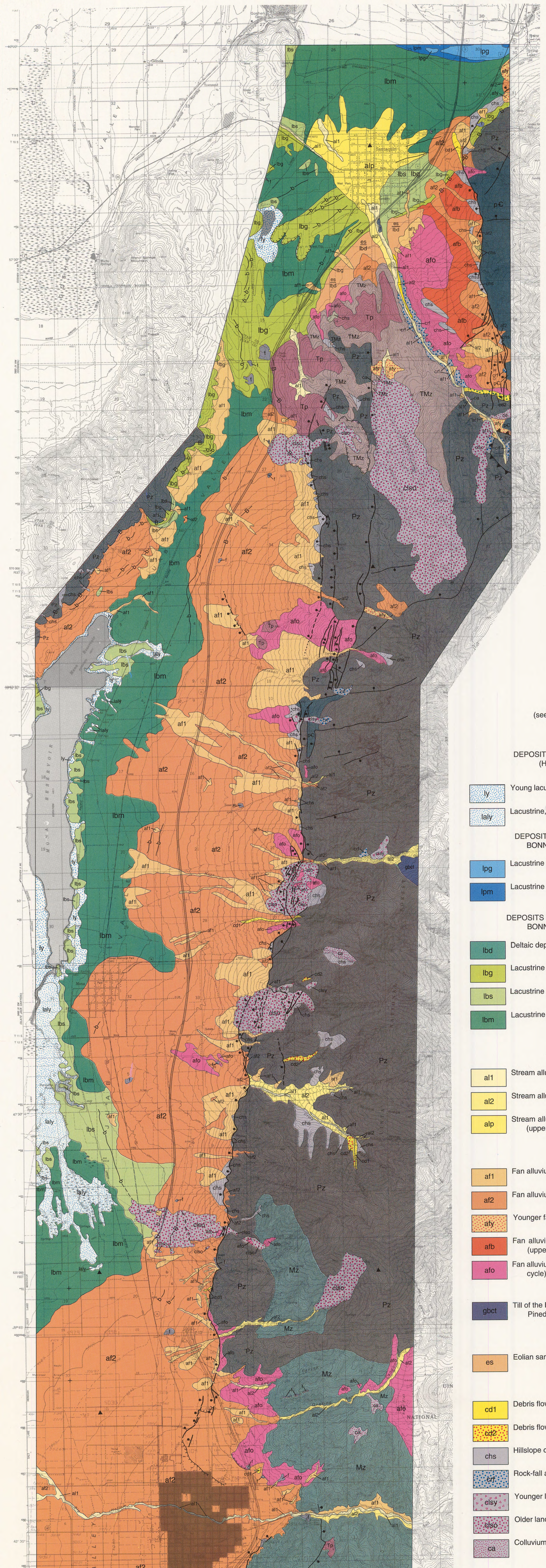
MAP 170
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources,
in cooperation with
The United States Geological Survey

SURFICIAL GEOLOGIC MAP OF THE NEPHI SEGMENT OF THE WASATCH FAULT ZONE, EASTERN JUAB COUNTY, UTAH

by
Kimm M. Harty, William E. Mulvey,
and Michael N. Machette
1997

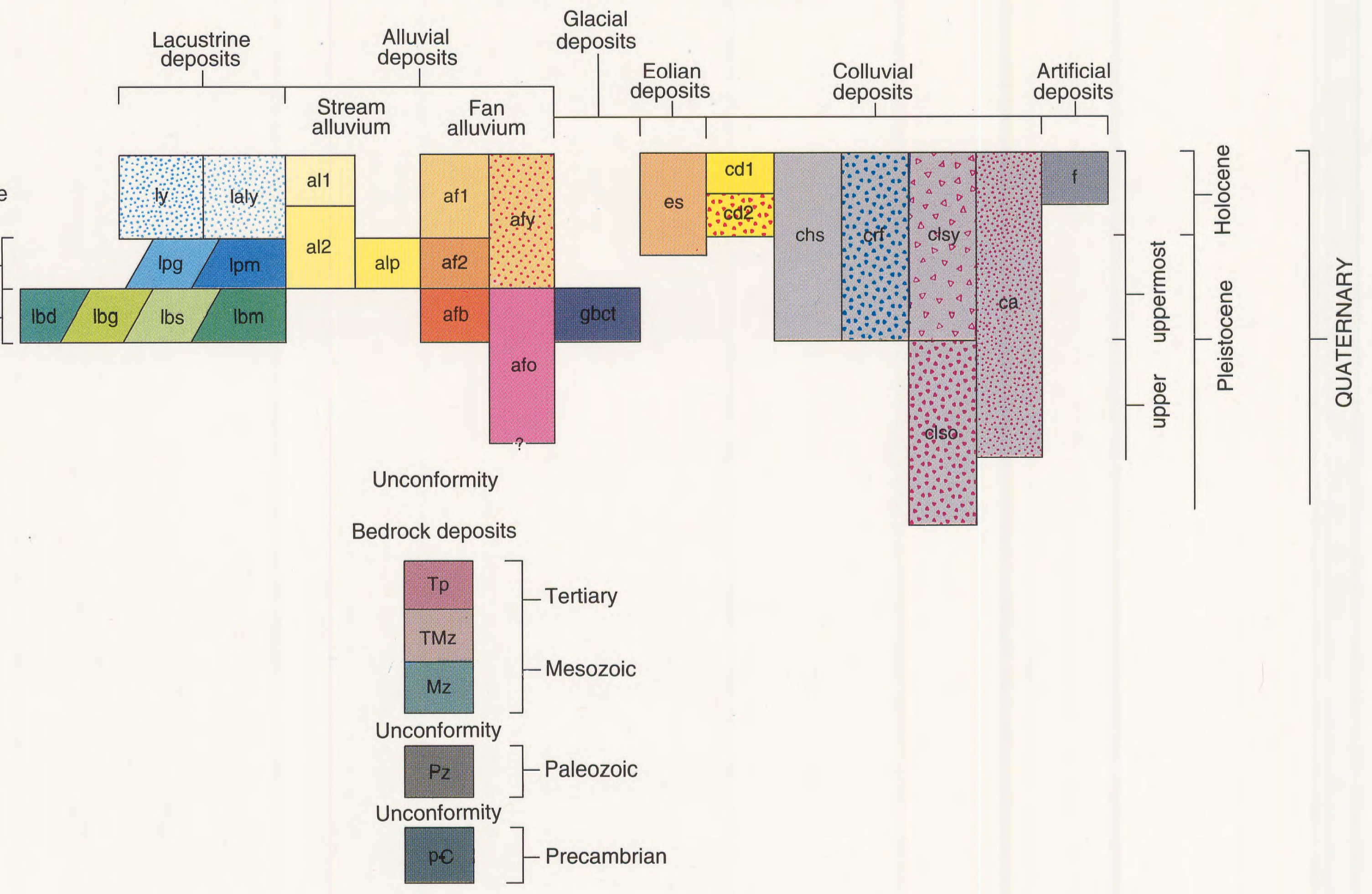


Cartography by Lori J. Douglas

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award 1434-93-G-2343 to the Utah Geological Survey. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Base map from U.S. Geological Survey, 1:24,000 scale Santaquin (1979), Mona (1979), and Nephi (1983) quadrangles.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

(see appendix in text pamphlet for detailed descriptions)

LACUSTRINE DEPOSITS

DEPOSITS YOUNGER THAN THE BONNEVILLE LAKE CYCLE (HOLOCENE TO UPPERMOST PLEISTOCENE)

ly	Young lacustrine and marsh deposits
laly	Lacustrine, marsh, and alluvial deposits, undivided

DEPOSITS OF THE PROVO (REGRESSIVE) PHASE OF THE BONNEVILLE LAKE CYCLE (UPPER PLEISTOCENE)

lpg	Lacustrine gravel
lpm	Lacustrine silt and clay

DEPOSITS OF THE BONNEVILLE (TRANSGRESSIVE) PHASE OF THE BONNEVILLE LAKE CYCLE (UPPERMOST PLEISTOCENE)

lbd	Deltaic deposits, primarily sand and gravel
lbg	Lacustrine gravel
lbs	Lacustrine sand
lbm	Lacustrine silt and clay

ALLUVIAL DEPOSITS

DEPOSITS OF STREAM ALLUVIUM

al1	Stream alluvium, unit 1 (upper Holocene)
al2	Stream alluvium, unit 2 (middle Holocene to uppermost Pleistocene)
alp	Stream alluvium related to the Provo phase of the Bonneville lake cycle (uppermost Pleistocene)

ALLUVIAL-FAN DEPOSITS

af1	Fan alluvium, unit 1 (upper Holocene)
af2	Fan alluvium, unit 2 (middle Holocene to uppermost Pleistocene)
afy	Younger fan alluvium, undivided (Holocene to uppermost Pleistocene)
afb	Fan alluvium related to Bonneville phase of the Bonneville lake cycle (uppermost Pleistocene)
afo	Fan alluvium, undivided (upper to middle Pleistocene; pre-Bonneville lake cycle)

GLACIAL DEPOSITS

gbct	Till of the Bells Canyon advance equivalent (uppermost Pleistocene, Pinedale equivalent)

EOLIAN DEPOSITS

es	Eolian sand and silt (Holocene to uppermost Pleistocene)

COLLUVIAL DEPOSITS

cd1	Debris flows, unit 1 (upper Holocene)
cd2	Debris flows, unit 2 (middle Holocene to uppermost Pleistocene)
chs	Hillslope colluvium (Holocene to uppermost Pleistocene)
crf	Rock-fall and talus deposits (Holocene to uppermost Pleistocene)
clsy	Younger landslide deposits (Holocene to uppermost Pleistocene)
clso	Older landslide deposits (upper Pleistocene to upper Tertiary?)
ca	Colluvium and alluvium, undivided (Holocene to middle Pleistocene)

ARTIFICIAL DEPOSITS

f	Artificial fill and associated disturbed ground (historical)

BEDROCK

Tp	Tertiary volcanic and sedimentary rocks (Paleogene)
TMz	Tertiary-Mesozoic sedimentary rocks (Paleogene and Upper Cretaceous)
Mz	Mesozoic sedimentary rocks (Cretaceous to Triassic)
Pz	Paleozoic sedimentary rocks (Permian to Cambrian)
p€	Precambrian metamorphic rocks (Proterozoic and Archean)

MAP SYMBOLS

Contact-Solid where well or approximately located; dotted where concealed.

Normal fault- Wasatch fault zone. Bar and ball on down-dropped side. Dashed where approximately located; dotted where concealed.

Normal fault-Bar and ball on down-dropped side of bedrock faults (compiled from Witkind and Weiss, 1991). Dashed where approximately located; dotted where concealed.

Thrust fault-Sawteeth on overriding plate or block in bedrock only (compiled from Witkind and Weiss, 1991).

Topographic escarpment-Escarpments formed by fluvial or lacustrine processes. Where escarpment coincides with the contact between map units, ticks face upslope; dashed where approximately located.

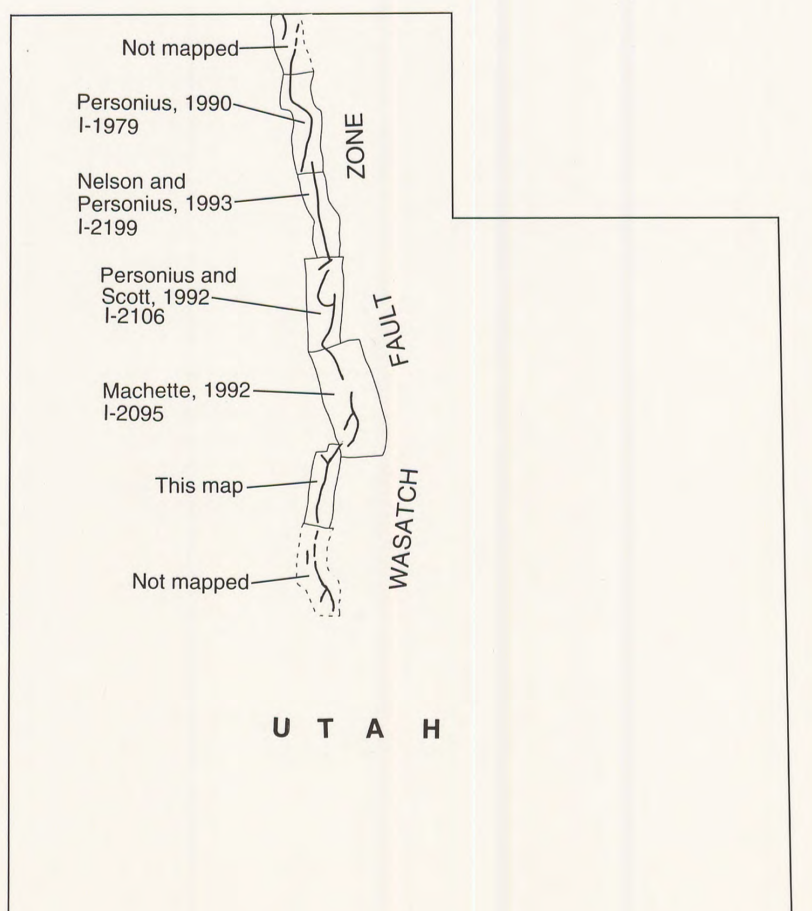
Landslide escarpment-Main and minor scarps formed by landsliding; most scarps are mapped within landslide deposits (clsy or clso); may coincide with geologic contacts; ticks face downslope; dashed where approximately located.

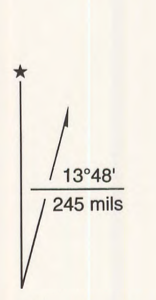
Major, continuous, or prominent shorelines related to levels of the Bonneville lake cycle-May coincide with contact or topographic escarpment.

—B————B— **Highest shoreline of the Bonneville (transgressive) phase**

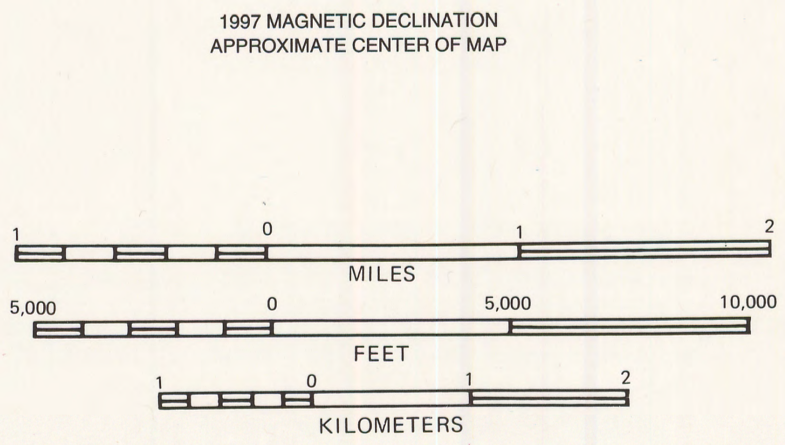
—b————b— **Other shorelines of the Bonneville phase**-Mostly transgressive; dashed where approximately located.

▲ + **Fiducial marks**





1997 MAGNETIC DECLINATION
APPROXIMATE CENTER OF MAP



SCALE 1: 50,000

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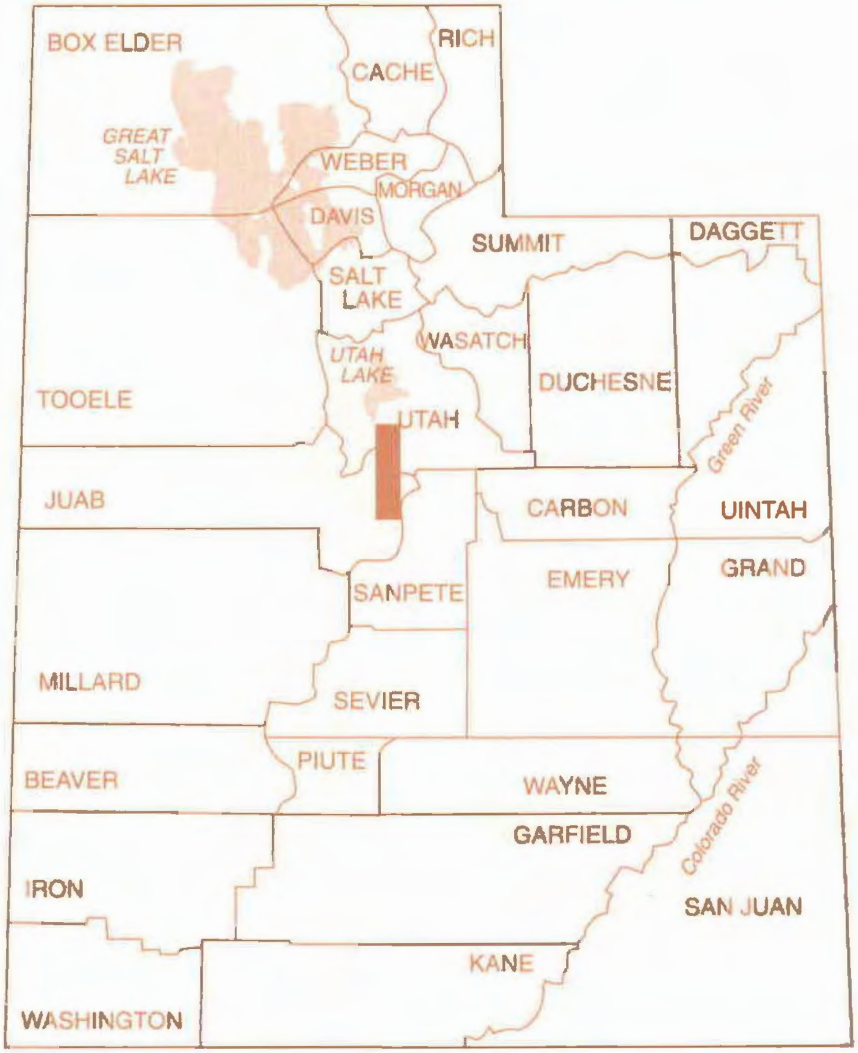

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UTAH DEPARTMENT OF NATURAL RESOURCES

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ISBN 1-55791-572-5

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Map 170 Nephi

Harty, Mulvey, Machette

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UGS Map 170

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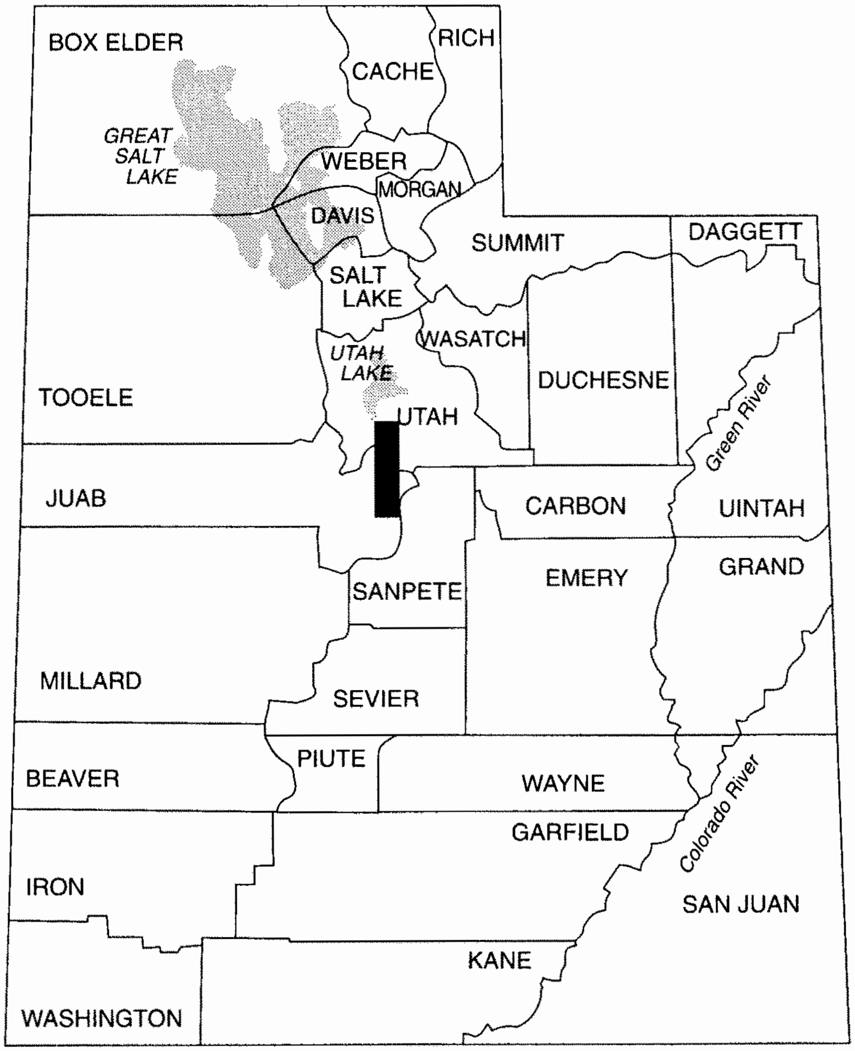

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by
Kimm M. Harty[1]*, William E. Mulvey*[2]*, and Michael N. Machette*[3]

ABSTRACT

The Nephi segment of the Wasatch fault extends 33 kilometers from north of Payson to south of Nephi. Quaternary deposits along the segment are middle Pleistocene to late Holocene in age, and consist primarily of coalesced alluvial fans and Lake Bonneville lake-bottom sediments. The Bonneville lake cycle spanned approximately 16,000 years (about 28,000 to 12,000 ^{14}C yr B.P.), but the lake occupied Juab Valley for only about 1,000 years during the lake's highstand (about 15,500 to 14,500 ^{14}C yr B.P.). Other Quaternary deposits in the mapped area include stream alluvium, landslides, glacial till, eolian deposits, and colluvium.

Three surface-faulting earthquakes have occurred on the Nephi segment during the middle to late Holocene. Morphology of the scarp formed by the most recent event and its lack of vegetation indicate that it may be the youngest surface-faulting event on the Wasatch fault. Radiocarbon dates from trenches indicate that it is younger than about 1,200 years, but the surficial expression leads researchers to suggest the most recent event may be as young as 300 to 500 years old. Based on trench data, the two previous events occurred less than about 4,000 (perhaps 3,000 to 3,500) years ago and between about 4,000 and 5,300 (perhaps 4,000 to 4,500) years ago (Hanson and others, 1981; Schwartz and others, 1983; Jackson, 1991). Little is known of the paleoseismic history during latest Pleistocene time, except that slip rates appear to have been much lower than in the Holocene.

INTRODUCTION

This map shows the surficial geology and faults of the Nephi segment of the Wasatch fault zone (WFZ). In this report we describe the surficial geology along the fault; discuss the height, slope, age, and distribution of fault scarps; and summarize the results of paleoseismic studies performed by the U.S. Geological Survey (USGS), universities, and private consultants. The WFZ is recognized as the most active fault zone in Utah, and the most likely source of future large, surface-faulting earthquakes to affect the populous Wasatch Front area of north-central Utah. This map extends USGS 1:50,000-scale surficial geologic mapping south to include all of the most active central segments of the WFZ (figure 1). The goal of this study, as for previous USGS mapping studies along the WFZ (Personius, 1990; Machette, 1992; Personius and Scott, 1992; and Nelson and Personius, 1993), is to provide basic geologic data needed for accurate

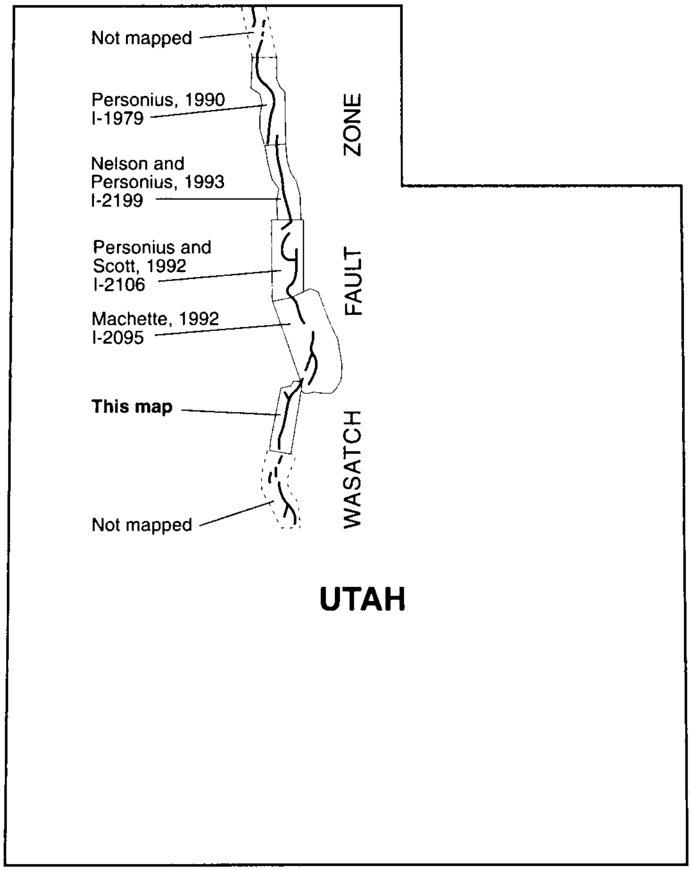

Figure 1. Index map showing series of fault maps along the Wasatch fault zone, Utah (modified from Machette, 1992).

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assessments of paleoseismic history and earthquake hazards associated with the WFZ. This study was jointly funded by the Utah Geological Survey (UGS) and the USGS under the National Earthquake Hazards Reduction Program (NEHRP).

The map encompasses the southernmost part of Utah Valley and the central and eastern parts of Juab Valley, including Nephi (population 3,515-1990 census), the county seat of Juab County (figure 2). Nephi is about 140 kilometers (87 mi) south of Salt Lake City. The map includes parts of three physiographic provinces: (1) the Middle Rocky Mountains (Wasatch Range), (2) the Basin and Range (Juab Valley), and (3) the Colorado Plateau (San Pitch Mountains).

Previous studies of segmentation of the WFZ (Schwartz and Coppersmith, 1984; Machette and others, 1991, 1992) agree with regard to the length and location of the Nephi segment, 33 kilometers (20.5 mi) long. It extends from approximately 3.5 kilometers (2.2 mi) north of Payson to approximately 3 kilometers (1.9 mi) south of Nephi (figure 2). Its southern end is defined by the end of Holocene fault scarps. A gap 15 kilometers (10 mi) long separates the Nephi and Levan segments (Machette and others, 1991).

Scarps of the Nephi segment of the WFZ exhibit some of the youngest morphology along the entire WFZ. Probably for this reason the Nephi segment was the subject of some of the first paleoseismic studies of the WFZ. Based on the observation of steep and relatively unvegetated fault scarps on Holocene alluvial fans of this segment, early researchers (Hanson and others, 1981; Hanson and Schwartz, 1982; Schwartz and others, 1983) estimated the timing of the most recent surface-rupturing earthquake to be about 300 to 500 years ago. Subsequent scarp-morphology (Machette, 1984) and trenching (Jackson, 1991) studies of the Nephi segment suggest that the most recent surface-rupturing earthquake may be older than the initial estimates, but likely occurred within the past 1,000 years.

METHODS

Mapping of the WFZ and surficial deposits along it was done on 1:20,000-scale black-and-white aerial photographs (1950, U.S. Department of Agriculture [USDA]) by K.M. Harty. Color aerial photographs (1:20,000 scale, 1984, USDA) and black-and-white 1:12,000-scale low-sun-angle aerial photographs (1970, Utah Geological Survey) also were used in critical areas. Air-photo mapping was field checked and compiled by W.E. Mulvey onto 1:24,000-scale topographic base maps using a first-order analytical stereo plotter. Many of the scarp data included in this report are from M.N. Machette's studies from 1983 to 1986. Many of the geologic-unit descriptions are from Machette's work on the adjacent Provo segment of the WFZ (Machette, 1992).

Numerous maps of surficial and bedrock geology, faults, and soils were consulted for this project. Maps showing surficial geology (Foutz, 1960; Hintze, 1962; Bissell, 1964; Cluff and others, 1973; Davis, 1983; Miller, 1982; Biek, 1991; and Witkind and Weiss, 1991) provided information on Quaternary stratigraphic and geomorphic relations. Fault maps by Cluff and others (1973, 1:24,000 scale) showed details of scarps and lineaments along the fault zone. Some contacts between Lake Bonneville deposits and distal parts of alluvial fans, which are gradational and difficult to map in the field, were approximated using U.S. Soil Conservation Service soil-survey data and maps (Swenson and others, 1972; Trickler and Hall, 1984). Most of the existing geologic maps are not sufficiently detailed, or the information is outdated, so we remapped much of the surficial geology along the fault trace and adjacent mountain and valley-floor areas. The bedrock geology in the Wasatch Range and northern San Pitch Mountains was compiled and simplified from the geologic map of the Nephi 30′ x 60′ quadrangle (Witkind and Weiss, 1991). The geologic map by Foutz (1960) was used to identify bedrock in Juab Valley just north of Mendenhall Creek. Paleoseismic assessments of fault movement at various sites along the Nephi segment of the Wasatch fault were done by Schwartz and others (1983), Machette (1984), Jackson (1991), and Machette and others (1992). We discuss results from these studies and integrate them with our field observations of the Nephi segment.

Differentiation of Quaternary geologic units follows standard convention and is based on relative-age criteria such as geomorphic expression, landform preservation, soil development, and stratigraphic position. To maintain continuity with the other USGS geologic maps, geologic map-unit symbols generally follow those used by Machette (1992) in the Provo area. Detailed descriptions of geologic units on the map are in the appendix.; many of the descriptions were taken directly or modified from Machette (1992). The northernmost part of the Nephi segment and its basinward extension, the Benjamin fault, are included on Machette's (1992) map of the Provo segment and are not reproduced here.

In addition to the surficial and generalized bedrock geology shown on this map, fault-scarp data (scarp heights) are also given for selected localities. When combined with the ages of faulted deposits, fault-scarp characteristics can be used to estimate slip rates and average recurrence intervals. Scarp data were derived from surface profiles of fault scarps made using an Abney level and stadia rod; values of scarp height and surface offset were measured from computer plots of scarp profiles. Assumptions and methods used to calculate slip-rate ranges for various sites along the Nephi segment are explained in the section of the report titled "Nephi Segment." Terminology used to describe fault-scarp morphology (figures 3A and 3B) follows that established by Bucknam and Anderson (1979) for single-event scarps and that of Machette (1992) for multiple-event scarps. Radiocarbon ages cited from other studies are appended as either "yr B.P." (radiocarbon years before present; or 1950 for uncalibrated ages), or "cal yr B.P." (calendar years before present for calibrated ages). Major shorelines associated with the transgressive (Stansbury and Bonneville shorelines) and regressive (Provo shoreline) phases of the most recent cycle of Lake Bonneville provide a means of relative age dating in the Lake Bonneville basin. Ages of the Bonneville Lake cycle are reported in radiocarbon years before present according to lake chronologies of Currey (1990) and Oviatt and others (1992).

The following informal time- and rock-stratigraphic designations are used to divide the Quaternary Period: (1) Holocene (0-10,000 years ago), (2) latest (uppermost) Pleistocene (10,000-

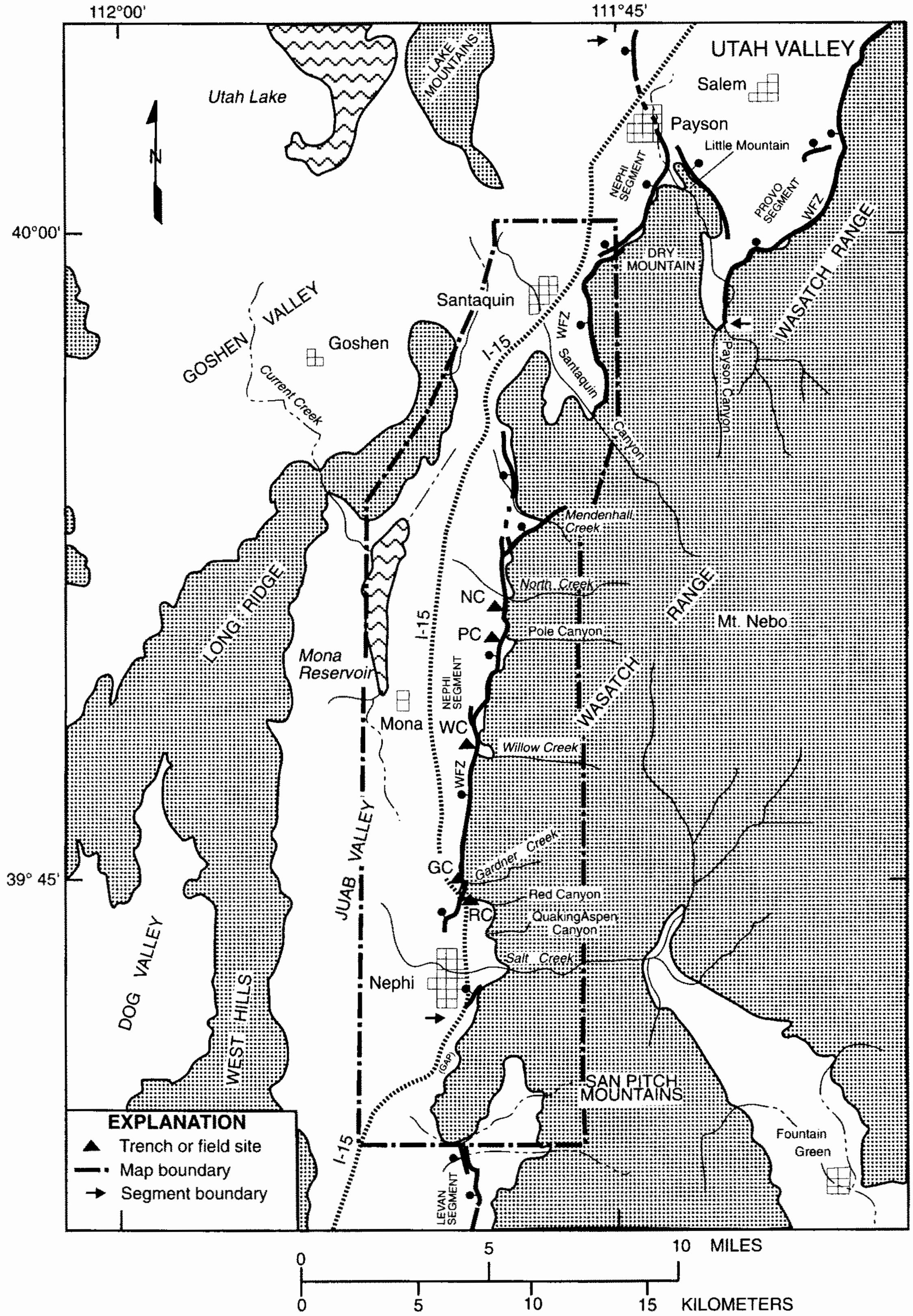

Figure 2. *Nephi segment of the Wasatch fault zone (WFZ), which extends from just north of Payson to Nephi, Utah. Faults are shown by heavy lines having a bar and ball on the downdropped side. The area south of the segment boundary lacks evidence of Holocene faulting. Also shown are important geographic features and towns. Trench and field sites are abbreviated as follows from north to south: NC, North Creek; PC, Pole Canyon; WC, Willow Creek; GC, Gardner Creek; RC, Red Canyon (modified from Machette and others, 1992). See Machette (1992) for detailed mapping of surficial geology and faults northeast of the map boundary.*

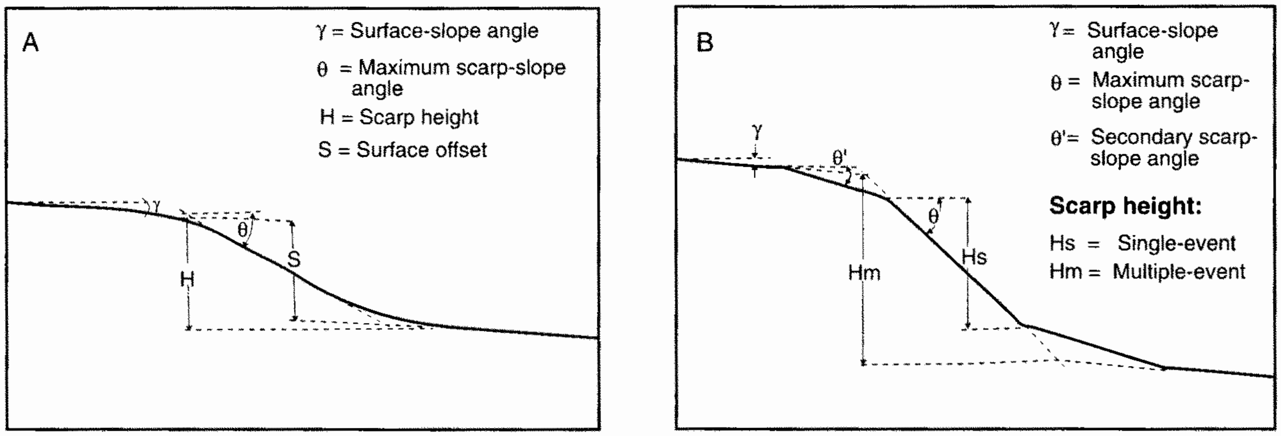

Figure 3. Fault-scarp nomenclature used in this report. A - schematic diagram of a single-event scarp (modified from Bucknam and Anderson, 1979). B - schematic diagram of a multiple-event fault scarp (modified from Machette, 1992).

30,0000 years ago), (3) late (upper) Pleistocene (10,000-130,000 years ago), (4) middle Pleistocene (130,000-750,000 years ago), and (5) early (lower) Pleistocene (750,000-1.6 million years ago).

QUATERNARY DEPOSITS AND DEPOSITIONAL HISTORY

Quaternary deposits along the Nephi fault segment range from middle Pleistocene to late Holocene in age. Coalesced alluvial-fan (af1, af2, afb, afy, afo) and Lake Bonneville lake-bottom deposits (lbm) dominate Juab Valley. Alluvial fans cover much of eastern Juab Valley along the mountain front. These deposits thin and fine toward the center of the valley, where sediment from the most recent cycle of Lake Bonneville (known as the Bonneville lake cycle) is exposed. The Bonneville lake cycle began about 28,000 ^{14}C yr B.P. and ended about 12,000 ^{14}C yr B.P. (Oviatt and others, 1992), but the lake occupied Juab Valley for only about 1,000 years during the lake's highstand from about 15,500 to 14,500 ^{14}C yr B.P.

Alluvial Deposits

Throughout the latest Pleistocene and into the Holocene, deposition of alluvial fans (units af1, af2, afy, afb) has been rapid and extensive, eroding and burying Bonneville shorelines and offshore (lake-bottom) deposits. Studies of alluvial fans in northern Utah indicate that rapid sedimentation took place during post-Bonneville time (Keaton and others, 1991; Mulvey, 1992), especially from about 4,000 to 5,000 years ago (Machette and others, 1992). Soils on upper and middle Holocene fans (units af1 and af2) are weakly developed because they have had limited time of exposure to soil-forming processes.

Juab and southern Utah Valleys have been characterized by alluvial-fan deposition that accompanied uplift of the Wasatch Range throughout the Pleistocene. Alluvial fans deposited mostly during and after the Bonneville lake cycle, in latest Pleistocene and Holocene time (units af1 and af2), dominate these valleys. Alluvial fans that predate the Bonneville lake cycle include some af2 deposits, and older fan deposits (unit afo) that are typically preserved in uplifted blocks and within pre-Bonneville landslides (unit clso). Unit afo is probably 100,000 to 250,000 years old as judged by the degree of carbonate soil development (Machette, 1992). Remnants of unit afo are preserved at the mouths of Pole, Gardner, and Quaking Asp Canyons. Deposition of these fans ceased as fault movement on the Nephi segment lowered the local base level and streams incised the fans on the upthrown side of the fault. Isolated remnants of older fan deposits are also present on the downthrown side of the fault; outcrops are best preserved in areas sheltered from Holocene deposition and where erosion has exposed these older units. Because remnants of Lake Bonneville shorelines are scarce (Bonneville level) or absent (Provo level) in Juab Valley, the ages of units af2 and al2 could not be tightly constrained and thus encompass a broad age range, equivalent to af2/al2 and af3/al3 units of Machette (1992).

Upper Holocene stream alluvium (unit al1) locally covers alluvial fans in Juab Valley. Thick sequences of stream alluvium (units al1 and al2) fill the channels of larger drainages in the Wasatch Range and San Pitch Mountains adjacent to Juab and southern Utah Valleys. Some of the older stream deposits (unit al2) were exposed by erosion in the high-precipitation year of 1983.

Colluvial and Landslide Deposits

Colluvial and landslide deposits cover a small percentage of the mapped area and mainly consist of debris flows (units cd1 and cd2), hillslope debris (unit chs), undivided alluvium and colluvium (unit ca), landslides (units clsy and clso), and rock-fall deposits (unit crf). Upper Pleistocene to Holocene debris-flow and debris-flood deposits (units cd1 and cd2) are preserved at the surface of some alluvial fans, and probably constitute a large part of the alluvial-fan sediment. Holocene to upper Pleistocene hillslope colluvium (unit chs) locally covers steeper slopes in the mountainous eastern part of the mapped area.

Several large Holocene landslide deposits (unit clsy) are present in eastern Juab Valley. Most are associated with the Pennsylvanian-Mississippian Manning Canyon Shale (within unit Pz on the map) and the Paleocene-Cretaceous North Horn Formation (within unit Tmz on the map). Older landslides (unit clso) associated with the slide-prone Manning Canyon Shale and the Jurassic Arapien Shale are also present along the mountain front. Most are large (1.9 to 3.2 million cubic meters [2.5 to 3.0 million yd^3]) earth slides or flows of pre-Bonneville age as determined from subdued surface morphology and the presence of the Bonneville shoreline on the surface of several landslides. The landslides have carbonate soils similar to those on the older alluvial fans (unit afo) in the mapped area. These large landslides traveled as much as 2 kilometers (1.2 mi) into Juab Valley. Local Holocene to upper Pleistocene talus and rock-fall deposits (unit crf) are present on steep mountain slopes and above stream channels in canyons in the eastern part of the mapped area.

Lacustrine History and Deposits

Unlike other major valleys along the WFZ in northern Utah, Juab Valley was inundated by Lake Bonneville only during its climb to the highstand at the Bonneville level. Outside Juab Valley, Lake Bonneville began expanding about 28,000 ^{14}C yr B.P. from levels similar to those of modern-day Great Salt Lake (Oviatt and others, 1992). The lake rose gradually, with intermediate oscillations (notably at the Stansbury shoreline between 21,000 and 20,000 ^{14}C yr B.P.), and slowed its rise as it approached its overflow threshold near Zenda, Idaho (1,552 meters [5,093 ft]). Lake Bonneville reached this threshold about 15,500 ^{14}C yr B.P. and remained at or near the highest Bonneville level for about 1,000 years, with one possible oscillation (the Keg Mountain oscillation of Currey [1990]). Catastrophic overflow caused by rapid downcutting of the threshold dropped the lake 108 meters (354 ft) to a bedrock threshold near Red Rock Pass, Idaho, where the lake stabilized at the Provo level (approximately 1,444 meters [4,737 ft]) about 14,500 ^{14}C yr B.P. (Oviatt and others, 1992). Since about 14,000 ^{14}C yr B.P., Lake Bonneville has been a hydrologically closed system as overflow ceased and the climate began to warm, shrinking the lake and dropping its level rapidly from the Provo shoreline. By about 12,000 ^{14}C yr B.P., the lake had dropped to levels possibly at or lower than those of modern-day Great Salt Lake (Currey and Oviatt, 1985; Oviatt and others, 1992; Currey, written communication, 1995). Great Salt Lake transgressed to form the Gilbert shoreline (about 1,296 meters [4,252 ft] in northern Salt Lake Valley) between 11,000 and 10,000 ^{14}C yr B.P., but this expansion did not reach Utah or Juab Valleys (Currey, 1982).

Paleohydrographs of Lake Bonneville constructed from radiocarbon-age data show that the lake reached the topographic threshold of Juab Valley about 18,000 ^{14}C yr B.P. (Oviatt and others, 1992). The lake entered the valley from the northwest, through Goshen Valley (figure 2). Water entered along present-day Current Creek (Goshen Canyon), where the threshold of Juab Valley is 1,460 meters (4,870 ft). Soon afterward, Lake Bonneville crossed the threshold between Utah and Juab Valleys at 1,525 meters (5,000 ft) or 65 meters (213 ft) higher. Sediment entering Lake Bonneville from Santaquin Creek built a small delta (unit lbd) at the mouth of Santaquin Canyon. Longshore currents eroded the delta front and built several large gravel spits (unit lbg) along the mountain front southwest of Santaquin Canyon. Summit Creek, which flows through Santaquin Canyon, has since eroded the northern part of the spit-delta complex. During the 1,000 years Lake Bonneville occupied Juab Valley, fine-grained lake deposits (lbm and lbs) accumulated in the center of the valley.

Because Juab Valley was a sheltered, shallow arm of Lake Bonneville, shorelines and other geomorphic features are poorly developed except at the north end, where the lake was deepest and exposed to north winds and long fetches across Utah Valley. Other than the spits south of Santaquin (unit lbg) in southern Utah Valley, we found few depositional Bonneville shoreline features in the mapped area. In Juab Valley, the Bonneville shoreline is primarily erosional, and is best preserved on the west side of the valley, outside the map area. Currey (1982) reports the Bonneville shoreline in southern Utah Valley near Cedar Hollow at 1,5581 meters (5,111.53 ft) in elevation. This elevation agrees well with shorelines mapped on 1:24,000-scale topographic base maps, which on the downthrown side of the Wasatch fault zone range from 1,548 to 1572 meters (5,080 to 5,160 ft) in elevation. The elevation of a Bonneville shoreline remnant on the upthrown side of the WFZ east of Santaquin is about 1,615 meters (5,298 feet). The Bonneville shoreline locally is etched onto large pre-Bonneville landslides (unit clso) below Mt. Nebo, and preserved locally on alluvial fans along the Nephi segment.

Lake Bonneville remained at the highest Bonneville shoreline until about 14,500 ^{14}C yr B.P. 16,800 years ago, when the Bonneville flood rapidly drained the lake from Juab Valley. The water level dropped below the Utah-Juab Valley topographic threshold, and retreated northwestward down Current Creek. The lake then stabilized at the Provo level and etched shorelines into Utah Valley just north of the mapped area. As the lake began its climate-induced regression from the Provo shoreline, Provo-level lacustrine sediments were deposited in southern Utah Valley (units lpm and lpg). Post-Bonneville stream flooding eroded Bonneville deep-water sediments deposited in the Current Creek drainage, leaving interbedded sand and silt deposits stranded and well exposed along drainage walls.

Young lacustrine sediments, including marsh and undivided alluvial deposits (units ly and laly) associated with modern lakes and wetlands, are mapped in localized areas mainly near the axis of Juab Valley. The largest exposed areas of young lacustrine sediments are along the perimeter of Mona Reservoir.

Other Deposits

Glacial sediment (unit gbct) deposited early in the Bonneville lake cycle is present in the upper part of Pole Canyon and in nearby drainages outside the mapped area. Till associated with terminal and lateral moraines (unit gbct), and glacial outwash (undifferentiated from unit al2) related to this advance are present in Pole Canyon. These deposits are probably equivalent to the Bells Canyon advance of Madsen and Currey (1979). This advance is associated with the Pinedale glaciation of the Rocky

Mountains from about 45,000 to 15,000 years ago (Porter and others, 1983).

Holocene to upper Pleistocene eolian sand and silt (unit es) derived from fine-grained lacustrine sediment form a mantle on Bonneville-level deltaic gravel southeast of Santaquin. Modern artificial fill and areas of disturbed ground (unit f), including borrow pits, cover small areas mainly in Juab Valley.

BOUNDARY BETWEEN THE PROVO AND NEPHI SEGMENTS

The boundary between the Provo and Nephi segments is an en echelon, overlapping right step in the Wasatch fault zone (figure 1; Machette, 1992). The Provo segment extends southward into Payson Canyon, east of Dry Mountain (Machette, 1992; Machette and others, 1992). The Nephi segment overlaps the Provo segment and extends about 3.5 kilometers (2.2 mi) north of Payson (figure 2) toward the town of Benjamin. Wheeler and Krystinik (1988) named the north-trending bedrock spur between these two segments the Payson salient. This feature consists of Precambrian to Paleozoic rocks of Dry Mountain and Tithing Mountain and volcanic rocks of Little Mountain (Machette, 1992). Little Mountain protrudes into Utah Valley at Payson and is mantled by lacustrine gravel below the Bonneville shoreline. It is bounded by young faults on the east and west sides (Machette, 1992). The western side of Little Mountain displays several down-to-the-west faults that form scarps on shoreline gravel of the Bonneville lake cycle (unit lbg). The southern end is terminated by an older west-striking normal fault (possibly low angle) that places Tertiary volcanic rocks against the Pennsylvanian Oquirrh Group. We suspect that this fault and similar ones mapped along the Wasatch Front (for example, by Davis, 1983) are the soles of large-scale, gravity-slide blocks that descended into Utah Valley during uplift of the Wasatch Range.

The northern end of the Nephi segment, the Benjamin fault, forms the west side of the Payson salient as shown by Machette (1992). Although the Benjamin fault and Springville fault (a splay of the Provo segment) appear to connect in the subsurface below Utah Valley, Zoback's (1983) gravity map shows that the deep part of the basin extends uninterrupted from east of Spanish Fork northwest under Utah Lake. Thus, the Springville and Benjamin faults must die out (lose structural throw) as they extend into Utah Valley.

NEPHI SEGMENT

The Nephi segment extends 33 kilometers (20.5 mi) from approximately 3.5 kilometers (2.2 mi) north of Payson to approximately 3 kilometers (1.9 mi) south of Nephi (figure 2). Its southern end is defined by the end of Holocene fault scarps and a gap 15 kilometers (10 mi) long that separates the Nephi and Levan segments (Machette and others, 1992). Along its length, the Nephi segment cuts Quaternary deposits of different ages, including Lake Bonneville deposits at its northern end. At several locations along the segment there are conspicuous scarps on pre-Bonneville deposits, such as at Gardner Canyon (figure 2, map). For much of its length, however, the fault is at the base of the mountains and forms the contact between bedrock and alluvial-fan and other surficial deposits. From North Creek south, the fault cuts across canyon mouths, uplifting the apices of a series of roughly correlative middle Holocene alluvial fans, thus forming spectacular multiple-event fault scarps. North of North Creek, the fault bifurcates and its principal strand takes a major right step over to Santaquin Canyon and then trends north along the base of Dry Mountain to Payson. At Payson the fault continues northward into Utah Valley and dies out in Lake Bonneville deposits near Benjamin (Machette, 1992).

The following sections describe the results of paleoseismic studies performed by previous workers (Schwartz and others, 1983; Machette, 1984; Jackson, 1991; and Machette and others, 1992) at various sites along the Nephi segment. These results are reported along with our field observations and measurements.

North Creek

Three trenches were excavated at North Creek (NC, figure 2) where the Wasatch fault zone offsets an alluvial fan dated at 4,580 ± 250 ^{14}C yr B.P. (Bucknam, 1978; Hanson and others, 1981; Schwartz and others, 1983), which corresponds to a dendrochronologic age of 5,300 cal yr B.P. (4,869 to 5,589 cal yr B.P.) (Machette and others, 1992). Evidence for three surface-faulting events was found at the site. Colluvial wedges representing the two most recent events (MRE) were exposed in the trenches, and a terrace incised into the uplifted part of the North Creek fan was inferred to be of tectonic origin, thus representing an older, third event (Schwartz and others, 1983).

The scarp's steep slope angles (40-42 degrees maximum), lack of vegetation near North Creek, and the proximity of nick-points in small ephemeral stream channels on the upthrown side indicate very recent movement of the fault. On this basis, Schwartz and others (1983) estimated an age of 400 ± 100 years ago for the MRE. However, dates from the trenches indicate that the MRE could have occurred as much as 1,000 years ago. Maximum limiting ages obtained for the youngest event are 1,110 ± 60 ^{14}C yr B.P. (975 or 1,048 cal yr B.P) and 1,350 ± 70 ^{14}C yr B.P. (1,289 cal yr B.P.) (Hanson and others, 1981; Hanson and Schwartz, 1982). Based on the thickness of colluvial wedges and heights of buried free faces, Hanson and others (1981) estimate a displacement during the MRE of 2.0 to 2.2 meters (6.6 to 7.2 ft).

Radiocarbon dating of a buried soil on the penultimate-event colluvial wedge yielded ages of 3,640 ± 75 ^{14}C yr B.P. and 1,650 ± 50 ^{14}C yr B.P. (Hanson and Schwartz, 1982). Similar age ranges for this unit were also obtained using accelerator mass spectrometry. Hanson and Schwartz (1982) believe that the older date (corresponding to between 3,930 and 3,980 cal yr B.P.) represents the minimum time since the penultimate event and that the younger date represents material incorporated into the soil prior to burial. The one-sigma error on the older date yields an age of 3,841 to 4,088 cal yr B.P., or about 4.0 ± 0.2 ka

(Machette and others, 1992). The displacement during the penultimate event was 2.0 to 2.5 meters (6.6 to 8.2 ft) (Hanson and others, 1981).

The oldest (third) recorded event occurred well before the penultimate event (4.0 ± 0.2 ka) and may coincide with the time of last deposition on the upfaulted North Creek alluvial-fan surface (5.3 ± 0.3 ka). The event uplifted the apex of the fan, which was then incised and abandoned. Later faulting (event 2) uplifted the fan, leaving evidence for the third event as an inset strath terrace. Displacement during the third event was estimated at 2.6 meters (8.5 ft), based on the depth of inset of the terrace below the fan surface just above the fault (Hanson and Schwartz, 1982; Schwartz and others, 1983).

As derived from the thickness of scarp-derived colluvial wedges, topographic profiles of the faulted surface, and the height of the tectonic strath terrace, the net vertical tectonic displacement (NVTD) for the three surface faulting events is 7.0 ± 0.5 meters (23.0 ± 1.6 ft) (Hanson and others, 1981; Hanson and Schwartz, 1982; Machette and others, 1992). Using the sum of the average NVTD values for the MRE (2.1 meters [6.9 ft]) and penultimate (2.2 meters [7.2 ft]) events, the slip-rate range at North Creek since middle Holocene time (about 5.3 ka) is 0.8 to 1.2 mm/yr (0.03-0.05 in/yr) (table 1). The middle Holocene slip rate was calculated by dividing the age of the oldest (third) faulting event (minus the time elapsed between the present and the most recent event) into the NVTD for the past two events. The slip-rate range was calculated by dividing this NVTD by: (1) the minimum age span, calculated by taking the estimated minimum age of the third event (4,869 cal yr B.P.) minus the maximum estimated age of the MRE (about 1,200 cal yr B.P.; Jackson, 1991), and (2) the maximum age span, calculated by taking the estimated maximum age of the third event (5,589 cal yr B.P.) minus the minimum estimated age of the MRE (about 400 cal yr B.P.; Hanson and others, 1981). Slip-rate ranges are given rather than one average rate because they better reflect the inherent uncertainty of dates used to calculate slip rates.

Pole Canyon

A multiple-event fault scarp that crosses the head of the Pole Canyon alluvial fan may represent three or more faulting events (PC, figure 2). Pole Creek has incised the upthrown part of the alluvial fan, exposing a stage II+ calcic soil on the fan surface, which suggests a probable early Holocene to late Pleistocene age for the surface. Recent erosion has deepened and widened the modern channel and exposed a colluvial wedge from the most recent event in the north wall of the streamcut. The wedge is composed of an open framework of coarse, angular clasts and organic material, penetrated by roots of trees and shrubs. Because of the open framework, the organic material in the wedge is probably illuviated from the A horizon of the modern soil.

Willow Creek

Incision along Willow Creek during spring flooding in 1983 exposed a fault and two scarp-derived colluvial wedges indicating at least two surface-faulting events (WC, figure 2) (Machette, 1984). The materials observed in this exposure have been removed by subsequent erosion, leaving only unfaulted deposits on the upthrown block of the fault.

Table 1.
Estimated slip-rate ranges for various sites along the Nephi segment of the Wasatch fault zone. Segment length is 33 km.

Site	**Slip-Rate Range (mm/yr)**	**Distance north from the south end of the Nephi segment (km)**
North Creek	0.8 - 1.2	18.5
Willow Creek	0.7 - 1.0	12
Gardner Creek	0.5 - 0.7	7.5
Red Canyon A	0.6 - 0.8	6.5
Red Canyon B	0.7 - 1.0	6.5

The fault scarp on the Willow Creek fan has an average height of 6.6 meters (21.7 ft), a maximum scarp-slope angle of 37 degrees, and a minimum surface offset of 5.2 to 6.0 meters (17.1-19.7 ft) (Machette, 1984). The fault scarp at North Creek, which formed by three surface-faulting events since middle Holocene time, has a height and maximum slope angle similar to the scarp at Willow Creek. The soil on the alluvial fan at Willow Creek has an A/weak Bs/stage I Ck horizon profile, which also is similar to the soil on the middle Holocene North Creek fan (Machette, 1984). Thus, the Willow Creek scarp probably represents the same three events as those identified at North Creek.

Because of the apparent similarity in ages of the faulted alluvial fans at North Creek and Willow Creek, and the likelihood that the scarp at Willow Creek represents the same three faulting events identified at North Creek, we used the age of the faulted middle Holocene fan at North Creek and the same minimum/maximum ages for the third and most recent events as used in the North Creek calculations to obtain an estimated slip-rate range since middle Holocene time of 0.7 to 1.0 mm/yr (0.03 - 0.04 in/yr) for Willow Creek (table 1). A NVTD of 3.7 meters (12.1 ft) was used to calculate the slip-rate range. This value is two-thirds of the average sum of the surface-offset range cited above, representing displacement during the MRE and penultimate events.

Gardner Creek

Faulted middle Holocene and upper Pleistocene alluvial-fan deposits are found at the mouth of Gardner Creek (GC, figure 2). The middle Holocene deposits are thought to be roughly 4,000 to 6,000 years old (similar in age to fans at North and Willow Creeks) and are offset 3.9 meters (12.8 ft; scarp heights are about 4.2 meters [13.8 ft]) (Machette, 1984), or about 40 percent less than at Willow Creek. The lesser scarp heights in similar-age deposits at Gardner Creek probably reflect their location near the end of the segment where displacement typically diminishes.

Assuming the faulted deposits at North Creek and Gardner Creek are the same age, and that the same three surface faulting events occurred at both sites, the estimated slip-rate range since middle Holocene time at Gardner Creek is 0.5 to 0.7 mm/yr (0.02-0.03 in/yr) (table 1). A NVTD of 2.6 meters (8.5 ft), two-thirds the NVTD, was used in this calculation.

Just to the north of Gardner Creek, Machette (1984) described a soil in faulted upper Pleistocene alluvial-fan deposits (unit afo). The alluvial-fan surface is characterized by a strongly developed soil with a K horizon 1 meter (3 ft) thick that has thin laminae (incipient stage IV morphology) in the upper 10 centimeters (3.9 in) above a strong stage III morphology. Overlying the K horizon is a Btk horizon 10 centimeters (3.9 in) thick, and a thin A horizon. A large part of the B horizon was probably engulfed by the K horizon (Machette, 1984). Even though the soil is formed in limestone-rich alluvium, the degree of soil development confirms the antiquity of the deposit, which is estimated to be about 250,000 years old. Fault scarps formed in this unit at Gardner Creek are 26 to 28 meters (85-92 ft) high, have slope angles of 38 to 40 degrees, and are buried at their bases by an unknown thickness of young fan alluvium (Machette, 1984). Between Gardner Canyon and Red Canyon, where the scarps are least buried, the maximum height is about 32 meters (105 ft). Using an average height of 30 meters (98 ft) and an assumed age of 250,000 years, Machette (1984) calculated a late Quaternary slip rate at Gardner Creek of 0.12 meters/ka (0.4 ft/ka). This slip rate is only about 15 percent of the middle to late Holocene slip rate (0.8 meters/ka [2.6 ft/ka]) at this locality, and may reflect major variations in slip rates through time (Machette and others, 1992).

Red Canyon

Jackson (1991) excavated a trench just north of Nephi on the alluvial fan of Red Canyon near the southern end of the Nephi segment (RC, figure 2). The trench crossed a fault scarp 5.5 meters (18 ft) high on distal alluvial-fan deposits. Three colluvial wedges were recognized in the trench.

A maximum age of about 1,400 yr B.P. for the MRE was obtained from a thermoluminescence (TL) age estimate and radiocarbon dating of a buried soil. The most probable age of the event was estimated at 1,200 years ago (Jackson, 1991) with an estimated displacement of 1.4 ± 0.3 meters (5 ± 1 ft). Radiocarbon dating of soil developed on a colluvial wedge yielded maximum ages for the penultimate event of 3,600 ± 400 and 3,900+500/-400 yr B.P. The preferred age of the event is 3,000 to 3,500 years (Jackson, 1991). Displacement for this event was estimated at 1.5 ± 0.2 meters (5 ± 1 ft). A third (oldest) event in the trench is post-latest Pleistocene based on the soil profile on the alluvial-fan surface. The most probable age is estimated at 4,000 to 4,500 years (Jackson, 1991), with 1.7 ± 0.3 meters (6 ± 1 ft) of offset.

Based on his estimates of the most probable timing of events at Red Canyon (1,200, 3,000 to 3,500, and 4,000 to 4,500 cal yr B.P.), Jackson (1991) inferred synchroneity with faulting at the North Creek site. However, his estimate for the MRE is older than that indicated by radiocarbon dating at North Creek. Because the trench is close to the end of the Nephi segment, not all of the faulting events at North Creek (near the center of the segment) may have ruptured as far south as the Red Canyon site or with as large a displacement (Machette and others, 1992).

Cumulative displacement at the Red Canyon site as measured from the thickness of the three colluvial wedges is 4.6 ± 0.8 meters (15.1 ± 2.6 ft) (Jackson, 1991). However, Jackson also reports a NVTD of 5.4 ± 0.3 meters (17.7 ± 1.0 ft), measured from an offset geologic unit in the trench. The slip-rate ranges for the Red Canyon site (A and B, table 1) were calculated using the same ages for faulted deposits and minimum/maximum surface faulting events as those used at North Creek. These ages were divided into: (1) the NVTD derived from thicknesses of the MRE and penultimate-event colluvial wedges (Red Canyon A, table 1) and (2) two-thirds of the NVTD measured from the offset trench unit (Red Canyon B, table 1). The slip-rate range calculated using thicknesses of colluvial wedges (0.6-0.8 mm/yr [0.02-0.03 in/yr], Red Canyon A, table 1) appears to conform to the general pattern of diminishing scarp height and correspondingly lower slip rates with proximity to the southern end of the fault segment (table 1). However, the slip-rate range calculated from the offset trench unit (Red Canyon B, table 1), which is usually a more reliable measurement of NVTD, does not conform to this pattern, and is the same as that calculated for Willow Creek.

City of Nephi

A fault scarp trends into the city from the north, but extends only to about 800 North Street (Cluff and others, 1973; Biek, 1991). The scarp is about 2 meters (7 ft) high at the north end of the city, but is only about 1 meter (3 ft) high along much of its length in Nephi where it is principally in distal alluvial-fan deposits of Quaking Asp Canyon and stream alluvium of Salt Creek. Cluff and others (1973) and Biek (1991) mapped some possible faults (lineaments) along the northeast edge of town, but we could find no evidence of surface offset in these areas.

A large (10 meters [33 ft] high) northwest-southeast-trending scarp on older alluvial-fan deposits is present south of the Nephi cemetery on the east side of town at about 5,200 feet (1,584 m) in elevation. Biek (1991) map-ped this as a fault scarp, although we interpret it as a fluvial scarp cut by Salt Creek when the stream occupied a channel north of its present position. Several short southwest-trending scarps on Holocene alluvial-fan deposits are present southeast of Nephi along the mountain front south of Salt Creek (depicted on map). These scarps mark the southern end of the Nephi segment.

NEPHI-LEVAN SEGMENT BOUNDARY

The Nephi and Levan segments are separated by a gap 15 kilometers (9.3 mi) long in Holocene and latest Pleistocene surface faulting, although older fault scarps on middle Pleistocene alluvial fans are present along the front of the San Pitch Mountains south of Nephi (Machette and others, 1992). Between Nephi and Levan, the segments are separated by Levan Ridge, a large alluvial fan built by Fourmile Creek that forms a drainage divide between the northern and southern parts of Juab Valley. The gravity map of Zoback (1983) shows a continuous gravity trough in Juab Valley through and beneath Levan Ridge, suggesting that the Wasatch fault zone continues through the gap but has been inactive for perhaps tens(?) of thousands of years (Machette, 1984; Machette and others, 1992).

SUMMARY

The Nephi segment of the Wasatch fault extends 33 kilometers (20 mi) from north of Payson to south of Nephi. Quaternary deposits along the segment range from middle Pleistocene to late Holocene in age. Coalesced alluvial fans and Lake Bonneville lake-bottom deposits dominate Juab Valley; alluvial fans cover much of eastern Juab Valley along the mountain front and thin toward the center of the valley, where sediment from the Bonneville lake cycle is exposed. The Bonneville lake cycle began about 28,000 ^{14}C yr B.P. and ended 12,000 ^{14}C yr B.P. (Oviatt and others, 1992), but the lake occupied Juab Valley for only about 1,000 years during the lake's highstand from about 15,500 to 14,500 ^{14}C yr B.P.). Other Quaternary deposits in the mapped area include stream alluvium, landslides, glacial till, eolian deposits, and colluvium.

Three surface-faulting events have occurred on the Nephi segment during the middle to late Holocene. The steepness of the scarp resulting from the most recent event and its lack of vegetation indicate that it may be the youngest surface-faulting event on the Wasatch fault. Radiocarbon dates from trenches indicate that it is younger than about 1,200 years, but the surficial expression leads researchers to suggest the most recent event may be as young as 300 to 500 years old (Hanson and others, 1981; Schwartz and others, 1983; Jackson, 1991; Machette and others, 1991). Based on trench data, the two previous events occurred less than about 4,000 (perhaps 3,000 to 3,500) years ago and between about 4,000 and 5,300 (perhaps 4,000 to 4,500) years ago (Hanson and others, 1981; Schwartz and others, 1983; Jackson, 1991). Little is known of the paleoseismic history during latest Pleistocene time, except that slip rates appear to have been much lower than in the Holocene (Machette, 1984).

ACKNOWLEDGMENTS

This map was completed through a cooperative project funded by the UGS and the USGS National Earthquake Hazards Reduction Program. We thank the many individuals who provided information, field assistance, and access to private property, including Jon King, Jeff Mendenhal, and Nancy S. Lackey. We also thank Gary E. Christenson and Stephen F. Personius for reviewing the map and text, Rebecca Hylland for drafting text figures, and Kent Brown for editing files and assistance in using the stereo plotter.

REFERENCES

Biek, R.F., 1991, Provisional geologic map of the Nephi quadrangle, Juab County, Utah: Utah Geological and Mineral Survey Map 137, scale 1:24,000.

Bissell, H.J., 1964, Wasatch fault of the south-central Wasatch Mountains, *in* Marsell, R.E., editor, Guidebook to the geology of Utah: Utah Geological Society Guidebook No. 18, p. 15-30.

Bucknam, R.C., 1978, Northwestern Utah seismotectonic studies, *in* Seiders, W., and Thomson, J., compilers, Summaries of technical reports, v. VII: Menlo Park, California, U.S. Geological Survey Office of Earthquake Studies, p. 64.

Bucknam, R.C., and Anderson, R.E., 1979, Estimation of fault-scarp ages from a scarp-height - slope-angle relationship: Geology, v. 7, p. 11-14.

Cluff, L.S., Brogan, G.E., and Glass, C.E., 1973, Wasatch fault, southern portion, earthquake fault evaluation, prepared for the Utah Geological and Mineral Survey: Oakland, California, Woodward-Lundgren and Associates, 79 p., scale 1:24,000.

Currey, D.R., 1982, Lake Bonneville - Selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p., scale 1:500,000.

—1990, Quaternary paleolakes in the evolution of semidesert basins, with special emphasis on Lake Bonneville and the Great Basin, U.S.A.: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 76, p. 189-214.

Currey, D.R., and Oviatt, C.G., 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago, *in* Kay, P.A., and Diaz, H.F., editors, Problems of and prospects for predicting Great Salt Lake levels - Proceedings of a NOAA Conference, March 26-28, 1985: Salt Lake City, Utah, University of Utah, Center for Public Affairs and Administration, p. 9-24.

Davis, F.D., 1983, Geologic map of the southern Wasatch Front, Utah: Utah Geological and Mineral Survey Map 55-A, scale 1:100,000.

Foutz, D.R., 1960, Geology of the Wash Canyon area, southern Wasatch Mountains, Utah: Brigham Young University Research Studies, Geology Series, v. 7, no. 2, 37 p.

Hanson, K.L., and Schwartz, D.P., 1982, Guidebook to Late Pleistocene and Holocene faulting along the Wasatch Front and vicinity - Little Cottonwood Canyon to Scipio, Utah: American Geophysical Union, Chapman Conference on Fault Behavior and the Earthquake Generation Process, Snowbird, Utah, 1982, 40 p.

Hanson, K.L., Swan, F.H., III, and Schwartz, D.P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah (North Creek site): Woodward-Clyde Consultants, sixth semi-annual technical report, U.S. Geological Survey contract report no. 14-08-0001-16827, 22 p.

Hintze, L.F., 1962, Structure of the southern Wasatch Mountains and vicinity, Utah: Brigham Young University Geology Studies, v. 9, pt. 1, p. 70-80.

Jackson, M.L., 1991, The number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Study 78, 23 p.

Keaton, J.R., Anderson, L.R., and Mathewson, C.C., 1991, Assessing debris-flow hazards on alluvial fans in Davis County, Utah: Utah Geological Survey Contract Report 91-11, 167 p.

Machette, M.N., 1984, Preliminary investigations of late Quaternary slip rates along the southern part of the Wasatch fault zone, central Utah, *in* Hays, W.W., and Gori, P.L., editors, Proceedings of conference XXVI, A workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 391-406.

—1988, American Fork Canyon - Holocene faulting, the Bonneville fan-delta complex, and evidence for the Keg Mountain oscillation, *in* Machette, M.N., editor, In the Footsteps of G.K. Gilbert -- Lake Bonneville and neotectonics of the eastern Basin and Range Province, Geological Society of America Guidebook to Field Trip 12: Utah Geological Survey Miscellaneous Publication 88-1, p. 89-95.

—1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Investigation Series Map I-2095, scale 1:50,000.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1992, Paleoseismology of the Wasatch fault zone - A summary of recent investigations, interpretations, and conclusions: U.S. Geological Survey Professional Paper 1500-A-J, p. A1-A59.

Machette, M.N., Personius, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., 1991, The Wasatch fault zone, Utah - Segmentation and history of Holocene earthquakes: Journal of Structural Geology, v. 13, no. 2, p. 137-149.

Madsen, D.B., and Currey, D.B., 1979, Late Quaternary glacial and vegetation changes, Little Cottonwood Canyon area, Wasatch Mountains, Utah: Quaternary Research, v. 12, no. 2, p. 245-270.

Miller, R.D., 1982, Surficial geologic map along the southern part of the Wasatch Front, Great Salt Lake and Utah Lake Valleys, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1477, 14 p., scale 1:100,000.

Mulvey, W.E., 1992, Debris-flood and debris-flow hazard from Lone Pine Canyon near Centerville, Davis County, Utah: Utah Geological Survey Report of Investigation 223, 40 p.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2199, 22 p., scale 1:50,000.

Oviatt, C.G., Currey, D.R., and Sack, Dorothy, 1992, Radiocarbon chronology of Lake Bonneville, eastern Great Basin, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 99, p. 225-241.

Personius, S.F., 1990, Surficial geologic map of the Brigham City segment and adjacent parts of the Weber and Collinston segments of the Wasatch fault zone, Box Elder and Weber Counties, Utah: U.S. Geological Survey Miscellaneous Field Investigations Series I-1979, scale 1:50,000.

Personius, S.F., and Scott, W.E., 1992, Surficial geologic map of the Salt Lake City segment and parts of adjacent segments of the Wasatch fault zone, Davis, Salt Lake, and Utah Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2106, scale 1:50,000.

Porter, S.C., Pierce, K.L., and Hamilton, T.D., 1983, Late Wisconsin mountain glaciation in the western United States, *in* Wright, H.E., editor, Late Quaternary environments of the United States, Volume 1 - The late Pleistocene, S.C. Porter, editor: Chapter 4, Minneapolis, University of Minnesota Press, p. 71-111.

Schwartz, D.P., Hanson, K.L., and Swan, F.H., III, 1983, Paleoseismic investigations along the Wasatch fault zone--An update, *in* Gurgel, K.D., editor, Geologic excursions in neotectonic and engineering geology in Utah, guidebook--Part IV: Utah Geological and Mineral Survey Special Study 62, p. 45-48.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes - Examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, no. B7, p. 5681-5698.

Swenson, J.L., Jr., Archer, W.M., Donaldson, K.M., Shiozaki, J.J., Broderick, J.H., and Woodward, Lowell, 1972, Soil survey of Utah County, Utah - central part: U.S. Department of Agriculture Soil Conservation Service, 161 p.

Trickler, D.L., and Hall, D.T., 1984, Soil survey of Fairfield-Nephi area, Utah, parts of Juab, Sanpete, and Utah Counties: U.S. Department of Agriculture Soil Conservation Service, 361 p.

Wheeler, R.L., and Krystinik, K.B., 1988, Segmentation of the Wasatch fault zone, Utah - Summaries, analyses, and interpretations of geological and geophysical data: U.S. Geological Survey Bulletin 1877, 47 p.

Witkind, I.J., and Weiss, M.P., 1991, Geologic map of the Nephi 30′ x 60′ quadrangle, Carbon, Emery, Juab, Sanpete, Utah, and Wasatch Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1937, scale 1:100,000.

Zoback, M.L., 1983, Structure and Cenozoic tectonism along the Wasatch fault zone, Utah: Geological Society of America Memoir 157, p. 3-27.

APPENDIX

DESCRIPTION OF MAP UNITS

LACUSTRINE DEPOSITS

DEPOSITS YOUNGER THAN THE BONNEVILLE LAKE CYCLE (HOLOCENE TO UPPERMOST PLEISTOCENE)

ly	**Young lacustrine and marsh deposits** - Clay, silt, and sand deposited in Mona Reservoir and marshes associated with low-water levels in the reservoir. Predominately reworked material from units lbs and lbm (Bonneville-age clays, silts, and sands), locally organic rich. Mapped at and below elevation of reservoir. Thickness unknown, probably <2 meters (5 ft).
laly	**Lacustrine, marsh, and alluvial deposits, undivided** - Undivided clay, silt, and sand in areas of mixed lacustrine, marsh, and alluvial environments. Mapped in the center of Juab Valley south of Mona Reservoir.

DEPOSITS OF THE PROVO (REGRESSIVE) PHASE OF THE BONNEVILLE LAKE CYCLE (UPPERMOST PLEISTOCENE)

lpg	**Lacustrine gravel** - Clast-supported, openwork pebble and cobble gravel; where poorly sorted it has a matrix of sand and minor silt. Commonly interbedded with or laterally gradational to sand facies; well sorted within beds; clasts usually subround to round, but some shoreline deposits marked by poorly sorted, calcium carbonate-cemented gravel. Thin to thick bedded. Typically forms wave-built bench at the highest Provo shoreline and several less well-developed shorelines at lower elevations. Gravel is commonly well cemented with calcium carbonate. Exposed thickness <10 meters (33 ft).
lpm	**Lacustrine silt and clay** - Predominately calcareous silt (commonly referred to as marl) with minor clay and fine sand; apparent bedding is thick or massive but commonly rhythmic on close inspection. Blocks of silt and clay lack conchoidal fracture, which is characteristic of unit lbm. Deposited in quiet-water environments, either in moderately deep-water basins, sheltered bays between headlands, or in lagoons behind barrier bars. Commonly overlies fine-grained clay and silt (unit lbm), implying deposition in decreasing water depth of a regressive lake; however, a lack of sharp disconformity between units lpm and lbm suggests no aerial exposure between the two lake phases. Shorelines not developed on this unit. Exposed thickness <5 meters (16 ft).

DEPOSITS OF THE BONNEVILLE (TRANSGRESSIVE) PHASE OF THE BONNEVILLE LAKE CYCLE (UPPERMOST PLEISTOCENE)

lbd	**Deltaic deposits** - Clast-supported pebble and cobble gravel in a matrix of sand and silt interbedded with thin pebbly sand; moderately to well sorted within beds; clasts subround to round; weak calcium carbonate cementation common along bedding. Some foreset beds have rhythmic, graded bedding suggesting annual varves (Machette, 1988). Mapped as an eroded remnant of a fan-delta complex at the mouth of Santaquin Canyon. Deposit has been reworked by streams during and after Lake Bonneville's fall to the Provo level. Exposed thickness 10 meters (33 ft).
lbg	**Lacustrine gravei** - Clast-supported pebble and cobble gravel with a matrix of sand and silt interbedded with lenses of pebbly sand; well sorted within beds; thin to thick bedded. Clasts usually subround to round; carbonate cemented, especially in spits in the southern part of Utah Valley. Forms constructional landforms such as spits, bars, and beaches. Forms wave-built bench (5-20 meters [16-60 ft] thick]) at the Bonneville shoreline and shorelines built during the transgression to the Bonneville shoreline.
lbs	**Lacustrine sand** - Mostly sand with minor pebbly gravel; well sorted within beds. Present in thin (0.6-3 meters [2-10 ft]), poorly developed shoreline deposits between 1,490 to 1,500 meters (4,900-4,930 ft). Developed as Lake Bonneville reworked distal alluvial-fan sediments.
lbm	**Lacustrine silt and clay** - Mostly silt with minor amounts of clay and fine sand. Forms thin apron (0.6-3 meters [2-10 ft]) deposited in offshore and nearshore quiet-water conditions. Commonly overlies sandy to gravelly deposits, implying deposition in increasingly deeper or quieter water of a transgressive lake.

ALLUVIAL DEPOSITS

These deposits consist of variable amounts of gravel, sand, silt, and minor clay deposited by perennial and intermittent streams and debris flows. Map units are separated into three ages of stream (floodplain and terrace) alluvium and three ages of alluvial-fan deposits. The relative ages and correlation of stream and fan deposits are based on the following criteria: (1) relation to lacustrine deposits and shoreline features of known age, (2) degree of soil development, (3) degree of morphologic expression, such as degree of preservation of initial surface morphology or degree of dissection, and (4) position relative to the modern stream level.

DEPOSITS OF STREAM ALLUVIUM

Stream deposits are mapped on floodplains and as thin strath terrace deposits along perennial and intermittent streams; gravel in these deposits generally is more rounded and better sorted than in equivalent-age alluvial-fan deposits. The sediment is commonly well sorted and usually has a clast-supported framework. Stream deposits are differentiated by their positions relative to levels of the Bonneville lake cycle and to modern stream levels.

al1 **Stream alluvium unit 1 (upper Holocene)** - Cobble and pebble gravel, gravelly sand, and silty sand and minor clay; moderately well-sorted clasts are subangular to round; thin to medium bedded. Deposited by perennial streams such as Santaquin Creek, North Creek, Willow Creek, and Salt Creek. Modern floodplains characterized by bar and swale topography and active stream channels. Terraces associated with modern floodplain are less than 2 meters (6 ft) above stream level and grade downslope into upper Holocene alluvial-fan deposits (unit af1). May include debris-flood deposits and colluvial deposits overlying alluvium along steep stream embankments.

al2 **Stream alluvium unit 2 (middle Holocene to uppermost Pleistocene)** - Cobble and pebble gravel, gravelly sand, and silty sand and minor clay; moderately well-sorted clasts are subangular to round; thin to medium bedded. Deposited by perennial streams in Pole Canyon, Willow Canyon, Quaking Asp Canyon, and along Salt Creek. Contains undifferentiated glacial outwash in Pole Canyon. Forms terraces (2-10 meters [6 to 33 ft]) above modern stream level, except in Pole Canyon where terraces are 30 meters (100 ft) high. Terraces grade downstream into alluvial-fan deposits (unit af2).

alp **Stream alluvium related to the Provo phase of the Bonneville lake cycle (uppermost Pleistocene)** - Gravelly sand, silty sand, and minor clay. Moderately well-sorted clasts are subangular to rounded; thin to medium bedded. Deposited at the mouth of Santaquin Canyon by streams graded to Provo level of Lake Bonneviile.

ALLUVIAL-FAN DEPOSITS

Alluvial-fan deposits are present on the piedmont (alluvial apron at the mountain front), typically at the mouths of ephemeral streams. The sediment is commonly poorly sorted and has a matrix-supported framework. Fan deposits are thickest along the base of the mountain front, and on the downthrown sides of the Wasatch fault zone.

af1 **Fan alluvium, unit 1 (upper Holocene)** - Clast-supported cobble and pebble gravel, bouldery near bedrock outcrops, in a matrix of sand, silt, and minor clay. Clasts are angular to subrounded, with rare rounded clasts from gravel (unit lbg) of the Bonneville lake cycle; medium to thick bedded to massive. Deposited by intermittent streams, debris floods, and debris flows graded to the modern stream level. Forms small, discrete fans with bar and swale topography on older alluvial fans (unit af2). May contain deposits of units cd1 and af2 too small to map separately but usually grades downslope into unit af2. No shorelines of the Lake Bonneville cycle are present on surfaces formed by this unit. Typical soil profile is a weak azonal (A horizon) to weak zonal with A and weakly developed calcic (stage I+) or cambic B horizons. Exposed thickness <5 meters (16 ft)

af2 **Fan alluvium, unit 2 (middle Holocene to uppermost Pleistocene)** - Clast-supported cobble and pebble gravel, bouldery near bedrock outcrops, in a matrix of sand, silt, and minor clay. Clasts are angular to subrounded, with rare rounded clasts from gravel (unit lbg) of the Bonneville lake cycle; medium to thick bedded to massive. Deposited by intermittent streams, debris floods, and debris flows graded to and just above the modern stream level. Forms large fans that bury lacustrine shoreline sediments (lbg, lbs). Also preserved downslope from distal parts of younger alluvial fans (unit af1). May include deposits of units cd1, cd2, and af1. Exposed thickness 2-5 meters (5-16 ft).

afb **Fan alluvium related to Bonneville phase of the Bonneville lake cycle (uppermost Pleistocene)** - Pebble and cobble gravel, locally bouldery in a matrix of sand, silt, and minor clay; poorly sorted; clasts angular to subangular; medium to thick bedded or massive. Deposited as alluvial fans by streams graded to a transgressing Lake Bonneville and its highest shoreline. Present near the mountain front east of Santaquin Canyon. Commonly covered by younger alluvium (units af1 and af2) and Holocene colluvium. Exposed thickness <5 meters (16 ft).

afo **Older fan alluvium, undivided (upper to middle Pleistocene; pre-Bonneville lake cycle)** - Undifferentiated fan alluvium that predates the Bonneville lake cycle. Clast-supported cobble and pebble gravel, in a matrix of sand, silt, and minor clay. Clasts are angular to subrounded. Deposits form uplifted remnants of fan surfaces at the mouth of Mendenhall Creek, Gardner Creek, Red Canyon, and Quaking Asp Canyon. Soils have A and moderately to strongly developed calcic (stage III to IV) or argillic B horizons. Thickness is unknown.

GLACIAL DEPOSITS

Glacial deposits are mapped only in Pole Canyon above 2,255 meters (7,400 ft) elevation. Till from Pole Canyon Basin reaches the incised part of Pole Canyon and forms several steep (35°-38°), high-fronted (30 meters [100 ft]) terminal moraines, and lateral moraines extending to higher elevations in Pole Canyon. Glacial deposits contain coarse grained, mainly boulder to cobble-size clasts of Permian and Pennsylvanian-age limestones (Pz) from the Oquirrh Group. The deposits are considered to be equivalent to the Bells Canyon advance in Little Cottonwood Canyon, and the Pinedale glaciation of the Rocky Mountains on the basis of geomorphic expression (steep slopes, sharp-crested moraines).

DEPOSITS OF TILL, BELLS CANYON EQUIVALENT (UPPERMOST PLEISTOCENE, PINEDALE EQUIVALENT)

gbct **Till** - Sandy cobble to boulder gravel in a matrix of silt and minor clay. Clasts are matrix supported, angular to subangular; crudely bedded or massive. Till forms well-developed terminal and lateral moraines. Thickness variable, may be as much as 32-35 meters (100-120 ft) thick.

EOLIAN DEPOSITS

es **Eolian sand and silt (Holocene to uppermost Pleistocene)** - Silt and minor fine-grained sand; calcareous; loose to moderately firm where cemented by secondary calcium carbonate. Silt is primarily latest Pleistocene to early Holocene loess, and is derived from fine-grained lacustrine sediment of Utah Valley, Juab Valley, and adjacent basins. Commonly forms a mantle 0.3-3 meters (1-10 ft) thick atop Bonneville-level deltaic gravels southeast of Santaquin. Has well-developed soil consisting of A, Bw, Bt, Bk, K, and Cox horizons.

COLLUVIAL DEPOSITS

These deposits consist of poorly sorted to unsorted, gravity-induced deposits; composition of clasts reflects the materials from which they were derived. Two ages of debris-flow and debris-flood deposits (units cd1 and cd2) are differentiated by their surface morphology and relations to present stream level and to alluvial deposits of similar age. Age of other colluvial deposits is uncertain.

cd1 **Debris flows, unit 1 (upper Holocene)** - Clast- and matrix-supported cobble-boulder gravel; matrix is composed of sand, silt, and clay; usually unsorted and unstratified except for interbedded fluvial sand and gravel layers. Surfaces commonly covered with angular rubble as well as fresh-appearing levees and channels. Deposited on surface of Holocene alluvial fans (units af1 and af2) and at the mouths of perennial and ephemeral drainages. Widespread flows were deposited during 1983.

cd2 **Debris flows, unit 2 (middle Holocene to uppermost Pleistocene)** - Clast- and matrix-supported cobble-boulder gravel; matrix is sand, silt, and clay; usually unsorted and unstratified except for interbedded fluvial sand and gravel layers. Deposits are heavily vegetated, but levees and bar-and-swale topography are still visible. Mapped along significant drainages in steep mountain valleys.

chs **Hillslope colluvium (Holocene to uppermost Pleistocene)** - Boulder, cobble, and pebble gravel, gravelly sand, silty sand, and sandy silt; usually unsorted, unstratified; clasts usually angular to subangular. Includes debris-flow, talus, and landslide deposits too small to show separately. Deposited by surface wash, creep, and other mass-wasting processes on moderate to steep mountain slopes and along stream valleys in steep-sided canyons.

crf **Rock fall and talus deposits (Holocene to uppermost Pleistocene)** - Boulder, cobble, and pebble gravel, commonly clast supported, with a matrix of sand, silt, and minor clay; usually unsorted, unstratified; clasts angular to subangular. Includes debris-flow and landslide deposits too small to show separately. Clasts deposited by gravity processes on steep mountain slopes and along stream cuts.

clsy **Younger landslide deposits (Holocene to uppermost Pleistocene)** - Unsorted, unstratified deposits that are mainly derived from the Paleozoic (unit Pz) Manning Canyon Shale and the Cretaceous-Tertiary North Horn Formation (unit TMz). Large landslides are present on York Hill, south of Santaquin, at the mouth of Mendenhall Creek, and at the head of Pole Canyon. Thickness variable.

clso **Older landslide deposits (upper Pleistocene to upper Tertiary?)** - Unsorted, unstratified massive earth slides and flows formed mainly from Paleozoic (unit Pz) Manning Canyon Shale. Large landslides are present along the length of the Nephi segment; the largest extends numerous kilometers into Juab Valley at Birch Creek. Quaternary movement on the Wasatch fault zone has displaced landslide deposits, but fault scarps are difficult to trace through the landslides and are difficult to distinguish from landslide scarps. The York Hill and Birch Creek landslides extend below the Bonneville shoreline (1,567 meters [5,140 ft]) and have Bonneville-level shorelines etched across them, indicating an age of more than 16,800 years. Maximum thickness undetermined; exposures >25 meters (82 ft) thick are common.

ca **Colluvium and alluvium, undivided (Holocene to middle Pleistocene)** - Undifferentiated stream alluvium, hillslope colluvium, and landslide deposits. Thickness variable.

ARTIFICIAL DEPOSITS

f **Artificial fill and associated disturbed ground (historical)** - Consists primarily of locally derived surficial debris disturbed during construction of reservoirs, flood-control structures, factories, highways, and gravel pits. Although present throughout the map area, only the largest of these areas are shown.

BEDROCK

Tp **Tertiary volcanic and sedimentary rocks (Paleogene)** - Consists of undivided sedimentary, volcanic, and volcaniclastic rocks.

TMz **Tertiary-Mesozoic sedimentary rocks (Paleogene and Upper Cretaceous)** - Consists of mudstone, claystone, sandstone, conglomerate, and limestone of the North Horn Formation.

Mz **Mesozoic sedimentary rocks (Cretaceous to Triassic)** - Consists of shale, siltstone, sandstone, and limestone.

Pz **Paleozoic sedimentary rocks (Permian to Cambrian)** - Consists of shale, siltstone, sandstone, conglomerate, limestone, and dolomite.

p€ **Precambrian metamorphic rocks (Proterozoic and Archean)** - Consists of low- to high-grade metamorphic rocks.