

**GEOLOGIC MAP OF THE  
DELL 7.5-MINUTE QUADRANGLE,  
CORDILLERAN FOLD AND THRUST BELT,  
SOUTHWEST MONTANA**

By

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Montana Bureau of Mines and Geology  
Open File Report MBMG 520

2004

This map conforms to the technical and editorial standards of the Montana Bureau of Mines and Geology.

Support for this project was provided by the EDMAP division of the National Cooperative Geologic Mapping Program of the U.S. Geological Survey under Contract Number 01HQAG0154.

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## INTRODUCTION

The geology of the Dell 7.5-minute quadrangle elucidates key structural and stratigraphic relationships essential to fully understanding the tectonostratigraphic evolution of southwest Montana. Cretaceous and Tertiary/Quaternary sediments and sedimentary rocks exposed in the Dell quadrangle record three primary tectonic phases: (1) development of Cretaceous basement-cored Laramide-style uplifts; (2) propagation of the Cretaceous Cordilleran fold and thrust belt and interaction with basement-cored foreland structures; and (3) Tertiary-Quaternary crustal extension. The Upper Cretaceous Beaverhead Group within the Dell quadrangle records the evolution of Sevier-style, thin-skinned deformation and, in part, the interaction of thin-skinned structures with older, basement-cored, foreland structures. The Tertiary Sixmile Creek and Renova Formations coupled with perched Quaternary alluvial deposits record the extensional history of the Red Rock Valley. Geologic mapping of the Dell quadrangle (Fig. 1) at the 1:24,000 scale provides the detail necessary to evaluate multiple structural-stratigraphic relationships within the Upper Cretaceous Beaverhead Group and Tertiary-Quaternary strata.

In this report we provide a detailed geologic map of the Dell 7.5-minute quadrangle with a brief overview of the geologic setting, stratigraphic nomenclature and structural-stratigraphic relationships. Additionally, we propose multiple working hypotheses that explain each of the key structural-stratigraphic relationships present in this area. Geologic mapping was conducted using a combination of aerial photographs (primarily for Quaternary geology) and extensive field verification of bedding contacts, attitudes, faults, and folds. In-depth field analysis was necessary to decipher structurally

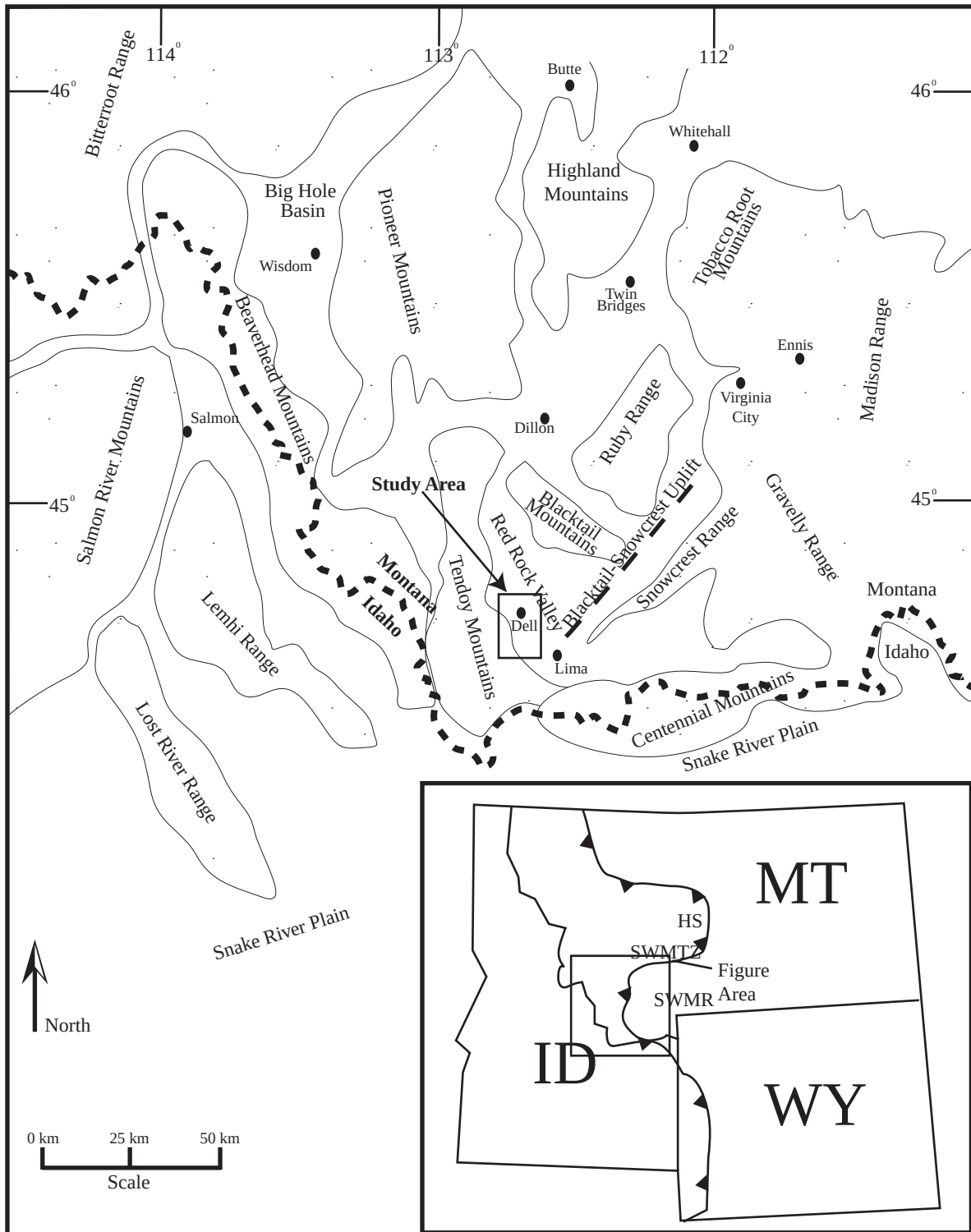


Figure 1. Location map showing tectonic context (inset map) and major mountain ranges (stippled areas) adjacent to the Dell quadrangle. Symbols used: HS- Helena salient; SWMTZ- Southwest Montana transverse zone; SWMR- Southwest Montana recess.

complex zones, especially those that are not well exposed (e.g., T. 14 S., R. 9 W., sec. 6, 7 and T. 13 S., R. 9 W., sec. 31).

## **GEOLOGIC SETTING**

The Dell quadrangle lies within the southwest Montana reentrant of the Cordilleran orogenic belt, south of the southwest Montana transverse zone and north of the Snake River Plain (Fig. 1). The easternmost (frontal) thrust sheets of the Cordilleran fold-thrust belt comprise the southern Beaverhead (Tendoy) Mountains, a portion of which is located in the western half of the Dell quadrangle. In the Dell quadrangle and adjacent areas the southwest Montana component of the Cordilleran thrust belt contains (from west to east) the Cabin thrust system, Medicine Lodge thrust plate, Four Eyes Canyon thrust plate, and frontal Tendoy thrust (Perry and others, 1983; Perry and Sando, 1983; Skipp, 1987, 1988; Perry and others, 1988; Williams and Bartley, 1988) (Fig. 2). The frontal thrust of the southwest Montana segment of the Cordilleran fold and thrust belt, the Tendoy thrust, is present in the southwestern corner of the Dell quadrangle. Here, it carries folded upper Paleozoic strata in its hanging wall. Displacement along the frontal Tendoy thrust decreases and is dispersed into a series of west-dipping blind thrusts toward the southeast. This thrust system is termed the Lima thrust system and cores the subsurface Lima anticline (Perry and others, 1988) (see cross section X-X”).

Additionally, this area occupies part of an overlapping zone characterized by both thin-skinned deformation (Cordilleran fold-thrust belt) and Laramide-style, basement-involved deformation (Blacktail-Snowcrest Uplift). The Blacktail-Snowcrest Uplift comprises the dominant Laramide-style uplift in southwest Montana forming a broad,

northeast-southwest-trending, basement-cored anticline that plunges southwest beneath the Tendoy Mountains. Perry and others (1983) termed the master basement-cored reverse fault that bounds the Blacktail-Snowcrest Uplift along its southern margin the sub-Snowcrest Range fault. Spatial and temporal interaction of this basement-cored, foreland structure with the encroaching, thin-skinned thrust belt has produced several structural complexities within the thrust belt southwest of Lima, MT whose interpretation is controversial. Some authors argue that thin-skinned thrust sheets of the encroaching Cordilleran thrust belt buttressed over the southwestern nose of the older, Blacktail-Snowcrest foreland structure (Perry and others, 1988; McDowell, 1997). The buttressing effect of this structural interaction may have led to development of out-of-sequence (westward-younging) thrust imbrication within the Tendoy thrust sheet (Perry and others, 1988). However, this problem has not yet been resolved.

Two general stages of extension are discerned in the Dell, MT region -- an early (Miocene-Oligocene?) stage that formed northeast-trending half-graben valleys, and a late (Pliocene to Quaternary) stage characterized by northwest-trending faults that form half-graben valleys (Lonn and others, 2000). More detailed interpretations of Cenozoic paleogeography and tectonics are available in Fields and others (1985), Hanneman and Wideman (1991), Kreps and others (1992), and Janecke (1994). The northwest-southeast-trending Red Rock normal fault (Fig. 2) is the major, seismically active, late-stage Neogene extensional structure that forms the western boundary of the Red Rock Valley half-graben, extending through the center of the Dell quadrangle. Motion along this late Cenozoic structure uplifted the Tendoy Mountains to their present position. The northeast portion of the Dell quadrangle comprises basin-margin alluvial fans and

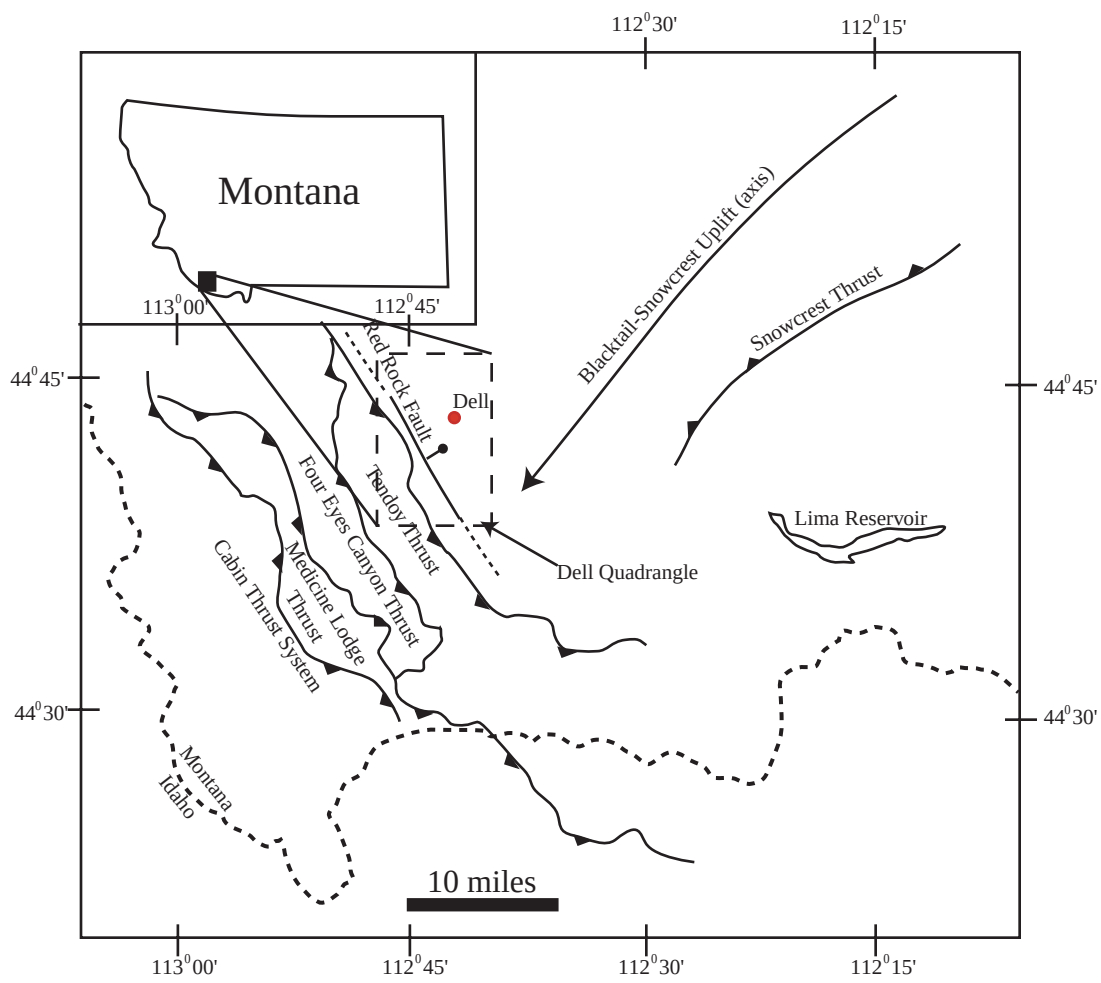


Figure 2. Map of structural elements within the Dell, MT area with inset map showing the regional location of the Dell quadrangle. Modified from Perry and others (1988).

associated colluvial deposits distributed along the Red Rock fault as well as Quaternary fluvial gravels and other surficial deposits on the floor of the Red Rock Valley associated with the Beaverhead (Red Rock) River.

## **DISCUSSION OF MAP UNITS AND STRATIGRAPHY**

Stratigraphic units mapped within the boundaries of the Dell 7.5-minute quadrangle include allochthonous Mississippian and Pennsylvanian limestone, dolomite and sandstone units as well as autochthonous Upper Cretaceous through Quaternary syntectonic sediment and sedimentary rocks. A correlation chart of map units and descriptions of these units are included as appendices A and B, respectively. Because the Cretaceous through Quaternary section comprises the greatest number of geologic units and records a significant portion of the tectonic history of the southwest Montana segment of the Cordilleran fold and thrust belt, detailed descriptions of map unit choices and description of these units are provided for further clarification.

### **Beaverhead Group (Upper Cretaceous-Paleocene?)**

The Beaverhead Group comprises the greatest volume of tectogenic sedimentary rocks in southwest Montana. This unit is of great consequence to the interpretation of the coeval development of Cordilleran thrust belt and Laramide structures (Blacktail-Snowcrest Uplift) because clast-type assemblages and lithofacies show considerable, but systematic lateral variation. Despite the interesting yet complex perspective these rocks offer, the vast lateral variation of lithofacies and petrofacies within the Beaverhead Group has rendered an extremely perplexing stratigraphic problem concerning the definition of

the Beaverhead Group and its subdivision. Authors with differing project objectives (e.g., detailed stratigraphic analysis versus geologic mapping over large areas) have proposed multiple stratigraphic definitions for the Beaverhead Group yet no one scheme is widely applied. A brief history of the nomenclature applied to the Beaverhead Group is provided in Figure 3. In this report we recognize the necessity for a stratigraphic definition and subdivision that affords a compromise between a highly divided section, useful for detailed stratigraphic analysis in a confined area, and a more generalized section, useful for geologic mapping over large areas. We propose that the assemblage of formal and informal stratigraphic units suggested by Haley and Perry (1991) provides a sufficient compromise, and have applied these stratigraphic terms in favor of others to suit the objectives of our study within the Dell 7.5-minute quadrangle (Fig. 3).

The nomenclature proposed by Haley and Perry (1991) applies the Beaverhead Group term to include siliciclastic strata (with subordinate lacustrine limestone) overlying the Frontier Formation (Cenomanian-Coniacian) that are subdivided into two formal members and several informal members. These members, both formal and informal, are defined in different locations primarily based on clast-type assemblage. In the Ashbough Canyon area, located to the north of the Dell quadrangle, three units are discerned. These units are the lowermost limestone conglomerate overlain by quartzite conglomerate and the uppermost Red Butte Conglomerate (Fig. 4). The Beaverhead Group exposed in the Lima Peaks area is divided into the Lima Conglomerate and two intertonguing unnamed sandstone tongues and an overlying quartzite conglomerate that roughly correlates with the quartzite conglomerate of Ashbough Canyon. Of these units, only the informal quartzite conglomerate (TKbq, also locally named the Little Sheep Creek conglomerate

| Period     | Age      | Lowell and Klepper<br>(1953) | Ryder and Ames<br>(1970) | Nichols and others<br>(1985) | Perry and others<br>(1989) | Dyman and others<br>(1991) | Haley (1985),<br>and this paper |
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| Cretaceous | Tertiary | Paleocene                    |                          |                              |                            |                            |                                 |
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| Cretaceous | Tertiary | Paleocene                    |                          |                              |                            |                            |                                 |
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| Cretaceous | Tertiary | Paleocene                    |                          |                              |                            |                            |                                 |
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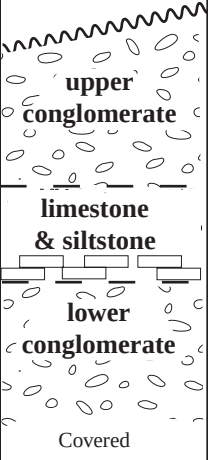
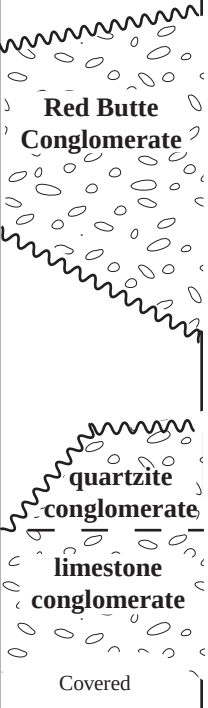
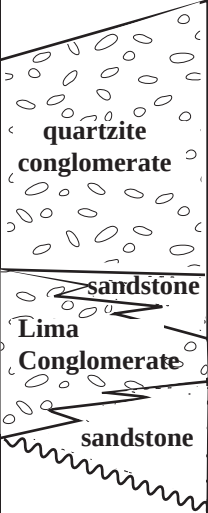
| Cretaceous | Tertiary  | Period        | Age | McKnight Canyon                                                                    |  | Ashbough Canyon                                                                     | Chute Canyon<br>↓ | Lima Peaks                                                                           |
|------------|-----------|---------------|-----|------------------------------------------------------------------------------------|--|-------------------------------------------------------------------------------------|-------------------|--------------------------------------------------------------------------------------|
|            |           | Epoch         |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            | Paleocene |               |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
| Late       |           | late          |     |  |  |  |                   |  |
|            |           | early         |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            |           | Maastrichtian |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            |           | Campanian     |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            |           | Santonian     |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            |           | Coniacian     |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            |           | Turonian      |     |                                                                                    |  |                                                                                     |                   |                                                                                      |
|            |           | Cenomanian    |     |                                                                                    |  |                                                                                     |                   |                                                                                      |

Figure 4. Summary of terms applied to Beaverhead Group strata in the Dell quadrangle.  
Modified from Haley and Perry (1991)

for a belt of this quartzite conglomerate that occurs in the vicinity of Little Sheep Creek) and overlying Red Butte Conglomerate (TKbr) were recognized and mapped within the boundaries of the Dell quadrangle. Complete descriptions of all members of the Beaverhead Group are not presented here, only those that crop out within the Dell quadrangle.

#### Beaverhead quartzite conglomerate

Three major outcrop belts of Beaverhead quartzite conglomerate have been recognized along the thrust belt front in southwest Montana, including the Divide, Tendoy, and Kidd quartzite conglomerate belts. Of these, only the Tendoy quartzite conglomerate outcrop belt (TKbq, in the vicinity of Little Sheep Creek) is present in the Dell quadrangle. Ryder and Scholten (1973) divided quartzite conglomerates from all three outcrop belts into two groups. These include the Kidd quartzite conglomerate and Divide quartzite conglomerate; the former term (Kidd) was applied to quartzite conglomerates present north of Dell, MT and the latter term (Divide) was applied to those south of Dell, MT. Due to the sparse outcrop and lack of a lateral stratigraphic correlation between quartzite conglomerate belts we adopt the terminology of Haley (1985) that combines all three exposures of quartzite conglomerate into the Beaverhead quartzite conglomerate. The informal Beaverhead quartzite conglomerate of Haley (1985) and Haley and Perry (1991) is equivalent to the “Little Sheep Creek conglomerate” of Perry and others (1989), and to the “Divide quartzite conglomerate” of Ryder and Scholten (1973) and Dyman and others (1995). Additionally, this unit is

included as an informal member of the Knob Mountain formation (not adopted here) of Haley (1985).

The Beaverhead quartzite conglomerate crops out in the south-central part of the Dell quadrangle directly south of Chute Canyon, forming grassy, rounded hills with sparse, poor exposures of quartzite conglomerate that are typically exposed on steep, forested slopes. Distinguishing characteristics of the quartzite conglomerate include: (1) the unique preponderance of quartzite clasts (> 60%); (2) the high degree of clast roundness; (3) low-angle inclined and horizontal stratification; (4) well-developed clast imbrication; and (5) overall well-sorted and well-organized internal fabric. Presence of pollen species *Proteacidites* sp. suggests a Coniacian through Maastrichtian age for this unit (Haley, 1985).

#### Red Butte Conglomerate of the Beaverhead Group

The Red Butte Conglomerate of the Beaverhead Group is superbly exposed in the vicinity of Red Butte, east of the Dell town center. The distinctive Red Butte Conglomerate is a formal member of the Beaverhead Group and is distinguished from other formal and informal members based on the following criteria: (1) characteristic red to brown color; (2) mixture of Triassic through Mississippian limestone with minor (fewer than 50%) quartzite clasts and subordinate recycled clasts (conglomeratic); (3) massive character with large paleo-incised gullies; (4) internally massive with subordinate coarse-tail graded beds, polymictic pebble to boulder conglomerate; (5) poorly sorted matrix; and (6) outsized (larger than surrounding matrix) boulders. The age of the Red Butte Conglomerate is uncertain but a mid-Campanian through

Maastrichtian age is suggested by the presence of recycled clasts of McKnight Canyon limestone and by its unconformable relationship with the overlying Sage Creek Conglomerate (Haley, 1985; Haley and Perry, 1991; Schmitt and others, 1995).

The Red Butte Conglomerate forms two main outcrop belts, one extending from the southern edge of Red Butte to the northern border of the Dell quadrangle, and a second extensive belt that occupies nearly the entire western margin of the Red Rock Valley. Strata of the latter outcrop belt of Red Butte Conglomerate locally onlap and are truncated by allochthonous Mississippian carbonate rocks carried in the hanging wall of the Tendoy thrust to the west, and are also truncated by the Red Rock normal fault on the east. Subordinate intraformational folding and faulting is present within the western outcrop belt, whereas extensive folding and faulting characterizes the Red Butte outcrop belt on the eastern side of the Red Rock Valley. These relationships are described more completely in following sections.

### **Sixmile Creek Formation**

The Tertiary Sixmile Creek Formation consists of consolidated, lithified, interbedded sandstone, siltstone and conglomerate. Fine-grained units of this formation are light-gray, fine- to medium-grained, calcareous sandstone with ancillary tuffaceous sandstone with thin interbeds of yellow to light-brown siltstone. Ripple cross-lamination, horizontal lamination, and trough cross-stratification with subordinate bioturbation comprise the internal character of fine-grained units, whereas subordinate thin lenses of well-sorted, stratified pebble conglomerate of a similar composition occur locally. Conglomeratic units of the Sixmile Creek Formation contain a distinctive, polymictic

clast-type assemblage that includes quartz arenites, limestone, dolomite, chert, gneiss, vesicular and amygdaloidal basalt, and quartzite (probably derived from the Belt Supergroup exposed in the Gravelly Range). Internally, conglomeratic units are well-organized, stratified, rounded, pebble to cobble conglomerates. Distinguishing characteristics of the Sixmile Creek Formation include: (1) consolidated, lithified character; (2) polymictic clast assemblage that includes Tertiary basalt; and (3) presence and locally abundant tuffaceous material (Fields and others, 1985; Gutmann and others, 1989; Ruppel and Lopez, 1984; and Lonn and others, 2000). This formation can be easily confused with Pleistocene and younger Quaternary gravels, but the Sixmile Creek Formation is considerably more lithified than the former. Previous workers included a thin veneer of Quaternary gravel with the Sixmile Creek Formation to emphasize Tertiary tectonics (e.g. Lonn and others, 2000). We do not include any Quaternary deposits with the Sixmile Creek Formation in this report. Fritz and Sears (1993) distinguished several members within the Sixmile Creek Formation. We do not employ these member names due to relatively poor exposures of Tertiary strata within the Dell quadrangle.

### **Quaternary Deposits**

Lithologically and compositionally, Quaternary deposits are similar to the Tertiary Sixmile Creek Formation, but are compositionally distinct from deposits of the Upper Cretaceous Beaverhead Group. Quaternary deposits are distinguished from the underlying Tertiary Sixmile Creek Formation based on the following criteria: (1) Quaternary deposits are less consolidated and unlithified; (2) younger Quaternary deposits are typically thinner than Sixmile Creek strata; and (3) younger deposits

frequently occupy perched surfaces or are concentrated in modern topographic lows such as modern channels.

## **STRUCTURAL AND STRATIGRAPHIC RELATIONSHIPS**

Structural and stratigraphic relationships are the fundamental building blocks of a sound tectonostratigraphic interpretation. The geology of the Dell 7.5-minute quadrangle exhibits key structural and stratigraphic relationships essential to fully understanding the three primary tectonic episodes that affected southwest Montana. These tectonic phases are the development of Cretaceous basement-cored Laramide-style uplifts, propagation of the Cretaceous Cordilleran fold and thrust belt, and interaction with basement-cored foreland structures and Tertiary-Quaternary crustal extension. In this section we outline the tectonic and stratigraphic relationships present in the Dell 7.5-minute quadrangle and propose several working hypotheses that, in conjunction with past and future investigations, expect to delineate the tectonic evolution of southwest Montana. Five key relationships further clarify the geologic history of the Dell quadrangle; these are divided into two groups, those recording propagation of the Cordilleran fold and thrust belt and interaction with the Blacktail-Snowcrest Uplift and those recording Tertiary-Quaternary extension.

### **Cordilleran Thrust Belt Relationships**

Two significant relationships exist between the frontal Tendoy thrust and two distinct lithosomes within Upper Cretaceous synorogenic strata of the Beaverhead Group. First, the Tendoy thrust places highly deformed and internally thickened Mississippian

and Pennsylvanian carbonate units (Snowcrest Range Group) on the undeformed Upper Cretaceous to Paleocene(?) Red Butte Member of the Beaverhead Group. This relationship occurs on the west side of the Red Rock Valley, extending north from Chute Canyon in the southwest part of the map area to beyond the northern boundary of the Dell quadrangle, possibly to McKnight Canyon. Along the outcrop belt where this relationship is exposed, the Tendoy thrust is in sharp contact with the underlying Red Butte Member. Although no progressive unconformities (growth structures) or unroofing sequences were identified in the Red Butte Member, possible onlapping relationships may occur in T. 13 S., R. 9 W. , sec. 19; however, outcrop exposures are not sufficient to unequivocally determine the nature of this contact. Additionally, the Tendoy thrust places deformed Mississippian through Pennsylvanian strata on undeformed Coniacian through Maastrichtian undifferentiated quartzite conglomerate just south of Chute Canyon.

Approximately 1,500 ft (500 m) south of Chute Canyon, in the south-central part of the map area, a third relationship occurs where the undated (Upper Cretaceous-Paleocene(?)) Red Butte Member and Maastrichtian through Coniacian quartzite member of the Beaverhead Group are juxtaposed. No evidence for a fault is observed in the vicinity of Chute Canyon (i.e., no fault surface, fault breccias, mineralized zones, slickenlines, or chatter marks). Hence, this contact may represent a fault contact that is completely covered, or it may represent depositional intertonguing of two poorly dated conglomerate lithosomes within the Beaverhead Group.

Allochthonous Mississippian to Pennsylvanian carbonate blocks resting on Beaverhead strata comprise the fourth relationship where two very large (0.31-0.62 mi

(0.5-1.0 km)) allochthonous limestone blocks are present just south of Chute Canyon and approximately 2 miles (3 km) north of Big Sheep Creek. North of Big Sheep Creek, near the west boundary of the map area, the allochthonous block of highly deformed Snowcrest Range Group rocks rests on the relatively undeformed Red Butte Member of the Beaverhead Group. South of Chute Canyon, a large block of highly deformed Snowcrest Range Group rocks rests on undifferentiated quartzite of the Beaverhead Group. We interpret these deformed allochthonous carbonate blocks as thrust klippen. These erosional remnants presently mark the former leading edge of the Tendoy thrust allochthon.

These four relationships are germane to understanding the timing and evolution of the Cordilleran fold and thrust belt because the Tendoy thrust cuts the Red Butte (proximal alluvial fan deposits) and quartzite members (distal fluvial deposits) of the Beaverhead Group, derived from uplifted strata in its hanging wall (Ryder and Scholten, 1973; Haley, 1985; Haley and Perry, 1991). During early Late Cretaceous to Paleocene time, emplacement of thrust allochthons in the Cordilleran fold and thrust belt (including the Tendoy thrust) uplifted rocks that were subsequently eroded, contributing detritus to the foreland basin where the quartzite member and lower Red Butte Member of the Beaverhead Group were deposited. Subsequently, the leading edge of the Tendoy thrust propagated basinward, uplifting Mississippian and Pennsylvanian rocks as well as strata of the Red Butte Member (suggested by the presence of recycled clasts) and eventually overrode these synorogenic deposits. The presence of klippen in front of the present (erosional) location of the Tendoy thrust trace, and lack of onlapping stratal successions and progressive unconformities within the Red Butte and quartzite members of the

Beaverhead Group all suggest that the latest phase of displacement along the Tendoy thrust facilitated structural transfer of these Beaverhead strata from the foredeep to wedge-top components of the southwest Montana foreland basin system (DeCelles and Giles, 1996).

The juxtaposition of Red Butte and undifferentiated quartzite members in the vicinity of Chute Canyon has two possible explanations. Either structural placement of older, undifferentiated quartzite on younger Red Butte Member has occurred as suggested by Lonon and others (2000) and Haley and Perry (1991), or alternatively, the lower strata of the Red Butte Member may be slightly older than previously thought and may simply intertongue with the quartzite member of the Beaverhead Group. Due to the poor exposures of the contact between the Red Butte and quartzite members coupled with poorly constrained Beaverhead stratigraphy and lack of absolute dating of the Red Butte Member, both interpretations of this contact are viable.

### **Extensional Tectonics**

The final structural-stratigraphic relationship observed in the Dell quadrangle involves the Red Rock fault and its prominent range-front slope break on the eastern side of the Tendoy Mountains and western side of the Red Rock Valley. The Red Rock normal fault system consists of a series of staggered, northwest-trending normal faults along the eastern margin of the Tendoy Mountains. The fault locally truncates multiple generations of Holocene terraces placing Upper Cretaceous Beaverhead strata against Quaternary alluvium (Harkins and others, 2003). The total stratigraphic displacement along this structure is difficult to determine because of the unknown subsurface thickness

of the Beaverhead Group combined with the inherent difficulty of distinguishing Cretaceous conglomerates from Tertiary and Quaternary conglomerates.

Because the Red Rock fault is seismically active, cuts Holocene deposits, and forms a northwest-southeast-oriented half graben, dropping the west side of the Red Rock Valley, it is classified as a late-stage (Pliocene through Holocene) structure (Hurlow, 1995, Lonn and others, 2000). Post-Tertiary progressive rotation of the half graben caused the successive abandonment of Quaternary surfaces on the east side of the valley forming a series of perched Pleistocene and younger sediments and geomorphic surfaces. It is possible that these younger Quaternary deposits merely mantle a partially exhumed Tertiary surface that was progressively rotated toward the southwest as suggested by Lonn and others (2000).

## **CONCLUSIONS**

New geologic mapping of the Dell quadrangle at 1:24,000 scale provides sufficient detail to evaluate multiple structural-stratigraphic relationships within the Upper Cretaceous Beaverhead Group and Tertiary-Quaternary strata that further illuminate the tectonostratigraphic development of southwest Montana. Upper Cretaceous strata of the Beaverhead Group record the evolution of the Cordilleran fold and thrust belt whereas Tertiary and younger strata record extensional deformation. Stratigraphic-structural relationships that elucidate the evolution of the Cordilleran fold and thrust belt include: (1) juxtaposition of Red Butte Conglomerate and undifferentiated quartzite conglomerate of the Beaverhead Group in the vicinity of Chute Canyon; (2) placement of allochthonous Mississippian-Pennsylvanian carbonates on the Red Butte

Conglomerate of the Beaverhead Group by the Tendoy thrust; (3) placement of allochthonous Mississippian-Pennsylvanian carbonates on Beaverhead undifferentiated quartzite conglomerate along the Tendoy thrust south of Chute Canyon; (4) presence of isolated, allochthonous blocks of Mississippian-Pennsylvanian carbonate rocks (klippen) located in Beaverhead strata south of Chute Canyon and north of Big Sheep Creek; and (5) normal-fault juxtaposition of Holocene sediments with Upper Cretaceous Beaverhead Group strata. These relationships record the progressive basinward propagation of thrust sheets with associated conglomerate deposition followed by the eventual thrust propagation over foreland basin deposits. Additionally, recent westward-down-dropping along the Red Rock normal fault caused exhumation of Tertiary topography and the successive abandonment of Quaternary surfaces on the east side of the Red Rock Valley half graben.

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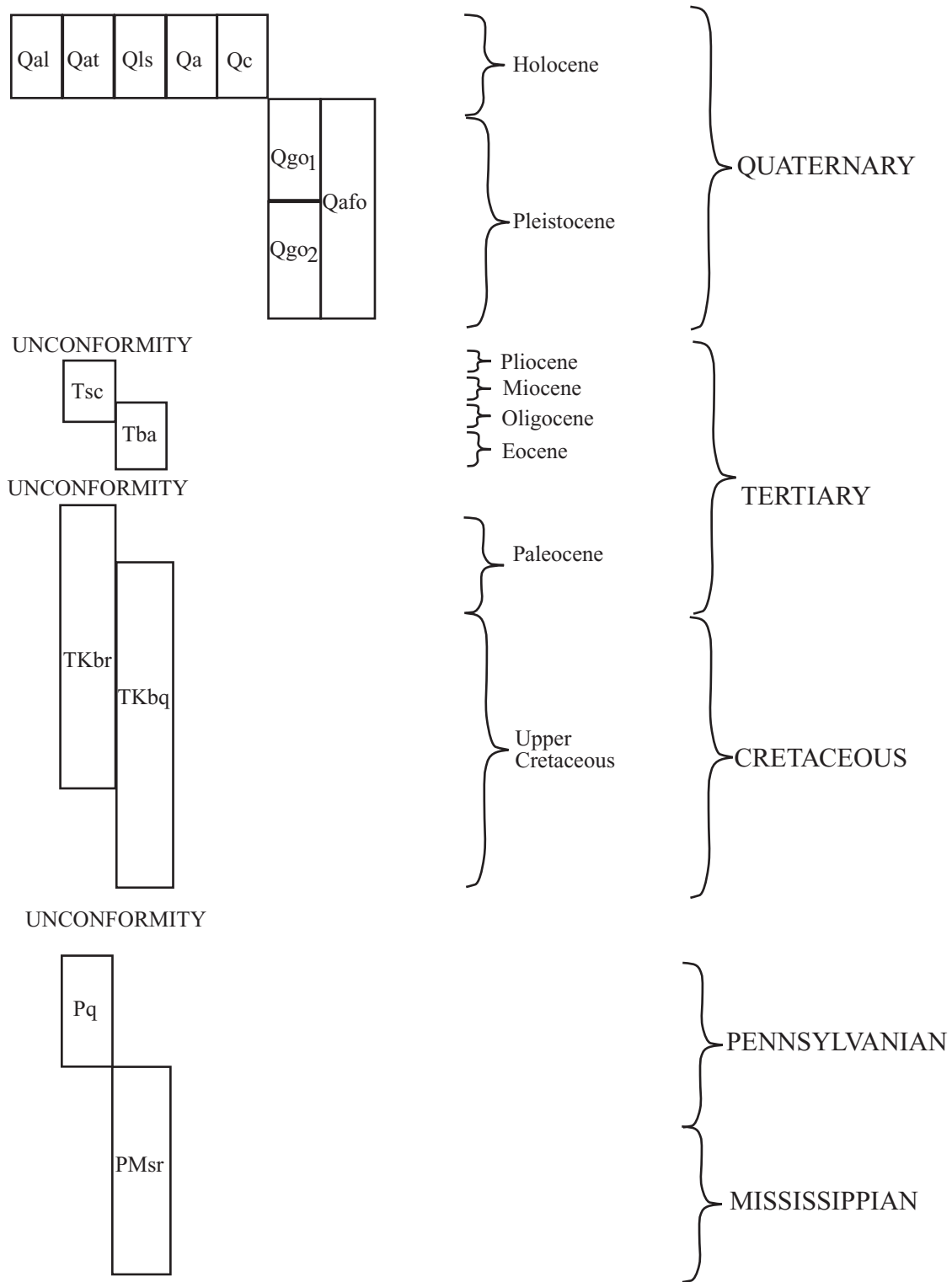
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# Appendix A CORRELATION OF MAP UNITS



## Appendix B

### DESCRIPTION OF MAP UNITS FOR THE DELL 7.5-MINUTE QUADRANGLE, MT

#### QUATERNARY UNITS:

**Qal Modern alluvium (Holocene)**- Generally unconsolidated gravel, sand and mud found in or near active, modern river channels and tributaries. Variable thickness.

**Qat Terrace deposit (Holocene)**- Unconsolidated alluvium forming tabular, elevated embankments approximately 6-18 ft (2-6 m) above the present elevation of the active river channel.

**Qls Landslide deposit (Holocene)**- Unconsolidated, chaotic collection of locally derived, angular boulders, sand, mud and plant debris. Landforms are characterized by lobate plan form and irregular, hummocky surface. Most commonly developed adjacent to steep, unstable slopes containing a higher relative percentage of fine-grained (shaley) source rock.

**Qaf Modern alluvial fan deposit (Holocene)**- Fan-shaped deposit of poorly sorted, unconsolidated gravel, sand and mud.

**Qao Alluvium, older, undivided (Pleistocene)**- Semi-consolidated, moderately sorted, polymictic gravel, sand and mud commonly 30-150 ft (10-50 m) above the present elevation of active river channels. Typically this unit is observed as discontinuous remnants within the Red Rock alluvial plain or as topographically higher, perched, alluvial deposits.

**Qgo<sub>1</sub> Glacial outwash fan deposits, younger (Pleistocene?)**- Semi-consolidated, polymictic gravel, sand and mud comprising broad, laterally extensive, semi-dissected fan-shaped deposits that occupy a stratigraphically lower position than older outwash fan deposits due to degradation. Using higher low-elevation and lower degree of dissection this unit is easily distinguished on aerial photographs. Thickness uncertain.

**Qgo<sub>2</sub> Glacial outwash fan deposits, older (Pleistocene?)**- Semi-consolidated, polymictic gravel, sand and mud comprising highly dissected, broad, fan-shaped deposits that occupy a slightly higher elevation than Qgo<sub>1</sub>. The relatively higher elevation and high degree of dissection define this unit on aerial photographs. This unit comprises the majority of perched alluvial deposits. Thickness uncertain.

**Qafo Alluvial fan deposits (Pleistocene)-** Semi-consolidated, poorly sorted, poorly organized, gravel, sand and mud comprising locally dissected, restricted fan-shaped deposits that occupy a higher elevation than any other alluvial deposit.

## **TERTIARY AND CRETACEOUS UNITS:**

**Tsc Sixmile Creek Formation, undivided (Pliocene-Miocene)-** Pale-brown, orange-yellow to tan, consolidated, lithified, calcareous siltstone and sandstone with isolated pods of conglomerate. Conglomerates contain sandstone, limestone, dolomite, basalt, and quartzite (Fields and others, 1985; Ruppel and Lopez, 1984).

**Tba Basalt, undivided (Tertiary)-** Black to dark-gray, columnar jointed, vesicular basalt with sparse zeolite-filled amygdules. Typically forms topographically distinct buttes and mesas.

**TKbr Red Butte Conglomerate, Beaverhead Group (Tertiary and Cretaceous)-** Dark-red to brown, matrix and clast-supported, poorly to moderately sorted limestone-, sandstone- and quartzite-clast conglomerate, with lenses of poorly to moderately sorted hematitic sandstone. Conglomerates form massive cliffs of amalgamated, lenticular, crudely bedded, poorly stratified, lenticular, massive pebble to boulder conglomerate. Matrix is poorly sorted consisting of mud and sand. Clast sizes reach a maximum of about 3 ft (1 m) diameter, yet the mode is approximately 2-8 inches (5-20 cm). Clast compositions vary slightly, but limestone remains the dominant clast type. The characteristic red color, distinctive petrofacies and lack of internal organization distinguish the Red Butte lithosome from other Beaverhead Group conglomerate lithosomes. This unit is only observed in the vicinity of Dell, MT due to lateral facies and petrofacies variation within the Beaverhead Group that are the result of lateral changes in depositional environment and provenance (Ryder, 1968; Haley, 1985; Lonn and others, 2000).

**TKbq Quartzite conglomerate, Beaverhead Group (Tertiary and Cretaceous)-** Gray to brown, moderately to well sorted, imbricated, quartzite-clast conglomerate with ancillary lenses of moderately to well sorted sandstone. Conglomerates are generally poorly exposed in the Dell area, typically forming small outcrop patches within densely forested slopes. These outcrops display well-organized, low-angle stratified and massive, amalgamated, lenticular beds of cobble conglomerate composed of rounded and oblate quartzite clasts. A paucity of large, outsized clasts and preponderance of smaller, cobble- and pebble-sized clasts coupled with the characteristic color and clast-type assemblage distinguish this lithosome of the Beaverhead from the Red Butte Conglomerate. South of Chute Canyon, the quartzite conglomerate intertongues with the Red Butte Conglomerate in a zone of lateral depositional lithofacies and provenance variation (Ryder, 1968; Haley, 1985; Lonn and others, 2000).

## **PENNSYLVANIAN AND MISSISSIPPIAN UNITS:**

**IPq    Quadrant Formation (Pennsylvanian)-** Brownish-yellow to white, locally silicified, well-sorted quartz arenite and litharenite sandstone with subordinate interbeds of limestone and dolostone. Typically forms high, massive cliffs that show evidence of internal structural thickening and brittle and plastic deformation (Roberts, 1964; Skipp and others, 1999; Lonn and others, 2000).

**IPMSr Snowcrest Range Group (Pennsylvanian and Upper Mississippian)-** Includes the Conover Ranch and Lombard Formations. Gray and dark-gray fossiliferous limestone (brachiopods, corals and crinoids are most common), calcareous mudstone siltstone and subordinate gypsum beds (Skipp and others, 1999; Lonn and others, 2000).

## Appendix C

### MAP SYMBOLS

|                                                                                     |                                                                                                                                                             |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
|    | Contact- Dashed where approximate, dotted where concealed.                                                                                                  |
|    | Normal fault- Dashed where approximate, dotted where concealed. Ball is placed on the downthrown side.                                                      |
|    | Thrust fault- Dashed where approximate, dotted where concealed. Teeth are placed on the upthrown side.                                                      |
|    | Strike slip fault- Arrows indicate direction of relative motion.                                                                                            |
|    | Anticline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.            |
|  | Syncline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.             |
|  | Overturned anticline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge. |
|  | Overturned syncline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.  |
|  | Landslide scarp- Line indicates landslide breakaway surface. Teeth are placed on the down-dropped side.                                                     |
|  | Parasitic folds                                                                                                                                             |
|  | Strike and dip of beds                                                                                                                                      |
|  | Strike and dip of overturned beds                                                                                                                           |

## Appendix D

### Cross Section X-X" Units for the Dell 7.5-minute quadrangle, MT

#### Units:

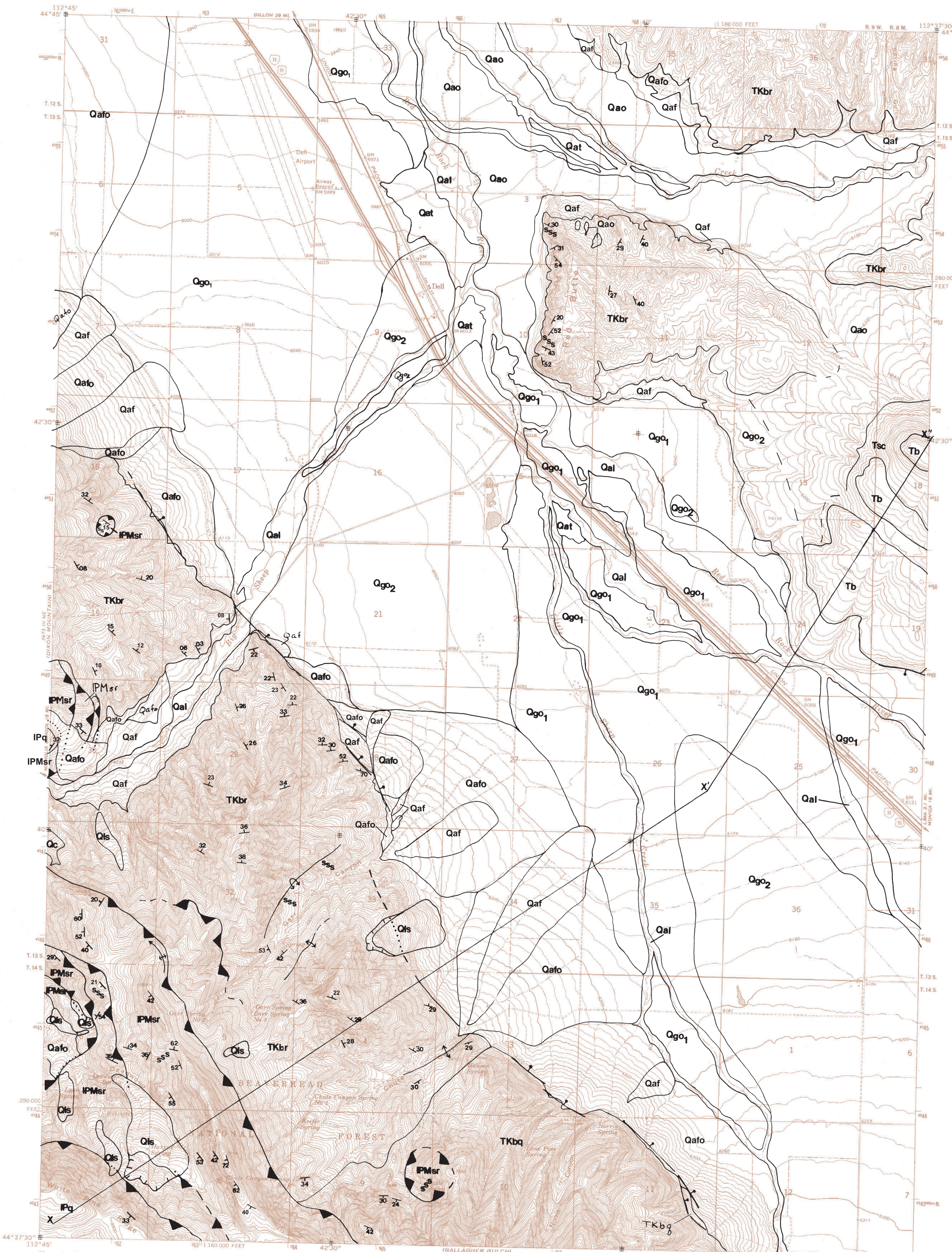
|      |                                                      |
|------|------------------------------------------------------|
| QTu  | Quaternary and Tertiary sedimentary units, undivided |
| Tba  | Tertiary basalt                                      |
| TKb  | Tertiary and Cretaceous Beaverhead Group             |
| Kf   | Cretaceous Frontier Formation                        |
| IPq  | Pennsylvanian Quadrant Formation                     |
| IPMr | Pennsylvanian-Mississippian Snowcrest Range Group    |
| Mu   | Older Mississippian rocks, undivided                 |

#### Symbols:

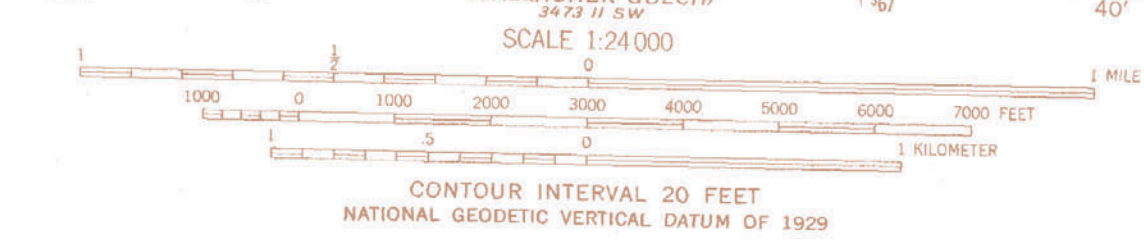
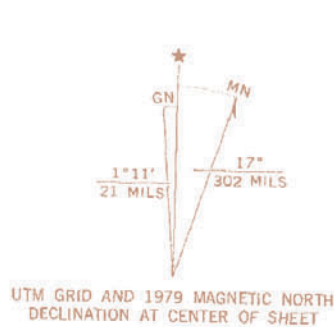
|                                                                                     |                                            |
|-------------------------------------------------------------------------------------|--------------------------------------------|
|    | Bedding contact                            |
|    | Fault                                      |
|  | Syncline                                   |
|  | Unconformity                               |
|  | Blind fault                                |
|  | Intraformational thrust and parasitic fold |
|  | Inferred reference bed                     |
|  | Inferred fault                             |
|  | Inferred unconformity                      |

#### Abbreviations:

|     |                       |
|-----|-----------------------|
| BIS | Bend in section       |
| CC  | Chute Canyon          |
| DG  | Deadwood Gulch        |
| WP  | White Pine Ridge      |
| LT  | Lima thrust           |
| TT  | Tendoy thrust         |
| RN  | Red Rock normal fault |



Mapped, edited, and published by the Geological Survey  
Control by USGS and USGS/USGS  
Topography by photogrammetric methods from aerial  
photographs taken 1954. Field checked 1965.  
Polyconic projection, 1927 North American datum  
10,000-foot grid based on Montana coordinate system,  
south zone  
1000-meter Universal Transverse Mercator grid ticks,  
zone 12



MAP SYMBOLS

- Contact- Dashed where approximate, dotted where concealed.

Normal fault- Dashed where approximate, dotted where concealed. Ball is placed on the downthrown side.

Thrust fault- Dashed where approximate, dotted where concealed. Teeth are placed on the upthrown side.

Strike slip fault- Arrows indicate direction of relative motion.

Anticline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.

Syncline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.

Overturned anticline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.

Overturned syncline- Line indicates trace of axial plane, dashed where approximately located, dotted where concealed. Arrow indicates direction of plunge.

Landslide scarp- Line indicates landslide breakaway surface. Teeth are placed on the down-dropped side.

Parasitic folds

Strike and dip of beds

Strike and dip of overturned beds
- 
- Cross Section X-X' Legend
- Units:

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Quaternary and Tertiary sedimentary units, undivided

Tsc

Sixmile Creek Formation

Tba

Tertiary basalt

TKb

Tertiary and Cretaceous Beaverhead Group

Kf

Cretaceous Frontier Formation

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Pennsylvanian Quadrant Formation

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Ms

Older Mississippian rocks, undivided

Abbreviations:

BIS

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Red Rock normal fault
- Symbols:

Bedding contact
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- Intraformational thrust and parasitic fold
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- Inferred fault
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