Potential for a Public Water Supply from the Madison Limestone in the Eastern Big Snowy Mountains and Little Snowy Mountains, Montana

Open File Report MBMG 449

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INTRODUCTION

Background and Purpose of the Study

The City of Roundup has been seeking an alternative to its existing public water supply for many years. Both the improvement of the existing supply and the possibility of nearby alternative supplies have been investigated through several studies, including Wheaton (1994) and Wheaton (1999). However, neither treatment of ground water from the Republic Number 1 mine, the existing supply, nor construction of a surface-water treatment facility and withdrawal of water from the Musselshell River has proved desirable. Therefore, the city chose to investigate a third alternative: exploration for and development of a ground-water resource near the major ground-water recharge area of the Big and Little Snowy Mountains, about 50 to 60 miles northwest of Roundup (Fig. 1). If a ground-water resource could be located and developed, a pipeline would be constructed to deliver water to Roundup. This report summarizes the first phase in evaluating the possibility of locating and developing a public water supply well in the Madison limestone aquifer close to the mountains.

The premise of this project is that the Madison limestone, a regionally significant aquifer, is capable of providing municipal water supply needs for the City of Roundup. On the north flank of the Big Snowy Mountains, the Madison limestone aquifer is the source for Lewistown′s Big Spring. Madison limestone rocks located on the south side of the mountains may have similar potential if tapped by properly located wells.

Choice of Potential Municipal Well Site

At the outset of the discussions in September, 1999, in Roundup, it was assumed that the lower south flank of the Big Snowy Mountains, on the gravel benches and near the mountain front, would be the most likely location to investigate the Madison water supply potential (Figs. 1, 2). The Madison limestone is exposed along the crest and down the upper south flank of the Big Snowy range. During the discussions, however, geologic and hydrologic reasons were offered for why this lower south flank of the Big Snowy range might not be preferable. These reasons include: (1) a more limited recharge area along most of the south flank as compared to the north flank, based on the asymmetric geometry of the Big Snowy Mountains anticlinal form; (2) the steep dip of bedrock on this southern mountain flank which increases drilling depth to the Madison; (3) uncertain position of the axis of the known synclinal fold in the Wheatland Basin to the south under gravels; a planned water well would need to be on the north side of this axis; (4) known poor Madison water quality in the Wheatland Basin, probably reflecting increased ground water temperatures related to the deeper level of Madison beds and to the longer retention time associated with water that is relatively far along the ground-water flow path. Thus, four other sites have

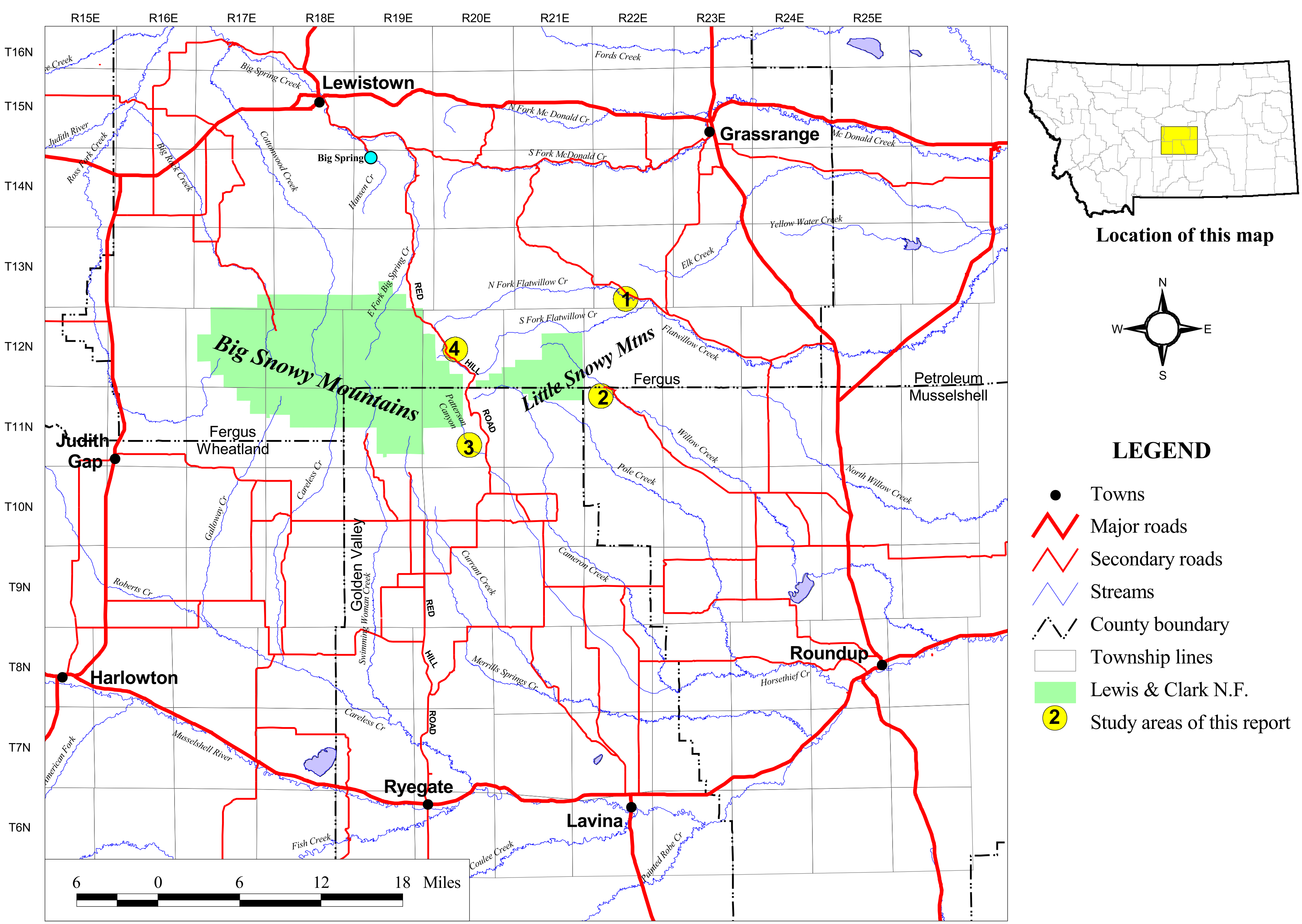

Figure 1. Location map for the four study areas and principal roads and streams of the region.

been evaluated -- (1) the Flatwillow Creek valley and (2) the Willow Creek valley, both on the east flank of the Little Snowies, (3) Patterson Canyon in the Big Snowies, and (4) the Middle Bench area between the North and South Forks of Flatwillow Creek in the Little Snowies (Figs. 1, 2). The first two areas were suggested at the September meeting; the latter two areas derive from analysis of existing geologic maps and hydrologic data during the course of preparing this report.

The Flatwillow Creek valley area was generally defined as the northern portion of T. 12 N., R. 22-23 E. (Figs. 1, 2), in the vicinity of Tyler on the N-Bar Ranch. This valley area lies on the gently northeast-dipping flank of the Little Snowy Mountains, down-gradient from the north flank of the Big Snowy Mountains where the Madison aquifer is exposed to recharge over a broad area. About 11 mi^2 of this recharge area probably supply the Madison aquifer below the Flatwillow valley.

The Willow Creek valley area was generally defined as where the creek comes through the mountain front, in the southern portion of T. 11-12 N., R. 22 E., (Figs. 1, 2) at the Musselshell-Fergus County line on the Pronghorn Ranch. Recharge to the Madison aquifer in the Willow Creek area appears to be limited to about 1-2 mi^2 of Madison aquifer outcrop near the eastern end of the Big Snowy anticline on its north flank.

The Patterson Canyon area is in the southern one-half of T. 11 N., R. 20 E. (Figs. 1, 2). It lies west of Red Hill Road on the south side of the Big Snowy anticline, within the Madison aquifer recharge area which here includes about 8 mi^2 of outcrop.

The Middle Bench area of the Little Snowies lies between the North and South Forks of Flatwillow Creek near the center of T. 12 N., R. 20 E. (Figs. 1, 2). This area is just down-gradient from the north flank of the Big Snowy Mountains where about 11 mi^2 of Madison aquifer outcrop can provide recharge.

Status of Geologic Information

The geology of the Big Snowy Mountains quadrangle and the east-adjacent Musselshell quadrangle has recently been mapped in detail by the Montana Bureau of Mines and Geology (MBMG) (Porter and Wilde, 1999, and Porter and others, 1996, respectively; map scales 1:100,000). These two maps provide the regional geologic framework for the areas being considered for a Madison municipal water supply. Regional hydrologic information for the Madison limestone was published by MBMG (Feltis, 1980a, 1980b). During the September, 1999 meeting in Roundup it was determined that the immediate need was for: (1) limited geologic field work and aerial photograph examination of the Flatwillow Creek and Willow Creek areas, looking for additional geologic details that might add to understanding of the rock units and structure to be encountered in these two areas; (2) evaluation of one or more well logs in the region to provide thicknesses of bedrock units for calculation of drilling depths; (3)

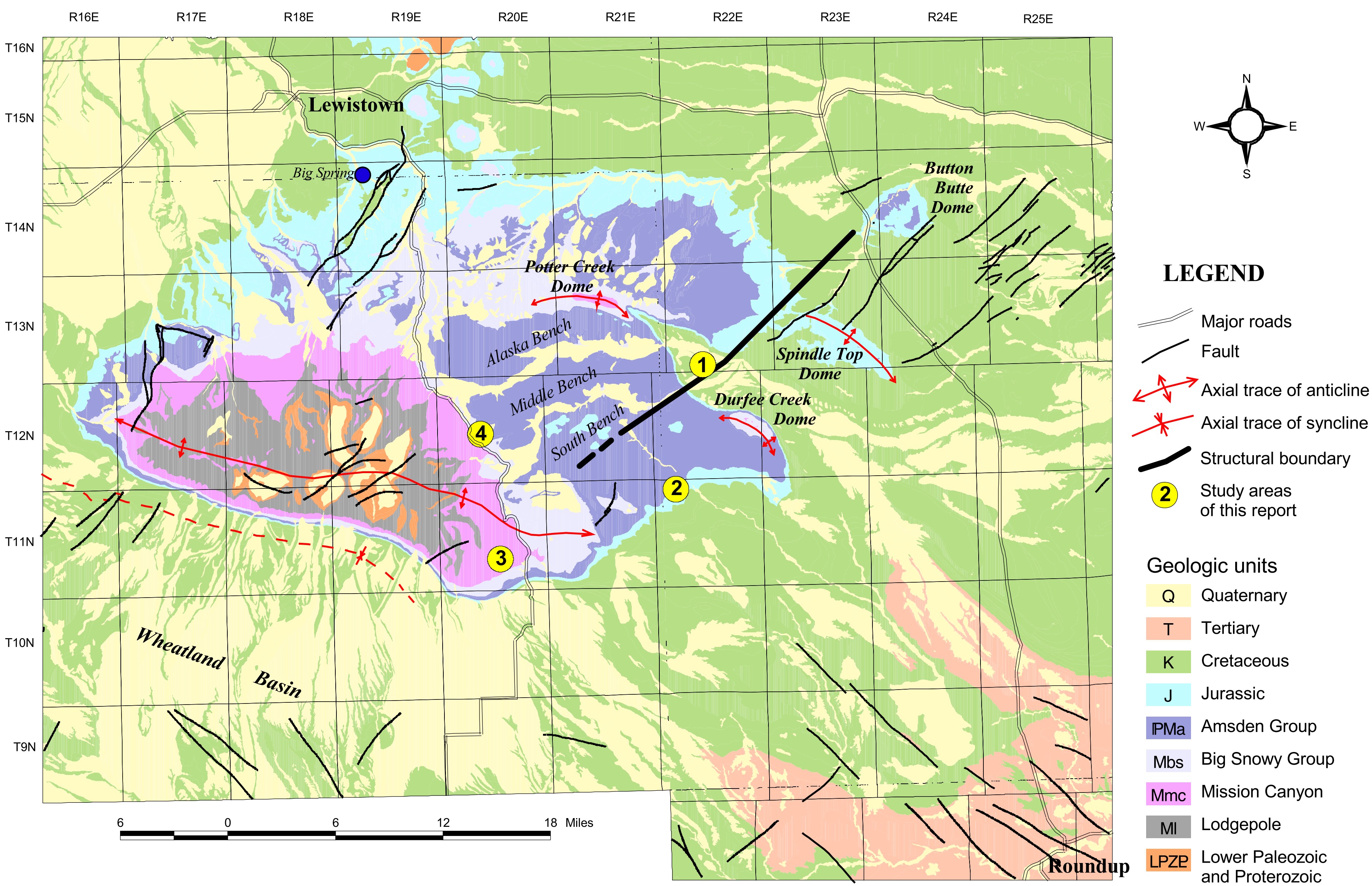

Figure 2. Regional geologic setting of the Big Snowy and Little Snowy Mountains. Heavy black line represents an apparent structural boundary; east of this line structural geology is complex; west of this line structural geology appears more predictable.

assessment of existing water quality/quantity information for the region; (4) assessment of the Flatwillow and Willow Creek valley areas for the occurrence of surface springs and water gain or loss in surface flow of streams; (5) evaluation of the geologic setting of the two valley areas with respect to recharge area, flow path, and potential influence of known geologic structures. During the course of conducting this work, particularly tasks 1 and 5, new understanding of the regional geologic framework became a basis for both the evaluation of the two originally planned areas (Flatwillow and Willow Creek valleys) and the recognition of the two additional areas (Patterson Canyon and Middle Bench).

GEOLOGIC SETTING

Regional Geologic Structure

As the geologic maps of the Musselshell and Big Snowy Mountains quadrangles indicate, the Madison limestone is extensively exposed in the Big Snowy Mountains where it is the main rock unit and forms a great arched or upfolded mountain mass. As these maps and the cross sections in Figure 3 also indicate, the axis of this great anticlinal fold (solid red line with opposing short arrows on figure 2) lies closer to the southern side of the mountains than to the northern side. The result of this asymmetry of the mountain mass is that the northern flank of the Big Snowy Mountains is broad and gently sloping in comparison to the steep southern flank (Fig. 3). This broad area of gentle dipslopes creates an area with excellent recharge potential. Rain and snowmelt waters soak into the limestones on the northern flank and flow downslope toward Lewistown's Big Spring and toward many other springs that produce Madison water along the mountain flanks. The Madison limestones are continuous from these broad, gently north-dipping slopes northeastward into the Little Snowy Mountains area, carrying Madison water beneath the surface (Figs. 2, 3). In fact, the Big Snowy and Little Snowy Mountains are a single mountain block; their distinction is a function of the topography developed across bedrock units of varying resistance to erosion. The central mass of the Big Snowies is the highly resistant Madison Group limestones (Fig. 4). The Little Snowies form the northeast flank of the mountain block; their rugged topography reflects the almost equally resistant Alaska Bench Formation limestones. Red Hill Road passes generally south-to-north where the topography is relatively low in less resistant beds of the Big Snowy Group.

The eastern Little Snowy Mountains are deformed into northwest-trending anticlinal and synclinal folds, such as Durfee Creek Dome and the Flatwillow valley, and are cut by several prominent northeast-trending normal faults (Fig. 2). The linear aspect of the southeast flank of the Little Snowies also suggests structural control on the bedrock. This pattern of intersecting northwest- and northeast-trending structure underlies all of central Montana and is well observed on the geologic maps of the region.

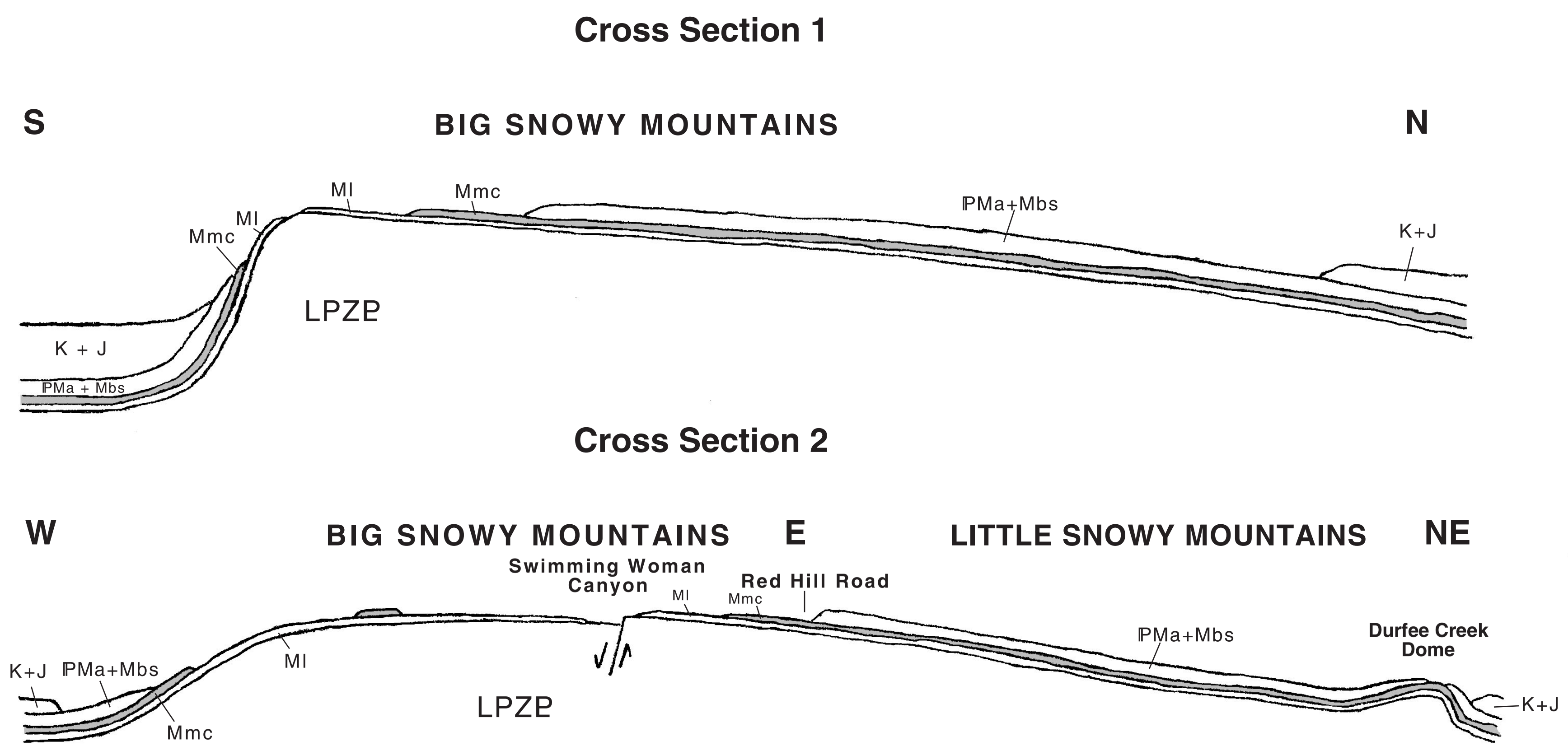

Figure 3. Schematic cross sections across the Big Snowy Mountains uplift. **Cross Section 1** is oriented south-to-north, showing the marked asymmetry of the uplift and the area of ground-water recharge of the Mission Canyon Formation (Mmc) aquifer. **Cross Section 2** is oriented west-to-east as far as Red Hill Road, then northeast across the Little Snowy Mountains to Durfee Creek Dome; it shows the Big and Little Snowy Mountains as areas of a single mountain block, a fault at Swimming Woman Canyon, and the asymmetry of Durfee Creek Dome. On Cross Section 2, apparent continuity of the Mission Canyon, from its recharge area in the Red Hill Road area eastward into the Little Snowies, may actually be broken by unrecognized folds and faults in the structurally complex eastern Little Snowies. See figure 4 for explanation of letter symbols. No horizontal or vertical scale implied; schematic only.

A generalized line may be drawn across the Little Snowy Mountains from south of Button Butte Dome southwestward up the lower South Fork of Flatwillow Creek to at least the upper reach of Willow Creek (Fig. 2). East of this line the potential for relatively complex subsurface bedrock conditions is significant; the Madison limestone aquifer is certainly folded and faulted in the subsurface of the eastern Little Snowies. The control that this deformed bedrock may exert on the ground-water flow system is unknown and difficult to predict. Thus, although the Madison limestones dip generally northeastward under the Little Snowies from their surface exposure along Red Hill Road in the Big Snowies, known and unrecognized geologic structures may redirect or completely interrupt ground water flow.

A poorly understood major thrust fault is known to underlie the Big Snowy Mountains at some depth (unpublished seismic line data). This east-west-trending fault is reported to dip about four degrees to the north, and data indicate that the Snowy Mountains crustal block has been transported up to four miles in a southward direction along the fault. This fault reflects the great compressional forces that dominated the region and produced the Rocky Mountains 65 million years ago; it has not been active since that time. Although very little is known about this thrust fault, the forces that produced it are the same forces that produced the folds and faults observed and mapped at the surface. Of considerable interest is the question of where this fault may have come to the surface, somewhere to the south in the Wheatland basin. Porter and others (1996) were not able to locate its surface expression.

Sedimentary Rocks of the Region

The Big and Little Snowy Mountains include a thick sequence of Paleozoic and Mesozoic sedimentary rocks (Fig. 4). Carbonates (limestone, dolomite) and evaporites (salt, gypsum, anhydrite) dominate the Paleozoic section, while sandstones and shales dominate the Mesozoic section. Although the Paleozoic and early Mesozoic rocks of central Montana represent a wide variety of ancient depositional settings, they have in common the fact that they were deposited within an ancient sedimentary basin called the central Montana trough (Maughan, 1993). This east-west-trending trough extended from Montana's western margin and occupied central Montana from North America's earliest geologic history until Late Cretaceous-Early Tertiary time about 65 million years ago. For much of its history the trough was drowned by the great continental seaways, but at other times it was partially exposed and subject to erosion. The trough was an unstable part of the earth's crust. Within it, periodic warping and faulting of individual crustal blocks occurred; reversal of movement was common. This repeated movement of crustal blocks greatly affected the distribution and the preservation of individual sedimentary rock layers. Many formations show a high degree of variability across the region, particularly with respect to thickness. It is common throughout the Big and Little Snowy Mountains for a formation to vary from several hundred feet thick to absent (Fig. 4). In Late Cretaceous time, compressional forces that uplifted the Rocky Mountains

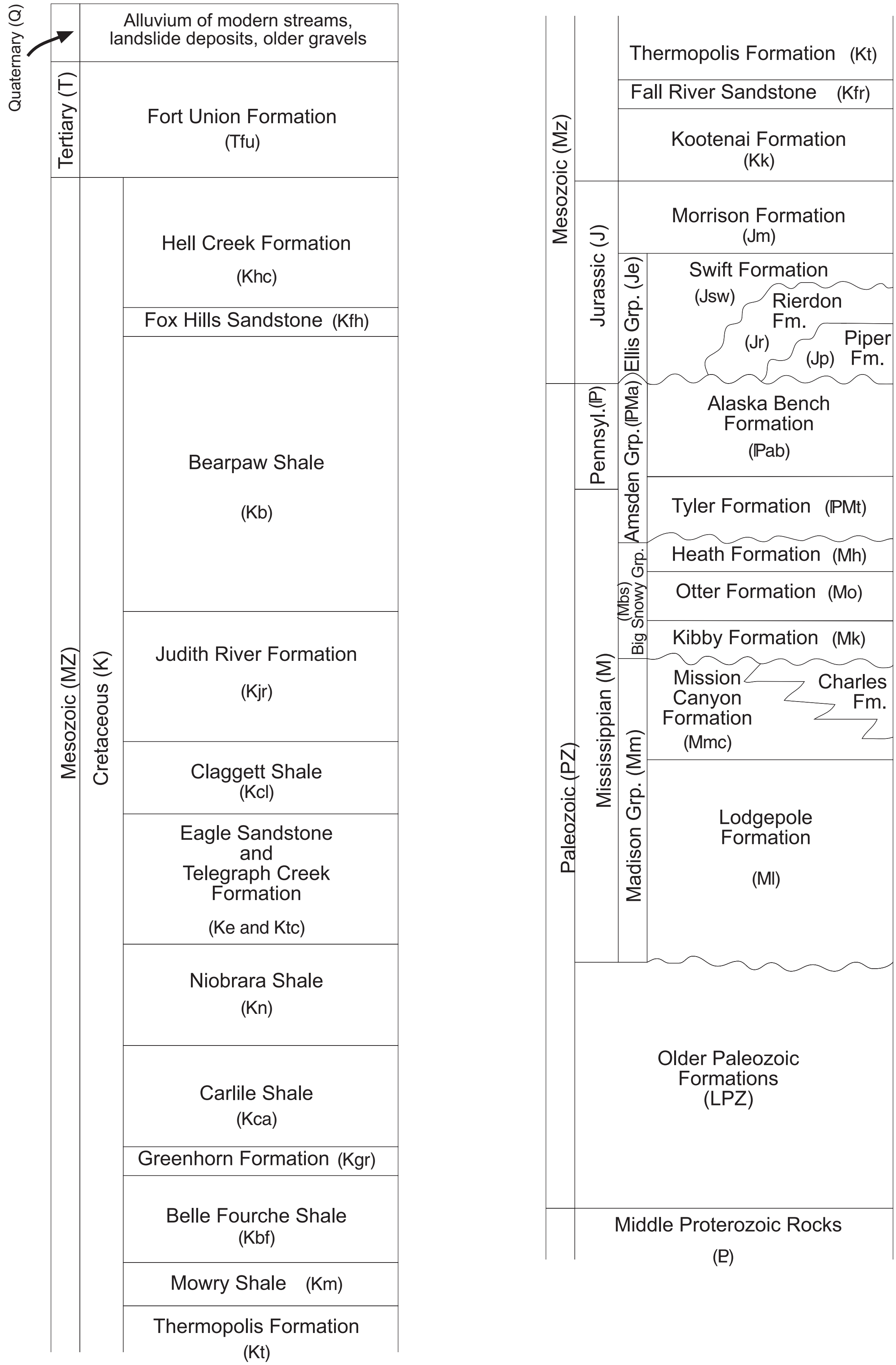

Figure 4. Chart showing names, letters symbols, and vertical succession of rock units exposed in region of Big and Little Snowy Mountains. Oldest units at bottom of right-hand column; youngest units at top of left-hand column.

inverted the central Montana trough. The uplifted Big and Little Snowy Mountains are an expression of part of that inversion.

The crest of the Big Snowy Mountains is formed by carbonates of the Madison Group (Mm) — the lower Lodgepole Formation (Ml) overlain by the Mission Canyon Formation (Mmc). The Mission Canyon is a major aquifer in central Montana and is the exploration target for a municipal water supply for Roundup. Immediately overlying the Mission Canyon and forming the uppermost formation of the Madison Group is the Charles Formation (Mc). The Charles is an evaporite sequence (salt, anhydrite, gypsum). This evaporite interval was largely removed by an ancient, post-Madison erosion event, but it may be present locally, and would bear directly on both quality and quantity of Madison ground water resources.

Overlying the Madison Group is the Mississippian age Big Snowy Group (Mbs) including the Kibby, Otter, and Heath formations (Mk, Mo, Mh, respectively). The Kibby is red-weathering sandstones, mudstones, and some evaporite; the Otter is bright green shales, and the Heath is dark limestone, black shale, and local evaporates. Formations of the Big Snowy Group, named for their occurrence in the Big Snowy Mountains, are highly variable in thickness and commonly absent locally. Above the Big Snowy Group is the Pennsylvanian-Mississippian age Amsden Group containing the Tyler Formation (IPMt) and Alaska Bench Formation (IPab). The Tyler contains sandstones and red mudstones; the Alaska Bench is white-weathering, brittle limestones that form the main area of the Little Snowies. Both of these formations are petroleum reservoirs at several oil fields in central Montana and are locally water-bearing, although not in volumes required for a municipal water supply.

Stratigraphically above the Amsden Group is the Jurassic (J) Ellis Group (Je) containing red beds and evaporates of the Piper Formation (Jp), yellow shale of the Rierdon Formation (Jr), and sandstones of the Swift Formation (Jsw). The upper Jurassic Morrison Formation (Jm) contains red beds and thin sandstones. Sandstones of the Swift and Morrison are generally low-yielding aquifers with poor water quality that is likely to be corrosive. Overlying the Jurassic age rocks, the basal Cretaceous (K) is the Kootenai Formation (Kk), predominantly red mudstone and sandstones. The Kootenai contains the thick basal sandstone known as the Third Cat Creek which is a good aquifer in the region, commonly used for domestic and stock water. The upper Kootenai is red beds and thin sandstones. The overlying brownish Fall River Sandstone (Kfr), also known as the First Cat Creek Sandstone, is commonly a good aquifer in the region. However, neither the basal Kootenai nor the Fall River provides adequate water for a municipal water supply. Above the Fall River, approximately 1,900 feet of gray shales characterize the Cretaceous strata up to the base of the Eagle Sandstone; the interval is largely nonwater-bearing. The Eagle is a regional aquifer but without adequate water volume for a municipal water supply.

Within the stratigraphic section just described, only the limestones of the Madison Group can provide adequate volumes of good-quality water for a municipal water supply for the City of Roundup. Where these beds are exposed along the crest of the asymmetric anticline forming the Big Snowy Mountains, meltwaters soak into the rock to initiate one of the major aquifers of the northern Rockies and plains region.

The Madison Aquifer

The Madison Group is a thick section of limestone and dolomite divided into two formations, the lower Lodgepole Formation (about 700 ft thick at Swimming Woman Canyon) and the upper Mission Canyon Formation (about 900 ft thick in Swimming Woman Canyon) (Maughan, 1993; Smith and Custer, 1987). An evaporite unit (anhydrite, gypsum), the Charles Formation, forms the uppermost Madison Group but is largely confined to the Williston Basin of eastern Montana. Major aquifers of the region are developed only in limestones of the Mission Canyon Member. Fluids (water, oil, natural gas) can be produced from these rocks (as from other sedimentary rocks) because of porosity and permeability. Porosity refers to the total open space in a rock including tiny spaces between grains, microfractures, larger fractures, solution cavities, and any other void space. This space, or porosity, is where the fluid is stored. Permeability refers to the size and interconnectedness of the pore spaces, and the ease with which a fluid can flow through the rock unit. Unless there is permeability, fluid cannot flow within the rock nor be pumped from it. Porosity and permeability in the upper Madison Mission Canyon Formation is related to extensive dissolution of limestone by ground water. The water moves along faults and fractures, dissolving rock as it flows and forming small and large solution cavities and abundant microporosity. This newly formed porosity is called secondary porosity, in contrast to primary porosity that may have been present in the original rock before the dissolution events. To produce large volumes of water, wells usually must encounter fractures and their associated solution cavities in the limestone.

Fractures in the Mission Canyon

Throughout the Rocky Mountain region the Madison Group limestones are highly fractured owing to the brittle nature of the limestone. When subjected to even minor stress within the crust, and particularly stress related to uplift and mountain-building, limestone tends to relieve the stress by fracturing, on scales from miles-long (lineaments) to microscopic.

Karst Surfaces of the Mission Canyon

The lime muds that slowly solidified to form the limestones had a complex depositional and erosional history. Periodic regional uplift raised the ocean floor sediments above sea level. Thus exposed to the air and to fresh (slightly acidic) rain water, the limestone surface underwent extensive erosion and dissolution. A deeply weathered, irregular surface developed called a karst surface, full of large and small cavities partly filled with red soils (terra rosa). Regionally, several such periods of karst development are recognized within the Mission Canyon Formation. In post-Madison time, about 330 million years ago, the western North American continent experienced major regional uplift that effectively drained the seas from the continent. Where overlying beds were removed by erosion, a deep karst topography was developed on the exposed Mission Canyon surface. This vast karst surface, and the other karst surfaces within the formation, are the reason for the high volumes of water the Mission Canyon is able to store and transmit.

Evaporite Rocks in the Mission Canyon

Evaporite beds are relatively common in the Mission Canyon (Maughn, 1993) but especially so in the Williston Basin of eastern Montana where the limestones interfinger with evaporates of the Charles Formation. Here, the Charles is the upper formation of the Madison Group (Fig. 4). After the post-Madison uplift and erosion, there remained some areas where the beds of the Charles Formation evaporite were not eroded away to expose the underlying Mission Canyon. In these areas the Mission Canyon's upper surface does not have the well developed upper karst surface observed elsewhere, and the potential volume of stored ground water is less. Additionally, where the evaporite beds remain, they provide dissolved salts to the ground water, potentially reducing its quality.

The stratigraphic relationship of the approximately 30 feet of evaporite beds above the Mission Canyon at Durfee Creek Dome (Porter, unpublished field data) must be further investigated because they suggest two potential concerns: (1) Evaporite deposits (gypsum, anhydrite) contain high levels of calcium sulphate that have a marked effect on water quality. It is important to learn whether these evaporite beds are present everywhere at the top of the Mission Canyon in the study area, or only locally; (2) These beds may be remnant Charles Formation beds, meaning that the upper Mission Canyon surface at this location was never exposed during the post-Madison erosion, and did not develop a karst surface. Alternatively, the evaporite beds may belong within the overlying Kibby Formation which was laid down long after the Mission Canyon karst surface was developed. Evaporite is common in the Kibby but not usually at the base of the formation. If the evaporite observed at Durfee Creek Dome belongs within the Kibby, then karst development on the upper Mission Canyon surface was probably not restricted, but the water quality issue remains.

Hydrologic Data for the Mission Canyon

Hydrologic maps by Feltis (1980a, 1980b) are useful for the Big Snowy Mountains but are based on data points that are distant from the Little Snowy Mountains. Ground-water quality in or near the Little Snowy Mountains has not been investigated. Water wells in the area produce from horizons above the Madison, and available Madison water-well data are too distant from the Little Snowies study areas to reflect water quality within the mountain front where it should be the best. Water quality data on maps by Feltis (1980b) indicate total dissolved solids loads of less than 1,000 mg/L for locations that are less than about 3 to 5 miles from the mountain front. Dominant ions are expected to be calcium, bicarbonate, and sulfate. However, data points on these maps are distant from the study areas in the Little Snowy Mountains.

Well Log Data: Formations and Thicknesses

The well log for the Continental #1 Government well drilled in 1956 in the Willow Creek valley (SW/4 section 18, T. 11 N., R. 23 E.), Musselshell County, is shown in Appendix 1. Annotated on the well log are the formation names and thicknesses of rock formations encountered in the well related to formations mapped at the surface. These "picks" for the tops of the formations believed to be present at this location are based on Maughan and Roberts (1967, Plate 2, well #38). These authors examined this same well log and based their interpretation on their extensive study of the Amsden Group (Tyler and Alaska Bench Formations) and Big Snowy Group (Kibby, Otter, and Heath Formations) (Fig. 4) in central Montana. They also used the well-log cuttings at the American Stratigraphic Company as the basis for the units they identify. These interpretations by Maughan and Roberts (1967) differ from the units and tops picked by the well-site geologist at the time the well was drilled and whose data are contained in the file on the well at the Montana Oil and Gas Conservation Board in Billings. Important differences are (1) a much thicker Alaska Bench Formation than is picked by the Continental geologist (who also called it Amsden); and (2) the bottom hole formation is identified as Heath Formation rather than Otter Formation as picked by the Continental geologist.

The information in Appendix 1 indicates that the Heath Formation is 270 feet thick at Durfee Creek Dome, and 76 feet thick at Beacon Hill 20.5 miles to the northwest. In the Continental well it is a minimum of 130 feet thick to the depth of well penetration. This information illustrates a critical aspect of the subsurface stratigraphy in the Big Snowy and Little Snowy Mountains region: formations of Mississippian, Pennsylvanian, and Jurassic age (Fig. 4) are highly variable in thickness regionally. This variability is very difficult to predict and relates to the geologic history of these rock sequences as they participated in the history of the central Montana trough in earlier geologic time. Primarily, the variability reflects (1) lateral changes in type of sedimentary rock originally deposited (facies changes), and (2) presence of regional unconformities (breaks in the sequence) caused by ancient erosional events during and after the time these sediments were being deposited. Thus, which units will be present in a well and how thick each will be is less predictable for these intervals than for other parts of the stratigraphic section. Nonetheless, within a local area, and based on the rock units mapped on the surface, subsurface units should be clear. The Continental # 1 Government well log would be a useful reference log for identifying rock units and thicknesses in a new drill hole, but significant local differences in units and thicknesses should be expected. The required penetration depth into the Mission Canyon Formation of the Madison is dependent upon encountering sufficient fractures and solution cavities to establish adequate water production; it cannot be known prior to drilling. Regionally, wells are drilled from 150 feet to 400 feet into the Mission Canyon to achieve desired ground-water yield.

EVALUATION OF STUDY AREAS

During discussions in Roundup, the potential for the lower south flank of the Big Snowy Mountains was downgraded because of anticipated geologic conditions that would negatively affect ground water resources (see p. 1). No additional time was spent on the lower south flank of the Big Snowies and this area is not discussed further in this report. Four other areas were identified and have been evaluated through discussions, analysis of existing hydrologic and geologic data, and minimal field work. They are: (1) the Flatwillow Creek valley and (2) the Willow Creek valley, both on the east flank of the Little Snowies, (3) Patterson Canyon in the Big Snowies, and (4) the Middle Bench area in the Little Snowies (Figs. 1, 2). Flatwillow Creek valley and Willow Creek valley were field investigated during one and one-half days of field time. During analysis of existing geologic maps for the Flatwillow and Willow Creek valley areas, two additional areas — the Patterson Canyon area and the Middle Bench area — were identified as prospective for adequate volumes of good quality water. Additional days were spent with aerial photographs and limited well logs, and available hydrogeologic information was assembled. The two recent geologic map publications, as well as the relevant 7.5-minute topographic base maps, were used in evaluating all areas. The remaining four areas are discussed below.

Flatwillow Creek Valley Area

Most of this narrow valley and the adjacent higher elevation area is owned by the N-Bar Ranch. As shown on the recent geologic map of the Musselshell quadrangle (Porter and Wilde, 1999), sedimentary rock units dip into the valley from both sides, forming a syncline in the valley bottom. The lowest part of the valley floor is underlain by gray-black shales of the Thermopolis Formation (Fig. 4), generally covered by alluvial deposits of the creek and by gravel deposits related to earlier positions of the creek. The Cretaceous Kootenai Formation, including red mudstones and the thick basal Third Cat Creek sandstone, forms the margins of the valley together with the overlying poorly exposed brownish Fall River Sandstone. Low along the valley walls, underlying the Kootenai, are the Jurassic Morrison and Swift Formations. Stratigraphically below these Jurassic units and higher on the valley walls is the Pennsylvanian Alaska Bench Formation, a series of white-weathering limestones and red mudstone that form the main area of the Little Snowies. Less well exposed in the Little Snowies, underlying the Alaska Bench Formation, are the Tyler Formation and the Heath, Otter, and Kibby strata.

In the Flatwillow Creek valley area, Mission Canyon limestone rocks are exposed only in three small patches on Durfee Creek Dome at the lower end of the valley.

Evaporite beds are observed above the Mission Canyon limestone on the Dome (Porter, unpublished field data). Presently it is unknown whether these beds are a remnant of the once extensive Charles Formation (uppermost formation of the Madison Group), or whether they are basal beds of the overlying Kibby Formation. In central Montana, the Charles was largely removed by post-Madison erosion, particularly across the old central Montana trough area. It is possible, however, that local remnants of the Charles evaporite remain. The correct assignment of the evaporite interval and the search for evaporite elsewhere in the Little and Big Snowies constitute an important problem that must be resolved. This evaporite problem relates to both quality and quantity of Madison ground water resources.

The limestones of the Mission Canyon Formation form a thick and continuous bedrock interval in the subsurface, extending southwestward some 15 miles to where they are exposed in the Red Hill Road area of the Big Snowies. However, structural features (folds and faults) recognized across the eastern Little Snowies (Fig. 2), and shown on the published geologic maps, suggest that the subsurface is structurally complex in the Flatwillow valley area. The synclinal Flatwillow valley itself forms a prominent northwest-trending structural re-entrant into the Little Snowy Mountains and could be underlain by a fault at depth for which there is no surface indication. A northeast-trending anticlinal fold (shown on geologic map MBMG 386) is projected beneath the alluvium of the South Fork of Flatwillow where the stream joins the North Fork.

Durfee Creek Dome (Figs. 2, 3) indicates a local change in dip of the bedrock that probably redirects ground-water flow and reduces the volume that actually flows into the Mission Canyon aquifer under the valley. Although several small areas of Mission Canyon limestone are exposed for ground-water recharge on this small dome, they are inadequate to make up for the loss of ground water that is probably being retarded and redirected by structural features as it flows toward the valley from the recharge area in the Big Snowies. On the north side of the dome at Durfee Creek Gap tufa deposits reflect earlier flow of hot water from the now dry spring (anecdotal information is that the hot spring has had erratic flow and ceased sometime in the 1950's). Waters coming to the surface in the Otter Formation probably came from the Madison (Mission Canyon) at depth, but the elevated temperature suggests that ground water may be highly mineralized from this point on down the valley.

Ground-Water Resources

The Mission Canyon recharge area that initially supplies ground water to this valley is on the order of 11 mi^2. The hydrologic maps by Feltis (1980a, 1980b) show aquifer characteristics for the Madison at a scale of 1:1,000,000. However, hydrogeologic interpretations shown on these maps for the Little Snowy Mountains area are based on very sparse data points, and therefore, while providing some useful information, cannot accurately define the water resource for the area. The potentiometric surface near Flatwillow Creek shown on these maps indicates the water level in wells completed in the Madison would rise to a level of between 4,000 and 4,200 feet above sea level. Thus, in general, wells could be expected to flow if drilled at locations in the Flatwillow valley to the east of Durfee Creek Dome. However, as noted above, the water quality is likely to be degraded east of the dome. West of the confluence of the North and South Forks, the water resource could be prospective. Drilling depths in the Flatwillow valley north of Durfee Creek Dome, if planned to intersect the center of the syncline where beds are flat-lying, would be on the order of 2,400 feet to the top of the Mission Canyon (based on Continental Oil #1 Govt. Well, and on data of Maughan and Roberts, 1967 (see Appendix 1). However, as noted above, it is possible that the Flatwillow valley is underlain by a northwest-trending fault whose effect on ground-water resources is unpredictable.

Willow Creek Valley Area

The Willow Creek valley, where east-flowing Willow Creek comes through the mountain front, is flanked by and underlain by the same bedrock units exposed in the Flatwillow Creek valley (Porter and Wilde, 1999; Porter and others, 1996) (Fig. 2). The geologic map of the Musselshell quadrangle indicates a general southeast dip of the bedrock (Alaska Bench Formation) that plunges underground where the Willow Creek valley opens through the mountain front. A short distance north, the beds swing around to a south dip along the south flank of Durfee Creek Dome (Figs. 2, 3). Additional aerial photograph study has located some northeast-trending faults on the southeast flank of Bald Butte (a knob of Swift Formation) that lies in a shallow syncline. Also, broad, shallow warping of the Alaska Bench Formation is suggested by estimated strike and dip data across the largely timbered area of the Willow Creek-Bald Butte-Durfee Creek Dome area. These folds, though shallow and difficult to define, could exert either positive or negative influence on ground-water flow in the underlying Madison.

The limestones of the Mission Canyon Formation, forming a thick and continuous bedrock interval exposed in the Red Hill Road area of the Big Snowies, extend eastward in the subsurface beneath the Willow Creek valley area as they do beneath the Flatwillow Creek valley. However, as in the Flatwillow Creek valley, structural features recognized across the eastern Little Snowies (Fig. 2), and shown on the published geologic maps, suggest that the subsurface is structurally complex in the Willow Creek area as well.

Ground-Water Resources

Evaluation of the regional structural setting and the Mission Canyon ground-water recharge area for this valley raises significant reason for caution about both quantity and quality of Mission Canyon ground water in this area. Ground-water flow in the Mission Canyon is presumed to derive from a small recharge area of about 1-2 mi^2 on the northeast flank of the main anticline of Big Snowy Mountains. It is doubtful whether Madison ground water, flowing east from this recharge area, flows uninterrupted into the Willow Creek valley area. Known folds and faults (Fig. 2), as well as possible unknown structures along this deformed eastern flank of the Little Snowies are likely to retard and redirect ground-water flow. The result could be less water volume, moving more slowly and taking on more dissolved solids.

The gaining reach of Willow Creek as it flows out of the mountains, together with the springs along the southern edge of Durfee Creek Dome, represent ground-water discharge to the surface-water system. The springs are issuing approximately at the contact between the Swift and overlying Morrison formations, with the underlying Alaska Bench forming the extensive dip slopes of the Little Snowy Mountains. Losing reaches along Willow Creek would be a more optimistic indicator for recharge to the ground-water systems. However, the lack of ground-water data, and the unanswered questions concerning the geologic structure do not permit identification of the source for these discharge points. The springs and gaining reach of Willow Creek may simply relate to ground-water flow through the shallow, weathered zone in the surface formations.

Based on the maps prepared by Feltis (1980a, 1980b), aquifer characteristics of the Madison in the Willow Creek valley area are expected to be very similar to those in the Flatwillow Creek valley area. Potentiometric surface should be near 4,000- to 4,200-feet above sea level. However, ground surface where Willow Creek leaves the mountains is about 4,200-ft above sea level, and flowing wells are not predicted for this area. During a brief field trip, the flow in Willow Creek was measured at two locations and found to increase downstream from 1 to about 5 cubic feet per second (cfs). Also, several springs exist along the south edge of the Little Snowy Mountains such as those that feed Spring Creek just east of Willow Creek. These springs and increasing baseflow of Willow Creek near the mountain front indicate ground-water discharge. The aquifer is not known, but is likely to be one or more of the rock formations above the Mission Canyon limestones. Specific conductance of Willow Creek at the two locations is about 540 umhos/cm and temperature is 8.7 to 8.9 C.

Drilling depth for a well in the Willow Creek valley can be approximated based on available data. Based on a 14-degree structural dip recorded on the geologic map of the area, and using the formation thicknesses reported in the nearby Continental Oil #1 Govt. well and by Maughan and Roberts (1967) (Appendix 1), a well spudded in the Alaska Bench Formation adjacent to the valley floor might require a total depth of about 1,400 feet to reach the top of the Mission Canyon. The amount of penetration required within the Mission Canyon, and the stratigraphic position within the Alaska Bench at ground surface are unknowns that would determine the actual drilling depth.

Patterson Canyon Area - South Flank of Big Snowy Mountains

During early discussions in Roundup at the outset of this study, the south flank of the Big Snowy Mountains near the base of the mountain front was discussed and found unfavorable for geologic and hydrologic reasons (see p. 1). Since that time, and in light of the geologic/hydrologic problems recognized in the Flatwillow and Willow Creek valley areas of the Little Snowies, the Big Snowies have been reconsidered. As noted earlier, this south flank of the highly asymmetric Big Snowy Mountains anticlinal form is steeply south-dipping (Figs. 2, 3). Bedrock units stratigraphically above the Mission Canyon occur low on the mountain flank and include the Kibby, Otter, Heath, Tyler, and Alaska Bench formations, in ascending order. Younger formations flank the mountains at still lower elevations — the Jurassic Piper, Rierdon, Swift, and Morrison formations. The Kootenai red beds and basal sandstone and the Fall River sandstone form the lowest hogback above the valley-forming Thermopolis shales. Occasional trees dot this hogback. Extensive and thick gravel deposits spread over large areas of this southern mountain flank and mask the underlying bedrock units. These gravels are composed mostly of limestone cobbles that were shed from the mountains during an earlier, perhaps wetter, climatic period.

Madison limestone beds form the upper flank and crest of the Big Snowy range. On this upper flank, the beds flatten out to very low dip angles as they approach the crest of the range. Thus, a water well location farther into the mountains than originally considered would avoid the steep dip, excessive drill depths, and possible synclinal axis problems that are anticipated lower on the flank under the gravel benches. The Patterson Canyon area is prospective. Red Hill Road passes just east of the canyon and could provide access. However, almost no detailed geologic and hydrologic data are available for the area. Missing are good readings of the strike and dip of Madison beds over the upper mountain flank. Also needed is careful examination of the upper surface of the Mission Canyon for evidence of overlying evaporite beds belonging either to remnant Charles Formation or to the overlying Kibby Formation.

Ground-Water Resources

In the Patterson Canyon area, approximately 8 mi^2 or more of exposed Mission Canyon Formation provide an adequate recharge area for this aquifer. It is important to determine the level of the water table within the Madison in this area, as well as the volume and quality of the water. It is possible that a well could be positioned far enough down the flank (but still on the Mission Canyon outcrop) to intercept a fully saturated aquifer possibly with artesian conditions. In any case, because of the high elevation of the Patterson Canyon area, gravity flow might be adequate to transport the water to Roundup.

The most desirable location for a test well located in the Patterson Canyon area would be within the top of the Mission Canyon just up slope from its contact with the overlying Kibby Formation (Fig. 2). Drilling depth would then be totally dependent on the amount of penetration within the Mission Canyon required to achieve sufficient yield to determine the water quality and potentiometric surface. Drilling depth here could be as shallow as 400 feet.

Middle Bench Area

The Middle Bench area of the Little Snowy Mountains lies between the headwater reaches of the North and South Forks of Flatwillow Creek (Figs 1, 2). The area is just east of Red Hill Road, the conventional boundary between the Big and Little Snowy Mountains. Bedrock in the area is dominated by the Pennsylvanian Alaska Bench Formation which appears to have very consistent dip to the northeast. Underlying the Alaska Bench Formation and well exposed progressively to the west are the Tyler, Heath, Otter, and Kibby Formations. These formations mostly lie just east of Red Hill Road which passes over the broad exposure of the Mission Canyon Formation (Porter and Wilde, 1999) that forms the east slope of the Big Snowies and dips northeast under the Little Snowies (Figs. 2, 3). Structural dips have not been measured but appear quite low in this area near the crest of the Big Snowy Mountains anticline.

Ground-Water Resources

Approximately 11 mi^2 of Mission Canyon outcrop recharge the Mission Canyon aquifer under Middle Bench (Figs. 1, 2). The topographic base maps show a few springs in these drainages beginning about 10 miles east of Red Hill Road, suggesting that the underlying Mission Canyon is saturated and coming to the surface. However, this idea should be tested; the spring water could, instead, just be accumulating in the fractured Alaska Bench bedrock at the surface. The optimum location for adequate, good-quality Madison water on either of these forks would be as far down stream as possible but still west of the structurally complex eastern Little Snowies.

A test well could be located in the Otter Formation just east of Red Hill Road. Drilling depth to the top of the Mission Canyon in relatively low-dipping beds would be approximately 500 feet. The amount of penetration required within the Mission Canyon would determine the total drilling depth, usually another 150-400 feet to provide adequate yield to the well.

REGIONAL GROUND-WATER FLOW

Using the regional topography (1:100,000 scale) and known geologic structures for the eastern Big Snowy and Little Snowy Mountains, probable ground-water flow patterns have been estimated (Fig. 5). Rain and snow meltwater enter the Mission Canyon ground-water system in the exposed recharge area of the eastern Big Snowies generally along and just west of Red Hill Road. In the northern recharge area the ground water flows generally northeast down structural dip-slope passing beneath the North Fork of Flatwillow Creek. These waters will ultimately flow up against the south-dipping flank of Potter Creek Dome, and may be diverted eastward under the northern

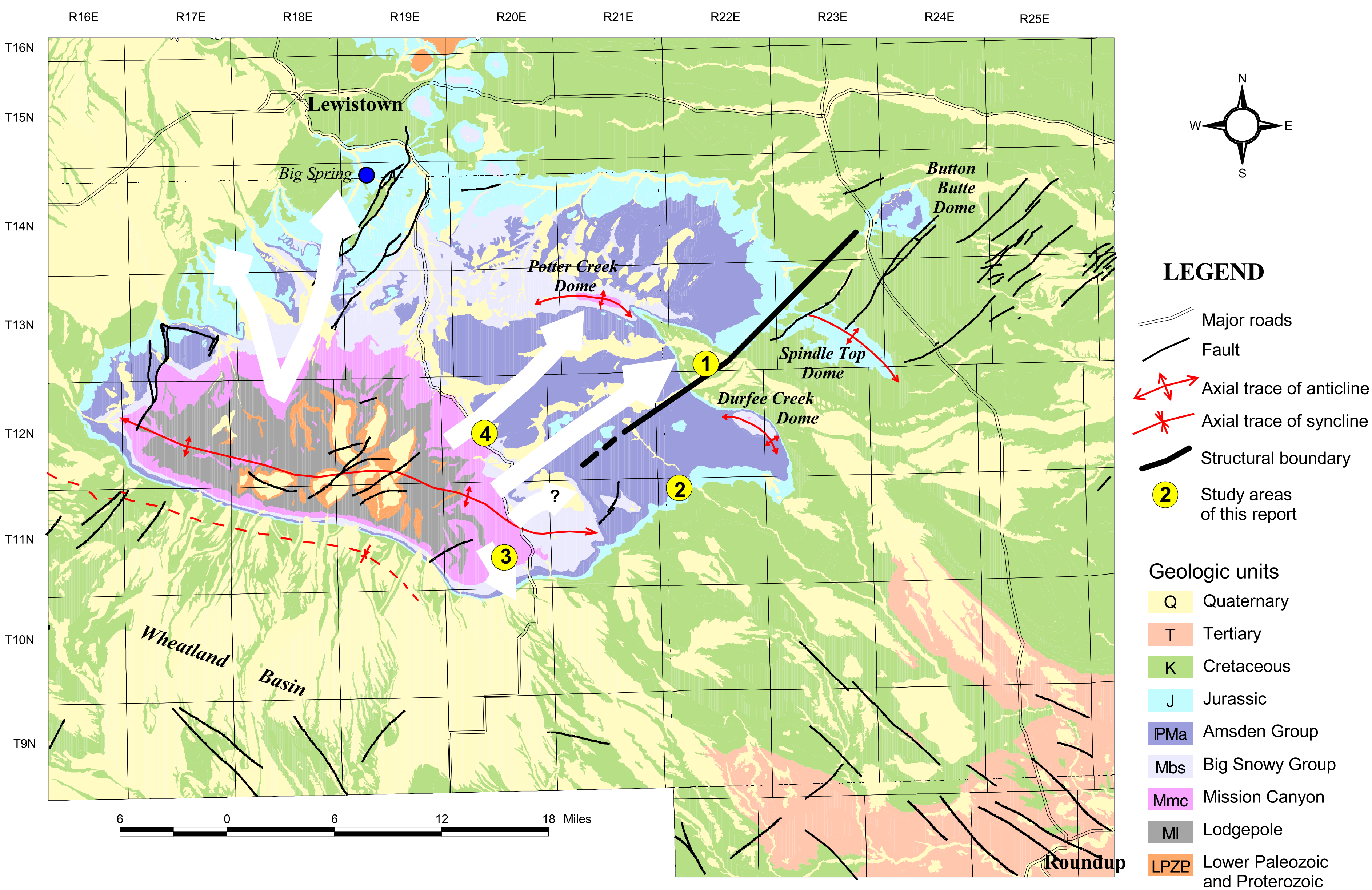

Figure 5. Projected ground-water flow paths (white arrows) in Mission Canyon Formation from recharge area in Big Snowy Mountains, based on geologic and topographic data.

end of the Flatwillow valley depending on the degree of saturation and potential confined pressure. Along its length, the North Fork does not cut deeply enough into bedrock to intersect the top of the Mission Canyon except at its upper reaches, and here the bedrock will be undersaturated. However, it is likely that along all of the North Fork, spring waters may be derived from the Mission Canyon and are coming to the surface along small fractures and weathered zones in overlying bedrock units. Ground water quality is wholly unknown along this northeast dipslope, but in general can be expected to degrade with increased distance from the recharge area as a function of residence time.

Between the North and South Forks of Flatwillow Creek under Middle Bench essentially the same flow conditions probably exist. Ground water is presumed to follow a generally unconfined flow path northeasterly down dip toward the Flatwillow valley syncline until at some point the aquifer is completely saturated, and builds confined pressure. Beyond this point, ground-water flow is controlled by the direction and gradient of the hydrostatic pressure (potentiometric surface).

South of the South Fork of Flatwillow Creek and east of the conceptual line that demarks the complex structural area (Figs. 2, 5), known and unknown geologic structures are likely to influence the flow pattern. This structural complexity of the eastern Little Snowies presents difficulties for both the Flatwillow and Willow Creek valley areas, particularly the Willow Creek area on the south side of Durfee Creek Dome (Figs. 2, 5). Ground water flowing northeast from the recharge area encounters folds and faults. It potentially becomes partially isolated which decreases the rate and volume of flow. Water that does not get caught in these structures will be redirected eastward and southeastward around the Dome's south flank. The extended residence time is likely to reduce water quality. Such water-quality degradation is suggested by the history of warm-spring flow at Durfee Creek Dome, although this warm water may have another origin.

In the Patterson Canyon area, there appears to be adequate Mission Canyon recharge area to saturate the Mission Canyon. However, structural dips are likely to change significantly over the area which will effect drilling depth to the saturation zone.

SUMMARY AND CONCLUSIONS

1. Regional ground water recharge to the deep regional aquifers occurs within the Big Snowy Mountains. Shallower aquifers, also recharged within the mountains, are historically less productive and thus unsuitable for a municipal water supply.

2. The principal deep aquifer in the region is the upper part of the Madison Group, the limestones of the Mission Canyon Formation. In central Montana this formation is up to 950 feet thick. The Mission Canyon's porosity and permeability reflect its geologic history: several periods of karst development during and after

formation of this limestone created extensive porosity and permeability. Approximately 30 square miles of Mission Canyon Formation limestones are exposed west of Red Hill Road between the North Fork of Flatwillow Creek and the Patterson Canyon area (Fig. 2).

3. Geologic maps indicate that the eastern and southeastern Little Snowy Mountains are structurally complex (Figs. 2, 3). A number of folds and faults are recognized and mapped; others may not have been recognized or may occur in the subsurface with no surface expression.

4. In general, geologic structure appears to be less complex west of a conceptual line that passes southwesterly across the Little Snowy Mountains (Fig. 2).

5. The valley areas of Flatwillow Creek and Willow Creek in the Little Snowy Mountains are not prospective areas for finding adequate volumes of good quality water for the City of Roundup. Both valleys may be too distant from the recharge area and, most importantly, both are within the structurally complex eastern Little Snowies (Fig. 2) where ground-water flow paths are unknown and unpredictable. Within this structurally complex area water quality is not expected to meet requirements for a municipal water supply because of retarded flow and longer residence time within the host rock. The Willow Creek valley area is additionally hampered by having an apparent very small recharge area (1-2 mi^2).

6. The upper reach of Willow Creek is probably all within the structurally complex eastern Little Snowies. However, one or more springs occur in the area, coming to the surface in the Alaska Bench Formation; they should be sampled for water quality and quantity.

7. The south flank of the Big Snowies has been reevaluated. The geologic problems that first seemed to disqualify the south flank of the Big Snowies could be overcome by drilling at the east end of the range and farther back into the mountain front, particularly in the Patterson Canyon area. Such a location minimizes drilling depth because it is in the recharge area that, here, is about 8 mi^2. This Big Snowy area offers the best possibility for a saturated aquifer leading to artesian flow, and further offers the best opportunity for gravity flow of captured water southeast over the shortest distance to the City of Roundup.

8. The Middle Bench area between the upper reaches of the North and South Forks of Flatwillow Creek east of Red Hill Road in the Little Snowies is highly prospective. This area is close to an ample recharge area (11 mi^2) and requires minimal drilling depths.

9. Further geologic and hydrologic evaluation in the field would be required at both the Middle Bench and Patterson Canyon localities in order to confirm the quality and quantity of the water resource. It is recognized that even with adequate and

favorable information about water quantity and quality in these upper drainages, they pose economic considerations significantly beyond what the lower valley areas might have posed relating to pipeline length and the probable need for pump facilities and power lines. Access, too, is made substantially more difficult, although dirt roads do extend most of the way up the two forks of Flatwillow Creek.

RECOMMENDATIONS

The results of the work to date, as reported above, have served to restructure the thinking that was originally applied to the question of a source of Madison water for the City of Roundup. The mountain-front valley areas of Flatwillow Creek and Willow Creek along the east flank of the Little Snowy Mountains are demonstrated to lie within a regional geologic setting that is structurally complex and substantially unpredictable in the subsurface, having unkown effect upon ground-water flow and quality. Westward, however, the Middle Bench area lies west of this structurally complex east flank and is much more favorable for a Mission Canyon water supply, as is the Patterson Canyon area of the Big Snowies. The following recommendations are made:

1. Water quality and quantity, and the potential for an artesian head.

(a) Water in the upper reaches of the North and South Forks of Flatwillow Creek, adjacent to Middle Bench, should be evaluated for quantity and quality. Springs adjacent to these streams, and springs in the Patterson Canyon area should be inventoried as a means of evaluating the potential water quality and quantity at the surface in each area.

(b) Stream-flow studies should be conducted along the mountain stretch of Willow Creek, both west of (South Bench area) and within the structurally complex eastern flank of the Little Snowies. These data will allow an evaluation of whether ground-water volumes are altered across the boundary of the structurally complex area. Such alterations could have implications for both quality and quantity of ground-water at the mountain-front test drill site.

(c) Test drill holes at the Willow Creek, Patterson Canyon, and Middle Bench areas would provide the necessary information about the water quantity and quality at depth within the Mission Canyon aquifer. The water chemistry of the aquifer in each area is of interest as it may relate to public health and to effects on pipeline materials. These drill holes would also allow prediction of the depth to the saturation zone before a major drilling program was contemplated. Drilling depth in the Willow Creek area is expected to be about 1,400 feet to top of the Mission Canyon. Drilling depth in the Patterson Canyon may be as little as 400 feet, if the site could be located on the Mission Canyon outcrop. In the Middle Bench area, the drilling depth to the top of the Mission Canyon is expected to be in the range of 1,100 feet.

2. Geologic information needed

(a) Very detailed examination is needed of the top of the Mission Canyon limestone in the recharge area of the Big Snowy Mountains and in the Durfee Creek Dome locality of the Little Snowies. We need to learn the distribution of the evaporite beds observed at Durfee Creek Dome and their stratigraphic relationship to the Mission Canyon. It is essential to learn whether the evaporite extends west into the recharge area. It is also important to learn whether these evaporite beds belong to the Charles Formation that conformably overlies the Mission Canyon in the region or whether the evaporite beds are part of the basal Kibby Formation. This information bears on both the quality of the water and the permeability of the Mission Canyon aquifer.

(b) Adequate strike and dip data are needed at each area to assist in visualizing the rocks in the subsurface. These data become very important in estimating drilling depths and in anticipating the behavior of drill pipe down hole. Structural dip data are available for bedrock exposures adjacent to the Flatwillow and Willow Creek valleys in the eastern Little Snowy Mountains, but are not available farther west in the upper reaches of these drainages west of the eastern flank of the Little Snowies. Structural dip data are also lacking along the south flank of the Big Snowy Mountains in the Patterson Canyon area.

With these additional geologic and hydrologic data, more precise sites for test-well drilling could be determined. The test-well drilling would, in turn, provide the basis for evaluating the potential for an adequate, good-quality municipal water supply from the Madison Limestone for the City of Roundup.

3. Application for Financial Assistance for Test-Well Drilling

Recognizing that a comprehensive and thorough exploration for a Mission Canyon ground-water resource for a municipal water system must include test-well drilling, we are recommending that the City of Roundup make application for outside financial assistance for this next phase of the geology/hydrology feasibility assessment. If an adequate resource of good-quality ground-water can be identified during this next phase of work, the engineering feasibility and cost analysis phase of the project will have a strong basis from which to proceed.

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APPENDIX 1

Continental Oil #1 Government well, SW section 18, T. 11 N., R. 23 E., Musselshell County, Montana. Well spudded in thin alluvium/colluvium above middle (sandy member) of Thermopolis Formation.

	Formation		Thickness (ft)	Depth (ft)
(Kt)	Thermopolis	(middle, sandy member)	242 to surface	242
(Ktsc)	Thermopolis	(lower, Skull Creek Member)	118	360
(Kds)	Dakota Silt	(lower part of Skull Creek)	58	418
(Kfr)	Fall River Sandstone (1st Cat Creek Ss)		95	513
(Kk)	Kootenai (including 2nd and 3rd Cat Creek Ss's)		439	952
(Jm)	Morrison		98	1050
(Jsw)	Swift		137	1187
(Jp/Jr)	? Piper (or ? Rierdon)		85	1272
(IPab)	Alaska Bench		254	1526
(IPMt)	Tyler		313	1839
(Mh)	Heath		130 ft to TD	1969
(Mo)	Otter		NP*	
(Mk)	Kibby		NP	
(Mc)	?Charles		NP	
(Mm)	Madison		NP	

* = not penetrated

For the Heath, Otter, Kibby, and Charles(?), and Mission Canyon formation thicknesses, reference must be made to the published literature. The following thicknesses are from the published measured sections of Maughan and Roberts (1967) on Durfee Creek Dome and at Beacon Hill on the northeast flank of the Big Snowies (radio tower site in section 36, T. 13 N., R. 19 E., east of Red Hill Road), and from Maughan (1993) and Smith and Custer (1987):

Heath (Durfee Creek Dome)	270	2239
(Beacon Hill, 20.5 mi. NW of Continental well)	76	2315
Otter (Beacon Hill, 20.5 mi. NW of Continental well)	290	2605
Kibby (Beacon Hill, 20.5 mi. NW of Continental well)	190	2795
Charles(?) (very thin on Durfee Creek Dome; Porter, unpublished data; may be basal Kibby)	est. 30	2825
Mission Canyon (Maughan, 1993; Smith & Custer, 1987)	900	