turbidite sandstone in the tuffaceous shale unit. The conglomeratic mudstone unit is localized along the eastern margin of the protobasin, east of the Bachelor Mountain quadrangle and its source was Paleozoic and Mesozoic sedimentary, volcanic, and plutonic rocks in the footwall of the Muddy-Grasshopper detachment fault to the east.

Lithology of the map units

Most map units can be distinguished on the basis of their lithofacies, depositional environment, and composition. Compositional differences provide a natural division among groups of siliciclastic deposits -- those that were shed laterally into the protobasin from its hanging wall (west) side, those that were shed from the footwall (east side), and two different deposit types that occupied the broad floor of the basin. Based on these distinctions, the authors subdivide the Medicine Lodge beds into western, eastern, and axial deposits.

Deposits of the western part of the Grant protobasin	Deposits of the axial part of the Grant protobasin	Deposits of the eastern part of the Grant protobasin
Tcg	$Tsht_3$	None are exposed in the Bachelor Mountain quadrangle
Tscg	$Tsht_2$	
Tsq		
Tshsq	$Tsht_1$	
Tmbv, Tmbq	Tsh	
Tsbq, Tsbv	Tfs, Tfs_1, Tfs_2, Tfs_3, Tfs_4	

Western deposits of protobasin: fan-delta complex

Western deposits include the conglomerate (Tcg), sandstone and conglomerate (Tscg), quartzose sandstone (Tsq), and shale and quartzose sandstone (Tshsq). Slides blocks and megabreccia masses composed of volcanic rock and Belt quartzite are also included in the western deposits. The conglomerate to shale units represent more proximal to more distal parts of a single large braided fan-delta system (e.g., Matoush, 2002) much like a geographically separate but probably coeval fan-delta in the Montana Medicine Lodge structural subbasin to the south-southeast of the map area (rudites of Flores and M'Gonigle, 1991) (Fig. 2). The conglomerate facies becomes finer to the north and south into coeval sandstone and shale of the axial lake beds. The western deposits are widely exposed in the Bachelor Mountain quadrangle because this part of the Grant protobasin was closer to the basin's western margin than to the Muddy-Grasshopper detachment fault along the active eastern margin of the protobasin. At the time the western deposits were laid down, the western margin of the basin was probably a simple east-tilted bedrock slope.

Lateral and vertical associations between the coarser and finer units in the western deposits suggest sharp eastward progradation of a conglomeratic braided fan delta early in the basin history, followed by more gradual transgression of lake beds over the top of the large fan-delta complex. After the fan delta receded to the west, it never returned to the preserved part of the basin. Thus, the western deposits represent a fan-delta complex.

Eastern deposits of protobasin (east of map area)

Eastern deposits are not preserved in the Bachelor Mountain quadrangle but do form a continuous north-trending belt to the east in the hanging wall of the Muddy-Grasshopper detachment fault. Conglomeratic mudstone and muddy conglomerate dominate this eastern lithofacies that also includes slide blocks and megabreccia masses composed of Paleozoic and Mesozoic rocks. These deposits were shed from the footwall of the Muddy-Grasshopper detachment fault, are confined to a zone 4-5 km west of the basin-bounding part of the Muddy-Grasshopper detachment fault, and lie more than 5 km east of the Bachelor Mountain quadrangle.

Axial protobasin deposits: fine-grained

Tuffaceous shale (Tsht) dominates the central part of the Grant protobasin and is especially thick in the stratigraphic middle of the Medicine Lodge beds ($Tsht_2$). Siliceous mudstone, tuffaceous paper shale, and organic-rich shale comprise this unit. The thickest tuffaceous shale and mudstone crop out along State Highway 324 west of Grant and thin to both the north and the south. Northward, the tuffaceous shale is replaced by coeval feldspathic sandstone (Tfs). The tuffaceous shale unit is widely preserved in the northern two-thirds of the Medicine Lodge structural subbasin (Fig. 2), and in the southern one-third of the Grasshopper structural subbasin. Tuffaceous shale is also present in some of the oldest exposed Medicine Lodge beds (Tsht1) and youngest Medicine Lodge beds ($Tsht_3$ and $Tsht_4$). White to [off-white] and tan weathering tuffaceous shale and mudstone contain negligible sand-sized particles and represent distal ash fall from an unknown source. Calderas in the Great Basin region of the southwestern U. S. were active at this time (Christiansen and Yeats, 1992) and are a more likely source than the less explosive vents of the Clarno and John Day areas to the west. Further work is needed to pinpoint the source of the ash, but initial chemical correlations and mineralogical analysis of some ashes are consistent with a Great Basin source (Michael Perkins, written comm., 2003; Eric Christiansen, written comm., 2004).

The fine grain size, parallel laminations, sedimentary structures, fish fossils, (Becker, 1969; Cavender, 1977; Gerald Smith, written comm., 1999), and facies associations are consistent with deposition in an open lake below wave base. Turbidite sands in the tuffaceous shale become progressively more prominent northward, northeast of the Bachelor Mountain quadrangle. Provenance data, the location of the tuffaceous shale units, and paleocurrent data show that the lacustrine tuffaceous shale beds filled the basin floor east of the western deposit. This lake occupied the southern part of the Grant protobasin and was a persistent but fluctuating feature during deposition of the Medicine Lodge beds.

A succession of two-mica-bearing feldspathic sandstone and mudstone, and pebbly sandstone interfingers with the tuffaceous shale (Tfs). Feldspathic granule sandstone is very diagnostic of this unit. This lithofacies replaces older parts of the tuffaceous shale lithofacies northward in the Grasshopper structural subbasin and overlies tuffaceous shale in the Bachelor Mountain quadrangle. Feldspathic sandstone appears at four stratigraphic intervals in the Medicine Lodge beds, from near the base to near the top of the unit. The second youngest feldspathic sandstone (Tfs2) is not present in the Bachelor Mountain quadrangle but is present farther to the northeast.

Sandstone bodies in the feldspathic sandstone lithofacies form prominent cemented ledges that weather to produce a colluvial cover on interbedded mudstone intervals. The proportion of sandstone to mudstone is therefore difficult to quantify but is locally as high as 2 to 1. Elsewhere sandstone dominates the feldspathic sandstone unit. Sandstone and pebbly sandstone beds are characterized by trough cross stratification, are locally pebbly at the base, and many have lenticular geometries. Pebbles in this unit are dominantly red Belt quartzite clasts, but plutonic, volcanic, and granite-gneiss clasts occur locally. The source of the small population of granite-gneiss pebbles is uncertain, but the pebbles resemble the bedrock of the Maiden Peak spur, south of the Bachelor Mountain quadrangle (Fig. 1b).

The presence of both biotite and muscovite within the feldspathic sandstone beds requires derivation from a distinctive source terrane north of the Grant protobasin (Thomas, 1995; Matoush, 2002; Janecke and others, 2004; Link and others, 2004) (Table 1). The Chief Joseph pluton (Fig. 2) at the less deformed southwest end of the Anaconda metamorphic core complex is probably the source for these two-mica-bearing sandstones (Thomas, 1951; Link and others, 2004; Janecke and others, 2004), but other more distant source areas are also possible. The Chief Joseph granite is about 50 km north-northwest of the Bachelor Mountain quadrangle. Argon cooling ages show that the plutonic source area cooled rapidly in Late Cretaceous to early Tertiary time (Table 1). Archean crystalline rocks near the Bachelor Mountain quadrangle could NOT have supplied the sediment in these feldspathic sandstones because they lack muscovite, a prominent component of the feldspathic sandstone (M'Gonigle and Hait, 1997). Moreover, these Archean rocks should have provided Precambrian detrital grains,

but such old grains were not observed in either the argon or zircon analyses of the feldspathic sandstone (Link and others, 2004; Janecke and others, 2004) (Table 1).

Altogether, these data suggest that the feldspathic sandstone in the Bachelor Mountain quadrangle was deposited by south-southeast–flowing, meandering to anastamosing streams that filled the floor of the Grant protobasin. These streams flowed south into a persistent lake in the southern part of the basin (that was filled by unit Tsht), and small deltas formed on the margin of this lake. The lake's northern margin was within the Bachelor Mountain quadrangle and the southern edge was more than 20 km to the south-southeast during times of high stands in the lake level (M'Gonigle, 1993).

Megabreccia blocks (Tmbq, Tmbv) and slide blocks (Tsbq, Tsbv) with a source to the west are concentrated in the lower part of the stratigraphic succession, below or above the conglomerate (Tcg) unit and its lateral equivalents. These distinctive deposits are common in the southern half of the Bachelor Mountain quadrangle and the northern half of the south-adjacent Jeff Davis Peak quadrangle (the Ti unit of M'Gonigle and Hait, 1997) in association with the finer lithofacies of the western deposits and with other marginal lacustrine rocks. To the north and the south, in the coarser lateral equivalents of these units, the conglomerate (Tcg), and in the sandstone and conglomerate (Tscg) there are fewer interbedded paleolandslide deposits. Several megabreccia masses and slide blocks are demonstrably rootless lenticular masses within the Medicine Lodge beds and must represent paleolandslide deposits. The paleolandslide deposits preferentially occur within open lacustrine to marginal lacustrine units (Tsq, Tshsq, and Tsht) and are most common between fan-delta lobes formed by the conglomerate (Tcg).

TABLE 1. Summary of GEOCHRONOLOGIC DATA from the Grant protobasin

Sample	Location	Sample Type	Unit	Age	References	Significance
Not known	GQ se$^{1}/_{4}$ 31-9s 12w	Fish fossil	Tfs	Oligocene	Cavender (1977)	Synrift
East Mill Point Locality	UTM 12 339103E 5010745N (NAD27)	vertebrates	Medicine beds east of Mill Point	Early Early Arikareean	Tabrum and Nichols (2001) Fields and others (1985)	Synrift Sample JJ-8 is from the middle of the vertebrate bearing section
JM95-35	UTM 12 338842E 4994881N (NAD27)	$^{40}Ar/^{39}Ar$ single crystal ages from detrital muscovite, biotite and potassium feldspar minerals in a two-mica-bearing feldspathic sandstone (Tfs4) near top of Medicine Lodge beds	Tfs4	Biotite and k-feldspar from sample JM-95-35 were analyzed by single-crystal laser fusion. Ten biotite crystals yielded a range in ages from 21.5 Ma to 81.8 Ma. Twenty K-feldspar crystals were fused, resulting in a range in ages of 54.42 Ma to 74.39 Ma.	This study	Source of the feldspathic sands was a plutonic body that cooled rapidly in the late Cretaceous to Early Tertiary. No Archean components were included
SUJ95-7	UTM 12 330398E 5000875N (NAD27)	$^{40}Ar/^{39}Ar$ single crystal ages from detrital muscovite, biotite and potassium feldspar minerals in a two-mica-bearing feldspathic sandstone (Tfs1) near bottom of the Medicine Lodge beds	Tfs1	Muscovite, biotite and potassium feldspar from this sample were all run as single crystals in the laser and step-heated. The B steps of the micas are shown plotted on an age probability diagram. The muscovite ages range in age from 53 Ma to 103 Ma while the biotite ages range from 35 Ma to 58.7 Ma. The potassium feldspar crystals were heated in four steps. The plateau ages are plotted on an ideogram. They range in age 47.07 to 69.09 Ma.	This study	Source of the feldspathic sands was a plutonic body that cooled rapidly in the late Cretaceous to Early Tertiary. No Archean components were included
JJ-8	UTM 12 339103E 5010745N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on biotite	Tuff high in Medicine beds east of Mill Point	27.57 $\pm$ 0.64 Ma	This study	Age of the upper part of the Medicine Lodge beds. These are synrift deposits and date slip on the Muddy-Grasshopper detachment fault
JJ-31	UTM 12 340201E 5008558N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on biotite	Tuff low in the conglomeratic mudstone unit of the Medicine Lodge beds	30.27 $\pm$ 0.28 Ma	This study	Age of the Medicine Lodge beds. These are synrift deposits and date slip on the Muddy-Grasshopper detachment fault
JM-95-36	UTM 12 338889E 4997049N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on groundmass concentrate from a basalt flow	Tba	27.59 $\pm$ 0.23 Ma	Janecke and others (1999)	Caprock of the Medicine Lodge beds
JJ-WB	UTM 12 334351E 4998057N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on groundmass concentrate from a basalt flow	Tba	27.76 $\pm$ 0.20 Ma	This study	Caprock of the Medicine Lodge beds
JM-95-13	UTM 12 339185E 4995514N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on groundmass concentrate from a intrusion	Tba	27.50 $\pm$ 0.78 Ma	Janecke and others (1999)	Caprock of the Medicine Lodge beds
SUJ-96-28	UTM 12 324398E 4987728N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on groundmass concentrate from a basalt flow	Tba	27.76 $\pm$ 0.20 Ma	This study	Caprock of the Medicine Lodge beds
JM81-181	UTM 12 332325E 4980880N (NAD27)	$^{40}Ar/^{39}Ar$ plateau age on groundmass concentrate from a brecciated volcanic lava flow	Tmbv at contact between the middle shale and upper shale (M'Gonigle and Hait, 1997)	47.67± 0.73 Ma**	This study	Documents that brecciated volcanic masses within the Cenozoic basin fill are paleolandslide deposits derived from the Challis Volcanics, not younger intrusions. This is about 900 m upsection from a 46.04 + 0.15 Ma volcanic of the Challis field (M'Gonigle and Dalrymple, 1995).
Suj 95-119	UTM 12 316984E 4983459N (NAD27)	$^{40}Ar/^{39}Ar$ near plateau age on groundmass concentrate from a brecciated basalt flow	Tmbv interbedded within Everson Creek beds	46.22±0.95 Ma**	VanDenburg, 1997	Documents that brecciated volcanic masses within the Cenozoic basin fill are paleolandslide deposits derived from the Challis Volcanics, not younger intrusions
Challis Volc. Group	Medicine Lodge basin	$^{40}Ar/^{39}Ar$	Tcv	48.69-45.7 Ma	M'Gonigle and others (1991)	Prerift
Challis Volc. Group	Horse Prairie basin	$^{40}Ar/^{39}Ar$	Tcv	48.94-46.01 Ma	VanDenburg and others (1998)	Prerift

** - Age in conflict with age of enclosing sedimentary rocks that was determined using argon geochronology and/or vertebrate biostratigraphy. We interpret "conflicting" ages as the volcanic age of a volcanic paleolandslide mass that was later shed into the Medicine Grant protobasin or Horse Prairie subbasin.
Source: Data of Janecke, McIntosh, M'Gonigle, Matoush, and Kickham. Some data were previously reported in Matoush (2002)

Youngest Medicine Lodge beds: basalt flows

Localized basalt flows are the youngest unit of the Medicine Lodge beds. Most of the flows filled a paleovalley that grossly coincides with the hinge of the Bannack Bench syncline east of the quadrangle (Fig. 1c). An outlier basalt flow lies northwest of Red Butte within the Bachelor Mountain quadrangle. All the basalt flows are Oligocene, erupted during a short interval between 27.5 and 27.8 Ma (Table 1).

Everson Creek Beds

The Everson Creek beds (Tec) are upper Oligocene to lower Miocene mudstone and pebbly feldspathic sandstone (M'Gonigle and Hait, 1997; VanDenburg and others, 1998). Pebbles are mostly flat, subrounded to rounded tuffaceous siltstone derived from tuffaceous shale (Tsht**)**. Two-mica-bearing feldspathic sandstones comprise varying proportions of the sandy material in the unit. Recycled pebbles are very abundant in channel deposits. Pebbly sandstones contain trough to planar cross stratification and well-developed pebble imbrications. The overbank mudstone deposits are present but not well exposed. Most of the Everson Creek beds were deposited by streams (VanDenburg, 1997).

The Everson Creek beds are much less tilted and deformed than the Medicine Lodge beds and lie in angular unconformity on tilted Medicine Lodge beds along the western margin of the Grant protobasin area (VanDenburg and others, 1998). Exposures of Everson Creek beds are mostly confined to a graben between the Meriwether Lewis fault and the Poverty Flats fault (see following discussion of structure). The basal contact of the Everson Creek beds is not exposed in the Bachelor Mountain quadrangle. Vertebrate fossils from related rock units along Everson Creek indicate a late early Arikareean (Oligocene) age (Nichols and others, 2001). The Everson Creek beds were distinguished from the Medicine Lodge beds by VanDenburg (1997), M'Gonigle and Hait (1997), and VanDenburg and others (1998). The late early Arikareean age (late Oligocene) of these deposits (Nichols and others, 2001) shows that the Everson Creek Beds are slightly younger than the youngest Medicine Lodge beds that are Arikareean.

Bannack Pass Beds

The Bannack Pass beds in the Bachelor Mountain quadrangle are fine-grained sandstone, siltstone, mudstone, and conglomerate. The sandstone is litharenite and may contain abundant glass shards. Rare conglomerate beds are derived from adjacent highlands. Beds are commonly 30-70 cm thick, and massive. Bedding and sedimentary structures are obscured by intense burrowing. Vertebrate fossils from correlative deposits at Bannack Pass show a lower to middle Miocene age (M'Gonigle, 1994; Barnosky, 2001). Rare Hemingfordian (Miocene) fossils along Maiden Creek (Nichols and others, 2001), and the conformity between the Everson Creek and Bannack Pass beds in Railroad Canyon, Idaho (Janecke, Retallack, and Dorsey, unpublished data) suggest that near the axis of the Horse Prairie structural subbasin, there was continuous deposition from Oligocene to middle Miocene time. Elsewhere in the region this time period is interpreted as a hiatus and major unconformity (e.g. Fields and others, 1985). G. Retallack (written comm.., **XXXX**) has suggested that a short, intense interval of warm humid climate may explain the near absence of Hemingfordian vertebrate fossils in the region because arid environments favor preservation of bone material and humid conditions favor floral preservation **(add citation here)**.

The Bannack Pass beds are preserved along the western margin of the Grasshopper Creek structural subbasin within a newly identified north-northeast-trending graben in the hanging wall of the Meriwether Lewis fault. The graben coincides with a prominent gravity low in the basin (Hanna and others, 1993). Elsewhere, the basin has almost no gravity expression (Hanna and others, 1993). The Bannack Pass beds within the graben probably

overlie a thick section of down-faulted Medicine Lodge beds and Everson Creek beds. The contact with the Everson Creek beds is not exposed but might be conformable in this area.

Structure

(Refer to Plate 1, geologic map)

Many of the faults in the Bachelor Mountain quadrangle are covered by Quaternary deposits (Plate 1, geologic map). Abrupt changes in the lithology of the basin-fill deposits, repetition and omission in the stratigraphic succession, photolineaments, changes in the attitude of bedded rock units, seismic reflection profiles, and gravity data were all used to supplement field studies of the structures in the area. The stratigraphic framework is based on analyses from the entire Grasshopper structural subbasin, not just from exposures in the Bachelor Mountain quadrangle.

The Grant protobasin was initially a very broad east-tilted half graben that formed in the hanging wall of the Muddy-Grasshopper detachment fault. This fault is only a few kilometers below the surface in the Bachelor Mountain quadrangle and is imaged on reflection seismic lines that cross the Grasshopper structural subbasin (Kickham, 2002; Matoush, 2002; Janecke and others, 1996, 2004). The west-dipping detachment fault reaches the surface 9-13 km east of the eastern margin of the Bachelor Mountain quadrangle (Fig. 1a, b, c).

The Medicine Lodge beds were deposited during slip on the basin-bounding Muddy-Grasshopper detachment fault within the Grant protobasin. This protobasin broke up internally along spaced west-dipping listric normal faults that soled into the Muddy-Grasshopper detachment fault after the 27.5 to 27.8 Ma basalts were deposited (Janecke, and others, 2004; Janecke, 2004). Similar stratigraphic intervals of the early synrift Medicine Lodge beds are exposed in smaller fault blocks that formed during the breakup phase of the protobasin's history. Everson Creek beds are sedimentary deposits of the breakup phase. They are not extensive in the Grasshopper structural subbasin but are widely exposed to the south in the western part of the Horse Prairie structural subbasin (VanDenburg, 1997; M'Gonigle and Hait, 1997; VanDenburg and others, 1998), where upper Oligocene Everson Creek beds were deposited in angular unconformity on older, tilted Medicine Lodge beds (the Bear Creek beds of Vandenburg and others, 1998).

Extensional folds are very prominent in the Grasshopper structural subbasin and include major basin-scale folds with north-south, southeast, and east-west trends. Basin-scale folds include the Bachelor Mountain anticline, the Coyote Flats syncline and anticline, and the Bannack Bench syncline. Smaller, more local extensional folds are present in the southern part of the quadrangle and include the Horse Prairie syncline and anticline.

The Bachelor Mountain quadrangle contains the southern three-quarters of the north- to north-northeast-trending Bachelor Mountain anticline. This large anticline is a double rollover anticline whose east-dipping limb formed first due to slip on the low-angle, listric Muddy-Grasshopper detachment fault. The west- to northwest-dipping western limb of the anticline formed later when the younger Meriwether Lewis normal fault was activated (Kickham, 2002). A complex network of normal faults coincides with the crest of the anticline and has dropped younger deposits (Tsht2) down into the core of the Bachelor Mountain anticline. Normal faults in the core of the anticline grow in slip and die out along strike, but overall appear to define a keystone graben on the former crest of the Bachelor Mountain anticline.

The Coyote Flats extensional folds are exposed in the Coyote Flat area and the area around Bachelor Mountain. This anticline-syncline pair plunges to the southeast, and has a different trend from most other folds in the area. The Coyote Flats syncline intersects the east-dipping limb of the Bachelor Mountain anticline. The overlap of these two structures produced a major reentrant in the generally east-dipping outcrop belts of Medicine Lodge beds on the east limb of the Bachelor Mountains anticline. Together with the covered South Fork normal fault, the

Coyote Flats syncline shifts map units westward more than 7 km from their positions north and south of the Coyote Flats syncline. The Coyote Flats anticline is composed of two oppositely facing monoclines that are spaced about 2 km apart. The Coyote Flats syncline and anticline parallel the South Fork fault and probably formed during the same enigmatic deformational event that produced the southwest-dipping Lemhi Pass fault to the southwest (VanDenburg and others, 1998; Janecke and Blankenau, 2003).

The western end of the Bannack Bench syncline is exposed in the northeast corner of the Bachelor Mountain quadrangle (Kickham, 2002). This major east-plunging syncline dominates the eastern Grasshopper structural subbasin but dies out when it intersects the orthogonal Bachelor Mountain anticline. The extreme western tip of this east-plunging syncline is exposed in the northeast corner of the Bachelor Mountain quadrangle. The Bannack Bench syncline formed above a west-plunging antiform in the underlying Muddy-Grasshopper detachment fault and probably resulted from the changes in strike of the listric fault.

The Horse Prairie Creek syncline and anticline parallel normal faults of the Maiden Peak fault zone and probably formed during the latter half of the basin's evolution, after the 27.59±0.23 Ma, 27.50±0.78Ma, 27.77±0.24Ma, and 27.76±0.20 Ma basalt flows were emplaced. Intersecting extensional folds produce a 2.5 km x 3 km basin north of Pierce Ranch.

Normal faults also cross the Bachelor Mountain quadrangle and follow a number of trends. The Meriwether Lewis fault forms the present western margin of the Grasshopper structural subsubbasin and is probably the largest normal fault in the quadrangle. Offset is difficult to estimate across this fault but probably exceeds 5 km (Kickham, 2002). The western strand of the Maiden Peak fault zone is another major normal fault in the basin. It forms the western margin of Red Butte and increases in throw southward (M'Gonigle and Hait, 1997). To the north, this west-dipping normal fault loses identity, is covered, and may be truncated by the newly identified Poverty Flats fault.

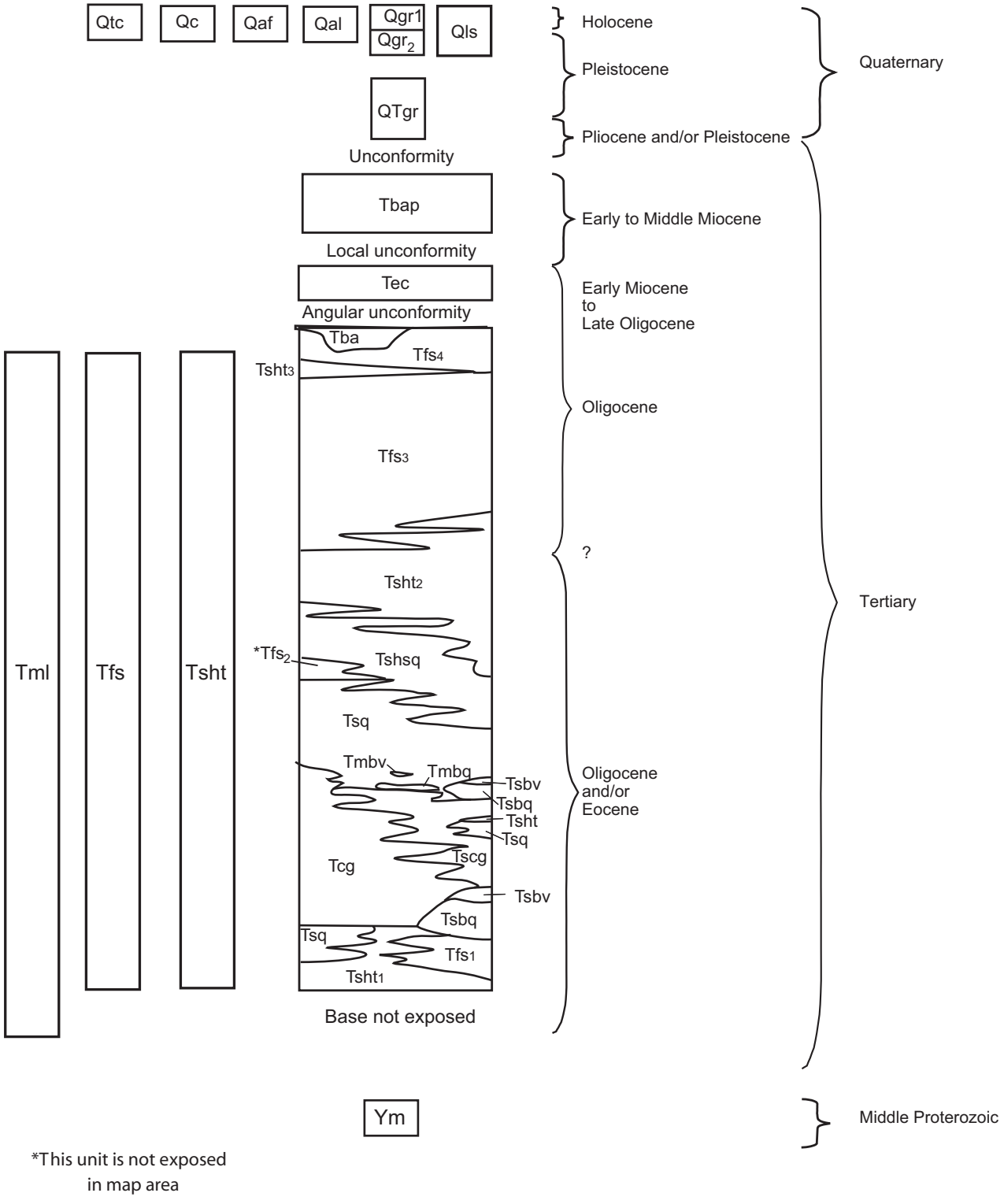
The Poverty Flats normal fault is a cryptic northwest-dipping fault that Janecke interpreted to explain a major northeast- to north-trending gravity low in the western Grasshopper structural subbasin (in data of Hanna and others, 1993). Several aligned lineaments coincide with the southeast margin of the gravity low, and mapping showed that the youngest Tertiary units, the Bannack Pass beds and the Everson Creek beds are largely confined to the hanging wall of this normal fault. These units are the youngest basin-fill deposits in the area and thus appear to be faulted down in a major graben between the Poverty Flats fault and the Meriwether Lewis normal fault. The Poverty Flats fault is probably an antithetic structure to the master Meriwether Lewis fault. No exposures of either fault were located, but map patterns suggest that the Poverty Flats fault and the Meriwether Lewis fault cut both the Bannack Pass beds and some of the overlying older gravel (QTgr). Steps in the landscape on pediment surfaces might be fault line scarps or degraded fault scarps. The Meriwether Lewis fault is the major range-front fault to the Big Hole Divide northwest of the area.

There is no evidence for the east-west-striking Horse Prairie fault zone of Scholten (1982) or Ruppel (1985, 1993) in the southern part of the Bachelor Mountain quadrangle. This fault was interpreted by these authors to have minor late Tertiary to Recent activity and to be expressed in brecciated quartzites along the fault's trace (Scholten, 1982). These brecciated quartzites are here reinterpreted as paleolandslide deposits within the Medicine Lodge beds because they are strata-bound, east-dipping deposits that overlie Cenozoic basin-fill deposits. There is extensive cover along Horse Prairie but nonetheless it is possible to correlate normal faults, extensional folds, and distinctive lithofacies within the Medicine Lodge beds across Horse Prairie. These correlations show that the Horse Prairie fault cannot lie buried beneath alluvial cover along Horse Prairie. The south-adjacent Jeff Davis Peak quadrangle preserves the continuation of the north-south structural and facies trends of the Bachelor Mountain quadrangle, and shows no evidence for a laterally continuous Horse Prairie fault (M'Gonigle and Hait, 1997; Janecke, unpublished mapping).

Quaternary History of Grasshopper Structural Subbasin of the Grant Protobasin

Erosional exhumation of the Grasshopper structural subbasin is occurring in the headwaters of the Missouri River drainage. Fluvial pediment gravel is preserved at many different levels and records the progressive lowering of base level within the basin. Exposures of thin pediment gravel adjacent to the modern streams and alluvial fans could be confused with deposits of greater thickness were it not for the many exposures of pre-Quaternary deposits high on hill slopes beneath thin, mesa-capping fluvial gravel deposits. Aerial photographs that show bedding traces of the underlying tilted sedimentary rocks confirm that many of the gravel deposits are thin pediment gravels, forming veneers on pediment surfaces. Fluvial deposits presently dominate the area, and glacial till is limited to small valley glaciers northwest of the area.

Correlation of Map Units



Description of Map Units in the Bachelor Mountain 7.5' Quadrangle

Qls **LANDSLIDE DEPOSIT**

Qal **ALLUVIAL DEPOSIT.** Alluvium of modern streams.

Qgr **GRAVEL DEPOSIT, UNDIFFERENTIATED**

Qgr1 **GRAVEL DEPOSIT**. Younger thin pediment gravel deposit from ancient streams and alluvial fans.

Qgr2 **GRAVEL DEPOSIT.** Older thin pediment gravel deposit from ancient streams and alluvial fans.

QTgr **GRAVEL DEPOSIT**. Highest-altitude gravel deposits overlying Bannack Pass. Bedding slopes slightly basinward (eastward and southeastward) reflecting the original depositional slope toward trunk streams in the east.

Qaf **ALLUVIAL FAN DEPOSIT**

Qc **COLLUVIAL DEPOSIT.** Colluvium was mapped separately in areas where it was so thick that the underlying deposit was no longer identifiable.

Qta **TALUS DEPOSIT**

Qtc **TALUS AND COLLUVIUM, UNDIFFERENTIATED**

Tbap **BANNACK PASS BEDS (EARLY TO MIDDLE MIOCENE)**. Fine-grained sandstone, siltstone, reworked tephra, mudstone, and conglomerate. Sandstones are litharenites; many contain glass shards, and weather to tan and buff colors. Tuffaceous beds are lighter colored. Rare conglomerate beds are derived from adjacent highlands. Beds are commonly 30-70 cm thick and massive. Bedding and sedimentary structures are obscured by intense burrowing. Vertebrate fossils from correlative deposits at Bannack Pass show an age of early to middle Miocene (M'Gonigle, 1994; Barnosky, 2001). Hemingfordian fossils along Maiden Creek (Nichols and others, 2001) suggest that locally, near the axis of the late rift basin, there was continuous deposition from Oligocene to middle Miocene time. The unit is preserved along the western margin of the Grasshopper structural subbasin within a newly identified north-northeast-trending graben southeast of the Meriwether Lewis fault. Thickness is uncertain due to discontinuous exposure.

Tec **EVERSON CREEK BEDS (LATE OLIGOCENE TO EARLY MIOCENE)**. Mudstone and pebbly feldspathic sandstone. Pebbles are mostly flat, subrounded to rounded, tuffaceous siltstone recycled from older uplifted tuffaceous shale beds of the Medicine Lodge beds. Two-mica-bearing feldspathic sandstones comprise varying proportions of the sandy material in the unit. The recycled pebbles are very abundant in channel deposits. Pebbly sandstones contain trough to planar cross stratification and well-developed pebble imbrications. Overbank mudstone deposits are present but not well exposed. The Everson Creek beds are much less tilted and deformed than the Medicine Lodge beds and lie in angular unconformity on tilted Medicine Lodge beds elsewhere in the Grant protobasin area (VanDenburg and others, 1998). The basal contact is not exposed in the Bachelor Mountain quadrangle. Exposures of Tec are mostly within a graben between the Meriwether Lewis fault and the Poverty Flats fault. Vertebrate fossils from correlative rock units along Everson Creek, in the Everson Creek 7.5' quadrangle to the south, indicate a late early Arikareean age (Nichols and others, 2001). The Everson Creek beds were separated from the Medicine Lodge beds by VanDenburg

(1997), M'Gonigle and Hait (1997), and VanDenburg and others (1998). Deposited in axial fluvial environment of Grant protobasin. Thickness in the Bachelor Mountain quadrangle is uncertain due to discontinuous exposure.

Tml **MEDICINE LODGE BEDS, UNDIVIDED (LATE OLIGOCENE-EOCENE)**. Sandstone, mudstone, conglomerate, paper shale, paleolandslide deposits, and capping basalt. These rocks were all deposited in the Grant protobasin. This protobasin encompassed the younger Medicine Lodge, Horse Prairie, and Grasshopper structural subbasins and once extended across parts of the adjacent mountain ranges. The Medicine Lodge beds rest in conformity to slightly angular unconformity on 45-46 Ma ash flow tuffs of the Challis Volcanic Group south of the quadrangle (M'Gonigle, 1993, 1994; M'Gonigle and Dalrymple, 1993, 1996; VanDenburg, and others, 1998). The capping(?) basalt flow and minor intrusions are Oligocene in age (27.77 to 27.50 Ma). Correlative sandstone, mudstone and conglomerate exposed east of Mill Point contain Earliest Arikareean vertebrate fossils (Nichols and others, 2001). The younger part of the Medicine Lodge beds contains a 30.27± 0.28 Ma and 27.57± 0.64 Ma ash fall tuff ($^{40}Ar/^{39}Ar$ laser fusion dates from single crystals within the ashes) (Matoush, 2002 and Kickham, 2002). Altogether, these data show that deposition of the Medicine Lodge beds may have begun as early as late middle Eocene time, about 45-46 Ma. Deposition continued and perhaps culminated in the Oligocene between 30 and 27 Ma.

Tba **BASALT OF MEDICINE LODGE BEDS (OLIGOCENE)**. Massive to columnar basalt. $^{40}Ar/^{39}Ar$ step heating on a concentrate of fresh groundmass yielded an age of 27.77±0.24 Ma (Sample SUJ 96-28: Janecke and others, 2004) on a basalt exposed in several fault blocks west of Red Butte. A 19.5± 1.1 Ma K-Ar age reported in VanDenburg and others (1998) (R. McDowell, oral comm., 1977) for this unit is incorrect. Five additional areas of basalt flows and shallow intrusions, with nearly identical $^{40}Ar/^{39}Ar$ ages of 27.50±0.78 Ma, 27.59±0.23 Ma, and 27.76±0.20 Ma on groundmass concentrates, cap the divide between Horse Prairie and Grasshopper Creeks to the northeast (Kickham, 2002; Matoush, 2002). These basalts formed during a single valley-filling eruptive event and yield the same $^{40}Ar/^{39}Ar$ ages as the single basalt flow at Red Butte.

Tfs_4 **FELDSPATHIC SANDSTONE, FOURTH OLDEST (= YOUNGEST), OF MEDICINE LODGE BEDS (OLIGOCENE)**. Feldspathic sandstone, siltstone, mudstone**,** shale, and, locally, white tuffaceous siltstone and paper shale. Beds of sandstone are laterally discontinuous channel deposits. Muscovite and biotite are prominent in many feldspathic sands along with quartz, plagioclase, and potassic feldspar. Granule and coarse sand size particles are the largest grains in these deposits. This unit is exposed west of Red Butte, beneath the 27.77±0.24 Ma columnar basalt. Deposited in axial fluvial environment of Grant protobasin.

$Tsht_3$ **TUFFACEOUS SHALE, YOUNGEST, OF MEDICINE LODGE BEDS.** White weathering tuffaceous paper shale, tuff, organic rich shale and mudstone, feldspathic siltstones and planar-bedded feldspathic sandstone. Detrital potassium feldspars from one sandstone in this unit were dated using $^{40}Ar/^{39}Ar$ in the Grant quadrangle to the east. Abbreviated step heating showed that cooling was rapid. The detrital K-spars cooled through the closure temperature between 54.42 and 74.39 Ma. Deposited in axial lacustrine environment of Grant protobasin.

Tfs_3 **FELDSPATHIC SANDSTONE, THIRD OLDEST (= YOUNGEST), OF MEDICINE LODGE BEDS.** Feldspathic sandstone, siltstone, mudstone, shale, and, locally, thin white tuffaceous paper shale. Peat is locally present. Sandstone is thin- to medium-bedded, trough cross-stratified. This thick unit may contain gravel beds derived from the footwall of the Muddy-Grasshopper detachment fault. Muscovite and biotite are prominent in many feldspathic sands along with quartz, plagioclase, and potassic feldspar. Unit is exposed in a structural

subbasin where the Coyote Flats syncline intersects the Horse Prairie Creek syncline. Deposited in axial fluvial environment of Grant protobasin.

$Tsht_2$ **TUFFACEOUS SHALE, SECOND OLDEST, OF MEDICINE LODGE BEDS.** White weathering tuffaceous paper shale, tuffaceous mudstone, and organic-rich shale and mudstone. Plant fossils are preserved in this unit. This unit probably correlated with Tsm and Tsu of M'Gonigle and Hait (1997). Deposited in axial lacustrine environment of Grant protobasin. More than 180 m thick along the line of Cross Section A-A'.

Tshsq **SHALE AND QUARTZOSE SANDSTONE OF MEDICINE LODGE BEDS**. White-weathering tuffaceous shale, mudstone, dark organic-rich shale, and well-sorted quartz arenite. The sandstone is commonly extremely well cemented by silica and weathers to an orange to pale-red color. Impressions of large, intact plant materials are diagnostic of this unit. Deposited in western part of Grant protobasin. Thickness varies; about 325 m thick along the line of Cross Section A-A'.

Tfs_2 **FELDSPATHIC SANDSTONE, SECOND OLDEST, OF MEDICINE LODGE BEDS.** Feldspathic sandstone, siltstone mudstone, shale, and locally thin white tuffaceous paper shale. Feldspathic sandstone in this stratigraphic level is exposed to the northeast near the Christiensen Ranch floral locality of Becker (1969). None has been identified within the Bachelor Mountain quadrangle. Deposited in axial fluvial environment of Grant protobasin. **NOTE:** This unit does not crop out in the Bachelor Mountain quadrangle

Tsq **SANDSTONE, QUARTZOSE, OF MEDICINE LODGE BEDS.** Quartz arsenate sandstone and white weathering tuffaceous shale. Plant impressions are common. The sandstone may be well cemented by silica cements. Pink to red quartz grains are scattered among the more abundant light quartz and quartzite grains. When it is well cemented this unit is extremely durable, resistant to erosion, and forms hogbacks. This unit overlies, underlies, and interfingers laterally with Tcg. Deposited in western part of Grant protobasin. Thickness is variable; about 425 m along the line of Cross Section A-A'.

Tscg **SANDSTONE AND CONGLOMERATE OF MEDICINE LODGE BEDS**. Quartzose sandstone, pebbly sandstone, and conglomerate, with some mudstone and shale. Unit is transitional between Tc and Tsq, is derived almost exclusively from metasedimentary rocks of the Belt Supergroup, and is exposed around Bachelor Mountain and southeast of Red Butte. Deposited in western part of Grant protobasin.

Tcg **CONGLOMERATE OF MEDICINE LODGE BEDS (EOCENE AND/OR OLIGOCENE)**. Conglomerate derived from the Missoula Group that is exposed to the west. Angular to subrounded clasts, mostly of pebble to cobble size, but boulder beds are also present in places. Grades laterally and up section into Tsc and Tsq. Clasts are red to maroon in the north but contain increasing proportions of light-colored quartzite clasts southward. In sections 3 and 4, T. 9 S., R. 13 W., in the middle of the quadrangle, light quartzite is more common than red clasts from the Missoula Group. The unit is exposed on the east and west flanks of the Bachelor Mountain anticline, and locally along the crest of the anticline where a complex keystone graben dropped the unit into the core of the anticline. Unit becomes finer-grained southward and is represented there by Tscg, Tsq, and Tshsq in a zone that coincides roughly with the modern Horse Prairie Creek. This area of finer sediment was probably an embayment in the lake's margin between the conglomeratic fan delta (Tcg) within the northern Bachelor Mountain quadrangle and a coeval fan delta to the south in the northern Medicine Lodge basin (Tc of M'Gonigle and others, 1991; M'Gonigle and Hait,

1997; Flores and M'Gonigle, 1991). Tcg exposures persist southward to the South Fork fault south of Bachelor Mountain. Normal faulting, down to the southwest, along the South Fork fault and the south plunge of the southern end of the Bachelor Mountain anticline drop the conglomerate into the subsurface. This unit is not part of the Cretaceous Beaverhead Group but was mapped that way in the past (Coppinger, 1974; Ruppel and others, 1993). Deposited in western part of Grant protobasin. More than 550 m thick along the line of Croaa Section A-A'. Thickness changes laterally; unit pinches out in the southern part of the Bachelor Mountain quadrangle.

MEGABRECCIA MASSES OF MEDICINE LODGE BEDS (EOCENE OR OLIGOCENE). Megabreccia masses are paleolandslide deposits from large run-out rock avalanches. Two source areas produced these paleolandslides: Middle Proterozoic Belt quartzite (Tmbq) and Challis volcanics (Tmbv)**.** All breccia masses within the Bachelor Mountain quadrangle had source areas to the west, in the hanging wall of the Muddy-Grasshopper detachment fault. Megabreccia and slide blocks are concentrated in the lower part of the stratigraphic succession, below or above the Tcg unit and its lateral equivalents. Paleolandslide deposits are more common between fan-delta lobes formed by Tcg, and thus appear to be associated with open lacustrine to marginal lacustrine units (Tsq, Tshsq, and Tsht). Deposited in western part of Grant protobasin.

Tmbq **MEGABRECCIA MASSES OF PROTEROZOIC BELT QUARTZITE CLASTS (EOCENE OR OLIGOCENE).** Brecciated masses of quartzite interbedded within Tsq and Tshsq. The composition of a brecciated mass is generally quite uniform but includes both off-white quartzite and red to maroon quartzite masses. Larger masses are present to the south in Medicine Lodge basin (M'Gonigle and Hait, 1997). These brecciated masses are interpreted as paleolandslide deposits. Deposited in western part of Grant protobasin.

Tmbv **MEGABRECCIA MASSES OF CHALLIS VOLCANIC GROUP CLASTS**. Brecciated masses of Challis Volcanics interbedded within Tsq. The composition of each brecciated mass is generally quite uniform but the separate masses differ in their composition. Most megabreccias are derived from lava flows but some tuffaceous masses are also present. Larger masses are present to the south in Medicine Lodge basin, but were originally interpreted as intrusive bodies into the Medicine Lodge beds there (M'Gonigle and others, 1991; M'Gonigle and Hait, 1997). All the breccia bodies are here reinterpreted as paleolandslide deposits based on their intensely brecciated character and their age. $^{40}Ar/^{39}Ar$ age determinations from masses of brecciated volcanic rocks enclosed in Medicine Lodge beds reveal ages that overlap with the short, intense period of Challis volcanism and are too old with respect to underlying dated units. Deposited in western part of Grant protobasin.

SLIDE BLOCK DEPOSITS OF MEDICINE LODGE BEDS. Large, nearly intact blocks of quartzite and/or volcanic rocks derived from the west. These blocks, up to 2 km long, occur in roughly the same stratigraphic position as the Tmbx unit, and have the same compositions, but are not brecciated. These blocks are interpreted as large paleorock slides that slid nearly intact into the basin from the west. The bases of the slide blocks are not exposed due to normal faults on their western margin or poor exposure. If the slide blocks represent intact bedrock, instead of paleorockslides, then they were enormous paleohighs during deposition of the Tfs, Tsh, and Tcg units. This unit is age-equivalent of Tc of M'Gonigle and Hait (1997). Deposited in western part of Grant protobasin.

Tsbq **SLIDE BLOCK OF PROTEROZOIC BELT QUARTZITE**. Large, nearly intact blocks of quartzite derived from the west. The largest such block, on the west flank of

Bachelor Mountain consists of pale to pastel weathering quartzite of the Belt Supergroup and a thin veneer of volcanic rocks. The volcanic rocks include biotite tuff and lava flows of intermediate composition. A second mass at Red Butte is composed of red and maroon quartzite of the Bonner Formation(?) of the Belt Supergroup, and preserves a thin cap of biotite-rich ash flow tuff. A third block, 1.75 km southeast of Red Butte, consists of Belt rocks but lacks any associated volcanic rocks. The slide block at Red Butte and the smaller one southeast of Red Butte are probably erosional remnants of a single rock slide. The base of these three blocks is not exposed due to normal faults on their western margin. Deposited in western part of Grant protobasin.

Tsbv **SLIDE BLOCK OF CHALLIS VOLCANIC GROUP ROCKS**. Nearly intact blocks of volcanic rocks (Tcv) derived from the west. The volcanic rocks include biotite tuff and lava flows of intermediate composition. At Red Butte, a slide block is composed of maroon quartzite of the Bonner Formation(?) of the Missoula Group overlain by a cap of biotitic ashflow tuff. The tuff correlates with the distinctive 47.53±0.6 Ma tuff of Curtis Ranch (Staatz, 1979; VanDenburg and others, 1998; VanDenburg, 1997). Deposited in western part of Grant protobasin.

Tfs_1 **FELDSPATHIC SANDSTONE, OLDEST, OF MEDICINE LODGE BEDS.** Feldspathic sandstone, siltstone, mudstone, shale, and locally thin white tuffaceous paper shale. Muscovite and biotite are prominent in many feldspathic sands along with quartz, plagioclase, and potassic feldspar (fluvial axial deposit). Granule and coarse sand size particles are the largest grains in these deposits. Detrital potassic feldspars from one sandstone in this unit were dated using $^{40}Ar/^{39}Ar$. Abbreviated step heating indicated that cooling was rapid. The feldspars cooled through the closure temperature between 47.07 and 69.09 Ma. Biotite ranged from 35 to 58.7 Ma and muscovite ages from 53 to 103 Ma. Unit is associated with massive to nodular tuffaceous siltstone and reworked tuff, some with well-developed root casts. Sandstone is laterally discontinuous and in the core of the Bachelor Mountain anticline it interfingers with quartz arenite sandstone and mudstone. Tcg overlies Tsf_1 along a sharp conformable contact. Tsf_1 is correlative with Tsl and or lower parts of Tsm of M'Gonigle and Hait (1997). Axial basin fluvial deposit.

$Tsht_1$ **TUFFACEOUS SHALE, OLDEST, OF MEDICINE LODGE BEDS.** White-weathering, tuffaceous paper shale, organic-rich shale, and mudstone, feldspathic and tuffaceous siltstones and planar-bedded feldspathic sandstone. This unit probably correlates with parts of Tsl of M'Gonigle and Hait (1997). Axial basin lacustrine deposit. About 325 m thick along the line of Cross Section A-A'

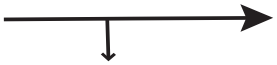
Tsht **TUFFACEOUS SHALE OF MEDICINE LODGE BEDS, UNDIFFERENTIATED.** Axial basin lacustrine deposit

Tfs **FELDSPATHIC SANDSTONE OF MEDICINE LODGE BEDS, UNDIFFERENTIATED.** Axial basin fluvial deposit

Ym **MISSOULA GROUP, UNDIVIDED (MIDDLE PROTEROZOIC).** Coppinger (1974) mapped these red, purplish, to off-white feldspathic quartzites as a pre-Bonner, Bonner, and post-Bonner unit within the Missoula Group. Subsequent compilations lumped all of these rocks, including the Wallace(?) unit of Coppinger that crops out immediately southwest of the quadrangle, within the Missoula Group (Ruppel and others, 1993). Recent field studies confirm this stratigraphic assignment for continuous Belt rocks northeast of Bloody Dick Creek (Don Winston, personal comm., 2004). No

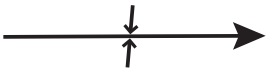
detailed studies were undertaken to clarify the stratigraphic position of the quartzites within the Missoula Group but they may lie above Paleoproterozoic metamorphic rocks north of Bloody Dick Creek (Ruppel and others, 1993; this study). The contact is very tectonized. Parts of the contact appear to dip north and the Missoula Group may have been deposited on the metamorphic rocks prior to formation of a steep cleavage in rocks on either side of the contact.

Explanation of map symbols



Monocline: axial arrow indicates plunge direction

Anticline: axial arrow indicates plunge direction



Syncline: axial arrow indicates plunge direction

Basin-bounding fault: dashed where uncertain, dotted where concealed. Parallel hatch marks on downthrown side.

Normal fault: dashed where uncertain, dotted where concealed. Bar and ball on downthrown side.

Thrust fault: dashed where uncertain, dotted where concealed. Teeth on upthrown (hanging wall) side.

Contact: dashed where uncertain, dotted where concealed.

Bedding trace

Lineament

Lineament and probable normal fault

Strike and dip direction of bedding; number indicates amount of dip in degrees

Approximate strike and dip direction of bedding

Strike and dip direction of bedding compiled from Kickham (2002), Matoush (2002), or Coppinger (1976

Strike and dip of fault plane as measured in the field; number indicates amount of dip in degrees

Horizontal to subhorizontal bedding

Sample site for ^{40}Ar / ^{39}Ar geochronology with sample number

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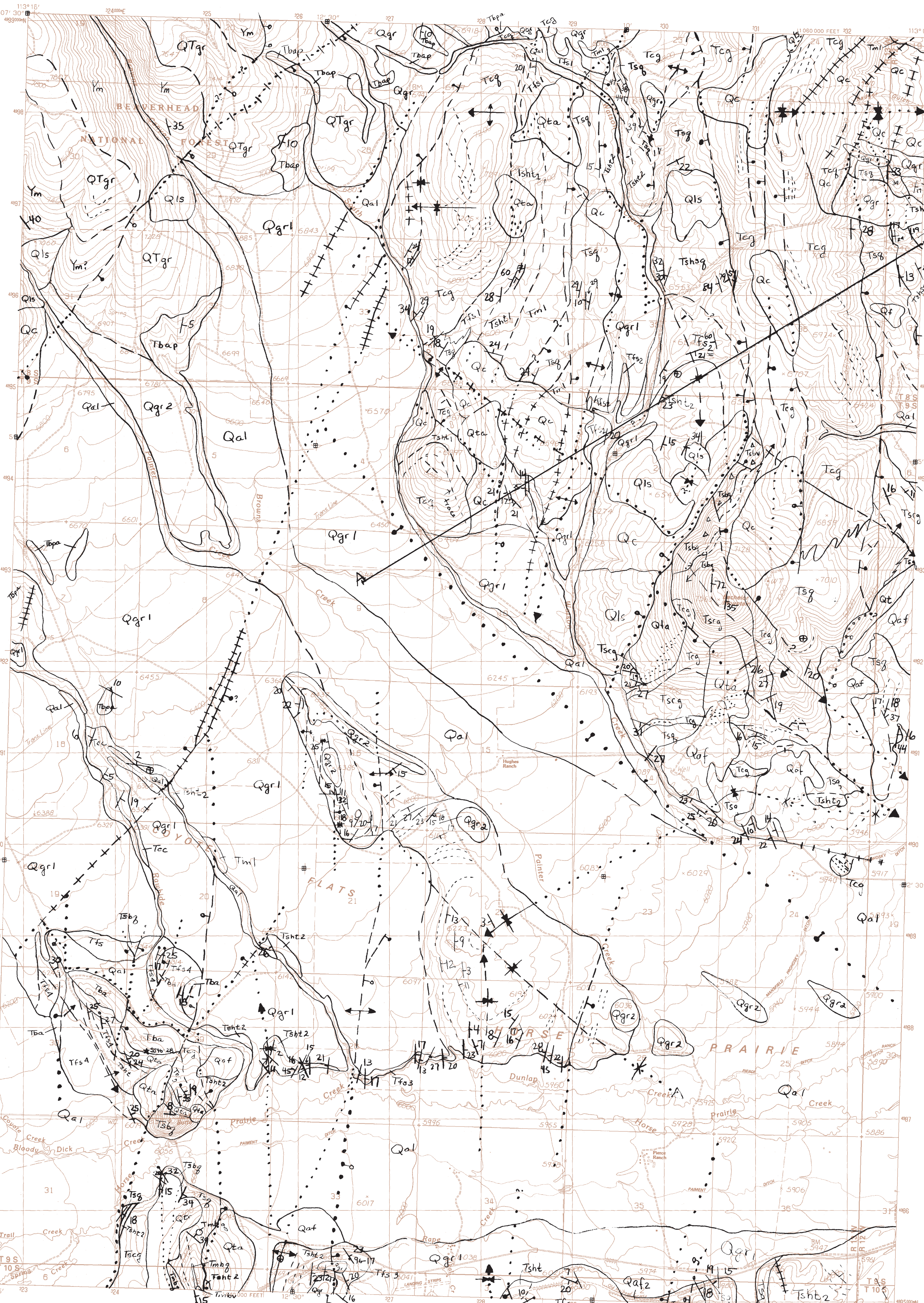


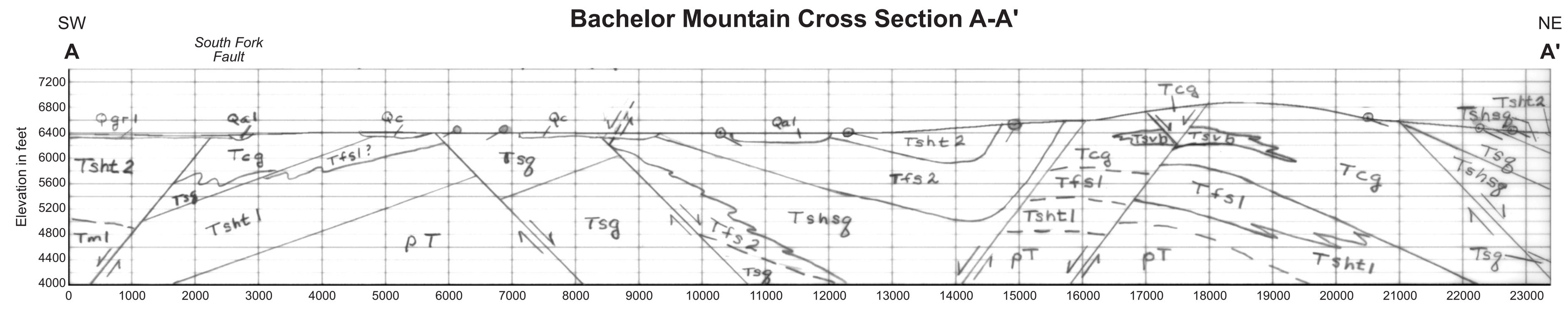
SCALE 1:24 000

KILOMETERS / METERS / MILES / FEET

CONTOUR INTERVAL 40 FEET
SUPPLEMENTARY CONTOUR INTERVAL 20 FEET

Base from U.S. Geological Survey
Bachelor Mountain 7.5' topographic quadrangle
Map date: 1988
Projection: MT-south; Lambert Conformal Conic
UTM zone 12; 1927 NAD

Bachelor Mountain Cross Section A-A'



Datum: mean sea level
No vertical exaggeration

Dip tadpole indicating the apparent dip of strata. Strike and dip measurements were projected as much as 300m onto the line of section.

Distance in feet

Scale: 1:24000

pT = pre-Tertiary sedimentary rocks. Includes Proterzoic Missoula Group rocks and possiblly some Tertiary Challis Volcanic Group rocks

Other units described in text

MBMG Open File 525

Geologic Map of the Bachelor Mountain 7.5' Quadrangle Southwest Montana

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2005

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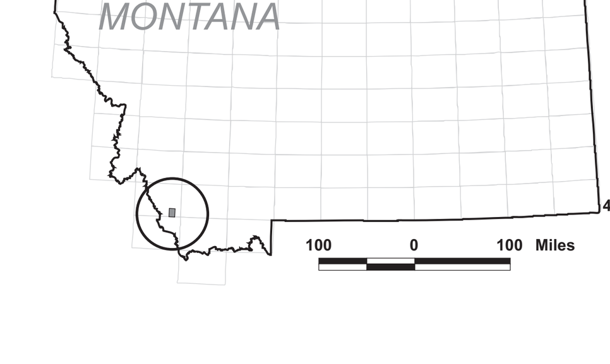

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