Altitude of the top of the Madison Group in part of Cascade County, Montana

by

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Author's Note: This map is part of the Montana Bureau of Mines and Geology (MBMG) Ground-Water Assessment Atlas for the Cascade-Teton Area ground-water characterization. It is intended to stand alone and describe a single hydrogeologic aspect of the study area, although many of the area's hydrogeologic features are interrelated. For an integrated view of the hydrogeology of the Cascade-Teton Area the reader is referred to Part A (descriptive overview) and Part B (maps) of the Montana Ground-Water Assessment Atlas 7.

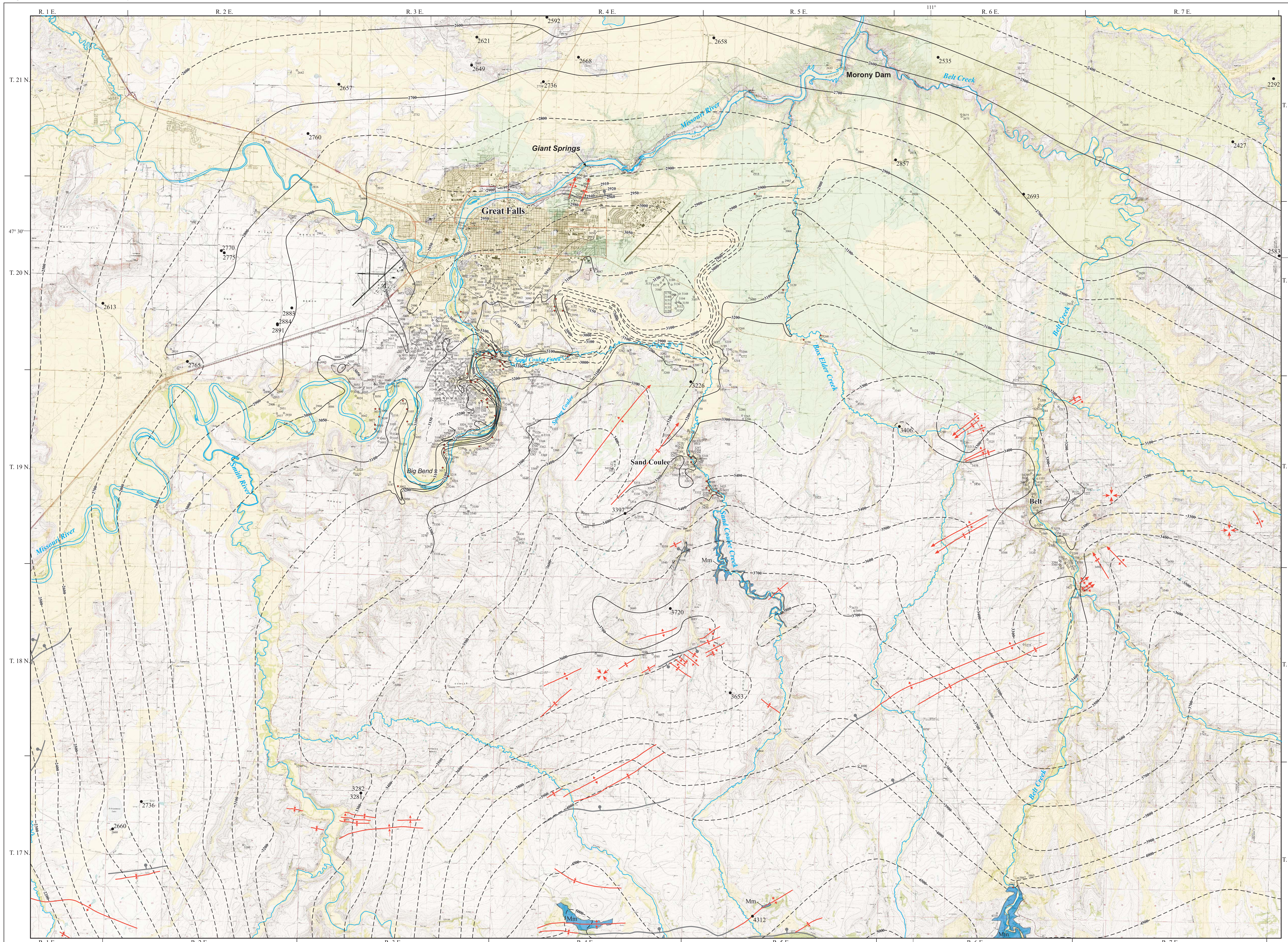

Figure 1. Altitude of the top of the Madison Group in parts of Cascade, Chouteau, and Judith Basin Counties; map location and extent is shown on figures 2 and 6.

Base information is from scanned versions of USGS 7½-minute quadrangles provided by the Montana Natural Resource Information System http://nris.mt.gov/

INTRODUCTION

The Mississippian Madison Group is an important and productive aquifer in Cascade County and the Great Falls area. This map shows the altitude above sea level of the top of the Madison beneath younger sedimentary rocks and unconsolidated surficial sediments (fig. 1). The altitude of the top of the Madison was estimated from well logs and outcrops. The Madison is the oldest rock unit and deepest aquifer used in the Cascade-Teton Area, except in the small areas where older rocks crop out in the Little Belt Mountains (figs. 1, 2).

Development of ground-water resources in the Madison aquifer began in the early 1900s, but increased significantly during the 1990s as land near Great Falls was subdivided and developed for housing reliant on domestic wells. Feltis (1980) mapped the regional structure of the Madison previously. Wilke (1983) mapped the subsurface altitude of the top of the Madison in the 15 townships centered on Great Falls (fig. 4) using an unknown number of water-well logs available at that time (the points were not shown on her map). The Madison water wells drilled since the 1980s provided data necessary for refining these older maps.

Geology

In Cascade County, the Madison Group is composed of two formations. The upper Mission Canyon is mostly massive to thick-bedded, fossiliferous limestone with thin chert interbeds, and the underlying Lodgepole Limestone is a thin-bedded fossiliferous limestone and subordinate mudstone (fig. 3). Within the study area, an erosional unconformity affected total Madison Group thickness; thicknesses range from about 1,200 to 1,700 feet. Solution breccias of limestone and some sandstone clasts in a matrix of reddish shale and residual soils are common near the top of the formation. In central Montana, solution breccias, soils, and caverns developed during erosion of the Madison rocks as early as the Mississippian (Petty, 2006), and periodically into the Jurassic (Mudge, 1972; Geraghty and Sears, 2004) when the region was subaerially exposed. Most caverns at the top of the Madison were filled with sediment when deposition resumed.

The Sweetgrass Arch is a broad northwest-plunging anticline that extends from the Little Belt Mountains, through Great Falls, and north into Canada (Perry, 1928; Lorenz, 1982). The arch controls the general subsurface position of the Madison Group and other strata. The previous structure maps show the Sweetgrass Arch with nearly evenly spaced, smooth structure contours on the top of the Madison (Feltis, 1980; Wilke, 1983).

Rocks of the Big Snowy, Amsden, and Ellis Groups overlie the Madison. These rocks thicken southwestward towards the Little Belt Mountains, and easterly and westerly away from the Great Falls area. Jurassic erosion caused thickness changes across the arch. On the axis of the arch, between Great Falls and Belt, all but the Swift Formation of the Ellis Group is absent and the Swift is generally less than 20 feet thick. The Morrison Formation overlies the Swift, or the Madison where the Swift is absent (fig. 3). Cretaceous rocks of the Kootenai and Blackleaf Formations also are gently folded by the Sweetgrass Arch, showing that the structure had a long history of activity that continued through the Cretaceous (Payenberg, 2003; Payenberg and others, 2003).

Quaternary stream and glacial deposits locally overlie the Madison on the crest of the Sweetgrass Arch. Prior to Pleistocene glaciation; the Missouri River flowed through an entrenched canyon, which is now lower Sand Coulee Creek valley. The trace of the pre-glacial channel extends through the Fields area to near the location of Morony Dam (figs. 2, 5; Fisher, 1909; Alden, 1932). The advance of the Laurentide ice sheet during the most recent Pleistocene glaciation dammed the Missouri River forming Glacial Lake Great Falls. Lake sediment back-filled the Missouri River valley and its tributaries, including the pre-glacial canyons cut into the Madison. Deglaciation and lake drainage resulted in rearrangement of the stream courses to their present locations. As part of their report on the engineering and subsurface geology of the Great Falls area, Lemke and Maughan (1977) mapped the thickness of Quaternary deposits from boreholes drilled for that project and examined water-well logs. Their map shows the meandering paleochannel of the Missouri River south and east of Great Falls represented on figures 1 and 5.

The locations of coal exploration boreholes and coal outcrops in the upper Morrison Formation in the central part of the map area (Kravits, 1981; Daniel and others, 1992) are shown in figure 6. The structure of the coal and laterally equivalent dark shale interval was used to understand stratigraphic relationships between the Madison and overlying formations.

Ground water

Water from the Madison aquifer is used for self-supplied and community domestic, stock, industrial, and minor irrigation purposes in the Great Falls area and south to the Little Belt Mountains. Ground water is produced from the Madison only where it is fractured or where solution cavities have developed; typically, the unfractured limestone is not sufficiently permeable to be considered an aquifer. The altitude of the subsurface and exposed Madison Group is important to water users in Cascade County because that determines drilling depths for wells. Most wells provide adequate amounts of water by penetrating a few tens of feet into the Madison; however, some wells on the flanks of the Little Belt Mountains must penetrate many hundreds of feet into the unit where the upper part of the Madison is undersaturated. Ground water in the Madison flows generally north and discharges to shallower formations or surface water, such as at Giant Springs where it flows in fractures through the overlying Kootenai Formation.

This map may be useful to individuals who must estimate drilling depths and completion levels for water wells and as an aid in planning new subdivisions or other developments reliant on Madison Group ground water. Depths to the top of the Madison can be calculated by subtracting the contoured altitude portrayed on the map from the land-surface altitude from a topographic map. The map also shows areas where the unit is exposed. Wells completed in the Madison reportedly yield an average of 30 gallons per minute (gpm), but maximum reported yields exceed 500 gpm.

DATA SOURCES AND MAP CONSTRUCTION

Data used for contouring the altitude of the Madison Group bedrock surface came from water-well logs, wireline and lithologic logs of hydrocarbon exploration boreholes, and surface geologic maps. Of the nearly 5,100 water wells with lithologic logs in Cascade County, about 750 were interpreted to intersect the top of the Madison Group. Five logs from water wells in Chouteau and Judith Basin Counties added control points north and east of Cascade County; there are no reported water wells in Teton County that encounter the Madison Group. All of the known penetrations of the Madison Group with confirmable locations were used in contouring. Well locations were verified by field visits (139 wells) or by comparison of well- and land-ownership records; some well locations were confirmed by talking to the well owners. Additionally, logs of wells that were drilled to aquifers above the Madison were used to constrain the maximum altitude of the Madison. Wireline or sample logs of oil and gas exploration wells were used to map the regional structure of the Madison Group in the map area (30 logs) and in the region (340 logs). All locations, reported altitudes, and tops of formations were checked for consistency.

A structure map of the Jurassic coal or dark shale interval near the top of the Morrison Formation (fig. 3) helps explain the timing of deformation (folding and faulting) for units below this horizon (fig. 6). Comparison of the structure portrayed on figure 1 with that shown on figure 6 indicates whether folding or faulting occurred before or after deposition of the Jurassic Morrison coals in any given area. Figure 6 was constructed by contouring data from 120 water-well logs, 17 other borehole logs, 44 coal exploration boreholes, and 177 surface locations of coal outcrops taken from the National Coal Resources Data System (NCRDS) coal database (Kravits, 1981, and Daniel and others, 1992).

All depth-to-formation values derived from well-log data were converted to altitudes above sea level by subtracting the depth values from land-surface altitudes. Land-surface altitudes at oil- and gas-well locations were taken from the logs themselves. For visited water-well logs, land surface altitudes were obtained from the 1:24,000-scale U.S. Geological Survey topographic maps. Altitudes for the remaining unvisited wells were obtained from 1:24,000 topographic maps for their inferred locations. The altitudes of the upper contact of Madison Group at outcrops mapped on 1:100,000-scale geologic maps were picked from topographic maps to aid contouring of the Madison. Faults and folds expressed in the surface formations in the area south of Great Falls (fig. 1) were used to constrain contours in small areas. Because of imprecision in the well-log data, contours were typically drawn only where multiple data points supported the contour placement. Contours were drawn by hand and then digitized.

The contour interval of figure 1 is 100 feet. However, because data are unevenly distributed across the map, a few supplementary contours could be drawn in areas with exceptional well control, and a 500-foot contour interval was used south of Great Falls. Where well data poorly constrain the position of contours, dashed (approximate) contours are used.

Water-well driller logs and well locations are stored in the Ground-Water Information Center database at the MBMG. Coal-, oil-, and gas-well log data are available through the MBMG. The outcrop areas of the bedrock were simplified from digital versions of published geologic maps (fig. 4).

DISCUSSION

Regional Configuration of the Bedrock Surface

The general configuration of the Madison top is a broad, north-northwest plunging anticline that begins with a broadly arching outcrop expression along the northern flank of the Little Belt Mountains. South of Great Falls, the western flank of the anticline trends north-south and dips west. East and north of Belt, the Madison dips to the northeast. Near Great Falls, the arch is slightly asymmetric with limbs dipping about 2 degrees southwest and about 1 degree northeast. Between these flanks, the crest of the broad anticline is irregular because of the Mississippian and Jurassic erosional unconformity and the erosion during the Pleistocene (fig. 1). In the northern part of the map, the more regular, northwest-plunging anticlinal form of the Sweetgrass Arch is evident.

Great Falls and Missouri River areas

The altitude of the Madison top in areas near and south of Great Falls is broadly anticlinal, with minor secondary folding, and is highly irregular in detail. Abundant well data between Great Falls and the Big Bend of the Missouri River clearly show the complex bedrock surface (figs. 1, 2). Secondary folding is evident in northeastern Great Falls area where a north-to-northeast plunging syncline-anticline pair is mapped near Giant Springs (fig. 1).

The most irregular area on the top of the Madison Group is the paleochannel of the Missouri River incised into the top of the Madison Group beginning 4–5 miles southwest of Great Falls, upstream of the Big Bend, extending up Sand Coulee Creek through Gibson and Johnson Flats and then trending northeast toward Morony Dam (figs. 2, 5). The channel is best defined in about 80 well logs that show Quaternary deposits directly overlying Madison Group limestone (fig. 1, red dots). At these locations, the overlying Jurassic and Cretaceous sedimentary rocks were eroded along the pre-glacial Missouri River and its tributaries, exposing the Madison Group. Quaternary alluvial and lake sediments were later deposited in the canyon covering the Madison and extending onto adjacent eroded Swift, Morrison, and Kootenai Formations.

The well-log data show that the base of the Missouri River paleochannel decreases in altitude downstream along the subaerial channel towards the northeast. The sediment-filled canyon is generally about one-quarter to one-half mile wide, and has a buried local relief of about 300 feet; at its narrowest, it is only about one-eighth mile wide with a buried local relief of 200–250 feet. The maximum thickness of fill recognized in well logs was 495 feet near the downstream end. Quaternary sediments are commonly 300–350 feet thick from the Big Bend to the confluence of the Missouri River with Sand Coulee Creek. At a few locations where data are sufficiently closely spaced, tributary canyons can be recognized. The most prominent tributary canyon is that of the paleo-Sun River where it entered the Missouri from the northwest in T. 20 N., R. 3 E., sections 25 and 36 (figs. 1, 5).

Outside of the Missouri River paleochannel, the top of the Madison beneath Jurassic and Cretaceous rocks is very irregular between the Great Falls International Airport and the Big Bend, southwest of Great Falls (fig. 1). Local relief of 50–75 feet over distances of one-quarter to one-half a mile is apparent in this area of dense well control. Data on the structure of the Morrison Formation dark shale interval in the Great Falls area are insufficient to show detail in the structure above the Madison (fig. 6). The local relief most likely reflects paleotopography on the erosional unconformity that defines the top of the Madison Group.

Folding, faulting, and fracturing of the Madison Group and overlying rocks influence ground-water flow and development. A steepened northward dip of the Madison in the northeastern Great Falls area, shown by the contour spacing near an altitude of 2,950 feet on the map (fig. 1) may be an east-west trending normal fault. These fractures are transverse to secondary folds mapped in the area, but are roughly parallel to N. 70 ° W. fractures at Giant Springs. Water is interpreted to travel along these fractures from the Madison through the Kootenai Formation to Giant Springs (Lemke and Maughan, 1977).

Sand Coulee and north flank of the Little Belt Mountain areas

The area south of Great Falls and the Missouri River paleochannel is drained by north-flowing streams from the Little Belt Mountains. well-log data from near the town of Sand Coulee show that Sand Coulee Creek and possibly Spring Coulee and other tributaries, were incised to the Madison Group; Glacial Lake Great Falls deposits eventually buried the canyons. The contours on figure 1 between the Sand Coulee Creek and Spring Coulee drainages show a northeast-plunging anticline-syncline pair in T. 19 N., R. 4 E. This structure is also apparent in the outcrop patterns of the overlying Jurassic and Cretaceous units shown on Vuke (2000), and is therefore related to structural folding and not erosion. Additionally, the overlying coal beds in the Morrison Formation are folded along the syncline near Sand Coulee Creek (fig. 6) and the syncline is not coincident with the creek valley (fig. 1). Therefore, this irregularity in the Madison surface, shown by the 3,200-foot contour, is probably not the result of incision. However, erosional removal of Jurassic rocks above the Madison in the stream channel near Centerville, as shown by wells and the 3,300- and 3,400-foot contours, shows that some of the irregularities in the Madison surface were due to paleochannel incision by the Missouri River and its tributaries before deposition of the glacial sediments.

On the north flank of the Little Belt Mountains, between the Smith River and Box Elder Creek (T. 18–19 N., R. 2–5 E.) there are some irregular northeast and east-northeast structural trends in the top of the Madison (fig. 1). These structures are coincident with some faults and folds in the overlying Kootenai Formation (fig. 1; Vuke, 2000) and the Morrison coal interval (fig. 6). The sparse well-log data suggest locally faulted anticlines and synclines are continuous along a trend of about N. 75º E. from about the Smith River to a few miles east of Belt. This tectonism must be Cretaceous or younger in age.

Belt area

The top of the Madison Group near the city of Belt and along Belt Creek is at a lower altitude than most adjacent areas (fig. 1). A number of wells near Belt indicate a northeast trending depression in the bedrock that is not coincident with the trend of Belt Creek. The southern and southwestern part of the depression is poorly defined by well data. The northeastern part of the depression, near Belt Butte, is near a small structural depression in T. 19 N., R. 7 E., section 19 (fig. 1). Vuke, Berg, and others (2002) interpreted this depression as a collapse structure where Cretaceous rocks collapsed into a void formed by dissolution of the Madison.

Kravits (1981) recognized thickening and thinning of coal intervals in the upper Morrison Formation between the town of Belt and the Smith River. He attributed localized subsidence of the Madison Group in collapse structures due to karstic erosion as a factor in controlling the distribution of coal depositional environments. Based on this previous work and the alignment of the east-northeast trending depression near Belt with the numerous structural features between Belt Creek and the Smith River, the Belt-area depression may be related to both structural deformation and collapse of karst features. The structure of the upper Morrison Formation in this area shows the regional form of the Sweetgrass Arch with secondary structural irregularities (fig. 6). For instance, southwest of Belt, there is a structural high in the Morrison, defined by the 3,700-foot contour (fig. 6), that is coincident with structure in the Madison (fig. 1). However, the basin in the Madison east and southeast of Belt (fig. 1) is not evident at the Morrison coal interval (fig. 6). These geologic relationships suggest that some downwarping in Jurassic rocks were a result solution collapse in the underlying Madison Group, and that sedimentation at and below the coal interval filled in a basin. Basin features recognized at land surface in Cretaceous rocks east of Belt (fig. 1), suggest that local areas of karst subsidence in the Madison Group continued into, or beyond, the Cretaceous (Vuke, Berg, and others, 2002).

SUMMARY

The altitude of the Madison Group top in Cascade County is highly variable, making prediction of drilling depths more problematic in some areas than would be inferred from earlier maps. The improved detail on this map should help people contemplating development of ground water from the Madison make more informed decisions. The variability is a result of structural deformation (folding and faulting) and a long history of erosion of the Madison. The main structural feature is the Sweetgrass Arch—a broad anticline that extends north-northwest from the northern flank of the Little Belt Mountains, through the city of Great Falls, and into southern Canada. East-northeast/west-southwest oriented folds and faults disrupt the Madison Group between Great Falls and the northern flank of the Little Belt Mountains. Solution collapse from karstic erosion in the upper Madison is evident near the town of Belt. The timing of the erosion and collapse began prior to and during Jurassic erosion and deposition in the area, and possibly may have continued during and after the Cretaceous.

The greatest local relief developed on the Madison Group was from stream erosion during pre-glacial, likely Pleistocene, incision by the Missouri River along a now buried paleochannel. The Missouri River eroded through the overlying Cretaceous and Jurassic strata, forming a narrow canyon in the Madison Group along what is now the lower reach of Sand Coulee Creek, Gibson Flats, Gerber, and Johnson Flats (Fisher, 1909; Alden, 1932; Lemke and Maughan, 1977). As the Pleistocene continental glacier advanced into the area, the Missouri was dammed forming Glacial Lake Great Falls. Lake sediments backfilled the Missouri River valley and its tributaries. Deglaciation and lake drainage caused rearrangement of the lower stream courses to their present locations.

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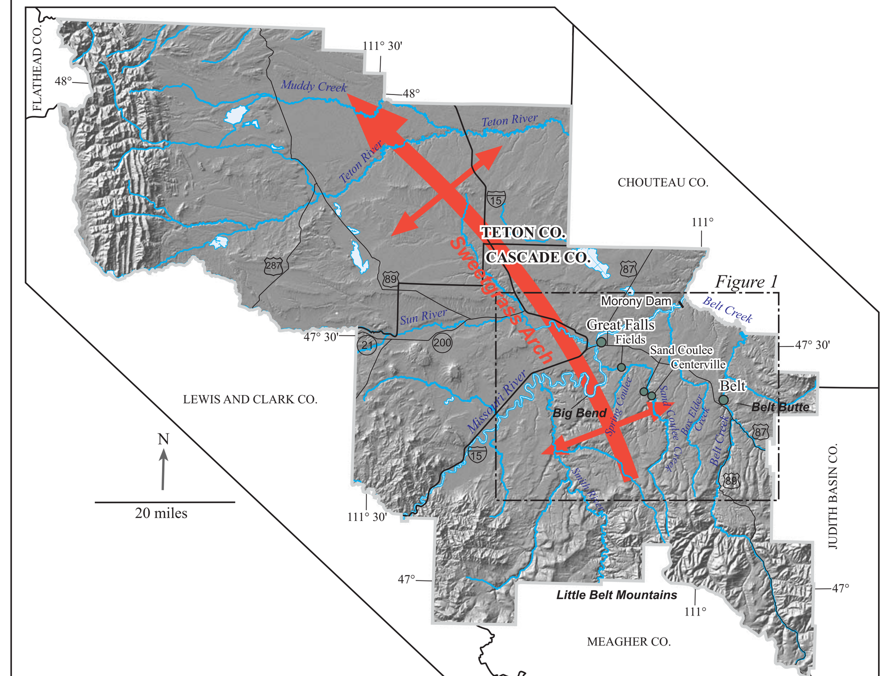


Figure 2. Index map of the Cascade-Teton Ground-Water Characterization Area showing cited principal cities, drainages, and physiographic locations.

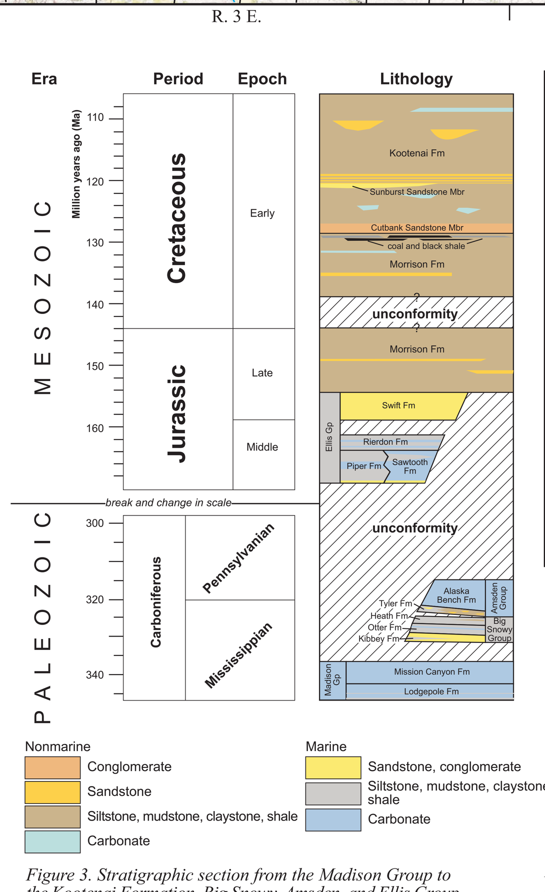


Figure 3. Stratigraphic section from the Madison Group to the Kootenai Formation. Big Snowy, Amsden, and Ellis Group rocks are discontinuous across the Sweetgrass Arch. Modified from Vuke and others (2007).

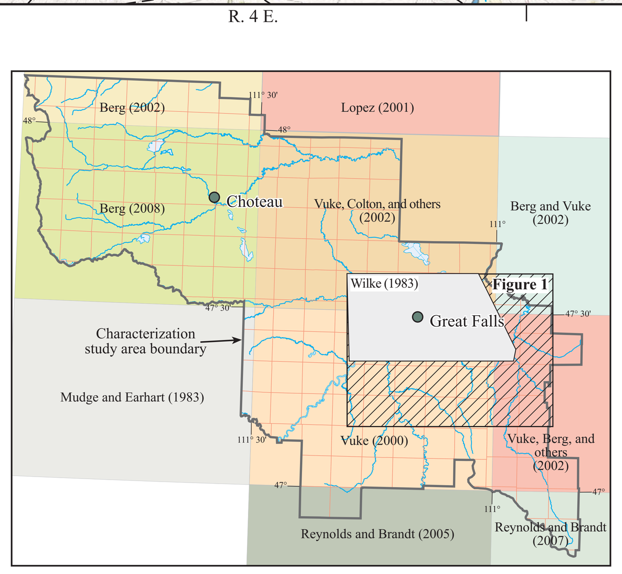


Figure 4. Geologic mapping in the Cascade-Teton study area recently completed at a scale of 1:100,000 is shown by the colored tiles. The extent of figure 1 is shown by the uncolored central area. Wilke's (1983) subsurface map extent lies within bounds of figure 1.

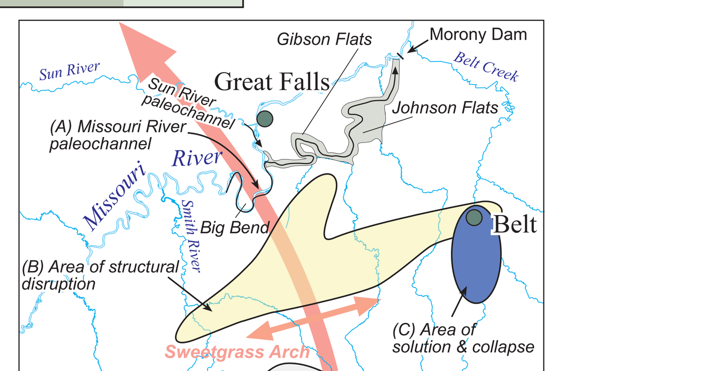


Figure 5. Simplified map showing irregularities on the subsurface Madison Group top. (A) location of the buried pre-glacial course of the Missouri River; (B) location of areas of structural disruption; and (C) possible solution-collapse feature near Belt. Locations of creeks and populated places referenced in the text are shown.

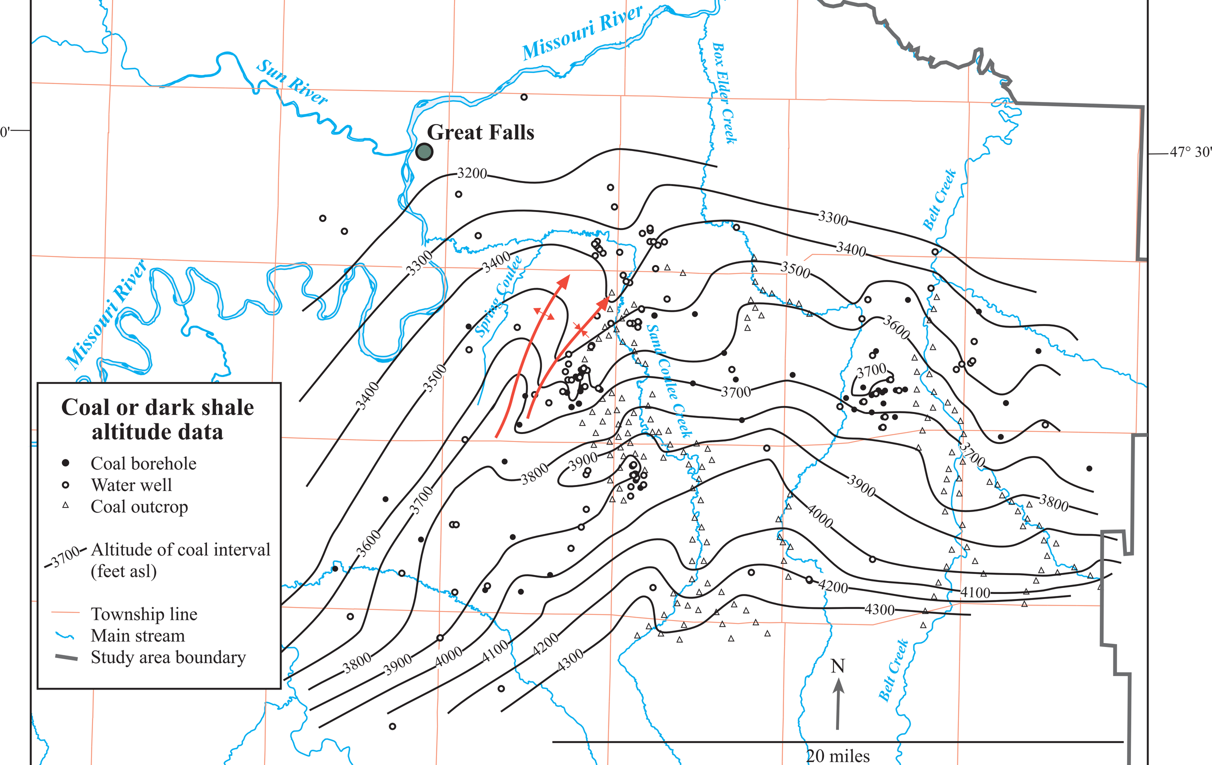
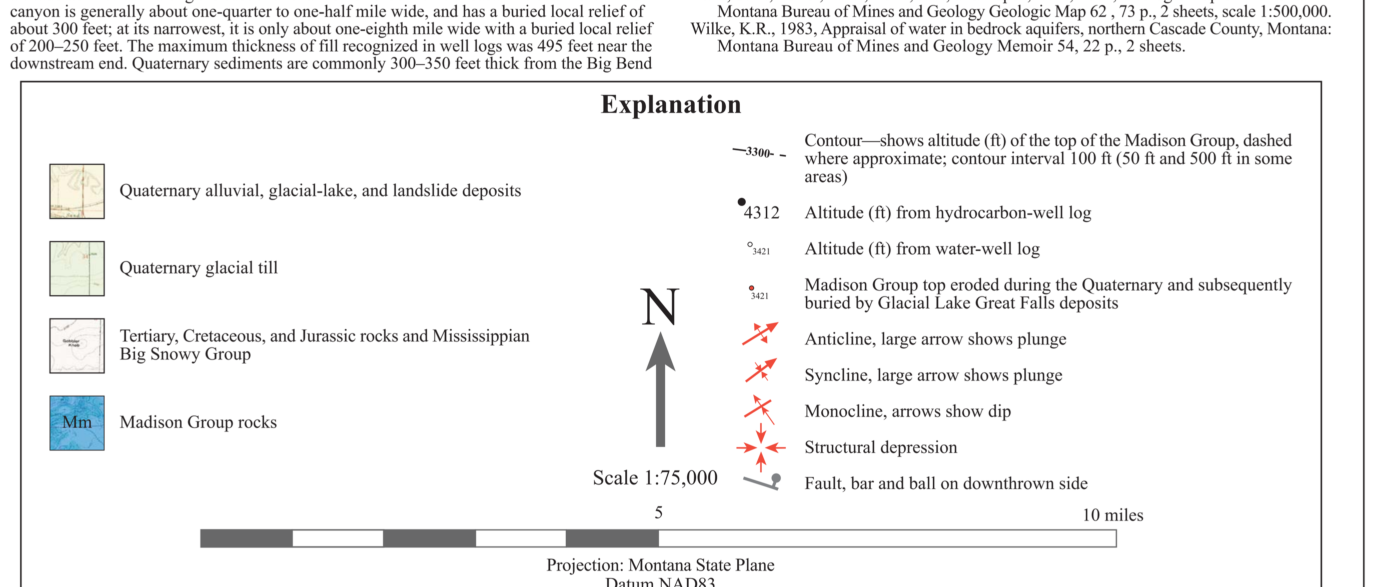


Figure 6. Altitude on top of coal or equivalent dark shale interval in the upper Morrison Formation.

Explanation



Projection: Montana State Plane
Datum NAD83