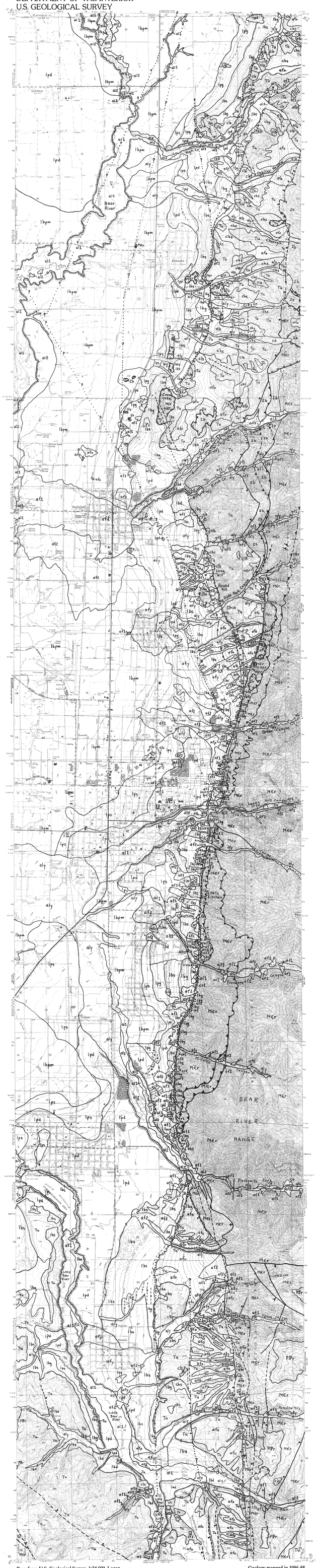
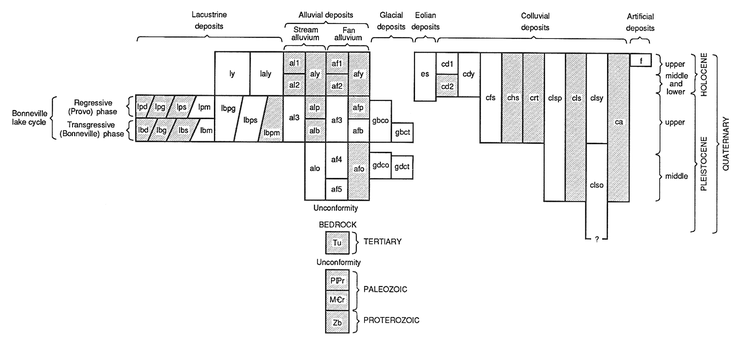


CORRELATION OF MAP UNITS

[This correlation shows surficial deposits mapped along the East Cache fault zone, as well as the Wasatch fault zone, Utah. Shaded map units in the correlation appear on this map; unshaded map units are included to aid correlation with other maps along the Wasatch (Personius, in press)]



DESCRIPTION OF MAP UNITS

ALLUVIAL DEPOSITS

[Consist of variable amounts of gravel, sand, silt, and minor amounts of clay, deposited by perennial and intermittent streams. These deposits are separated into five stream (flood-plain and terrace) alluvium map units and five alluvial-fan map units. Stream deposits are mapped on flood plains and as thin strath terrace deposits along perennial streams. Gravel in these deposits generally are more rounded and better sorted than those in the alluvial-fan deposits. Stream deposits are differentiated by their vertical positions at or below the 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 relationships 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 zone]

Deposits of Stream Alluvium

al1 **Stream alluvium (upper Holocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand, silt, and minor clay; contains thin sand lenses; moderately sorted; clasts subangular to rounded; thin to medium bedded. Deposited by perennial streams (High Creek, Summit Creek, Spring Creek, Logan River, Blacksmith Fork, East Fork, Little Bear River) on the modern flood plain and in low terraces less than 5 m above modern stream level. May include minor sheetwash and slump deposits overlying alluvium along steep stream embankments. Deposits along Summit Creek (Smithfield Canyon) and Green Canyon near North Logan grade downslope into large Holocene alluvial fans (af1). Also includes predominantly sandy alluvium and silty flood-plain deposits of the Bear River in extreme northwest corner of map area, and fine-grained deposits in channels of spring-fed creeks on the valley floor. Exposed thickness less than 5 m

al2 **Stream alluvium (middle Holocene to uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand, silt, and minor clay; contains thin sand lenses; moderately sorted; clasts subangular to rounded; thin to medium bedded. Deposited by perennial streams (Bear River, High Creek, Logan River, Blacksmith Fork, and Little Bear River); forms terraces more than 5 m above modern stream level (except at Blacksmith Fork, where terrace is 2-3 m above modern stream), usually inset into Bonneville-lake-cycle lacustrine gravel. Exposed thickness less than 5 m

aly **Younger stream alluvium, undivided (Holocene to uppermost Pleistocene)**--Undivided post-Provo-regression flood-plain and terrace gravel, sand, and silt deposits. Mapped along numerous intermittent streams in the Bear River Range; includes small areas of hillslope colluvium, alluvial-fan, debris-flow, and low alluvial-terrace deposits. May grade downslope into map units af1 or af2. Locally thin, silty deposits along intermittent spring-fed streams on valley floor are included in map unit lbpm. Includes two areas between Richmond and High Creek where alluvium was deposited as a thin veneer over map unit lbpm. Also includes low-relief areas containing the modern flood plains of Logan River and Blacksmith Fork on valley bottom, where insufficient relief prevents distinguishing late Holocene from earlier Holocene deposition. These deposits are less gravelly than those in intermittent streams in the mountains. Thickness probably less than 10 m

alp **Stream alluvium (uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand, silt, and minor clay; contains thin sand lenses; moderately sorted; clasts subangular to rounded; thin to medium bedded. Deposited by perennial and intermittent streams graded to the Provo shoreline at City Creek, Summit Creek, and Hyde Park Canyon. Exposed thickness less than 5 m

alb **Stream alluvium (upper Pleistocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand, silt, and minor clay; contains thin sand lenses; moderately sorted; clasts subangular to rounded; thin to medium bedded. Deposited at Oxkiller Hollow, Nebo Creek, Summit Creek, and Birch Creek while they were graded to the Bonneville shoreline. Contains debris flows and has fan morphology on south side of High Creek. Exposed thickness less than 5 m

Alluvial-Fan Deposits

af1 **Fan alluvium (upper Holocene)**--Clast-supported pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; poorly sorted; clasts angular to subrounded, with very rare well-rounded, recycled Bonneville-lake-cycle gravel clasts; medium to thick bedded to massive. Deposited by intermittent streams, debris flows, and debris floods graded to modern stream level; forms small discrete fans along the mountain front between Smithfield and Blacksmith Fork, large fans at Smithfield Canyon and Green Canyon (near North Logan), and small, steep alluvial cones in major canyons where steep tributaries enter canyon floor. Distinguished from older fan deposits by sharpness of debris flow levees and channels. Also includes small young fans derived entirely from high escarpments in lacustrine gravel (lbg, lpg, lpd). May contain small deposits of debris flow (cd2) and fan alluvium (af2). No lacustrine shorelines occur on surfaces. Typically thins downslope often pinching out valleyward on map unit lbpm. Exposed thickness less than 5 m

af2 **Fan alluvium (middle Holocene to uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; poorly sorted; clasts angular to subrounded, with rare well-rounded, recycled Bonneville-lake-cycle gravel clasts; medium to thick bedded. Deposited by perennial and intermittent streams, debris flows, and debris floods, graded several meters above modern stream level. Distinguished from younger fans by more subdued debris-flow levee morphology. Locally includes some small fans derived entirely from large escarpments in lacustrine gravel (lpd). Exposed thickness less than 5 m

afy **Younger fan alluvium, undivided (Holocene to uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; poorly sorted; clasts angular to subrounded; medium to thick bedded. Deposited by intermittent streams, debris flows, and debris floods, graded to or slightly above modern stream level. Mapped only in the northern and southern fault segments where Holocene fans cannot be subdivided morphologically, as they can be in the central segment. Identified by fresh alluvial deposition shown on 1938 aerial photographs between North Logan and Smithfield. No lacustrine shorelines occur on surfaces. Typically thins downslope, pinching out valleyward on map unit lbpm. Exposed thickness less than 5 m; probable maximum thickness between Smithfield and Green Canyon (near North Logan) 1-2 m

afp **Fan alluvium related to Provo shoreline (uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; poorly sorted; clasts angular to well rounded, usually with 10-50 percent well-rounded recycled Bonneville-lake-cycle gravel clasts; medium to thick bedded. Deposited by streams graded to the Provo shoreline at Green Canyon (near Hyrum), Hyrum Canyon, and Paradise Dry Canyon. Forms a gravel veneer 2-5 m thick over finer Bonneville-lake-cycle prodelta silt (lbpm, lbs)

afo **Older fan alluvium (middle Pleistocene; pre-Bonneville lake cycle)**--Clast-supported pebble, cobble, and boulder gravel, in a matrix of sand, silt, and minor clay; poorly sorted; clasts angular to rounded, with no recycled lacustrine gravel; medium bedded to massive. Forms dissected surfaces 15-300 m above modern streams cut on Tertiary rocks north of Green Canyon (near North Logan) and south of Blacksmith Fork; not present along the steep central range front. Geomorphic surfaces are partly correlative with the McKenzie Flat surface of Williams (1948). Contains abundant large rounded quartzite boulders from Paleozoic and upper Proterozoic formations. Also includes outliers of possible debris flow origin exposed on valley floor north of Smithfield and Logan, surrounded by map unit lbpm. Contains deposits of several ages, including two hillslope fans at Oxkiller Hollow and Cherry Creek which may be contemporaneous with the Bonneville lake cycle. Exposed thickness less than 10 m, commonly present as only a thin discontinuous veneer on Tertiary rocks

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 Provo shoreline and the regressional phase of the lake cycle, (2) deposits associated with the Bonneville shoreline and the transgressional phase of the lake cycle, and (3) undivided Bonneville-lake-cycle sediments that cannot be assigned to either 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]

Provo (Regressional) Phase Deposits

lpd **Deltaic deposits related to Provo and younger shoreline (uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand and minor silt; interbedded with thin sand beds; moderate to well sorted within beds; clasts subround to round; deposited as foreset beds with original valleyward dips of 30° to 35°. Commonly capped with topset beds less than 5 m thick which are less well sorted than forset beds, and which may grade upslope into alluvial-fan (afp) or terrace (alp) deposits. Mapped at the mouths of High Creek, Cherry Creek, City Creek, Summit Creek, Hyde Park Canyon, Logan River, Spring Creek (Providence Canyon), Millville Canyon, and Blacksmith Fork. Much material may have been redeposited from Bonneville shoreline deposits at the time of the Bonneville flood. Includes as many as 11 sub-deltas graded to lake levels below the Provo shoreline. Portion of distal Bear River delta in extreme northwest corner of map area is dominantly composed of silt and fine sand. Exposed thickness less than 25 m

lpg **Lacustrine sand and gravel related to Provo and younger shoreline (uppermost Pleistocene)**--Clast-supported pebble and cobble gravel, in a sparse matrix of sand and silt; commonly interbedded (sometimes rhythmically) with thin sand beds; good sorting in beds; clasts subround to round; thin to thick bedded; bedding ranges from horizontal to original dips of as much as 10° to 15°. Deposited in beaches, bars, and spits, typically south (downdrift) of Provo deltas. Mapped at and below the Provo shoreline (1,470-1,475 m in map area); grades downslope into deposits of map units lps or lbpm. Exposed thickness less than 5 m

lps **Lacustrine sand and silt related to Provo and younger shoreline (uppermost Pleistocene)**--Coarse to fine sand, silt, and minor clay; typically rhythmically bedded; good sorting in beds; thin bedded; ripple laminations common; bedding ranges from horizontal to original dips of as much as 10°. Deposited as nearshore sediments valleyward from Provo-level deltas (lpg, lpd) at Hyde Park Canyon, Logan Canyon, and Providence Canyon. Grades downslope into and is partly time equivalent to map unit lbpm. Exposed thickness less than 5 m

Bonneville (Transgressive) Phase Deposits

lbd **Deltaic deposits related to Bonneville shoreline (upper Pleistocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand and minor silt; interbedded with thin sand beds; moderately to well sorted in beds; clasts subround to round. Deposited as foreset and topset beds; mapped at the mouths of Summit Creek, Birch Creek, Logan River, Millville Canyon, and East Fork. Deposit is more gravelly if Bonneville shoreline was at the range front (Birch Creek, Millville Canyon), and more sandy if shoreline extended far into the canyons in an embayment (Logan Canyon, Blacksmith Fork). Exposed thickness less than 10 m

lbg **Lacustrine gravel and sand related to Bonneville shoreline (upper Pleistocene)**--Clast-supported pebble and cobble gravel, in a matrix of sand and silt; interbedded with sand beds; clasts usually subround to round, but may include angular to subangular boulders derived from steep mountain front; dip of bedding ranges from horizontal to 25°. Deposited in beaches, bars, spits, and small deltas. Mapped between the Provo and Bonneville shorelines (1,475-1,575 m); typically forms wave-built benches at the highest (Bonneville) shoreline, and several less well developed intermediate shorelines in the map area; commonly partly covered by hillslope colluvium (chs) or rockfall talus (crt). Exposed thickness less than 10 m

lbs **Lacustrine sand and silt related to Bonneville shoreline (upper Pleistocene)**--Coarse to fine sand, silt, and minor clay; typically rhythmically bedded; good sorting in beds; ripple laminations common; bedding ranges from horizontal to original dips as much as 10°. Deposited as nearshore sediments valleyward from map units lbd and lbg and as lagoon fill behind barrier bars; gradational contacts with map units lbg and lbpm. Overlies Tertiary rocks as a thin veneer north of Smithfield; thicker (as much as 10 m exposed) south of Hyrum. At mouths of major canyons, water-well logs show this unit to be as thick as 52 m underneath Provo deltas (lpd)

Undivided Bonneville-Lake-Cycle Deposits

lbpm **Lacustrine silt and clay related to Provo and Bonneville shoreline (upper Pleistocene)**--Clay, silt, and minor fine sand deposits of the Bonneville lake cycle; usually thick bedded; deposited in deep and (or) quiet water on the basin floor. Generally in gradational contact with map units lps or lpg, in places in indistinct contact with distal portions of map units af1, af2, or afy and as mapped may contain small deposits of these units. Contact with coarser alluvial deposits and lacustrine sediments is often obscured by agriculture, and must be inferred from soil surveys or from limits of historic alluviation visible on 1938 air photos. 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 indicate typical thickness 12-15 m

COLLUVIAL DEPOSITS

[Consist of poorly sorted to unsorted, gravity-generated deposits; composition of clasts generally reflects deposits from which they were derived. Debris flows included in the deposits are derived from shallow debris slides in fine-grained deposits trenched by major streams, and are smaller, finer grained, and more areally restricted than debris flows included in map units af1, af2, and afy]

cd2 **Debris flow (middle Holocene to uppermost Pleistocene)**--Matrix-supported sparse gravel with abundant sand and silt matrix; usually unsorted and unstratified. Mapped on south side of Logan River west of the canyon mouth where steep escarpments in map units lbs and lpg have failed by debris slides and debris flows. Exposed thickness less than 5 m

chs **Hillslope colluvium (Holocene to upper Pleistocene)**--Pebble, cobble, and boulder gravel, usually supported by a matrix of sand, silt, and clay; usually unsorted, unstratified, except for basal concentration of clasts; clasts angular to subangular. Commonly mapped at the base of hillslopes composed of Tertiary tuffs and sandstones where colluvium is a mixture of dark, fine-grained weathering products of tuff and resistant, rounded quartzite boulders from higher fan gravel (afo). Solifluction(?) striping common on moderately steep slopes below map unit afo north of Smithfield Canyon. Where pediment surface has been destroyed by erosion, colluvial pediment gravel mantle slopes cut on Tertiary deposits (Tu). Includes small debris flow and landslide deposits. Deposited by slope wash and mass-wasting processes operating on steep slopes along the mountain front and along steep stream cuts. Exposed thickness less than 5 m

crt **Rockfall (talus) deposit (Holocene to upper Pleistocene)**--Poorly sorted and stratified rock rubble, ranging in size from boulders to sand and silt; clasts usually angular; sparse sand and silt matrix, especially sparse near surface of deposit. Deposited by gravity processes below steep cliffs of Paleozoic and upper Proterozoic rock at the mountain front and in steep canyons. Exposed thickness less than 10 m

cls **Landslide deposit (Holocene to middle Pleistocene)**--Unsorted, unstratified deposits ranging in size from sand and silt to boulder-rich gravel and bedrock blocks; usually deposited by sliding, slumping, and flowing below moderately steep slopes. In Tertiary rock terrane, commonly occurs on north-facing slopes as shallow debris slides in swale colluvium, or as rotational bedrock slumps at the range front. In Paleozoic bedrock terrane, massive rock slides and block glides are more common. Slumps and slump-flows formed where rivers incised deep valleys through Provo-level deltas and underlying Bonneville silt. Thickness variable, from less than 1 m for debris slides to more than 25 m for bedrock slumps

ca **Colluvium and alluvium, undivided (Holocene to middle Pleistocene)**--Contains stream and fan alluvium, hillslope colluvium, and small landslide deposits. Mapped in upper reaches of smaller canyons in Bear River Range, mainly from air photos. Thickness unknown

BEDROCK

Tu **Tertiary sedimentary rocks**--Consists of sedimentary rocks of the Salt Lake Formation (Pliocene and Miocene). Dominant lithology is conglomerate, with minor tuffaceous sandstone, siltstone, and freshwater limestone. Mapped along the northern and southern fault segments between major splays of the East Cache fault zone; absent along the central fault segment

PPr **Younger Paleozoic sedimentary rocks (Lower Permian to Pennsylvanian)**--Consists of Oquirrh Formation (Lower Permian to Lower Pennsylvanian). Mapped only in the southeastern corner of the map area where rocks compose the crest of the westernmost ridge of the Bear River Range

MCr **Older Paleozoic sedimentary rocks (Mississippian to Cambrian)**--Consists of sedimentary rocks of Mississippian through Cambrian age, including the Lodgepole Limestone (Lower Mississippian) and Chesterfield Range Group (Upper and Lower Mississippian), Leatham Formation (Mississippian? and Upper Devonian), Water Canyon Formation (Lower Devonian), Laketown Dolostone (Silurian); Fish Haven Dolostone (Lower Silurian and Upper Ordovician), Swan Peak Quartzite (Middle Ordovician), and Garden City Limestone (Ordovician); St. Charles Formation (Lower Ordovician and Upper Cambrian), Nounan Formation (Middle Cambrian), Bloomington Formation (Middle Cambrian), Blacksmith Limestone (Middle Cambrian), Ute Limestone (Middle Cambrian), Langston Dolomite (Middle Cambrian), and Geerston Canyon Quartzite (Lower Cambrian). Overall lithology is approximately 60 percent dolomite, 15 percent limestone, 25 percent sandstone and quartzite, with minor conglomerate

Zb **Lower part of Brigham Group (Late Proterozoic)**--Includes metasedimentary rocks of the Mutual Formation and unnamed Precambrian quartzites

Contact--Dashed where approximately located

Normal fault--Bar and ball on downdropped side. Dotted where concealed, dashed where approximately located, and queried where origin is uncertain. Height of fault scarp and amount of geomorphic surface offset (in parentheses) shown in meters. Trench locations shown with cross bar and abbreviated trench name: WC-1, Woodward-Clyde test pit; EC-1, East Cache trench

Thrust fault--Sawteeth indicate overriding plate or block (mapped in bedrock only); dashed where approximately located

Major shorelines related to levels of the Bonneville lake cycle--May coincide with geologic contacts

—B— **Highest shoreline of the Bonneville level**

—P— **Highest shoreline of the Provo level**

—x— **Undesignated shorelines of the Bonneville lake cycle**

Topographic escarpment--Escarpments along stream channels, terraces, and deltas; formed primarily by fluvial processes; may coincide with geologic contacts. Hachures extend upslope from the solid line

Landslide escarpment--Major headscarps and fissures in landslides and lateral spread deposits; may coincide with geologic contacts. Hachures extend downslope from the solid line

Gravity slide blocks--Large intact blocks of Tertiary and Paleozoic deposits which have slid westward off the Bear River Range. Underlain by a planar surface dipping 20°-22° W.; probably equivalent to the low-angle normal fault mapped between Hyde Park Canyon and Summit Creek

• 3 **Localities mentioned in text**--Numbered localities corresponding to those described in the Discussion

DISCUSSION

INTRODUCTION

This map shows surficial deposits and faults that offset them along the East Cache fault zone in northern Utah. The East Cache fault is a north-trending normal fault that extends about 77 km along the eastern side of Cache Valley (an east-tilted graben) at the base of the Bear River Range. The following discussion includes a summary of the methods used in this study, a description of the Quaternary deposits along the East Cache fault zone, a description of the fault segments, and estimates of the age, size, and distribution of fault scarps along the fault zone.

The East Cache fault zone lies about 20-25 km east of the Brigham City and Collinston segments of the Wasatch fault (Personius, in press). In addition to map units mapped along the East Cache fault, the correlation of map units includes surficial units mapped along the adjacent Wasatch fault zone for comparison. Together, the information on the two parallel fault zones can be used to describe the paleoseismic history of the region and to identify key sites for further detailed studies.

Most major fault zones are thought to consist of several seismically independent segments (Schwartz and Coppersmith, 1984). The concept of fault segmentation is critically important to paleoseismic analysis of active fault zones because surface faulting during a major earthquake is often restricted to a single segment of the fault zone. The Wasatch fault zone has as many as 12 segments (Machette and others, 1987) which have an average length of about 30 km. The East Cache fault zone extends about 77 km, of which the 54 km in four 7 1/2-minute quadrangles (from north to south, Richmond, Smithfield, Logan, and Paradise) is shown on this map (fig. 1). To the north and south of the map area range-front morphology is more subdued and Quaternary deposits are rarely offset. Geologic evidence (McCalpin, 1986) suggests the East Cache fault zone in the map area is composed of three segments that (from north to south) have lengths of at least 25 km, 15 km, and at least 14 km. The northern segment may extend northward another 13 km into Idaho, or that subdued range front may be formed by another (less active) fault segment. Similarly, the southern segment may extend 10 km beyond the map area and connect with the James Peak fault (Nelson and Sullivan, 1987), but the inferred fault trace is poorly expressed. The height and distribution of fault scarps along the East Cache fault zone are shown on the map. The age of offset surficial deposits and the height of fault scarps can be used to calculate slip rates and average recurrence intervals at various places along the fault.

Previously published and unpublished geologic and soils maps exist at various scales for most of the map area (Cluff and others, 1974; Davis, 1985; Dover, 1985; Galloway, 1970; Lowe, 1987; Mendenhall, 1975; Mullens and Izett, 1964; Peterson, 1936; Rogers, 1978; Swan and others, 1983; Williams, 1948, 1962). However, I remapped the surficial geology along the mountain front because existing maps either were not detailed enough or used outdated stratigraphic terminology. Most of my mapping was done in the field on 1:20,000-scale air photos flown by the Agricultural Stabilization and Conservation Service in 1937, before significant urbanization in Cache Valley. In addition, I used photography from the U.S. Soil Conservation Service (1966, 1:20,000 scale) and color-infrared photos from the National High-Altitude Mapping Program (1:60,000 scale). The scarp measurement data shown on the map were derived from slope measurements made in the field with an Abney level and stadia rod. Scarp heights and surface offsets were measured from scarp profiles plotted by computer. Terminology used to describe fault-scarp parameters follows that established by Bucknam and Anderson (1979) and Machette (1982).

QUATERNARY DEPOSITS AND DEPOSITIONAL HISTORY

This discussion of late Quaternary depositional history of the Cache Valley area is summarized from regional papers by Scott and others (1983) and Currey and Oviatt (1985). Most of the surficial deposits along the East Cache fault zone were deposited during the last cycle of Lake Bonneville (known as the Bonneville lake cycle) between 30 ka and 10 ka (thousands of years ago) and in the Holocene (<10 ka) (Williams, 1962). Lake Bonneville began rising from a low level about 30 ka and rose slowly, with several fluctuations and pauses, to the Bonneville shoreline near 1,570 m (5,150 ft) above sea level about 16 ka. After 1,000-2,000 years at or near this level, the lake dropped about 110 m to an altitude of about 1,460 m; 4,790 ft) as a consequence of catastrophic downcutting of the threshold at Red Rock Pass in southeastern Idaho. The resulting Bonneville flood deposited debris northward onto the southern Snake River Plain (Gilbert, 1890; Malde, 1968). In the map area, this rapid decline in lake level was accompanied by rapid erosion of Bonneville shoreline sands (lbs), gravels (lbg), and deltaic deposits (lbd); much of this debris was redeposited as deltas (lpd) at the Provo shoreline near the mouths of major canyons. Between 14 and 13 ka, the lake level began to drop in response to further downcutting of the Red Rock Pass threshold, isostatic rebound of shoreline areas, and changing climatic conditions. Lake Bonneville had reached the level of modern Great Salt Lake (1,283 m; 4,208 ft) about 11 ka and rose briefly to the Gilbert shoreline (1,295 m; 4,278 ft) about 10 ka. Since then, the lake level has remained within 10 m of the level of the modern Great Salt Lake.

As the level of Lake Bonneville receded from the Provo shoreline, alluvial fans (af2) were deposited at canyon mouths along the mountain front. In some areas, such as between Logan and Hyrum, deposits of late Holocene age (af1) are restricted to small deposits covering parts of the surfaces of larger alluvial fans (af2). Elsewhere, particularly between Green Canyon and Smithfield, alluvial deposits of Holocene age (af1) are much more abundant, and extend valleyward to overlap lake-floor silts and clays (lbpm). Debris flows, common along the Wasatch Front (Wieczorek and others, 1983), are rare in the map area, probably because of the higher permeability of bedrock exposed in the Bear River Range, and lack of clayey, fine-grained colluvium.

Pre-Bonneville-lake-cycle deposits are preserved on extensive dissected pediment surfaces (afo) cut into Tertiary deposits north of Smithfield, and south of Hyrum. These pediment surfaces are truncated by the highest Bonneville shoreline (elevation about 1,570 m; 5,150 ft); deeply incised drainages grade to that shoreline. On the basis of the considerable pre-Bonneville erosion of these surfaces and the strong soil developed on the alluvial gravels, I estimate that these deposits are probably 100,000-200,000 years old. The pre-Bonneville-lake-cycle deposits along the northern and southern segments in the map area span a wide range of elevations, and cannot be physically correlated with each other or with other glacial or lacustrine deposits.

FAULT DESCRIPTIONS

The relatively well dated sequence of Quaternary deposits in the map area greatly aids in the interpretation of Quaternary faulting along the East Cache fault zone. Although the East Cache fault zone extends both north and south of the area mapped, the map area includes the most active portion of the fault based on geomorphology. The following is a description of the morphology of the fault zone starting with the northern segment at the Utah-Idaho border, continuing with the central segment near Logan, and finishing with part of the southern segment.

Within the map area, the northern segment of the East Cache fault zone extends from the Utah-Idaho boundary to south of Hyde Park, Utah. The northern segment as mapped is 25 km long; it may extend as far north as Preston, Idaho, an additional distance of 13 km (fig. 1). The overall morphology of the range front in the northern segment is dominated by two escarpments, a western one where Tertiary rocks rise as much as 600 m above the valley floor, and an eastern one where Late Proterozoic and Paleozoic rocks rise from 300 to 400 m above the Tertiary rocks, toward the range crest (elevation 2,800-3,040 m; 9,184-9,971 ft).

The eastern escarpment is mapped as an unconformable contact between softer Tertiary and harder Proterozoic rocks and relief may be related to differential weathering and erosion along most of its length (Mendenhall, 1975, pl. 1; Galloway, 1970, pl. 1). However at two localities, north of Cherry Creek and along the north side of Summit Creek, Mendenhall mapped a down-to-the-west high-angle normal fault at the base of this escarpment, with a throw of at least 1,500 m. Cluff and others (1974) mapped the main eastern trace of the East Cache fault zone as a high-angle structure somewhat east of the base of the escarpment. These differences in interpretation between previous mappers (Galloway, 1970; Cluff and others, 1974; Mendenhall, 1975; Dover, 1985) and the poor rock exposures make it difficult to determine whether this fault displaces uppermost Tertiary deposits. At one locality, in map unit afo south of Oxkiller Hollow, it appears this eastern fault may displace older Quaternary deposits. Thus, I conclude that this fault which comprises the easternmost of four faults of the East Cache fault zone in this segment, probably has not experienced significant displacement since early-mid Quaternary time.

The western escarpment is inferred to lie above another strand of the East Cache fault zone, on the basis of the straightness and steepness of the escarpment. However, throw on this fault cannot be more than several hundred meters, because well logs filed in the Office of the State Engineer, Logan, Utah and shallow canal cuts show Tertiary deposits are present under thin cover on much of the valley floor. Faulting visibly displaces Quaternary deposits at only one locality, in the Provo-level delta on the north side of High Creek. A 10 m-high gravel pit wall (loc. 1, on map) exposes a north-trending series of at least five normal faults which define a 30 m-wide graben. Displacement on individual faults ranges from 0.33 to 3.0 m, but total displacement across the entire graben only amounts to 0.4 m. All faults are unconformably overlain by the uppermost 1 m of deltaic topset beds, which indicates that faulting occurred very late in the construction of the Provo-level delta (14 ka?). However, no other deposits of the Bonneville lake cycle show surface displacements along the projected strike of this graben. The graben may be the surface expression of a seismogenic fault, or could be the headscarp of a lateral spread caused by seismic shaking from paleoearthquakes on the East Cache or Wasatch fault zones.

Two faults are inferred to exist under the valley floor. The eastern of these inferred faults was mapped by Mendenhall (1975, pl. 1) and is defined by an abrupt westward thickening of valley fill shown by geophysical evidence, and by the westward limit of landslide outliers of Paleozoic bedrock. A continuation of the same fault extending southward is shown in the map area where it bounds the westernmost bedrock outliers. The position of the westernmost fault inferred by Mabey (1985), is based on a steep westward-sloping gravity gradient. Neither of these two westernmost faults has any surface expression.

The character of the northern segment changes south of Crow Mountain (4 km northeast of Smithfield, Utah), where the range front changes to a strike of N. 20° W. and becomes straighter and steeper. Between Crow Mountain and Green Canyon (east of North Logan) the main displacement on the East Cache fault zone is inferred to underlie the escarpment where Tertiary rocks rise abruptly above the valley floor. Faults in bedrock along this trend are visible on the southern part of Crow Mountain, and are inferred to create the horst-and-graben structure expressed at Long Hill and Round Hill, 2.5 km northeast of Hyde Park. The southernmost part of this fault displaces pre-Bonneville-lake-cycle alluvial-fan gravels 3.0 km east of Hyde Park in a series of broad, low scarps. Owing to the undulating nature of the faulted fans and the disturbance of the scarps by agriculture, net displacement is hard to estimate, but may be as much as 20 m. If these alluvial surfaces are 100,000-200,000 years old, then a long-term slip rate of 0.1 to 0.2 m/1,000 years can be estimated. A concealed fault is mapped to the west of the main escarpment, roughly coincident with the Provo shoreline at an elevation of 1,463 m (4,799 ft). Evidence for a down-to-the-west normal fault in about this position includes the following: (1) Tertiary rocks present within 5 to 30 m of the surface between this fault and Long Hill, (2) a fault exposed in pre-Bonneville alluvium in a roadcut 1.3 km east of 4th East St. in Hyde Park and (3) a steep eastward-sloping gravity gradient (Mabey, 1985). This concealed fault is projected northwestward to merge with the two western buried faults discussed previously.

At the southern end of the northern segment, a southward-tapering "wedge" of Tertiary rocks bounded by the range-front escarpment on the west, by Proterozoic and Paleozoic rocks on the east, and by Smithfield Canyon on the north may be a southward-tilted fault block. This southward-tilted block may have formed as major down-to-the-west displacement transferred from the more northwesterly trending, broadly spaced, subparallel faults of the northern segment to the single main fault of the central segment. Several lines of evidence suggest the southern one-third of the northern segment is a transition zone between contrasting fault behavior to the north and south. First, the fault zone changes from a broad zone of three to four faults north of Crow Mountain to a single trace south of this tilted block. Second, gravity data (Mabey, 1985) imply a fundamental change in subsurface geometry in the transition zone. "North of Smithfield, where Tertiary rocks extend under the valley at relatively shallow depth, the area of thickest Cenozoic fill is about 14 km from the range front."..."South of Smithfield, the gravity pattern suggests a normal fault zone near the range front, and that the greatest thickness of Cenozoic strata is within 4.8 km of the range front" (Mabey, 1985). Third, pediment surfaces cut onto Tertiary rocks of the range front in the "wedge" rise rapidly northward, gaining 500 m in elevation in 9 km. This rise in elevation cannot be traced north of Smithfield Canyon, in part because of a large Tertiary landslide complex which transported huge blocks of Proterozoic and Paleozoic rocks as large as 1 km^2 from the range crest 2.5 km westward onto the valley floor (Mendenhall, 1975; Galloway, 1970). Faceted spurs indicate that the range front on the eastern side of the block (the escarpment between Tertiary and Proterozoic rocks) is more similar to the range front of the central segment than it is to the rest of the range front of the northern segment (McCalpin, 1986). This similarity suggests that until recent geologic time, uplift on the southern part of the northern segment of the East Cache fault zone was a continuation of uplift on the single fault trace of the central segment.

The central segment of the fault zone extends from about 1.5 km north of Green Canyon southward to the mouth of Blacksmith Fork Canyon, a distance of 15 km. Throughout its length the central segment of the fault zone is expressed as one or more small fault scarps at the base of a linear, steep-faceted range front. In contrast to the two adjacent segments, no Tertiary deposits crop out along the central segment, presumably because of downfaulting along a single master fault at the range front and subsequent burial by Quaternary deposits.

The only fault scarps displacing Bonneville-lake-cycle or younger deposits occur in the northern half of the central segment, where scarps diverge from the base of faceted spurs as much as 400 m between Green Canyon and Providence Canyon. South of Providence Canyon post-Bonneville-shoreline faulting may have occurred, but no scarps are evident. Active colluvial processes at the base of the faceted spurs may have obliterated any evidence.

Swan and others (1983) mapped fault scarps between Green Canyon and Providence Canyon and measured three scarp profiles to determine net tectonic offsets. Between Green Canyon and Logan Canyon, scarps offset Bonneville-level sands and silts (lbs), the Provo delta (lpd), and a post-Provo strath terrace (aly) roughly 12 m below the Provo delta surface. A "test pit" across a scarp 150 m south of Green Canyon exposed a "20-m wide zone containing 6 to 7 faults having down-to-the-west displacement" (Swan and others, 1983). No displacement data were given. Because the scarp parallels irregular transgressive shoreline deposits, net offset cannot be reconstructed by surface profiling. However, multiple events were inferred by Swan and others based on observed faulting of scarp-derived colluvium. Multiple west-facing escarpments between the Bonneville shoreline and Provo shoreline may be fault scarps (as implied by mapping of Cluff and others, 1974) or transgressive shorelines. A 2 m-deep trench cut 1.7 km south of Green Canyon in July 1987 across a subdued 5 m-high escarpment uphill of the main trace of the East Cache fault zone revealed a minimum 2 m down-to-the-west displacement of Bonneville transgressive gravels and overlying loess. This evidence suggests that in the area between Green Canyon and Logan Canyon most escarpments parallel to the Bonneville shoreline may be underlain by faults.

On the Provo delta and post-Provo terraces north of the mouth of Logan Canyon, a 3 m-high scarp represents 1.4 m of net vertical tectonic displacement, spread over a graben zone 100 m wide (Swan and others, 1983). The fault underlying the 3-m scarp was exposed near the center of the post-Provo terrace in a south-facing roadcut when U.S. Highway 89 was constructed in the 1930's. Peterson (1936) photographed the cut, which exposed well-stratified Bonneville sands and silts (pro-delta?) overlain by about 1 m of bouldery strath-terrace gravel. Prodelta deposits are displaced along a vertical fault by more than the height of the cut (4.9 m), whereas terrace gravels appear to be displaced about 3 m, an amount similar to the surface scarp height. Recurrent faulting, with at least two events offsetting the prodelta deposits, the latest of which also offset the overlying strath terrace and Provo delta surface, can be interpreted from these relations. Alluvial fans north of Logan Canyon (af1) are not faulted, and in one case (immediately north of the Logan Country Club golf course) a fan clearly buries the scarp which displaces the Provo delta, indicating that there has been no late Holocene faulting.

South of Logan Canyon, the fault follows a steep gully and is well expressed atop the Bonneville delta (lbd) as a west-facing scarp. Between Logan Canyon and Dry Canyon the scarp is roughly 150 m west of the range front, but to the south gradually nears the front and loses expression 2 km south of Logan Canyon. Surface offsets in this 2 km-long stretch reconstructed from eight scarp profiles range from 2.2 to 4.2 m. The scarps are best expressed on the tops of ridges of dissected Bonneville nearshore sands and silts, and do not offset Holocene alluvium in gullies between the ridges. Swan and others (1983) noted that "the fault scarp . . . is visible on the steep sides of the gullies, indicating that at least some of the faulting that produced the scarp occurred after the Bonneville deltaic deposits were eroded." Additional evidence for the multiple-event nature of this scarp includes the following: (1) the surface offsets (2.2 to 4.2 m) are roughly twice that of the scarps north of Logan Canyon, which displace younger (Provo and post-Provo) deposits; and (2) inflections exist in some scarp profiles which may be the result of scarp rejuvenation.

Headscarps of old landslides are also common in Bonneville sands and silts south of Logan Canyon. All landslide scarps are truncated by gullies which dissect the Bonneville sediments. Furthermore, no landslide deposits are preserved below the headscarps on Provo deltas or on alluvial fans graded to the Provo delta. These geomorphic relations suggest that the landslides occurred before or during the occupation of the Provo shoreline. Wave and stream action on the delta surface presumably obliterated landslide toe deposits, after which gullies graded to the Provo shoreline were cut into the landslide terrain. A trench across the scarp south of Log