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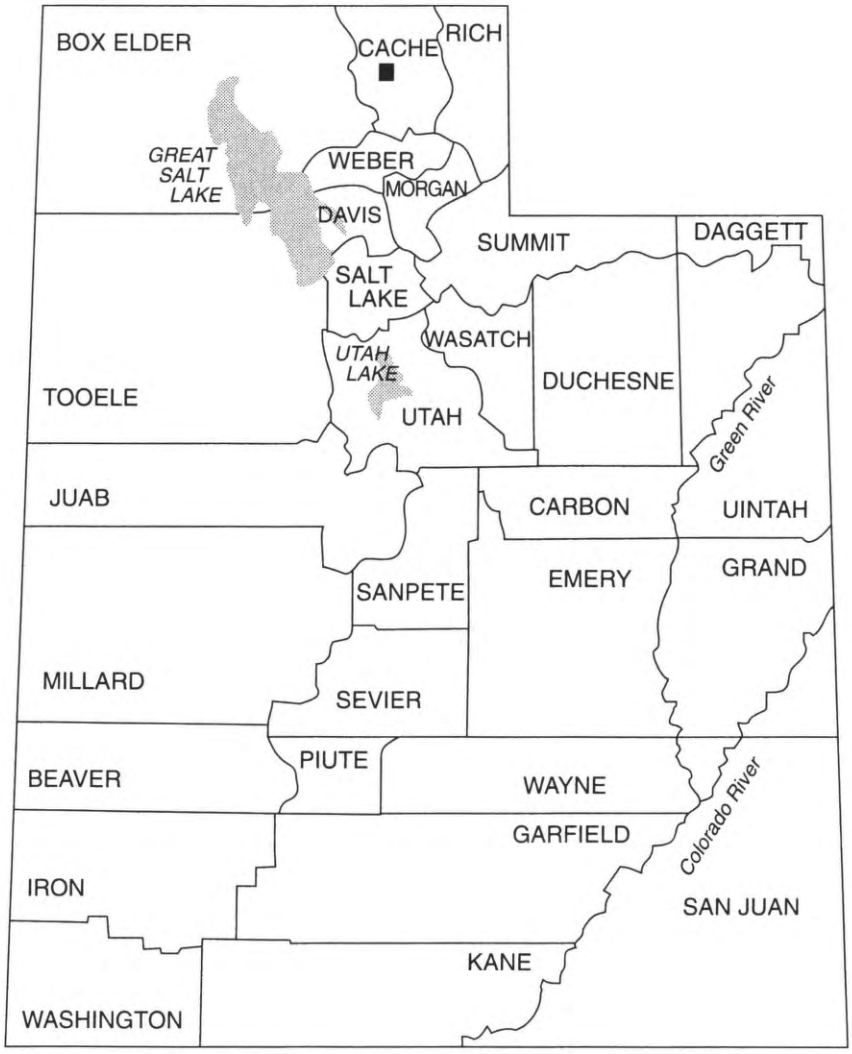

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GEOLOGIC MAP OF THE LOGAN 7.5′ QUADRANGLE CACHE COUNTY, UTAH

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James P. Evans, James P. McCalpin[1], David C. Holmes
Department of Geology, Utah State University, Logan, Utah 84322-4505

ABSTRACT

The Logan, Utah 7.5′ quadrangle is underlain by Paleozoic sedimentary rocks of the western Bear River Range, and Tertiary rocks and Quaternary sediments deposited in the Cache Valley. Paleozoic rocks are predominantly limestones and dolostones of Late Cambrian through Pennsylvanian and Permian(?) age. Clastic sedimentary rocks make up the rest of the section. Paleozoic rocks record deformation during the Cretaceous Sevier orogeny. In the central two-thirds of the quadrangle, the Providence Canyon thrust fault places Ordovician through Devonian rocks, which are overturned to the west, on Devonian and Mississippian rocks that form the west limb of the Logan Peak syncline.

Tertiary deposits are only present in the subsurface in the Logan quadrangle. They consist of Eocene(?) Wasatch Formation conglomerate, and Miocene-Pliocene(?) Salt Lake Formation conglomerate, siltstone, and tuffaceous sandstone that are up to 8,000 feet (2,440 m) thick in Cache Valley.

Quaternary units were deposited in the deltas, shorelines, and lake bottom of Lake Bonneville. Prominent units were deposited during the Lake Bonneville high stand (approximately 16,000-15,000 years ago) at a present-day elevation of ~5,100 feet (1,555 m) and during the Provo shoreline still-stand (~14,500-13,500 years ago), when the lake was at an elevation of 4,780 to 4,790 feet (1,457 to 1,460 m). Other Quaternary deposits include alluvial stream and fan deposits, landslides, slumps and/or flows, and colluvial deposits.

The mountain front of the Bear River Range formed due to slip along the East Cache fault, an active normal fault with about 16,400 to 21,000 feet (5.0 to 6.4 km) of offset. Fault scarps along the East Cache fault are in Lake Bonneville deposits and in post-Provo-phase alluvial deposits near the mouth of Logan Canyon. Excavations across fault scarps indicate that two surface rupturing earthquakes occurred along the East Cache fault in the past 15,000 years. The East Cache fault lies at the very base of the Bear River Range in most of the map area.

The most valuable mineral resource in the quadrangle is Quaternary sand and gravel. Geologic hazards in the quadrangle include flooding, mass wasting, and earthquakes.

INTRODUCTION

The Logan, Utah 7.5′ quadrangle encompasses a portion of the western Bear River Range and the eastern margin of Cache Valley in northern Utah. The map area contains exposures of Paleozoic sedimentary rocks and Quaternary sediments. The Paleozoic bedrock units record contractional deformation that occurred during the Cretaceous Sevier orogeny. Unconsolidated Quaternary units exposed in the quadrangle were deposited in the Cache Valley basin, which formed during basin-and-range extensional faulting. Tertiary sedimentary rocks are concealed by the Quaternary units in this basin.

The map is a compilation of 1:24,000-scale mapping of surficial deposits by J.P. McCalpin, bedrock mapping by D.C. Holmes and J.P. Evans, and stratigraphic and sedimentologic

[1] *now at GEO-HAZ consultants, P.O. Box 1377, Estes Park, Colorado 80517*

studies of Paleozoic rocks presented in numerous masters theses at Utah State University (cited in the text). Surficial geology was originally mapped by J.P. McCalpin for his 1:50,000 map of the East Cache fault zone (McCalpin, 1989) In addition, we compiled stratigraphic information on the Paleozoic rocks presented by U.S. Geological Survey workers in the area. Field mapping was done on aerial photographs and topographic base maps between 1986 and 1991.

This map completes the series of 7.5′ scale geologic maps of the western Bear River Range mountain front in Utah. Mapping to the north by Lowe and Galloway (1993), and Brummer and McCalpin (1995), and to the south by Mullens and Izett (1964) help define the major structural and stratigraphic relationships along the Bear River Range front. The Logan 7.5′ quadrangle was included on smaller scale geologic maps of Williams (1948, 1958) and Dover (1995).

BEDROCK STRATIGRAPHY

Introduction

Bedrock units in the Logan quadrangle consist of over 12,000 feet (3,600 m) of Cambrian through Permian(?) rocks. The lower part of the section (Cambrian through Late Silurian) contains mainly limestones and dolostones which were deposited in the Cordilleran miogeocline (Hintze, 1988). Devonian rocks consist of sandy limestones, sandstones and a thick dolostone formation, whereas Mississippian rocks are primarily limestones with some sandstones. The Pennsylvanian and Permian(?) Wells Formation equivalent rocks record clastic deposition along the margin of the Oquirrh basin (see Jordan and Douglass, 1980). Bedding-plane parallel thrust faults are common in the area and may contribute to the variations in stratal thickness of sedimentary rock units in the quadrangle.

Cambrian

St. Charles Formation (Ꞓsc)

The oldest rocks exposed in the quadrangle are thin-bedded limestone and massive gray dolostone of the St. Charles Formation, which is Cambrian and earliest Ordovician in age (Taylor and others, 1981). Thin slivers of these rocks are exposed in the hanging wall of a thrust fault along the western edge of the Bear River Range north of Logan Canyon (see also Galloway, 1970; Lowe and Galloway, 1993).

Ordovician

Garden City Formation (Ogc)

Thin- to medium-bedded, medium- to light-gray limestone and minor dolomitic limestone comprise the Ordovician Garden City Formation. Only the upper part of the Garden City Formation is exposed in the quadrangle; it is present in the northern half of the quadrangle along the westernmost edge of the Bear River Range. The Garden City Formation consists of crystalline and fossiliferous limestone, micritic limestone, silty limestone, and thin- to medium-bedded dolostone. The lower part of the formation contains numerous intraformational conglomerate beds, and in the upper part of the formation black chert lenses and stringers are common. Measured thicknesses of this unit range from 1,400 feet (426 m) in Green Canyon, north of the Logan quadrangle (Williams, 1948), to 1,160 feet (354 m) in Blacksmith Fork Canyon, southeast of this quadrangle (Ross, 1949).

Swan Peak Formation (Osp)

Overlying the Garden City Formation is perhaps the most easily recognized unit of the area. The Swan Peak Formation consists of three distinct lithologies (Williams, 1948; Francis, 1972): a lower interbedded sequence of blue, gray, and brown shale, minor thin-bedded quartzite, and gray limestone beds; a middle purple and gray quartzite with abundant burrows, ripple marks, fish fragments, and disarticulated trilobites and cephalopods; and an upper light-brown to white and tan, well-indurated, medium-grained quartzite with burrows in the lower portions. The thickness of the Swan Peak Formation decreases southward from 401 feet (122 m) in Green Canyon, north of the Logan quadrangle, to 283 feet (86 m) in Logan Canyon (Galloway, 1970), to 134 feet (41 m) east of Providence (Van Dorston, 1969). The lower unit is commonly covered by vegetation, but on the north side of Logan Canyon the gradational contact between the Garden City and Swan Peak Formations is exposed. The base of the Swan Peak Formation was mapped at the first series of shales above gray, cherty limestone. The upper contact with the Fish Haven Dolomite is an unconformity commonly marked by a dolomitic sandstone or solution breccia 1 to 3 feet (0.3 to 1 m) thick. This contact is commonly faulted and hydrothermally altered along much of its length in the quadrangle, and small adits have been dug along the contact.

Fish Haven Dolomite (Ofh)

The youngest Ordovician unit in the map area is the Fish Haven Dolomite. The Fish Haven Dolomite is a dark-gray to black, thick-bedded, fine- to medium-crystalline dolostone (Mecham, 1973). The unit contains rare bioturbated sandy layers, remnants of algal mats, and tabulate (*Halysites* sp. and *Favosites* sp.) and rugose corals. Near the top of the formation the Fish Haven Dolomite is medium gray and contains chert nodules. The unit has a uniform thickness of 130 to 145 feet (40 to 44 m) in and near the Logan quadrangle (Mecham, 1973). The local absence of Fish Haven south of Logan Canyon is due to structural thinning. The unit lies above the Swan Peak Formation, marked by a regional unconformity (Oaks and others, 1977), and its upper contact with the Silurian Laketown Dolomite is marked by a change from dark-gray, mottled dolostone to light-gray, massive dolostone of the Laketown Dolomite. The contact between the two units was mapped at the top of the highest dark-gray dolostone bed.

Silurian

Laketown Dolomite (Sl)

The only Silurian unit in the region is the Laketown Dolomite, which is a massive, cliff-forming, light-gray dolostone. The dolostone is fine and medium crystalline, medium to thick bedded, and contains sparse corals, brachiopods, cephalopods, and algal mats (Budge, 1966). The unit is 1,150 feet (350 m) thick in Green Canyon, north of the Logan quadrangle (Williams, 1948), and 1,610 feet (491 m) thick in Blacksmith Fork Canyon, southeast of the quadrangle (Budge, 1966).

Devonian

Water Canyon Formation (Dwc)

The Water Canyon Formation consists of the lower, Card Member and the upper, Grassy Flat Member (Taylor, 1963; Williams and Taylor, 1964). The Water Canyon Formation is exposed on ridge crests in the map area so was not split into members in this mapping project.

The Card Member is a light-gray, white, and light-brown, thin-bedded, argillaceous dolostone with locally developed intraformational breccia (Taylor, 1963). The Card Member is poorly exposed and the base of the member is mapped at the first thin-bedded sequence above massive, light-gray outcrops of Laketown Dolomite.

The Grassy Flat Member consists of interbedded dolostone, siltstone, intraformational breccia and calcareous sandstone, and thin beds of dolostone. The member is purple, gray, brown, yellow, and white. The top of the Grassy Flat Member is marked by an abrupt change from slope-forming, thin-bedded, sandy horizons to massive, dark-gray beds of the Hyrum Dolomite. A measured section (Taylor, 1963) on the south side of Logan Canyon, in the northeast corner of the quadrangle, shows the Card Member to be 251 feet (76 m) thick and the Grassy Flat Member to be 335 feet (102 m) thick.

Hyrum Dolomite (Dh)

The Hyrum Dolomite is a cliff-forming sequence of limestone and dolostone. The Samaria Limestone Member (Eliason, 1969) is at the base of the formation, and consists of fossiliferous, thin- to medium-bedded, yellow, gray, brown, and tan dolostone and limestone. Above the Samaria the Hyrum Dolomite consists of medium- to dark-gray dolostone which exhibits medium to thick bedding. Much of the upper part of the Hyrum Dolomite is devoid of fossils (Eliason, 1969; Williams, 1948). Thicknesses of the Hyrum Dolomite range from 1,011 feet (308 m) in Logan Canyon northeast of the quadrangle to 932 feet (284 m) in Blacksmith Fork Canyon (Eliason, 1969). The upper contact with the Beirdneau Formation is mapped below the first series of thin-bedded, sandy, tan dolostones of the Beirdneau Formation.

Beirdneau Formation (Db)

The Beirdneau Formation is a thin- to medium-bedded, gray, tan, yellow and brown, arenaceous dolostone which grades upward into a predominantly sandstone sequence. The sandstone is tan, yellow, and white, and quartz content varies across the region (Eliason, 1969). Cross-bedding, thin laminations, ripple marks, and mud cracks are common sedimentary features in this formation. Overlying the sandstone sequence is an upper carbonate unit which contains light-gray and tan, sandy dolostone, and a capping limestone. Thickness ranges from 1,087 feet (331 m) in Blacksmith Fork Canyon to 524 feet (160 m) in Logan Canyon (Eliason, 1969).

The capping limestone of the Beirdneau Formation is a thin (30 to 60 feet [9 to 18 m] thick), resistant layer which is locally referred to as the "contact ledge." Williams (1948) included the "contact ledge" in the Mississippian rocks of the range; however, Sandberg and Poole (1977) later assigned it a Devonian age. The "contact ledge" thins southward and is not exposed in the southern part of the quadrangle.

Mississippian and Devonian

Leatham Formation (MDl)

The Leatham Formation is present sporadically in the quadrangle, and its lower and upper contacts are unconformable (see Sandberg and Gutschick, 1979). Where present it consists of a thin-bedded, black, gray, and brown siltstone and limestone ranging in thickness from 0 to 80 feet (0 to 24 m). The Devonian and earliest Mississippian age was determined by Sandberg and Gutschick (1979). The unit forms recessive, vegetated slopes, in marked contrast to the overlying cliff-forming Lodgepole Limestone.

Mississippian

Mississippian units are the Lodgepole Limestone, Little Flat Formation equivalent, and Monroe Canyon Limestone equivalent. The term equivalent is used because detailed stratigraphic studies of these rocks in the Bear River Range have not been performed, and the Little Flat and Monroe Canyon type sections are in a different thrust plate. Brazer terminology, previously used by Williams (1948, 1958), is not used because Brazer type sections are in yet another thrust plate. Using the names Little Flat and Monroe Canyon follows the suggestion of Mullens and Izett (1964), the usage of Dover (1995), and is based on descriptions of these formations in southern Idaho (Dutro and Sando, 1963; Sandberg and Gutschick, 1979; Sando and others, 1981) and adjacent Utah (Sando and others, 1976).

Lodgepole Limestone (Ml)

The Lodgepole Limestone is a medium- to dark-gray limestone which forms prominent cliffs referred to as the "Chinese Wall" (Williams, 1958). The formation is a micrite, biomicrite,

and biosparite, with chert layers distributed throughout. A middle unit is richer in micrite and forms slopes between upper and lower, resistant, ledge-forming sequences (Williams, 1948). Fossils are common in the Lodgepole and include brachiopods, corals, crinoids, gastropods, and bryozoans. The Lodgepole Limestone is 690 feet (210 m) thick in Blacksmith Fork Canyon (Mullens and Izett, 1964).

Little Flat Formation equivalent (Mlf)

The Little Flat Formation equivalent unit consists of quartz sandstone and siltstone, and minor amounts of limestone, phosphatic limestone, dolostone, shale, and chert. Rocks in this unit are brown, gray, light yellow, and orange. The unit is 1,206 feet (367 m) thick in Blacksmith Fork Canyon (Brazer Limestone, member A of Mullens and Izett, 1964). The Little Flat may thin northward or the thickness may be variable due to bedding-plane thrust faults. The contact with the underlying Lodgepole Limestone is conformable, and was mapped at the first appearance of phosphatic shale and the thin-bedded sandstones of the Little Flat Formation which commonly form recessive slopes.

Monroe Canyon Limestone equivalent (Mmc)

The Monroe Canyon Limestone equivalent unit consists of a lower, thick-bedded, massive, cliff-forming limestone; a middle, medium-bedded limestone; and an upper, cherty limestone (Dover, 1995). The upper and lower limestone units are gray to brown-gray, and contain corals, crinoids, chert, and oolitic beds. The Monroe Canyon Limestone was estimated as 750 to 1,150 feet (228 to 350 m) thick by Berry (1989) in the Porcupine Reservoir quadrangle to the southeast, and about 800 feet (245 m) was measured in Blacksmith Fork Canyon (Brazer Limestone, members B and C of Mullens and Izett, 1964). The contact between the Little Flat and Monroe Canyon is gradational, and was mapped at the first resistant series of thick limestone beds.

Pennsylvanian and Permian(?)

Wells Formation (IPPw)

Pennsylvanian and possibly Permian rocks are found along the eastern edge of the quadrangle, where a thick, poorly exposed sequence of sandstones and sandy limestones underlie vegetated slopes located on the flanks of Little and Big Baldy peaks. Because the upper part of the unit has been eroded away and fossils are scarce, it is not known if Permian rocks are present in this unit. Williams (1948) and Jordan and Douglass (1980) used the name Wells Formation for the Pennsylvanian and Permian(?) rocks in and near the Logan quadrangle; however, Williams (1958), Dover (1995), and Mullens and Izett (1964) employed the name Oquirrh Formation for the same rocks. Confusion over the name stems from difficulties in defining the limits of the Oquirrh basin and its shelf, and the lack of fossils in the rocks. Jordan and Douglass (1980) interpreted the Bear River Range to have been part of the Wells shelf and Oquirrh slope. Based on lithologic similarities to Wells Formation rocks exposed in the Crawford Mountains (Welsh and Bissell, 1979; Chamberlain, 1980) and in Idaho (Skipp and others, 1979; Skipp and Hall, 1980), and Pennsylvanian-Permian paleogeography (Welsh and Bissell, 1979; Jordan and Douglass, 1980), we use the term Wells Formation.

In the quadrangle this unit consists of fine- to medium-grained, brown to gray, calcareous, quartz sandstone with interbeds of gray, sandy limestone. The total thickness of the unit is undetermined in the quadrangle, as the top of the unit is not exposed. Mullens and Izett (1964) reported a thickness of 600 feet (183 m) in the Paradise quadrangle, immediately south of the Logan quadrangle, while Berry (1989) reported 900 feet (275 m) in the Porcupine Reservoir quadrangle to the southeast. The contact between the Monroe Canyon and Wells Formation is unconformable (Berry, 1989), and was mapped at the top of a dark-gray limestone in the Monroe Canyon Formation equivalent unit.

Tertiary

Tertiary sedimentary rocks (Tu) are not exposed in the quadrangle, but are present in the subsurface and provide constraints on the amount of slip on the East Cache fault. Tertiary rocks are the Eocene(?) Wasatch Formation, and the Pliocene and Miocene(?) Salt Lake Formation. The Wasatch Formation is reddish conglomerate. The Salt Lake Formation consists of conglomerate, tuffaceous siltstone and sandstone, and freshwater limestone. Conglomerate of the Salt Lake Formation consists of carbonate and quartzite, clast-supported deposits with carbonate sand matrix. The tuffaceous sequences consist of fine-grained siltstone and sandstone, commonly rich in volcanic ash (Brummer, 1991). Thicknesses of the Salt Lake Formation are highly variable, but drill-hole data northwest of Logan indicate a thickness of ~6,200 feet (1,890 m) (Brummer, 1991).

QUATERNARY DEPOSITS

Quaternary deposits in the quadrangle were mapped using 1:20,000 aerial photographs and field investigations. The descriptions of map units given below and the discussion of Quaternary depositional history are adapted from McCalpin (1989). These deposits may be up to 1,000 feet (300 m) thick in the western edge of the quadrangle (see Case, 1985; Brummer, 1991).

Alluvial Deposits

Alluvial deposits consist of variable amounts of gravel, sand, and silt, and lesser amounts of clay deposited by perennial and intermittent streams. Stream deposits are separated into three units Qal_1, Qal_2, and Qalu, which were deposited in channels, floodplains, and on terraces. Alluvial-fan deposits are also sepa-

rated into three units, Qaf_1, Qaf_2, and Qaf_3. Stream deposits are mapped on floodplains and as thin strath terrace deposits along perennial streams. Gravel in these deposits is generally more rounded and better sorted than in alluvial-fan deposits. Stream deposits are differentiated by their vertical positions at or below the prominent levels of the Bonneville lake cycle and above the modern stream level. Alluvial-fan deposits lie at the mouths of most canyons along the mountain front. Fan deposits are differentiated by the following criteria: (1) crosscutting relations with other alluvial deposits or lacustrine shorelines of known age, (2) their height above modern stream level, and (3) differences in morphologic sharpness of debris-flow levees and channels. Fan deposits are thickest near the mountain front, on the downthrown side of the East Cache fault.

Undivided Holocene to latest Pleistocene stream alluvium (Qalu)

Undivided stream alluvium of Holocene to latest Pleistocene age consists of floodplain and terrace gravel, sand, and silt deposited after the Provo-level stand of Lake Bonneville (~14,500 to 13,000 years ago). The unit is mapped along numerous intermittent streams and includes small areas of hillslope colluvium, alluvial-fan, debris-flow, and low alluvial-terrace deposits. In some places these deposits may grade downslope into alluvial-fan deposits (Qaf_1, or Qaf_2). We also include some low-relief areas in the modern floodplains of Logan River and Blacksmith Fork in this unit, where insufficient relief prevents distinguishing late Holocene from earlier Holocene deposition. Such deposits are less gravelly than those mapped along intermittent streams in the mountains. The thickness is probably less than 33 feet (<10 m).

Middle Holocene to latest Pleistocene stream alluvium (Qal_2)

Middle Holocene to latest Pleistocene stream alluvium consists of clast-supported, pebble and cobble gravel in a matrix of sand, silt, and minor clay. Gravels may also contain thin sand lenses, and are moderately sorted and thin to medium bedded. This unit was deposited by perennial streams (Logan River, Blacksmith Fork), forms terraces usually more than 16 feet (>5 m) above modern stream level, and is usually inset into gravel deposits of Lake Bonneville. The exposed thickness is less than 16 feet (<5 m).

Late Holocene stream alluvium (Qal_1)

Late Holocene stream alluvium consists of clast-supported, pebble and cobble gravel in a matrix of sand, silt, and minor clay. These deposits contain thin, sand lenses, are moderately sorted and are thin to medium bedded. Alluvium was deposited by perennial streams (Spring Creek, Logan River, Blacksmith Fork, Little Bear River) on the modern floodplain and in low terraces less than 16 feet (<5 m) above modern stream level, and may include minor sheet-wash and slump deposits overlying alluvium along steep stream embankments. Exposed thickness is less than 16 feet (<5 m).

Middle Pleistocene (pre-Bonneville lake cycle) fan alluvium (Qaf_3)

Middle Pleistocene (pre-Bonneville-lake-cycle) fan alluvium is exposed only at the mouth of Logan Canyon near First Dam and consists of clast-supported pebble, cobble, and boulder gravel in a matrix of sand, silt, and minor clay. It is poorly sorted with angular to rounded clasts, and contains no reworked lacustrine gravel. These deposits also contain abundant large subangular to rounded boulders from Paleozoic formations present in the Bear River Range. Maximum exposed thickness in cuts along the Logan River is approximately 33 feet (~10 m).

Middle Holocene to latest Pleistocene fan alluvium (Qaf_2)

Middle Holocene to latest Pleistocene fan alluvium consists of clast-supported, locally bouldery, pebble, and cobble gravel in a matrix of sand, silt, and clay. These deposits are poorly sorted with angular to subrounded clasts, and rare well-rounded clasts that were reworked from Lake Bonneville deposits. This map unit was deposited by perennial and intermittent streams, debris flows, and debris floods, which were graded several meters above modern stream level. These older fans possess a more subdued debris-flow levee morphology than do younger fans. Locally the unit includes some small fans which are derived entirely from large escarpments in lacustrine gravel. Exposed thickness is less than 16 feet (<5 m).

Late Holocene fan alluvium (Qaf_1)

Late Holocene fan alluvium consists of clast-supported, pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and clay. The gravel is poorly sorted with angular to subrounded clasts, and very rare well-rounded clasts that were reworked from Lake Bonneville deposits. Bedding is medium to thick bedded or very thick bedded. Fan alluvium was deposited by intermittent streams, debris flows, and debris floods graded to modern stream levels. The alluvium forms small discrete fans along the mountain front, and small, steep alluvial cones in major canyons where steep tributaries enter the canyon floor. Late Holocene fans are distinguished from older fans by their sharper debris-flow levees and channels. This map unit also includes small, young fans derived entirely from high escarpments in lacustrine gravel. In places, the unit may contain small deposits of older debris-flow and fan alluvium. No lacustrine shorelines occur on fan surfaces in this unit. Typically, these deposits thin downslope and pinch out valleyward. Exposed thickness is less than 16 feet (<5 m).

Lacustrine Deposits

Lacustrine deposits consist of gravel, sand, silt, and clay deposited in the fluctuating waters of Lake Bonneville. Lacustrine deposits in the map area are divided into three groups: (1) deposits associated with the Bonneville shoreline and the transgressional phase of the Bonneville lake cycle, (2) deposits associated with the Provo and younger shorelines and the regressional

phase of the Bonneville lake cycle, and (3) undivided Lake Bonneville deposits that cannot be assigned to a specific phase of the Bonneville lake cycle. Sediments deposited near the mountain front are mostly gravel and sand; silt and clay were deposited in quieter, deeper water on the valley (lake) bottom, in sheltered bays between headlands, and less commonly in lagoons behind barrier bars.

Bonneville (transgressional) phase deposits

Deltaic deposits related to the Bonneville shoreline (Qlbd): Deltaic deposits related to the Bonneville shoreline are late Pleistocene in age and consist of clast-supported, subrounded to rounded pebble and cobble gravel in a matrix of sand and minor silt. Gravel is interbedded with thin sand beds. This unit was deposited as deltaic foreset and topset beds and is mapped at the mouths of the Logan River Canyon and Millville Canyon. These deltaic deposits are more gravelly where the Bonneville shoreline was at the range front (Millville Canyon), and more sandy where the shoreline extended far into the embayments in the canyons (Logan Canyon; Qlbs at Blacksmith Fork Canyon). The unit is nearly pure sand at elevations of 4,800 to 5,150 feet (1,470 to 1,570 m) northeast of River Heights on the south side of the Logan River, suggesting longshore transport from the embayed mouth of the canyon. Exposed thickness is less than 33 feet (<10 m).

Lacustrine gravel and sand related to the Bonneville shoreline (Qlbg): Lacustrine gravel and sand related to the Bonneville shoreline are late Pleistocene in age and consist of clast-supported pebble and cobble beds in a matrix of sand and silt with interbedded sand beds. Clasts are usually subrounded to rounded, but may include angular to subangular boulders derived from the adjacent steep mountain front. Dip of bedding ranges from horizontal to 25 degrees. This unit was deposited in beaches, bars, spits, and small deltas. It is mapped between the Provo and Bonneville shorelines at elevations of 4,840 to 5,160 feet (1,475 to 1,572 m), and includes wave-built benches at the Bonneville shoreline and several less-developed intermediate shorelines in the map area. Shoreline deposits are commonly partly covered by hillslope colluvium or rockfall talus. The exposed thickness is less than 33 feet (<10 m).

Lacustrine sand and silt related to the Bonneville shoreline (Qlbs): Lacustrine sand and silt related to the Bonneville shoreline is late Pleistocene in age and consists of coarse to fine sand, silt, and minor clay that is typically rhythmically bedded. Deposits are well sorted with ripple laminations; original bedding dips range from horizontal to as much as 10 degrees. These sands were deposited as nearshore sediments and as lagoon fill behind barrier bars. At mouths of major canyons, water-well logs show this unit to be as thick as 170 feet (52 m) underneath Provo deltas.

Provo (regressional) phase deposits

Deltaic deposits related to the Provo and younger shorelines (Qlpd): Deltaic deposits related to the Provo and younger shorelines are latest Pleistocene in age and consist of clast-supported pebble and cobble gravel in a matrix of sand and minor silt deposited at elevations between 4,820 feet and 4,480 feet (1,470 and 1,366 m). These gravels are interbedded with thin sand beds and contain subrounded to rounded clasts deposited as foreset beds with original valleyward dips of 30 to 35 degrees. The deltaic gravels are commonly capped with topset beds less than 16 feet (<5 m) thick that are less well sorted than foreset beds, and which may grade upslope into alluvial-fan or terrace deposits. This unit is mapped at the mouths of Logan River, Spring Creek (Providence Canyon), Millville Canyon, and Blacksmith Fork Canyon. Much of the material in these deltaic deposits may have been reworked from Bonneville-level shoreline deposits at the time of the Bonneville flood (see below). The unit may include as many as 11 sub-deltas (not differentiated on map) graded to lake levels below the Provo shoreline. The exposed thickness of this unit is less than 82 feet (<25 m).

Lacustrine sand and gravel related to Provo and younger shorelines (Qlpg): Lacustrine sand and gravel related to Provo and younger shorelines is latest Pleistocene in age and contains clast-supported pebble and cobble gravel in a sparse matrix of sand and silt. These gravels are commonly interbedded (sometimes rhythmically) with thin sand beds and contain subrounded to rounded clasts. The deposits are thin to thick bedded, with original bedding dips ranging from horizontal to as much as 15 degrees. These beaches, bars, and spits typically formed south (downcurrent) of Provo deltas. This unit is mapped at and below the Provo shoreline between elevations of 4,820 to 4,840 feet (1,470 to 1,475 m) in the map area. The exposed thickness is less than 16 feet (<5 m).

Lacustrine sand and silt related to Provo and younger shorelines (Qlps): Lacustrine sand and silt deposits related to Provo and younger shorelines are latest Pleistocene in age and consist of coarse to fine sand, silt, and minor clay that is typically rhythmically bedded. Beds are thin, with common ripple laminations. Original bedding dips range from horizontal to as much as 10 degrees. These fine-grained sediments were deposited in nearshore environments valleyward from Provo-level deltas at Logan and Providence Canyons. Exposed thickness is less than 16 feet (<5 m).

Undivided fine-grained Lake Bonneville deposits (Qlf)

Undivided deposits of Lake Bonneville are related to both the Provo and Bonneville shorelines and other lake levels. These deposits are late Pleistocene in age and consist of thin-bedded clay, silt, and minor fine sand deposited in deep and/or quiet water on the basin floor. The contact of this map unit with coarser alluvial deposits and lacustrine sediments is often obscured by agricultural development, and must be inferred from soil surveys or from limits of historical alluviation visible on 1938 aerial photographs. The percentage of silt increases near mouths of major canyons, and decreases valleyward and between canyon mouths. Logs of water wells between Hyde Park and North Logan (in the Smithfield quadrangle to the north) indicate the typical thickness is 40 to 50 feet (~12 to 15 m).

Mass-Wasting Deposits

Mass-wasting deposits are poorly sorted to unsorted, and their composition and texture varies greatly depending on the

material from which they were derived. Deposits mapped in the quadrangle include mixed alluvium and colluvium, slumps, slides, and flows. Minor debris flows are included in the alluvial fan deposits (Qaf_1, Qaf_2, and Qaf_3).

Undivided alluvium and colluvium (Qac)

This unit mostly contains undivided Holocene and Pleistocene(?) hillslope colluvium and fan alluvium, and consists of pebble, cobble, and boulder gravels mixed with sand, silt, and clay. The map unit also contains small areas of landslide deposits and stream alluvium.

Holocene and Pleistocene(?) slides and slumps (Qms)

These slumps or slides of uncertain Quaternary age are only mapped along the base of the Wells Formation between Millville Canyon and Dry Canyon. The unit is unsorted and unconsolidated, fine-grained sediment with few clasts, and was derived from the base of the Wells Formation.

Holocene to latest Pleistocene slope-failure deposits (Qmsf)

Holocene to latest Pleistocene slope-failure deposits are unsorted, unstratified, matrix-supported, sparse gravel with abundant sand and silt matrix. This unit is mapped on the north and south sides of the Logan River west of the canyon mouth, where Provo-level deltaic deposits (Qlpd) exposed in steep escarpments overlie Bonneville shoreline deposits. These slopes have failed by slump, slide, and/or flow of the fine-grained material. Other slope failures are reported between those mapped along the escarpments on both sides of the river, but their existence is not well documented (see Utah Geological Survey files; McCalpin, 1994).

Late Quaternary Depositional History

This discussion of the late Quaternary depositional history of the Cache Valley area is summarized from Scott and others (1983), Currey and Oviatt (1985), and Currey (1980). Most of the surficial deposits in the quadrangle were deposited during the last cycle of Lake Bonneville (known as the Bonneville lake cycle) between 30,000 and 10,000 years ago, and in the Holocene (<10,000 years ago) (see Williams, 1962). Lake Bonneville rose slowly, with several fluctuations, from a low level about 30,000 years ago and paused at the Bonneville shoreline, locally near 5,150 feet (1,570 m) above sea level, by about 16,000 years ago. After 1,000 to 2,000 years at or near this level, the lake dropped about 360 feet (110 m) to an elevation of about 4,790 feet (1,460 m) as a consequence of catastrophic downcutting of the lake outlet at Red Rock Pass in southeastern Idaho. In the map area, this rapid decline in lake level was accompanied by rapid erosion of Bonneville shoreline sands, gravels, and deltaic deposits; much of this debris was redeposited as deltas at the Provo shoreline near the mouths of major canyons. The Provo-level delta deposits form prominent flat surfaces in the quadrangle, including surfaces on the eastern edge of Logan where the campus of Utah State University is located. After 13,500 years ago, the lake level began to drop and reached the approximate level of modern Great Salt Lake some time between 12,500 and 11,500 years ago and rose briefly to the Gilbert shoreline (4,278 feet [1,295 m]; the lake did not occupy Cache Valley) between 11,000 and 10,000 years ago (Murchison, 1989). Since then, the lake level has remained within 33 feet (10 m) of the level of modern Great Salt Lake (Currey, 1980).

As the level of Lake Bonneville receded from the Provo shoreline, alluvial fans were deposited at canyon mouths along the mountain front. Between Logan and Hyrum, deposits of late Holocene age are restricted to small areas covering parts of the surfaces of larger alluvial fans.

STRUCTURAL GEOLOGY

The quadrangle exhibits abundant evidence of deformation in two separate orogenic events: the mostly Cretaceous Sevier orogeny, and the Miocene to Holocene basin-and-range deformation. Paleozoic rocks along the western margin of the Bear River Range were folded and faulted during Sevier contraction, and were later subjected to extension by basin-and-range faulting. We will first describe the older, Sevier orogenic structures, and then describe the evidence present in the quadrangle for basin-and-range normal faulting and seismicity.

Sevier Contractional Structures

Williams (1948) first described, but did not explicitly show on his map, contractional structures along the western margin of the Bear River Range. He did map the axis of Logan Peak syncline just east of the Logan 7.5′ quadrangle. Subsequent work by Galloway (1970; see also Lowe and Galloway, 1993), Mendenhall (1975), Sprinkel (1979), and Dover (1995) document the presence of folded rocks and several west-dipping thrust faults in Cambrian through Mississippian rocks along the western margin of the range.

In the Logan quadrangle, the most prominent contractional structure is the Providence Canyon thrust fault (Dover, 1983, 1995) and related folds which are exposed over an approximately 6 mile (~10 km) trace length between a point 1 mile (1.62 km) north of Blacksmith Fork Canyon to Dry Canyon (south of Logan Canyon). Along its central, relatively straight part, the west-dipping thrust juxtaposes overturned-to-the-west Devonian Water Canyon Formation and Hyrum Dolomite on moderately to steeply dipping Devonian Hyrum Dolomite and Beirdneau Formation, and Mississippian Lodgepole Limestone. A thrust splay is present just to the west in this central part (plate 1). To the south and north the main thrust cuts down-section in both the hanging wall and footwall, and is in Silurian Laketown Dolomite at the range front. Rocks in the hanging wall are all overturned to the west with shallow to moderate dips.

Although the map relationships of older-on-younger rocks and structures related to the Providence Canyon thrust fault indicate a contractional origin, cross sections strongly suggest that the Providence Canyon thrust has been reactivated in a normal sense. Cross sections which honor the stratal thicknesses and dips of units show that the thrust juxtaposes younger rocks on older rocks in the subsurface (plate 2). Reactivation of Sevier thrust faults was suggested for the area by Sprinkel (1979), and is one of the few mechanically feasible ways to create such structural relationships (Brummer, 1991). Later Tertiary reactivation of the Providence Canyon thrust explains the cross-cutting relationship between the bedding-plane thrusts and the Providence Canyon thrust in the southern part of the quadrangle.

Several other west-dipping thrust faults are present in the quadrangle. Previously mapped (Dover, 1995), west-dipping thrusts along the mountain front have limited extents. We see evidence of these thrusts for only about one mile (1.6 km) north of Providence Canyon. A small thrust related to folding is present north of Dry Canyon. Two small thrusts lie along the range front north of Logan Canyon (see also Galloway, 1970; Lowe and Galloway, 1993). A west-dipping thrust fault cuts the Silurian Laketown Dolomite in the hanging wall of the Providence Canyon thrust; it probably steps off the Providence Canyon thrust and accounts for dip discordance and apparent thickening of the Laketown Dolomite.

Thrust faults dip gently eastward and westward, parallel to sub-parallel to bedding, throughout the Bear River Range. Two mappable east-dipping thrusts are exposed in the southern third of the Logan quadrangle. The westernmost juxtaposes Devonian Hyrum Dolomite on Silurian Laketown Dolomite, omitting the Devonian Water Canyon Formation. The nearby eastern thrust places Mississippian Lodgepole Limestone on the Hyrum Dolomite. East-dipping thrusts and west-verging folds are exposed in similar stratigraphic levels in Blacksmith Fork Canyon, immediately south of the Logan quadrangle. East-dipping, bedding-plane parallel thrusts are exposed along the west limb of the Logan Peak syncline (Galloway, 1970; Mendenhall, 1975), and west-dipping, bedding-plane parallel thrusts are also found on the east limb of the Logan Peak syncline. These faults and associated folds appear to be related to bedding-plane slip generated during folding of the Logan Peak syncline. These structures tend to structurally thicken units throughout the quadrangle, and may be one cause of stratal thickness variations in the quadrangle.

A small tear fault cuts rocks north of Dry Canyon. This fault was shown by Williams (1948) as an east-striking fault which dies out eastward. Dover (1995) showed the fault continuing to the southeast along Dry Canyon. Our work supports William's (1948) interpretation. We find evidence for the fault along the ridge south of Logan Canyon, but lose its trace in massive beds of Laketown Dolomite. A fault with similar trend, but dip-slip movement, is exposed to the east, and cuts the Silurian Laketown Dolomite, and the Devonian Water Canyon Formation and Hyrum Dolomite.

Basin-and-Range Normal Faulting

The dominant normal fault in the quadrangle is the East Cache fault, a major west-dipping, Neogene normal fault which forms the boundary between Cache Valley and the Bear River Range. The entire fault is approximately 48 miles (77 km) long and is divided into three segments based on tectonic geomorphology (McCalpin, 1989, 1994). The Logan 7.5' quadrangle contains the central segment, 12.4 miles (20 km) long, which has evidence of Holocene movement.

The subsurface form of Cache Valley and the East Cache fault was studied in detail by Evans (1991), and relevant subsurface data are incorporated into the Logan quadrangle cross sections (plate 2). Cache Valley is underlain by a thick sequence of gently east-dipping Tertiary sedimentary rocks which are up to 10,000 feet (3,048 m) thick and were deposited in the hanging wall of the East Cache fault. Subsurface data constrain the dip of the East Cache fault to between 45° W and 68° W (Evans, 1991). The fault may have a slightly curved form, dipping nearly 68° W at the surface, and flattening to a dip of 50° W to 55° W at depth. Cutoffs on the Tertiary Wasatch Formation inferred from subsurface data for the hanging wall cutoff, and projection of the Tertiary Wasatch Formation exposed in the Bear River Range (Dover, 1995) indicate that net slip on the fault is approximately 16,000 feet (5,000 m) in the southern part of the quadrangle. The form of the fault, and thus net slip, is not well constrained in the vicinity of cross-section A-A′ in the northern part of the quadrangle. The fault has a minimum dip of 45° W, and the geometry of hanging-wall strata suggest a dip as great as 70° W. Net-slip estimates thus vary from 18,000 to 21,000 feet (5,485 to 6,400 m) for the steeper and shallower dipping fault, respectively.

The morphology of the range front is controlled by normal faulting and erosion of the overturned beds of the western edge of the range. Well-developed faceted spurs (up to seven sets southeast of Logan; McCalpin, 1989) exist along the central segment of the East Cache fault zone, but only in the areas where overturned-to-the-west beds lie in the footwall of the East Cache fault. South of the end of the Providence Canyon thrust, faceted spurs are not as prominent and the range-front topography is more subdued.

In the Logan quadrangle, the fault is marked by a single master fault trace, and locally one or more small splays immediately west of the steep range front. North and south of the central segment the fault divides into two or three splays that do not exhibit prominent fault scarps or the steep mountain front present in the Logan quadrangle. Fault scarps on the central segment of the East Cache fault zone that displace sediments of the Bonneville lake cycle (or younger deposits) are found between Providence Canyon and Green Canyon (in the Smithfield quadrangle north of Logan; see Cluff and others, 1974; Swan and others, 1983; McCalpin, 1989, 1994; Lowe and Galloway, 1993). These scarps are as much as 1,220 feet (400 m) west of the faceted spurs of the mountain range.

The Provo-level deltaic deposits and the post-Provo-level stream terraces north of the mouth of Logan Canyon display fault scarps 3.9 to 9.8 feet (1.2 to 3.0 m) high in the fairways of the Logan Country Club (Swan and others, 1983; McCalpin and Forman, 1991), and represent 4.6 feet (1.4 m) of net vertical displacement, spread over a zone up to 330 feet (100 m) wide (McCalpin, 1994). No late Holocene faulting has occurred north

of Logan Canyon, and north of the Logan Country Club golf course an alluvial fan (Qaf_1) buries a fault scarp.

South of the golf course, the underlying fault was exposed in the 1930s in a road cut along U.S. Highway 89 and photographed (figure 1) by Peterson (1936). The fault displaces well-stratified, Bonneville sand and silt (Qlbs; possible pro-delta deposits) and overlying post-Provo-level, strath terrace deposits (Qal_2). Peterson (1936) reported offset of 16 feet (4.9 m)(his text) and greater than 16 feet (>4.9 m)(his figure). Although no scale is given on the original photograph, the nearby 11.2-foot (3.4 m) thickness of strath gravels was used to estimate scales on figure 1. Thus, the contact between the sandy pro-delta deposits (B) and underlying lacustrine gravels (A) is displaced vertically 21 to 22 feet (6.4 to 6.8 m), while the base of the strath terrace gravels (C) seems to be displaced an amount (3.7 feet [1.13 m]) similar to surface scarp heights (3.9 to 4.6 feet [1.2 to 1.4 m]) to the north.

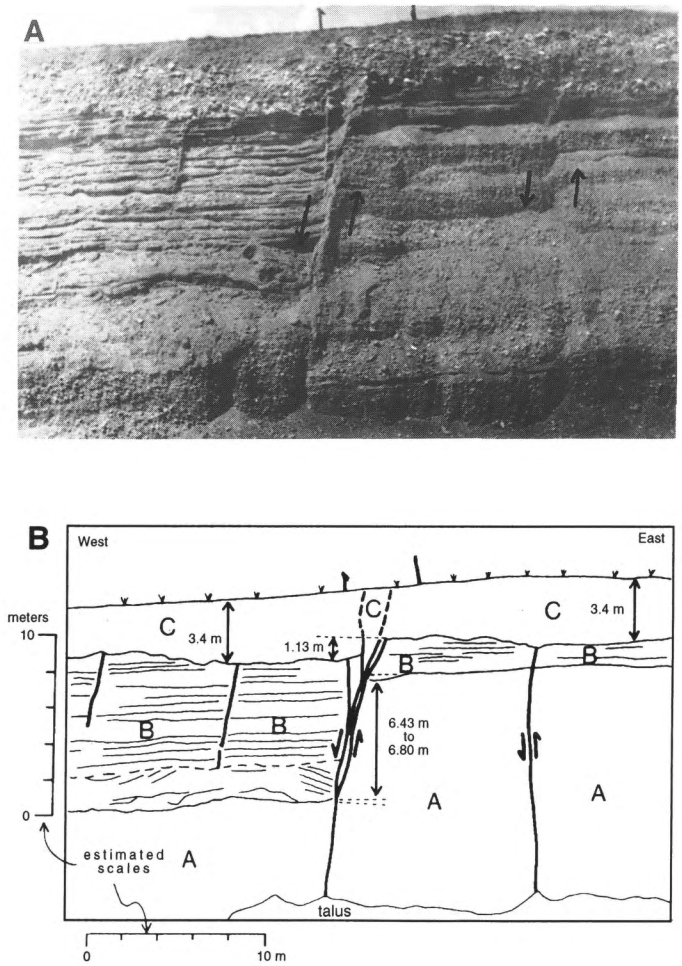

Figure 1. *Photograph and sketch of U.S. Highway 89 road cut near the mouth of Logan Canyon. A) Photograph of the road cut taken in the 1930s (Peterson, 1936). B) McCalpin's 1994 sketch of the Peterson photograph showing correlation of strata and inferred fault displacements. Unit A = well-stratified gravel possibly deposited during the Bonneville transgression; unit B = Bonneville pro-delta(?) sand and silt; unit C = post-Provo strath terrace gravel.*

A trench (EC2 on plate 1) across an approximately 4-foot (1.2-m)-high scarp on the Logan Country Club showed 3.8 feet (1.15 m) of down-to-the-west vertical offset. This is consistent with the offset in the strath terrace gravels in the road cut. The age of this faulting event was estimated at about 4,000 years ago from radiocarbon dating methods (McCalpin, 1994). Prior to this latest faulting event there must have been 17.0 to 18.4 feet (5.2 to 5.6 m) of displacement already existing on the fault. This displacement may have occurred during the older event recognized in trench EC1 (see below), or be the result of this older event and an even earlier event or events (see McCalpin, 1994 for details).

A fault scarp is also present south of the mouth of Logan Canyon, and together with an antithetic fault forms a small depression in Lake Bonneville sediments (Qlbs) 490 feet (150 m) west of the range front. Scarp heights (19.7 to 22 feet [6.0 to 6.7 m]) and profiles yield an estimated of 7.2 to 13.75 feet (2.2 to 4.2 m) of vertical offset (McCalpin and Forman, 1991; McCalpin, 1994). Detailed study of the stratigraphy exposed in trench ECl across this scarp (McCalpin, 1994) and dating of deposits in the trench (McCalpin and Forman, 1991; McCalpin, 1994) show that two surface rupture events occurred along the central segment of the East Cache fault zone. The older event occurred between ~13,000 years ago and 15,540 ± 130 yr B.P., and the younger event occurred between ~4,000 and ~7,000 years ago. Vertical displacement at the trench site was 2.6 and 5.9 feet (0.8 and 1.8 m) for the younger and older event, respectively (McCalpin and Forman, 1991).

Between Hells Kitchen and Providence Canyon the range front is dominated by Holocene alluvial fans which do not display fault scarps. Several north-trending lineaments in Bonneville nearshore sands north of Providence Canyon could be either of tectonic origin or intermediate-stage Lake Bonneville shorelines. Basement excavations for houses east of Providence revealed west-dipping faults with up to 4.9 feet (1.5 m) displacement in nearshore sands, but such faults have no surface expression. However, a single, large, anomalous scarp exists 2,300 feet (700 m) north of Providence Canyon at roughly the level of the Bonneville shoreline. The scarp is developed in a severely eroded remnant of pre-Bonneville fan alluvium (Qaf_3) and has a minimum height of 69 feet (21 m) and surface offset of 28 feet (8.5 m). Surface offset is a minimum height because the scarp base is covered by Bonneville shoreline deposits, which bury alluvial-fan gravels correlative with the surface remnant on the upthrown block. This scarp was created partially by erosion at the highest Bonneville shoreline and probably is also partly tectonic, because the Bonneville shoreline is extremely indistinct both north and south of this old fan remnant. This locality is the only one in the central segment where pre-Bonneville deposits preserve surface expression of faulting.

Immediately south of Providence Canyon a northwest-trending scarp, 12.3 feet (3.75 m) high, offsets a gravelly Bonneville shoreline embankment. This short scarp has an anomalous (NW) strike, and does not seem to align with known fault scarps north of Providence Canyon, although it is aligned with an abrupt direction change in Spring Creek. Because an erosional origin is not indicated, it has been assumed the scarp is tectonic (Swan and others, 1983). The net surface offset across the scarp is

estimated to be 4.9 to 5.7 feet (1.5 to 1.75 m), but this estimate is imprecise because of the width (230 to 262 feet [70 to 80 m]) of the back-tilted zone west of the scarp.

In the southern half of the central segment, between Providence Canyon and Blacksmith Fork Canyon, the range front forms a broad west-facing arc along which no fault scarps are visible (dotted on map). If the surface faulting that created the scarps in the northern half of the central segment extended into the southern half, the evidence has been buried by Holocene fans or destroyed by rapid range-front erosion.

ECONOMIC DEPOSITS

Industrial mineral resources in the Logan quadrangle consist mainly of gravel and sand used for construction. Active pits recover gravel and sand from Provo-stage deltaic deposits (Qlpd) near Hyrum (section 27 and 34, T. 11 N., R. 1 E.; section 3, T. 10 N., R. 1 E.). Smaller active and inactive pits are located in Providence, Logan, and Hyrum. See Utah Department of Highways (1965) for additional information. Several old gravel pits have been filled and recontoured for housing developments (compare 1961 and 1986 versions of U.S. Geological Survey Logan 7.5′ topographic quadrangle).

Crystalline, high-calcium limestone from the Mississippian Monroe Canyon Limestone was quarried at the head of Providence Canyon in the adjacent Logan Peak quadrangle. The limestone was used locally for sugar processing and crushed stone (Williams, 1958; Bryce Tripp, verbal communication, 1992).

Low-grade phosphate rock is found at the base of Little Flat equivalent unit in this and adjacent quadrangles. Analyses of samples from the Millville Canyon area demonstrated 9.4 to 28.4 percent P_2O (Dover and Bigsby, 1983), while samples from Providence Canyon reportedly contained about 4 to 70 percent $Ca_2(PO)_3$ (Peterson, 1914), and 5.3 to 13.9 percent P_2O_5 (Cheney, 1957, table 1). Mullens and Izett (1964, p. 23-24) reported and estimated P_2O_5 content at 1 to 2 percent for the same phosphatic zone in Blacksmith Fork Canyon in the southeast corner of the quadrangle.

Small prospect pits in the northern part of the quadrangle are located along small zones of hydrothermal alteration along faults and the Swan Peak-Fish Haven contact. This might be a southern extension of alteration associated with metallic mineralization noted by Dover and Bigsby (1983) and Bigsby (1982) in the Mount Naomi Roadless Area. However, in the Logan quadrangle, the alteration is at a higher stratigraphic level and accompanies deformation features.

Exploration for oil and gas in the area in the 1970s focused on determining the hydrocarbon potential in Tertiary basin-fill deposits. The Amoco Lynn Reese well in the Smithfield quadrangle explored for these deposits, but oil shows consisted of very heavy tars (T.L. Patton, oral communication, 1987; see also Brummer, 1991). Some potential for oil and gas may exist in Permian and Pennsylvanian rocks beneath the Willard thrust sheet in the region (Chidsey, 1984). However, interpretations of seismic reflection profiles, time-temperature analyses (Oaks and Runnells, 1992), and conodont alteration indices (Sando and others, 1981) suggest that little hydrocarbon potential exists in the Logan quadrangle beneath the Willard thrust sheet.

WATER RESOURCES

The Logan quadrangle and adjacent regions are a significant source of water. Population growth in the Cache Valley will likely increase the demands on this resource. Published reports on the water resources of the valley include Bjorklund and McGreevy (1971), and Kariya and others (1994).

The majority of surface waters in the quadrangle comes from the Logan River and Blacksmith Fork (Bjorklund and McGreevy, 1971). These streams originate in the Bear River Range, and flow into the Bear River drainage system. Average annual discharge for the Logan River measured over a 77 year period (1914-1990) is 104,300 acre-feet (128.6 million cubic meters), and the total average combined discharge of the Logan River and the Logan, Hyde Park, and Smithfield Canal is 197,800 acre feet (242.9 million cubic meters), as measured from 1896 to 1990 (ReMillard and others, 1991). Blacksmith Fork has an average annual discharge of 95,630 acre feet (117.9 million cubic meters), as measured from 1913 to 1990 (ReMillard and others, 1991).

Ground water in the quadrangle is supplied by precipitation which enters and moves through deposits in Cache Valley and rocks of the Bear River Range, and by irrigation and stream water (Bjorklund and McGreevy, 1971). Ground water from the Bear River Range is discharged from springs near the mountain front (Bjorklund and McGreevy, 1971). In Cache Valley, large alluvial fans at the mountain front are coarse-grained deposits that form highly productive aquifers with large transmissivities (Bjorklund and McGreevy, 1971). Aquifer tests in wells near Logan in these fans show that some wells can produce 3,500 gallons/minute (13,248 liters/minute)(Beer, 1967) and yields of 500 gallons/minute (1,893 liters/minute) may be possible within much of the area (Bjorklund and McGreevy, 1971). From 1936 to 1970, little or no long-term change in ground-water levels was observed, although some seasonal fluctuations were noted (Bjorklund and McGreevy, 1971). Since that time a general decline in ground-water levels has occurred (Kariya and others, 1994, figure 15).

GEOLOGIC HAZARDS

The potential geologic hazards in the Logan quadrangle are (1) earthquakes, (2) floods, (3) mass wasting, (4) problem soils, and (5) shallow ground water. The following is a brief survey of these hazards. A study on radon levels in Paradise area is in preparation (Black and Solomon, 1996). Detailed site investigations should be performed in areas of specific concerns.

Earthquakes

The geologic record of past earthquakes clearly shows that the quadrangle has been subjected to large surface-rupturing

earthquakes on the East Cache fault. The data summarized in the "Basin-and-Range Normal Faulting" section show the location and history of the faults in the area. If rupture occurs at depths of 6 to 10 miles (10 to 15 km) (see Smith and Bruhn, 1984; Jackson and White, 1989), the geometry of the East Cache fault in the Logan quadrangle (Evans, 1991) indicates that earthquake foci would lie under the central and western part of the Cache Valley.

The geomorphic evidence, along with detailed geochronology and trenching studies, point to two seismic events which ruptured the surface subsequent to formation of the Bonneville shoreline (McCalpin, 1989, 1994; McCalpin and Forman, 1991). Based on the cumulative maximum vertical displacement of 13.75 feet (4.2 m), the paleoearthquakes which caused these displacements are estimated as M_S 6.7 to 7.1 and were probably limited to the central segment of the East Cache fault zone (McCalpin and Forman, 1991). The estimated recurrence interval between the two events is 10,300 ± 1,300 years, and the time since the last rupture is about 4,000 years (McCalpin and Forman, 1991; McCalpin, 1994). It is very important to note, however, that the recurrence interval is calculated from poorly constrained events. Thus, one should not infer any prediction of future rupture based on these data.

The potential risks posed by an earthquake in the area include surface rupture, ground shaking, subsidence, liquefaction and related ground failure, and slope failure.

The region of likely surface rupture closely follows the map trace of the East Cache fault shown on our map and in McCalpin (1989). The fault trace lies west of the mountain front in the vicinity of Logan. It crosses a part of the Logan City Country Club in the southwest corner of section 25, T. 12 N.; R. 1 E.; and continues northward through a residential neighborhood. Southward the fault probably crosses a portion of the lower (or First) dam on the Logan River, and lies approximately 500 feet (150 m) west of the mountain front in the hills east of a residential area. Farther south, between Dry Canyon and Blacksmith Fork Canyon, the fault lies very close to the range front.

Ground shaking due to earthquakes, either surface-rupturing events or an earthquake with no surface rupture, may pose a significant risk in the entire quadrangle. The relative intensity of ground shaking is highly dependent on the nature of the local geology. Fine-grained, unconsolidated sediments in steep-sided, sediment-filled basins, such as Cache Valley, are particularly susceptible to large ground motions (see Olig, 1991). Ground-shaking potential in Cache Valley was mapped by Youngs and others (1987). They estimated peak ground accelerations of 0.15 to 0.20 g having a 10 percent probability of being exceeded in 50 years (the acceleration due to an earthquake is expressed as a fraction of the gravitational acceleration of the earth on bodies at the earth's surface, which is 9.8 m/sec^2). The criterion of a 10 percent probability in 50 years is a common standard for building design. However, the estimates of Youngs and others (1987) do not take into account local geology, such as thick, soft sediments in deep basins. Logan experienced a peak acceleration of 0.12 g in the relatively small M_L 5.7 Cache Valley earthquake in 1962 (Smith and Lehman, 1979). However, peak accelerations due to a surface-rupturing earthquake on the central segment of the East Cache fault zone would likely be much greater than those generated by the 1962 Cache Valley event. A M_S 7.0 earthquake is capable of producing accelerations greater than 0.6 g depending on distance, local geology, path of rupture, and other effects. It is very likely that accelerations for a large event on the East Cache fault would exceed 0.12 g. Damage to buildings that are not designed to withstand earthquake shaking begins at ground accelerations of approximately 0.1 g. Accelerations of 0.26 and 0.29 g were recorded near the Cypress overpass which was destroyed in the 1989 Loma Prieta, California earthquake (Olig, 1991).

Subsidence is a result of down-dropping and tilting of the hanging wall of normal faults. In Cache Valley, the valley floor would drop down and tilt to the east while the adjacent Bear River Range would move up during an earthquake on the East Cache fault. Subsidence of the Lost River Valley due to the 1983 M_S 7.3 Borah Peak, Idaho earthquake varied from 4 feet (1.2 m) adjacent to the fault to zero about 12 miles (19 km) from the fault (Stein and Barrientos, 1985). The consequences of subsidence include flooding in regions of lakes or where the ground surface drops below the water table, changing stream paths, and altering the gradients of engineered structures such as sewers, canals, and roads (Keaton, 1987). It is likely that subsidence due to slip on the East Cache fault would result in greatest vertical displacement near the fault trace, as happened in the Borah Peak earthquake.

Liquefaction occurs in saturated, cohesionless sand and silt which lose the ability to support loads due to a short period of increased pore pressure caused by ground shaking. Liquefaction is most likely in areas of shallow ground water combined with sediments that lack cohesion during short-term saturation by water. Anderson and others (1990) described the liquefaction potential for Cache Valley using a method developed for the northern Wasatch Front. Most of the quadrangle is rated as having very low to moderate potential for liquefaction (Anderson and others, 1990). Very low potential is defined as regions which require ground accelerations of 0.25 g to induce liquefaction; low is 0.18 to 0.25 g; moderate is 0.10 to 0.18 g; and high is less than 0.10 g required to generate liquefaction. However, moderate to high liquefaction potential exists in the northwestern part of the quadrangle, corresponding to regions underlain by alluvium (Qalu), beginning approximately at the confluence of Blacksmith Fork and Logan River, and trending northwest along the Logan River. Liquefaction potential decreases up stream along both rivers. "The Island" region of Logan (section 34, T. 12 N., R. 1 E.; section 3, T. 11 N., R. 1 E.) is ranked as moderate to low (Anderson and others, 1990). The western side of the map is rated as moderate to low liquefaction potential, corresponding to fine lacustrine deposits (Qlf, Qlps).

Slope failures (slides, falls, and slumps) may be triggered by earthquakes larger than approximately M_L 4.0 (Christenson, 1991). Rock falls commonly result from earthquakes in mountainous regions, and the steep, exposed cliffs of the canyons in the eastern side of the Logan quadrangle are quite susceptible to earthquake-induced falls. Few slumps or slides were mapped in the Logan quadrangle. However, several small slumps (Qmsf) exist at the base of steep slopes along the Logan River. Numerous existing and new houses at the head and base of these slopes are near potential failure zones. This zone (unit Qlbs) exists

along the north and south sides of the Logan River for about 2 miles (3.2 km) downstream from the mouth of the Logan Canyon. Other slumps or slides (Qms) are exposed at the base of the Wells Formation in the upper reaches of Providence Canyon (see section on Mass Wasting).

Floods

The hazards posed by floods in the quadrangle result from the narrow, east-trending valleys in the Bear River Range that drain catchment basins that extend east of the quadrangle. Past floods in the area resulted from high runoff due to snow melt in the spring, and due to intense, short-duration thunderstorms (cloudbursts) in the summer. Melt-induced floods and peak discharges for the Logan River occurred May 24, 1907 (2,480 cubic feet per second=cfs [70.2 cubic meter/second=cms]), March 21, 1916 (2,000 cfs [56.6 cms]), and May 31, 1984 (1,980 cfs [56.1 cms]) (James and others, 1980; ReMillard and others, 1985, 1991). The Blacksmith Fork experienced melt-induced floods in May, 1917 (1,620 cfs [45.9 cms]) and May 16, 1984 (1,650 cfs [46.7 cms]) (ReMillard and others, 1985, 1991). The Logan River also flooded in 1896, 1897, 1912, 1916, and 1921 (James and others, 1980), but few data exist regarding peak discharges or the extent of damage in these floods.

Storm-induced floods resulted in debris flows and "mud floods" along Blacksmith Fork on May 30, 1939, and in Providence and Millville Canyons and adjacent flood plains on August 18, 1959 (Butler and Marsell, 1972; James and others, 1980) and in May, 1971 (Gingery Associates, Inc., 1976). Debris floods are debris flows with more than 50 percent water (Wieczorek and others, 1983); the "mud floods" of 1959 in Millville and Providence (Spring Creek) Canyons were probably debris floods. The 1959 floods resulted from approximately 1 inch (2.54 cm) of rain falling in several minutes over the Millville and Spring Creek drainages, (Gingery Associates, Inc., 1976). Damage to residential areas in Providence and Millville resulted from water floods and debris floods in and outside of the floodplains of the two streams. Small debris flows in the upper part of Providence Canyon, east of the Logan quadrangle, occurred after heavy rains in early June, 1991 and resulted in small, sediment-laden floods in the lower portion of the canyon. Parts of the Providence city water supply were muddied by the silt carried downstream.

Determination of future flood risk is "notoriously poor" (James, 1985) for canyon mouths in Utah. Federal Insurance Administration Flood Hazard Boundary Maps and flood insurance rate maps only estimate flooding potential. Among the reasons cited, James (1985) included (1) large discharge floods are rare events which require an unusual set of weather patterns that are difficult to predict, (2) floods may be a result of large runoff or large storms, but the two are not independent as heavy autumn rains may saturate the shallow soils and result in heavier surface runoff in the spring, (3) channel shapes and paths may vary from one flood to another, or even during the same flood, and (4) many floods are actually debris flows, and it is difficult to estimate the amount of soil, rocks, and vegetation which may be incorporated into a single flood event.

Mass Wasting

Mass wasting is a class of processes in which rock, soil, and debris move down slope primarily under the influence of gravity. Mass movements are classified as (1) flows, in which material moves down slope as a slurry or viscous fluid made up of soil, rock, vegetation, and water, (2) slides or slumps, which are masses of soil or rock which have a fairly distinct failure plane which is relatively flat (slide) or curved (slump), and (3) falls, which are the result of pieces of rock falling from outcrops in steep cliffs or from steep talus slopes.

Mass movement may be initiated by high precipitation or runoff, which increases the weight of the potential failure mass and decreases its cohesion; ground shaking due to seismicity; and by human activities such as excess irrigation, cutting steep slope angles into deposits susceptible to failure, and adding building loads to a slope.

Mapped complex slope failures (slumps, slides, and/or flows) (Qmsf) are located on both sides of the Logan River in sections 34 and 35 (T. 12 N., R. 1 E.), where steep slopes of fine-grained Lake Bonneville deposits (Qlbs) have failed. A small flow in May 1984 dammed an irrigation canal. A small debris flow also occurred in the late summer of 1990 beneath an irrigation canal north of Canyon Road at approximately 800 East in Logan. These historic and prehistoric slope failures indicate that steep slopes of fine-grained lacustrine deposits have potential for failure.

Flows or slumps too small to map are also found at the base of hills underlain by the lacustrine sands of the Bonneville stage east of River Heights. The thick soils developed at the base of these hills suggest that downslope transport of the soils has occurred (J. Boettinger, personal communication, 1996).

Debris flows, common along the Wasatch Front (Wieczorek and others, 1983), were not mapped separately but are included in alluvial-fan deposits. Thus, in addition to the hazards demonstrated by small historic flows, the alluvial fans may be potential hazard sites.

Slides or slumps (Qms) were mapped near the base of the Wells Formation in the upper reaches of Millville and Providence Canyons. The fine-grained, relatively poorly cemented basal sandstones and siltstones immediately above the resistant limestone in the Monroe Canyon Formation equivalent unit appear to be very susceptible to failure because the top of the Monroe Canyon acts as an aquitard to the downward movement of ground water. These slides and slumps pose little threat to humans, but may occasionally disrupt stream flows and affect downstream water supplies.

Talus slopes are rock-fall deposits beneath steep cliffs and slopes. We do not map these deposits as a separate unit, but they are common throughout the steep portions of the map area. Rock falls may occur at any time, and may be triggered by earthquake ground shaking (see section on earthquakes).

Problem Soils

Problem soils contain large amounts of clays that have a high shrinking-swelling potential due to hydration and drying. Such

soils have been mapped in the western part of the Logan quadrangle (Erickson and Mortensen, 1974). These soils are developed on fine-grained silts and clays deposited in deeper parts of Lake Bonneville (Qlf). No evidence of problem soils was found during this investigation.

Shallow Ground Water

Shallow ground water poses hazards of liquefaction induced by earthquakes (see liquefaction discussion in earthquakes section) and flooding. Bjorklund and McGreevy (1971) examined the ground-water levels of the Cache Valley, and show that a significant part of the Logan quadrangle has shallow ground water. However, ground-water levels have generally declined since their investigation (Kariya and others, 1994, figure 15). Bjorklund and McGreevy (1971) show that the northwest quarter of the quadrangle has ground water at or very near the ground surface. This region roughly corresponds to the area underlain by fine-grained lake bottom sediments (Qlf). A narrow strip east of this zone is underlain by ground water at a depth of 0 to 10 feet (0 to 3 m) below the ground surface.

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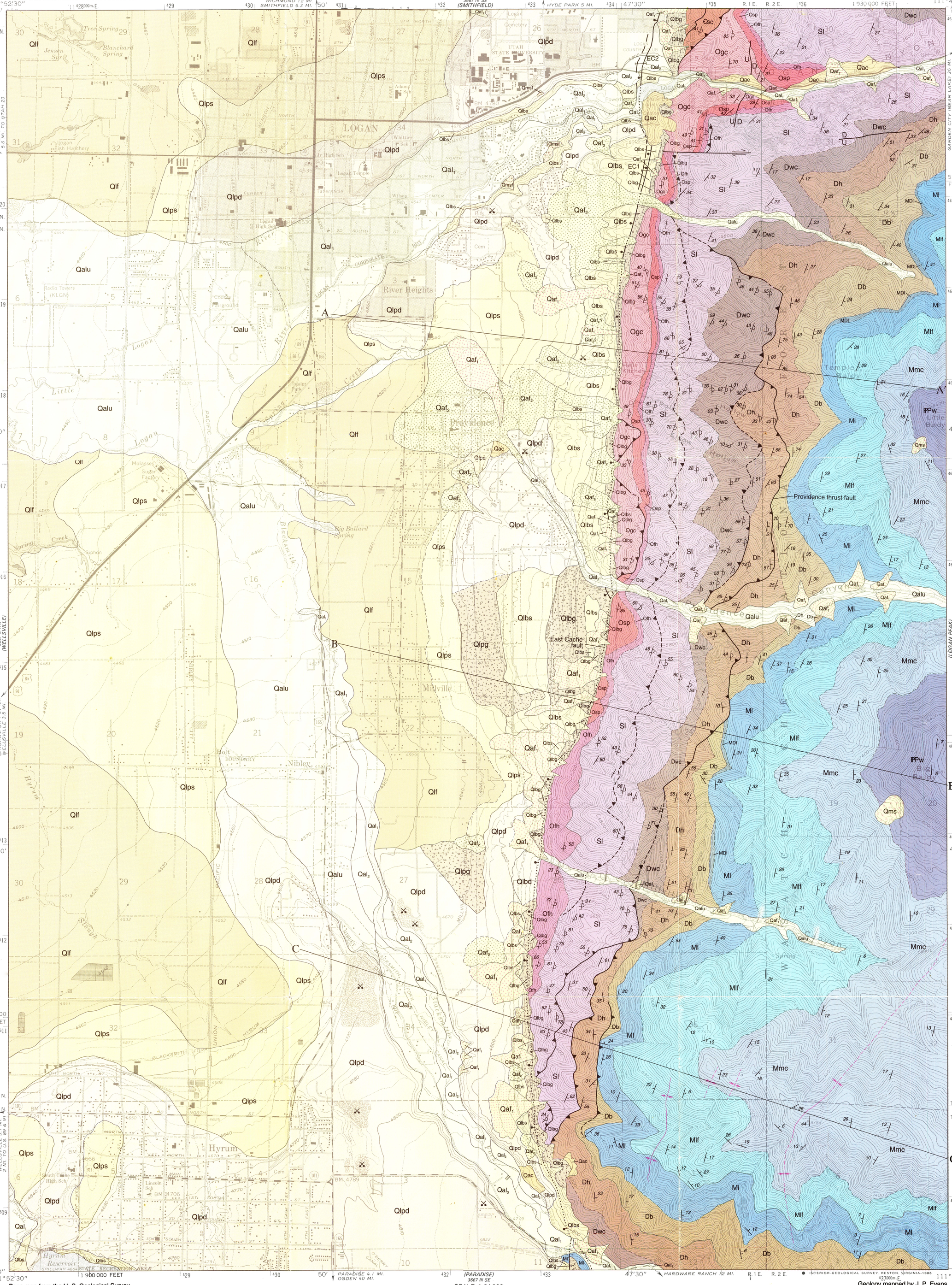
Plate 1
Utah Geological Survey Miscellaneous Publication 96-1
Geologic Map of the Logan Quadrangle



Base map from the U. S. Geological Survey
Logan 7.5' Quadrangle, 1986

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS

14°18' E
254.2 MILS

1996 MAGNETIC DECLINATION
AT CENTER OF SHEET

UTAH

QUADRANGLE LOCATION

Geology mapped by J. P. Evans,
J. P. McCalpin and D. C. Holmes
between 1986 and 1991,
revisions by J. P. Evans and
Jon K. King (UGS) in 1993 and 1994.
Lori J. Douglas, Cartographer

GEOLOGIC MAP OF THE LOGAN QUADRANGLE, CACHE COUNTY, UTAH

by

James P. Evans
James P. McCalpin
David C. Holmes

1996

EXPLANATION OF MAP UNITS

Qms — Holocene and Pleistocene (?) slides and slumps - *Fine-grained sediment with few clasts, derived from the base of the Wells Formation.*

Qac — Undivided alluvium and colluvium - *Holocene and Pleistocene (?) pebble, cobble, and boulder gravels mixed with sand, silt, and clay; deposited as hillslope colluvium and fan alluvium, with small areas of landslide deposits and stream alluvium.*

Qmsf — Holocene to latest Pleistocene slope-failure deposits - *Unsorted and unstratified matrix-supported sparse gravels with abundant sand and silt matrix; located at the base of steep hillsides of Lake Bonneville deltaic and sandy deposits, where the hillsides have failed by slide, slump and/or flow.*

Qlf — Undivided fine-grained Lake Bonneville deposits - *Lacustrine clay, silt, and fine sand deposits in deep and/or quiet water in Lake Bonneville, and not related to any specific shorelines; typically 40 to 50 feet (~12 to 15 m) thick.*

Qlps — Lacustrine sand and silt related to Provo and younger shorelines - *Nearshore deposits of coarse to fine sand, silt, and minor clay; typically rhythmically bedded; exposed thickness less than 16 feet (<5 m).*

Qlpg — Lacustrine sand and gravel related to Provo and younger shorelines - *Clast-supported pebble and cobble gravel in a sparse matrix of sand and silt with interbedded thin sands; deposited in beaches, bars, and spits, typically south of Provo deltas; exposed thickness less than 16 feet (<5 m).*

Qlpd — Deltaic deposits related to the Provo and younger shorelines - *Clast-supported pebble and cobble gravel in a matrix of sand and minor silt, with thin sand beds; mostly deposited at the time of the Bonneville flood; exposed thickness less than 82 feet (<25 m).*

Qlbs — Lacustrine sand and silt related to the Bonneville shoreline - *Coarse to fine sand, silt, and minor clay with typically rhythmical bedding; deposited in a nearshore environment and as lagoon fill; up to 170 feet (52 m) thick in subsurface below Provo deltas.*

Qlbg — Lacustrine gravel and sand related to the Bonneville shoreline - *Clast-supported pebble and cobble beds in a matrix of sand and silt, with interbedded sand; deposited in beaches, bars, spits, and small deltas; exposed thickness less than 33 feet (<10 m).*

Qlbd — Deltaic deposits related to the Bonneville shoreline - *Clast-supported pebble and cobble gravel in a matrix of sand and minor silt, with thin sand interbeds; deposited in deltas; exposed thickness less than 33 feet (<10 m).*

Qaf_1 — Late Holocene fan alluvium - *Clast-supported pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; has sharper debris-flow levees and channels than the middle Holocene and older fans; exposed thickness less than 16 feet (<5 m).*

Qaf_2 — Middle Holocene to latest Pleistocene fan alluvium - *Clast-supported, locally bouldery, pebble and cobble gravel in a matrix of sand, silt, and clay; deposited in alluvial fans of post-Bonneville lake cycle; exposed thickness less than 16 feet (<5 m).*

Qaf_3 — Middle Pleistocene (pre-Bonneville lake cycle) fan alluvium - *Clast-supported pebble, cobble, and boulder gravel in a matrix of sand, silt, and minor clay; only exposed at the mouth of Logan Canyon where the Logan River has cut through younger deposits; maximum exposed thickness about 33 feet (~10 m).*

Qalu — Undivided Holocene to latest Pleistocene stream alluvium - *Sand, silt and gravel on undifferentiated post-Provo-stand floodplains and terraces; mapped where the age of the alluvium (Qal_1 vs. Qal_2) cannot be determined; probably less than 33 feet (<10 m) thick.*

Qal_1 — Late Holocene stream alluvium - *Clast-supported pebble and cobble gravel in a matrix of sand, silt, and minor clay, with thin sand lenses; located on modern floodplains and low terraces; exposed thickness less than 16 feet (<5 m).*

Qal_2 — Middle Holocene to latest Pleistocene stream alluvium - *Clast-supported pebble and cobble gravels, in a matrix of sand, silt, and minor clay, with thin sand lenses; present on terraces more than 16 feet above modern stream levels; exposed thickness less than 16 feet (<5 m).*

Qu — Undifferentiated Pre-Bonneville-lake-cycle deposits - *Uncemented sand, clay, and gravels of pre-Bonneville Quaternary deposits; only shown on cross sections.*

Tu — Undifferentiated Tertiary deposits - *Tuffaceous siltstone and sandstone, conglomerate, and fresh-water limestone of the Salt Lake Formation; basal deposits may be conglomerates of the Tertiary Wasatch Formation only shown on cross sections.*

IPPw — Wells Formation - *Incompletely exposed fine to medium-grained, brown to gray, calcareous, quartz sandstone and interbedded, gray limestone; thickness exposed in quadrangle is 600 feet (183 m).*

Mmc — Monroe Canyon Limestone equivalent - *Lower, gray to brown-gray, thick bedded, massive, cliff-forming limestone; middle, medium-bedded, yellow to yellow-brown, poorly exposed siltstone; and upper, cherty, gray to gray-brown limestone; thickness varies from 750 to 1,150 feet (228 - 350 m).*

Mlf — Little Flat Formation equivalent - *Brown, gray, light-yellow, and orange, quartz sandstone and siltstone; with minor limestone, phosphatic limestone, dolostone, shale, and chert; 1,206 feet (368 m) thick; may thin northward or thickness may vary due to bedding-plane thrust fault.*

Ml — Lodgepole Limestone - *Prominent, cliff-forming, medium- to dark-gray limestone consisting of micrite, biomicrite, and biosparite with chert layers throughout; contains brachiopod, coral, gastropod, and bryozoan fossils; 690 feet (210 m) thick.*

MDl — Leatham Formation - *Poorly exposed, thin-bedded, black, gray, and brown siltstone and limestone; 0 to 80 feet (0 - 24 m) thick.*

Db — Beirdneau Formation - *At top is 30 to 60 feet (9 - 18 m) thick, gray, resistant limestone known as the "contact ledge;" remainder is thin- to medium-bedded, gray, tan, yellow, and brown, arenaceous dolostone which grades upward to a predominantly tan, yellow, and white sandstone with cross bedding, thin laminations, ripple marks, and mud cracks; 524 to 1,087 feet (160 - 331 m) thick, and thins northward.*

Dh — Hyrum Dolomite - *Cliff-forming, massive, medium- to dark-gray dolostone in upper part, which lacks fossils; lower sequence is thin- to medium-bedded, yellow, gray, and tan dolostone and limestone; 932 to 1,011 feet (284 - 308 m) thick, thinning southward.*

Dwc — Water Canyon Formation - *Upper, Grassy Flat Member (not mapped separately) is purple, gray, brown, yellow, and white, interbedded dolomite, siltstone, intraformational breccia, calcareous sandstone, and thin beds of dolostone; lower, Card Member (not mapped separately) is light-gray, white, and light-brown, thin-bedded, argillaceous dolostone, with local intraformational breccia; total thickness 586 feet (179 m).*

Sl — Laketown Dolomite - *Massive, cliff-forming, light-gray, fine- and medium-crystalline, medium- to thick-bedded dolostone, with coral, brachiopod, and cephalopod fossils, and algal structures; 1,150 to 1,610 feet (350 - 490 m) thick.*

Ofh — Fish Haven Dolomite - *Dark-gray to black, thick-bedded, fine- to medium-crystalline dolostone with rare bioturbated sandy layers, remnants of algal mats, tabulate corals (*Halysites *sp. and* Favosites *sp.), and rugose corals; 130 to 145 feet (40 - 44 m) thick.*

Osp — Swan Peak Formation - *Upper part is light-brown to white and tan, well-indurated, medium-grained quartzite with burrows in the lower portion; middle part is purple and gray quartzite with burrows, ripple marks, fish fragments, and disarticulated trilobites and cephalopods; lower part in interbedded blue, gray, and brown shale, minor, thin-bedded quartzite, and gray limestone; total thickness 134 to 283 feet (41 - 86 m).*

Ogc — Garden City Formation - *Only upper part is exposed in quadrangle; it contains light- to medium-gray, crystalline and fossiliferous limestone, micritic limestone, silty limestone, and thin- to medium-bedded dolostone; black chert lenses and stringers common; 1,160 to 1,400 feet (354 - 427 m) thick, thins southward.*

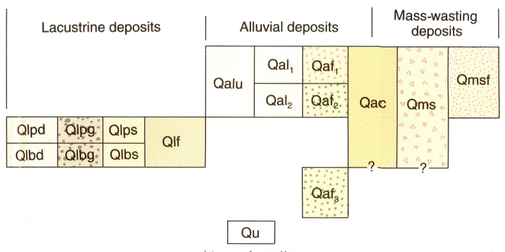
Ꞓsc — St. Charles Formation - *Thin-bedded, gray and black limestone and massive, gray dolostone; incompletely exposed in hanging wall of thrust fault.*

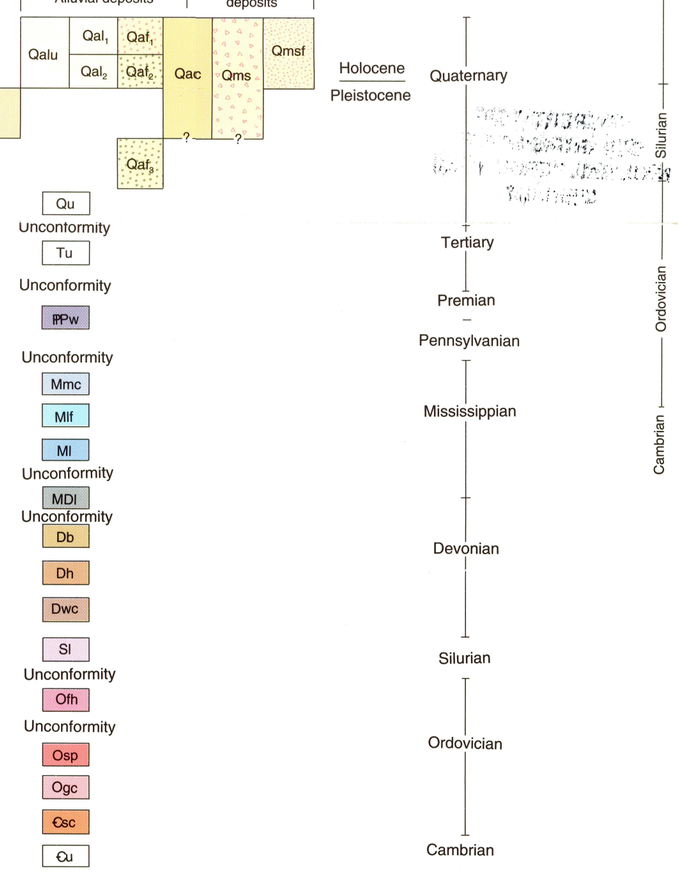
Ꞓu — Undifferentiated Cambrian strata - *Only shown on cross sections.*

MAP SYMBOLS

- Contact between units - *dashed where approximately located, dotted where concealed*
- Thrust fault - *teeth on upthrown plate, dashed where approximately located*
- Normal fault - *bar and ball on downthrown side, dashed where approximately located, dotted where concealed*
- U / D — Steeply dipping normal fault - *U on upthrown side, D on downthrown side (dip more steeply than faults with bar and ball)*
- Strike-slip fault - *arrows indicate relative motion*
- Reverse fault reactivated in a normal slip sense (on cross sections)
- EC-1 — Locations of trenches dug acros the East Cache fault
- 37 — Strike and dip of beds - *numbers indicate dip in degrees*
- 61 — Strike and dip of overturned beds
- Anticline axis
- Syncline axis
- x — Prospect
- A — A′ — Location of cross sections

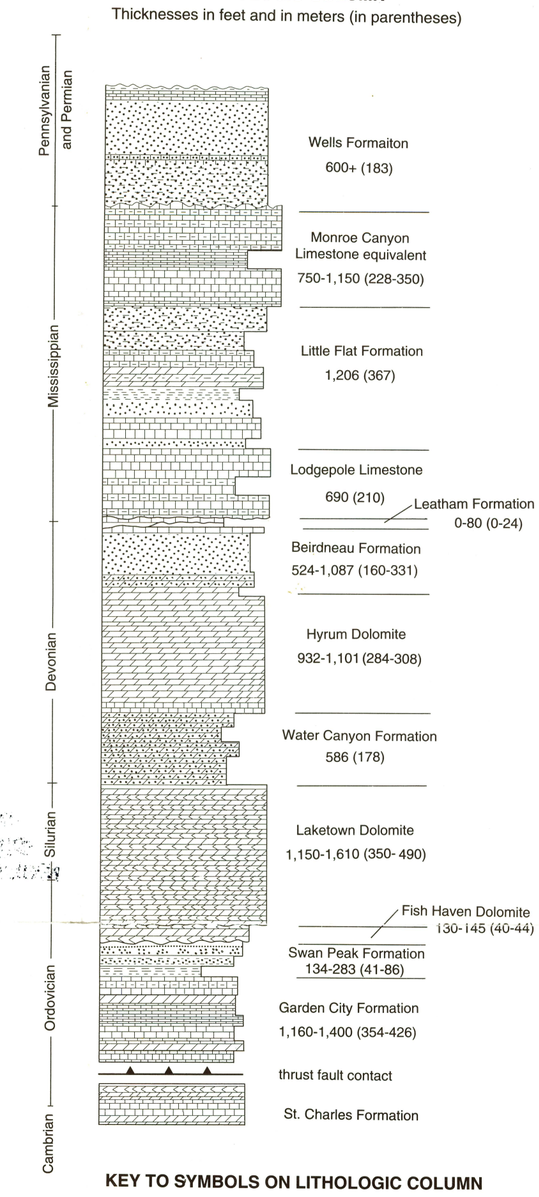
CORRELATION OF MAP UNITS



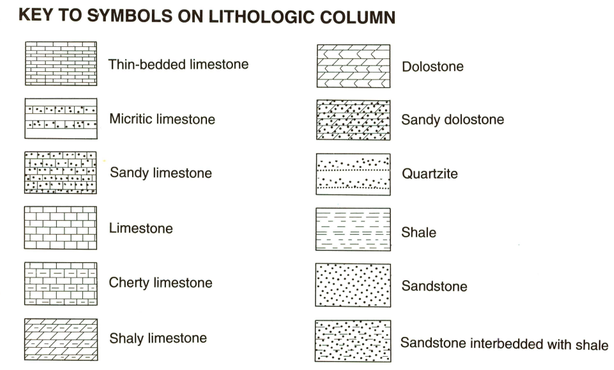


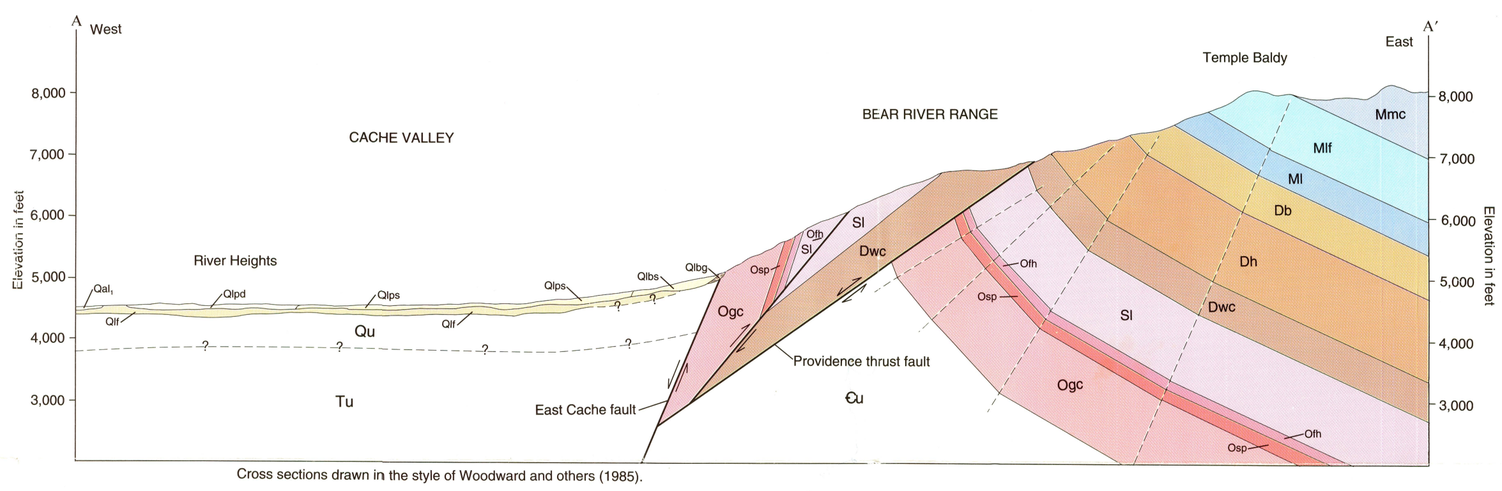
LITHOLOGIC COLUMN

Thicknesses in feet and in meters (in parentheses)



KEY TO SYMBOLS ON LITHOLOGIC COLUMN





Cross sections drawn in the style of Woodward and others (1985).