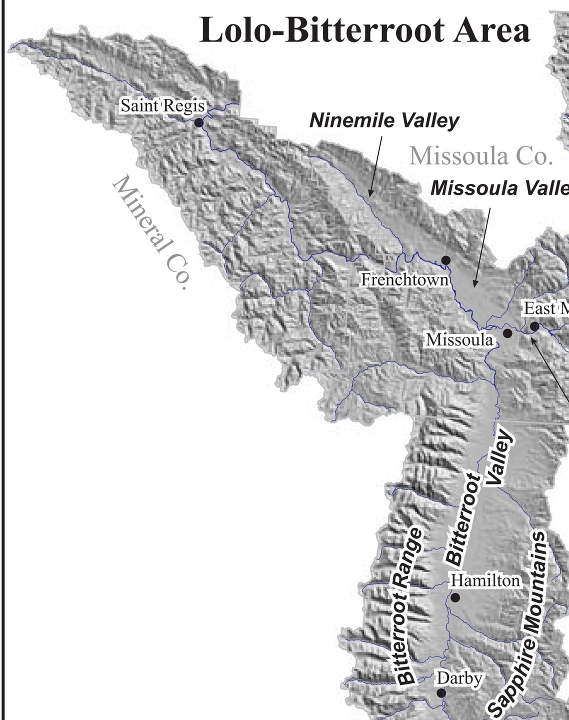


Figure 2. Index map showing the principal cities, drainages, and physiographic locations.

Relative Ages and Labels	Map Units	Characteristics	Units on Previous Maps
Qsc	Quaternary sediments – coarse-grained	Light to medium brown and grayish brown sand and gravel; some silt and clay; along active stream valleys and areas of sheetwash; contains minor amount of colluvium; thicknesses average 40 ft, but reach 300 ft in paleochannels along the Clark Fork River; ground water commonly near land surface; will produce significant quantities of water to wells.	Holocene Qal Alluvium of modern channels and floodplains Qaty Alluvium of younger alluvial terrace levels Qct Colluvium and talus deposits Qls Landslide and earthflow deposits Holocene and/or Pleistocene Qaf Alluvial fan deposit, younger (Qafy) and older (Qafo) Qat Alluvium on alluvial terrace Qs Alluvium undivided Qgo Outwash Qgk Kame deposit Qa Avalanche deposit Qbf Boulder fan deposits, older (Qbfo) and younger (Qbfy) Qgf Glacial-lake flood deposits
Qsf	Quaternary sediments – fine-grained	Grayish brown, light to dark yellowish brown gravelly silt, light pink silt and sand, and silty and/or clayey gravel; thicknesses range from 1 to 300 ft; generally does not produce water.	Qg Glacial deposits, undivided Qgl Glacial lake deposit Qgt Glacial till Qm Glacial moraine Qls Landslide deposit
Ts, Tsc, Tsf	Tertiary sedimentary rocks – coarse-grained and fine-grained	Yellowish brown to light gray pebbly sandstone, pebble and cobble conglomerate; uncemented to moderately cemented; light tan to gray claystone and siltstone; rare carbonaceous shale and lignite; water wells completed in sandstone and conglomerate yield adequate supplies of water to wells for household use.	Tab Alluvium of braid plains Taf Alluvial fan deposit, silty (Tas) and boulder fans (Tab) Tss Silt and sand Tsf Sedimentary deposit, fluvial Tgc Gravel and clay Tb Ancestral Bitterroot River deposits, gravel facies (Tbg), clay facies, and boulder-cobble facies (Tbc) Trd Dunbar Member of Renova Formation Tgc Gravel and clay Tc Older colluvium Ts Sediment or sedimentary rocks, undivided
Tm	Tertiary mylonite	East- and southeast-dipping zone of well-foliated, erosionally resistant metamorphic rocks that define the Bitterroot Range front.	Tmy Mylonite, a 600–1500 ft thick east-dipping zone of intensely deformed, foliated metamorphic rock.
Tgws	Tertiary Willow Creek and Skalkaho stocks	Pink to white, fine- to medium-grained nonfoliated granodiorite.	Tgw Granodiorite of the Willow Creek Stock Tgs Granodiorite of the Skalkaho Stock
TKi	Tertiary and Cretaceous igneous rocks	White to pink, medium- to coarse-grained granular and porphyritic intrusive rocks; lesser amounts of volcanic rocks; where fractured, the rocks can provide adequate supplies of water to wells for household use.	Intrusive and extrusive igneous rocks, including: augen gneiss; biotite-muscovite granite; Burnt Ridge Pluton; Canyon Lake Pluton; diorite and gabbro; felsic volcanic rocks; granite; granodiorite; granodiorite and monzogranite of the Paradise Pluton; hypabyssal intrusive or flows; Painted Rocks Pluton; Piquett Creek Pluton; rhyolite and andesite; rhyolite or rhyolitic sediment; rhyolite tuff; tonalite; and volcanic rocks, undivided.
Pzb	Paleozoic rocks	Sandstone, quartzite, shale, limestone, and dolomite of various formations; the rocks provide inadequate to minimally adequate water to wells for household uses.	PDs Permian–Devonian sedimentary rocks Ꞓf Flathead Formation Ꞓh Hasmark Dolomite Ꞓrl Red Lion Formation Ꞓs Cambrian sedimentary rocks, undivided Ꞓsh Silver Hill Formation
Yb	Proterozoic Belt Supergroup rocks	Metamorphosed sandstone, shale, siltstone, limestone, and dolomite of various formations; where fractured, the rocks can provide adequate supplies of water to wells for household use.	Belt Supergroup and related Proterozoic rocks: Bonner Formation; Burke Formation; calc-silicate gneiss of the middle Belt carbonate; Empire Formation; Garnet Range Formation; gneissic metasedimentary rocks, undivided; Helena Formation; McNamara Formation; middle Belt carbonate, informal; Missoula Group; Mount Shields Formation; Pilcher Formation; Prichard Formation; Revett Formation; schist and gneiss; Shepard Formation; Snowslip Formation; Spokane Formation; St. Regis Formation; Wallace Formation; and Proterozoic dikes.

Figure 4. Stratigraphic diagram showing units of original map sources and how units were combined for this map. Descriptions of map units are generalized from the dominant lithologies.

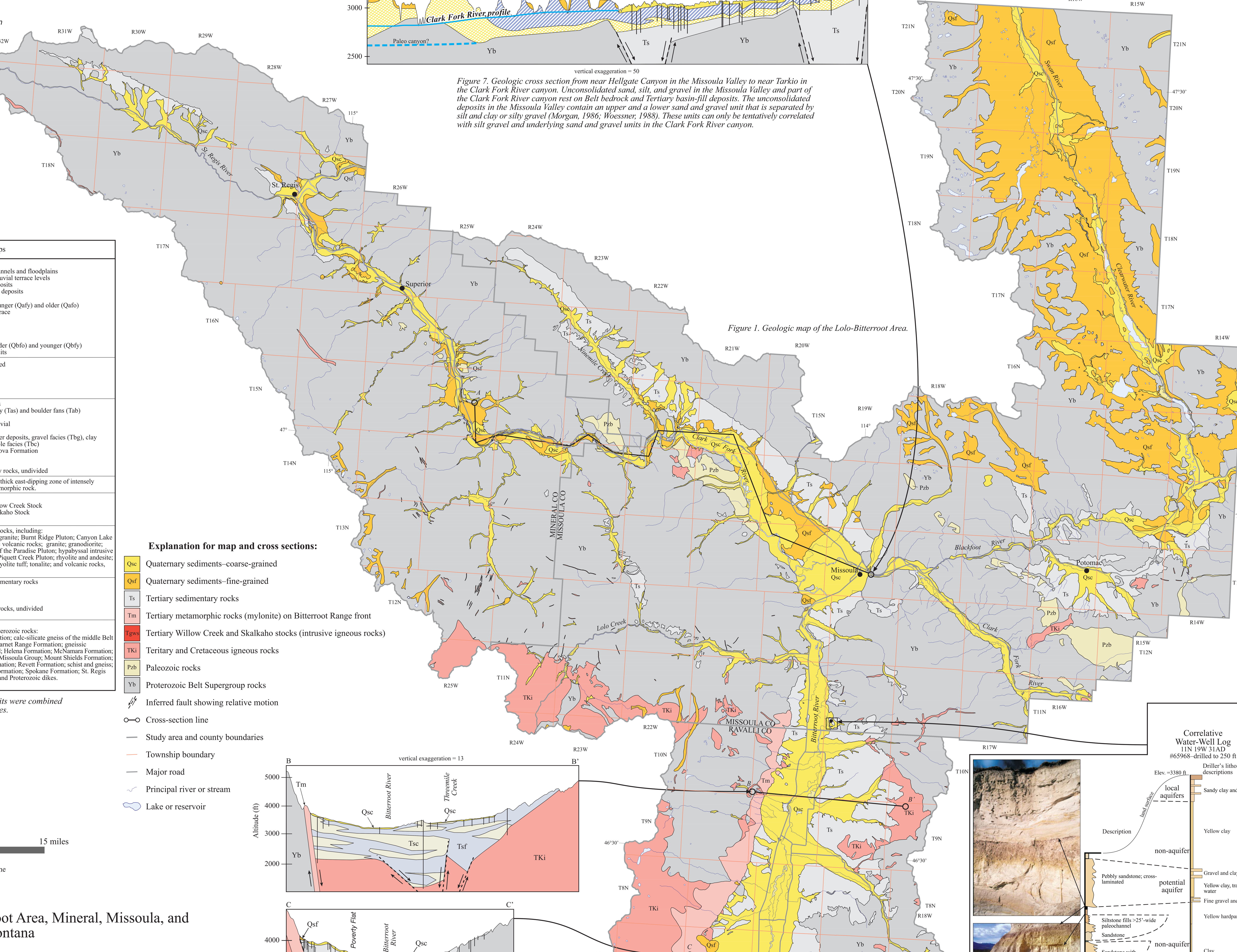


Figure 1. Geologic map of the Lolo-Bitterroot Area.

Explanation for map and cross sections:

- Qsc Quaternary sediments–coarse-grained
- Qsf Quaternary sediments–fine-grained
- Ts Tertiary sedimentary rocks
- Tm Tertiary metamorphic rocks (mylonite) on Bitterroot Range front
- Tgws Tertiary Willow Creek and Skalkaho stocks (intrusive igneous rocks)
- TKi Tertiary and Cretaceous igneous rocks
- Pzb Paleozoic rocks
- Yb Proterozoic Belt Supergroup rocks
- Inferred fault showing relative motion
- Cross-section line
- Study area and county boundaries
- Township boundary
- Major road
- Principal river or stream
- Lake or reservoir

N

Scale 1:250,000

0 5 10 15 miles

Projection Montana State Plane
Datum NAD83

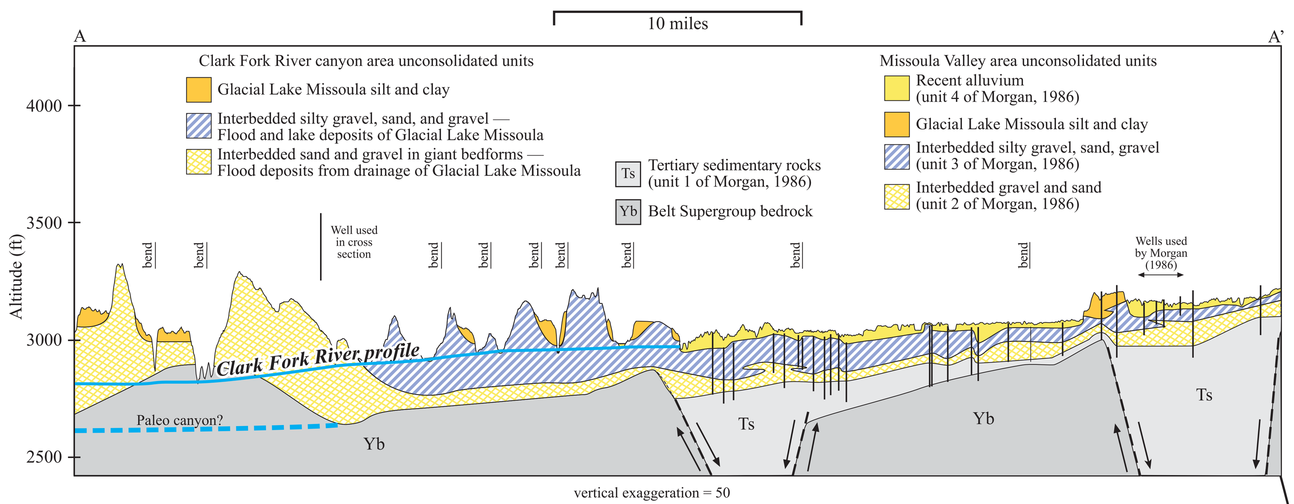


Figure 7. Geologic cross section from near Hellgate Canyon in the Missoula Valley to near Tarkio in the Clark Fork River canyon. Unconsolidated sand, silt, and gravel in the Missoula Valley and part of the Clark Fork River canyon rest on Belt bedrock and Tertiary basin-fill deposits. The unconsolidated deposits in the Missoula Valley contain an upper and a lower sand and gravel unit that is separated by silt and clay or silty gravel (Morgan, 1986; Woessner, 1988). These units can only be tentatively correlated with silt gravel and underlying sand and gravel units in the Clark Fork River canyon.

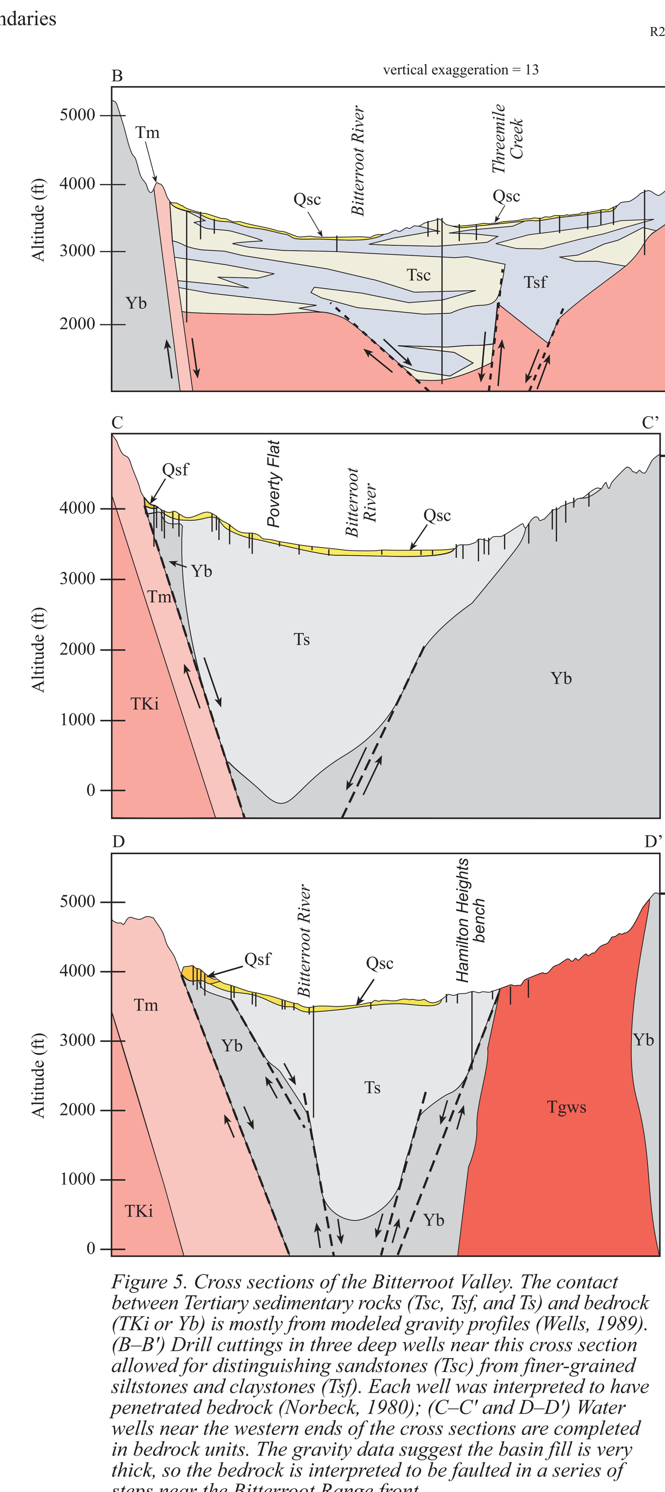
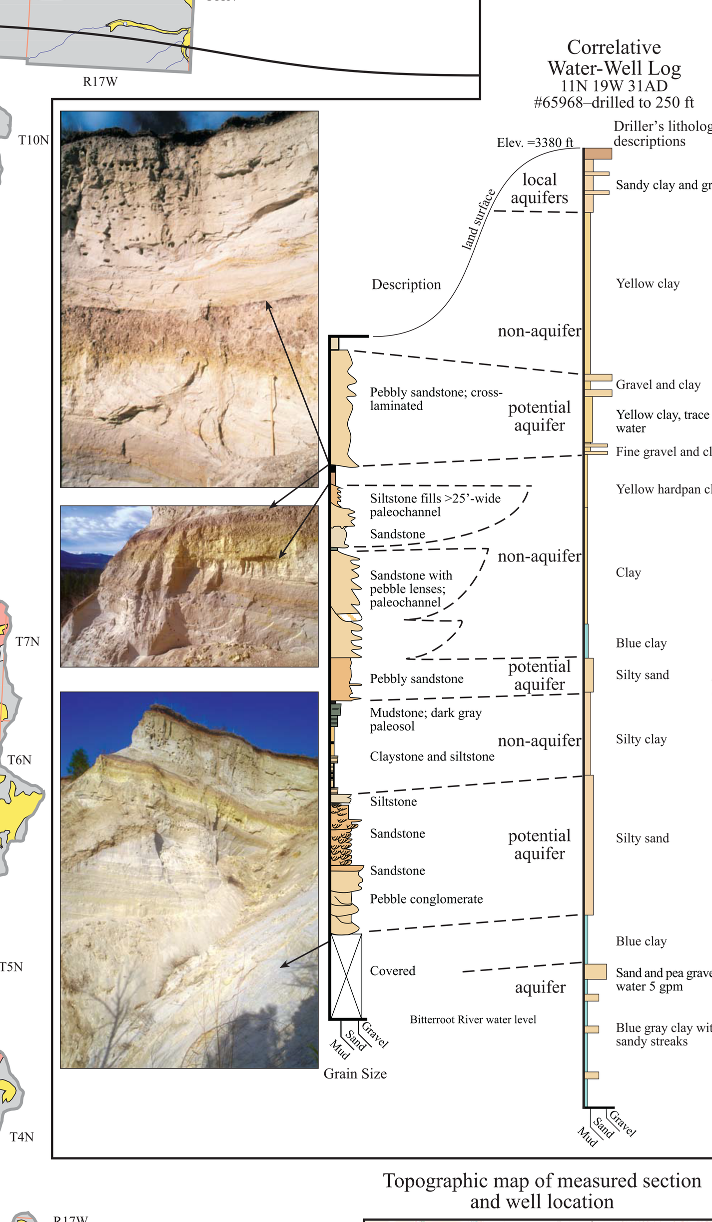
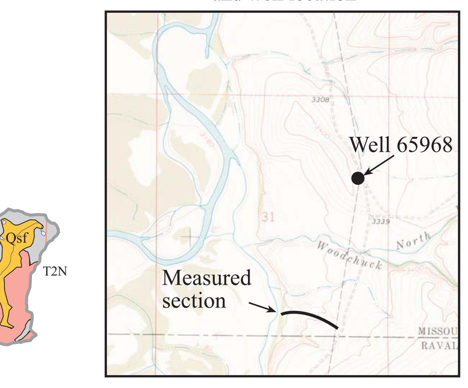


Figure 5. Cross sections of the Bitterroot Valley. The contact between Tertiary sedimentary rocks (Tsc, Tsf, and Ts) and bedrock (TKi or Yb) is mostly from modeled gravity profiles (Wells, 1989). (B–B') Drill cuttings in three deep wells near this cross section allowed for distinguishing sandstones (Tsc) from finer-grained siltstones and claystones (Tsf). Each well was interpreted to have penetrated bedrock (Norbeck, 1980); (C–C' and D–D') Water wells near the western ends of the cross sections are completed in bedrock units. The gravity data suggest the basin fill is very thick, so the bedrock is interpreted to be faulted in a series of steps near the Bitterroot Range front.





Topographic map of measured section and well location

Figure 6. Representative measured section of Tertiary strata in the Bitterroot Valley. Correlations between the section and a log of a neighboring water well show how more detail is evident in surface sections, but the general lithologies can be traced between closely-spaced data points. Pebbly sandstones and conglomerates are ancestral Bitterroot River deposits (Lonn and Sears, 2001).

Hydrogeologic Framework of the Lolo-Bitterroot Area, Mineral, Missoula, and Ravalli Counties, Montana

by

Larry N. Smith

Author's Note: This map is part of the Montana Bureau of Mines and Geology (MBMG) Ground-Water Assessment Atlas for the Lolo-Bitterroot 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 Lolo Bitterroot Area the reader is referred to Part A (descriptive overview) and Part B (maps) of the Montana Ground-Water Assessment Atlas 4.

INTRODUCTION

The Lolo-Bitterroot Ground-Water Characterization Area includes all of Mineral and Ravalli Counties and Missoula County outside of the Flathead Indian Reservation. The geology on this map (fig. 1) is simplified to show geologic units significant to the ground-water hydrology.

The Lolo-Bitterroot Area consists of bedrock-cored mountains, intermontane valleys, and canyons along major streams (fig. 2). Valleys and canyons are the primary areas of habitation and ground-water development. Major valleys include the Bitterroot Valley, the Missoula Valley, the Seeley-Swan Valley, the Potomac area, and the Ninemile Valley. Canyon areas discussed here are mostly along the Clark Fork River upstream from Missoula and downstream of Ninemile Creek, to the county boundaries.

METHODS

Geologic mapping in the Bitterroot, Missoula, and Seeley-Swan valleys was compiled and simplified from the sources shown in figure 3. The grouping of units is outlined in figure 4. In a few areas, such as just north of Hellgate Canyon, contacts derived from previously published maps were adjusted so they would be continuous across map boundaries. Previous mapping in valleys between Frenchtown and St. Regis and also in the Ninemile Valley was inadequate for understanding the hydrogeology, and these valleys were mapped for this study (L.N. Smith, unpublished mapping, fig. 3). The geology of the valleys and canyons is known to varying degrees of accuracy because of varied detail of mapping and differing densities of vegetative cover. All geologic maps were compiled from digitized versions, and simplified using Arc/InfoTM.

GEOLOGIC OVERVIEW

For the purpose of describing the hydrogeology, geologic units within the study area may be most simply grouped into three categories: bedrock, Tertiary sedimentary rocks, and unconsolidated surficial sediments (typically Quaternary in age). Bedrock, as defined here, consists of consolidated rock that is commonly fractured, and those fractures may remain open so they are the primary conduits of ground water. Fractures are important to ground-water hydrology of bedrock because water storage and movement is almost entirely along fractures. Bedrock is exposed in the mountains surrounding the valley, and is present beneath unconsolidated sediments and Tertiary sedimentary rocks within the valleys. Bedrock in the Lolo-Bitterroot Area is primarily metasedimentary rock of the Belt Supergroup (Yb) and Mesozoic and Tertiary intrusive igneous rocks (TKi). Lesser amounts of Paleozoic sedimentary rocks (Pzb) occur locally, and high-grade metamorphic rocks (Tm) define the east-facing Bitterroot Range front. Two of the Tertiary intrusive igneous rocks, the granodiorites of the Willow Creek and Skalkaho Stocks, are shown separately because they are known to contribute trace amounts of arsenic to ground water (LaFave, 2006a). All bedrock units are fractured along faults and joints, but the fractures have not been mapped consistently across the area.

Valleys and canyons contain locally great thicknesses of weakly indurated sedimentary rocks and up to 200 ft of unconsolidated sediments. The Tertiary sedimentary rocks and Quaternary sediments are referred to as "basin fill." Tertiary sedimentary rocks (Ts) include claystone, shale, siltstone, sandstone, locally thick conglomerate, coal, and volcaniclastic sedimentary rocks containing beds of volcanic ash. The sediments accumulated in various basins during the Eocene–Miocene development of basins and ranges in western Montana (Crosby, 1984; Fields and others, 1985; Constenius, 1996; Harris, 1997; Lonn and McFaddan, 1999; Lonn and Sears, 2001). The Tertiary strata range from unconsolidated to strongly consolidated in outcrop; most units can be characterized as weakly consolidated. Tertiary sedimentary rocks overlie bedrock and are locally extensive in the subsurface. Exposures are common in the Bitterroot and Missoula valleys, northwest of Missoula along the Ninemile Valley, in the Seeley-Swan Valley and Potomac areas, and locally in the Clark Fork River canyon areas upstream and downstream of Missoula.

In many places, Tertiary rocks that underlie alluvium form a basal confining unit for aquifers developed in the alluvium. The Tertiary rocks typically have low permeability, but can be local aquifers where sandstone and conglomerate are permeable, especially in the Bitterroot Valley. Gravity profiling and local 3-dimensional modeling were used to estimate their thicknesses along cross sections in figure 5. Mapping and subsurface data are generally not detailed enough to distinguish the coarser-grained Tertiary rocks from the finer-grained Tertiary rocks on this map. However, they are shown diagrammatically on cross section B-B' which had good subsurface well-log data (Tsc and Tsf in fig. 5). Wells completed in Tertiary rocks, like those in the hills to the north and south of Missoula, are typically reported to produce at rates less than 5 gallons per minute (gpm) but occasionally yields as much as 20–75 gpm are reported.

Unconsolidated sediments at the land surface include sand and granule- to boulder-sized gravel (Qsc on the map) and clayey and silty gravel and bedded silt and clay (Qsf on the map). Sand and gravel units were deposited both during and after periods of glaciation. Glaciers occupied the higher portions of many mountain valleys and the entire Seeley-Swan Valley. Glaciers deposited glacial till, which is mostly clayey and silty gravel. Bedded silt and clay were deposited in valleys during stands of Glacial Lake Missoula, a lake that was impounded on the Clark Fork River upstream of the current Montana/Idaho border (Alt, 2001). The lake attained a maximum altitude of at least 4150 ft, and shoreline features between altitudes of 2780 and 3770 ft are prominent in the area.

Sand and gravel, interbedded with and overlain by bedded silt and clay deposits, were deposited before glaciation and during flood events when Glacial Lake Missoula drained. The uppermost sand and gravel deposits in stream valleys are less than 50 ft thick in most areas and represent stream deposition during and after waning phases of glaciation.

DESCRIPTIONS OF SELECTED AREAS

Bitterroot Valley

The Bitterroot Valley lies between the Bitterroot Range and the Sapphire Mountains. The valley contains floodplain and river terraces along the Bitterroot River, and valley-center sloping benches developed on Tertiary sedimentary rocks; foothills and steep bedrock fronts flank the bounding mountain ranges. Vegetation consists mostly of grasses and shrubs, with deciduous forests near drainages.

A metamorphic "mylonite" rock (Tm) defines the eastern slope of the Bitterroot Range. Belt Supergroup rocks and igneous intrusive rocks make up the interior of the Bitterroot and Sapphire Mountains, and underlie most of the valley. Bedrock is an aquifer and is penetrated by water wells near the valley perimeter. The valley between bedrock outcrops is underlain by Tertiary sedimentary rocks (fig. 5). Local aquifers in Tertiary rock units include sandstone, pebbly sandstone, and minor conglomerates; clasts of granitic and Belt Supergroup bedrock are dominant. These sandy and gravelly beds (fig. 6) were deposited 30–40 million years ago by a large axial drainage, termed the ancestral Bitterroot River (Lonn and Sears, 2001).

Stratification in the beds, and the beds themselves, have the lenticular cross-sectional shape of stream deposits (fig. 6). Upper bed boundaries of sandstones are typically gradational with siltstones and claystones. Claystone, siltstone, and silty sandstone beds are prominent, especially as thin (1–8 ft thick), color-banded units that show ancient soil (paleosol) structures. Clayey conglomerates (debris-flow units) are common on the upper parts of the benches on the valley sides. In general, sandy deposits are laterally and vertically discontinuous, and may be difficult to correlate between locations. Fine-grained deposits may be thinner than sandy zones but are laterally more continuous, especially where they were deposited across ancient land surfaces as paleosols.

Quaternary surficial units are mostly sand and gravel deposits and are less than 60 ft thick. Most deposits are sand and gravel on floodplains and adjacent terraces of the Bitterroot River and its tributaries and alluvial fan deposits; in side valleys somewhat silty sand and gravel accumulated during the waning stage of glaciation. There are small areas of glacial till near the mouths of some of the tributary valleys in the Bitterroot Range. Surficial deposits, other than till, are significant aquifers.

Most wells in the Bitterroot Valley are completed in Quaternary sand and gravel or Tertiary coarse-grained sedimentary rocks that are near the land surface, called the shallow basin-fill aquifer (LaFave, 2006a, b). The Quaternary sand and gravel aquifers are the most productive in the valley. The more deeply buried Tertiary sedimentary rocks and bedrock are locally adequate aquifers for domestic and stock usage.

Missoula and Ninemile valleys

The Missoula Valley is a broad northwest-trending valley that contains a segment of the Clark Fork River and the lowermost reach of the Bitterroot River. Terrace surfaces above the current floodplains are extensively modified by urban and suburban development. Valley vegetation is mostly grass and shrubs, with mixed forests along main-stem and tributary drainages.

Ninemile Creek is a major tributary to the Clark Fork River, and the valley it occupies is controlled by the same structures that control the Missoula Valley. Where the Clark Fork River exits the Missoula Valley near the confluence of Ninemile Creek the open character of its course changes to a narrow, steep-walled canyon. The Ninemile Valley contains pasture along floodplains and low terraces and is otherwise densely vegetated by evergreen forest on the broad foothill regions between bedrock in the neighboring mountain ranges.

Tertiary sedimentary rocks include clay-rich siltstone and sandstone exposed within and around the Missoula and Ninemile Valley perimeters. The lithologies are similar to those in the Bitterroot Valley, but conglomerates containing granitic clasts are less common. Poor exposures and the rarity of known fossils make correlation between the different outcrops difficult.

Unconsolidated Quaternary sand and gravel deposits in the center of the Missoula Valley are generally greater than 100 ft, and locally greater than 200 ft thick. Most of the sand and gravel is interbedded with and overlain by Glacial Lake Missoula silt and clay, and thus was deposited before or during glacial time. The youngest sand and gravel units in the Clark Fork and Bitterroot stream valleys and throughout the Ninemile Valley are less than 50 ft thick in most areas and represent Holocene and latest Pleistocene stream and outwash deposits.

Morgan (1986) described the basin-fill sequence in the Missoula Valley as consisting of four units, from oldest to youngest: (1) gray, green, brown, and red clay and silty sand; (2) sand and gravel; (3) tan to yellow silty clay; and (4) sand and gravel. His informal terminology has been used in more recent studies (e.g., Woessner, 1988). Mapping and interpretation of well-log data support correlating Morgan's unit 1 with Tertiary sedimentary rocks. Unit 2 correlates with Glacial Lake Missoula flood deposits, fills a paleochannel in the Frenchtown area, and is the major aquifer in the Missoula Valley. Unit 3 was likely deposited as lake beds in a stand of Glacial Lake Missoula. Unit 4 includes late Lake Missoula flood deposits, glacial outwash, and recent alluvium.

Most wells in the Missoula and Ninemile valleys are completed in Quaternary sand and gravel within 80 ft of land surface, the shallow basin-fill aquifer. Quaternary sand and gravel reach thicknesses greater than 200 ft near Missoula and Frenchtown, areas where the deep basin-fill aquifer is penetrated by only a few wells. Fewer wells are completed in Tertiary sedimentary rocks; those typically produce 5 gpm. Bedrock units along the valley perimeters typically produce 10 gpm and are adequate aquifers for domestic and stock purposes.

Seeley-Swan Valley

The Seeley-Swan Valley is the area between the Swan and Mission Ranges northwest of the town of Seeley Lake to beyond the Missoula County boundary. The valley was completely ice-filled during the last glaciation, producing ice-sculpted topography and rolling hills. The Seeley-Swan Valley is covered by a dense evergreen forest.

Rocks of suspected Tertiary age occur in the deep subsurface of the Seeley-Swan Valley in the northeastern portion of the map (Crosby, 1984). Near Seeley Lake and Placid Lake, weakly consolidated silty and clayey, likely Tertiary, sedimentary rocks overlie Belt bedrock in the subsurface. Outcrops of these rocks have not yet been recognized near Seeley Lake, possibly due to the extensive glaciation, dense vegetative cover, and lack of detailed mapping. Surficial deposits include clayey glacial till and surficial sand and gravel deposited as outwash from retreating glaciers and along modern streams. Buried outwash deposits along the Clearwater River, Swan River, Morrell Creek, and other drainages are the primary aquifer in the valley.

Most wells in the Seeley-Swan Valley are in the Morrell Creek drainage near Seeley Lake, a location that has thick outwash alluvium sequences that partially fill a valley cut in bedrock. Thin beds of sand and gravel within or below glacial till and poorly understood Tertiary sedimentary rocks beneath till are locally adequate deep basin-fill aquifers. Bedrock aquifers are close enough to land surface to encounter in wells in only scattered areas, mostly on the west side of the valley and south–southwest of Seeley Lake.

Potomac Area

Potomac is a community in a small, mostly rural intermontane valley, about 20 miles east of Missoula. The valley bottom is mostly pasture and grassland. In the Potomac area 0–30 ft of stream channel and floodplain deposits overlie several hundred feet of Tertiary siltstones and minor sandstones, that in turn overlie Belt Supergroup bedrock. Water wells are completed both within the sedimentary rocks and in the subjacent bedrock, so the thickness of the Tertiary rocks is better known in this valley than in many of the other, deeper, valleys.

Clark Fork River Canyons

The Clark Fork River valley and its tributaries upstream of Hellgate Canyon and downstream of the Ninemile Valley have steep inner canyons and uplands with mostly rolling topography. The Clark Fork River has incised Belt Supergroup bedrock, local areas of Tertiary sedimentary rocks, and locally thick sequences of Quaternary gravel, sand, and silt. Some of the wider portions of the canyons have nearly flat uplands that are forested or in crops. With a few exceptions, unconsolidated, mostly sandy and gravelly sediments cover the canyon bottoms.

Tertiary sedimentary rocks occur locally in the subsurface upstream of Hellgate Canyon and at the surface and subsurface along the southwestern side of the Clark Fork River canyon near St. Regis. Significant thicknesses of sandstone and conglomerate in the St. Regis area dip toward the Clark Fork and St. Regis rivers and are covered by Tertiary siltstones and claystones and Quaternary sediment. A large percentage of the wells deeper than 100 ft in this area are completed in these Tertiary sandstones and conglomerates; some of them are flowing artesian wells producing >50 gpm.

The Quaternary sediments are similar to those in the Missoula Valley (fig. 7). The earliest deposits are sand and gravel that are locally interbedded with and overlain by bedded silt and clay. These sequences are more than 500 ft thick in gravel-cored landforms (top left of fig. 7). Boulder-sized clasts, thick beds of gravel, and landforms up to 300 ft tall indicate deposition by high-energy, high-volume floods from the draining of Glacial Lake Missoula. Glacial-lake silt was deposited across the gravel on benches where the canyon is wide. As much as 130 ft of sand and gravel accumulated in some tributary drainages as alluvium was transported down the smaller valleys. Post-glacial stream sediments occur along the modern stream channels and may make up some of the terraces in the inner valleys.

Many of the wells in the Clark Fork River canyons penetrate the deep basin-fill aquifer where Quaternary sand and gravel deposits are greater than 80 ft thick. Because the Clark Fork River and its tributaries have incised through the Quaternary deposits, ground-water levels are generally greater than 50–80 ft below land surfaces. Fractured bedrock is also an important aquifer in the canyons.

DATA SOURCES

Original versions of the geologic maps are available through the MBMG and USGS as attributed in figure 3. Base layers of physiography, hydrography, townships, and cultural features were derived from NRIS data sets.

ACKNOWLEDGMENTS

This work was supported by the Ground-Water Characterization Program at the Montana Bureau of Mines and Geology. The map and text were improved due to reviews by Gary Icopini, Tom Patton, John Metesh, and Ed Deal.

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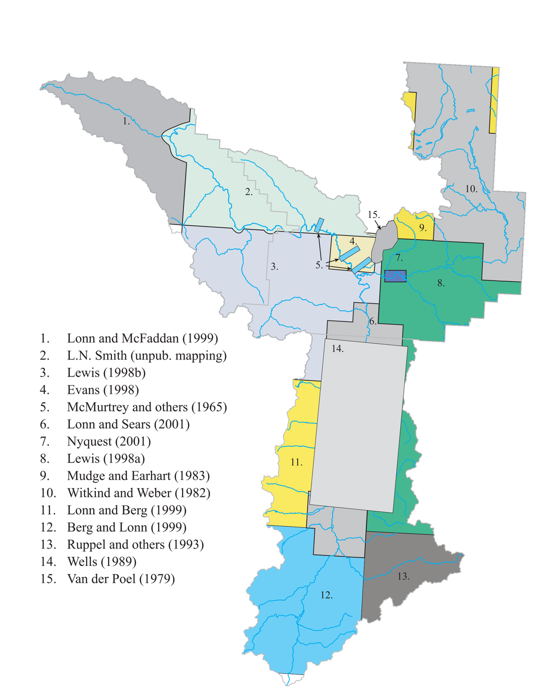

Figure 3. Index to previous maps from which contacts were compiled.