

INDEX MAP SHOWING SERIES OF FAULT

MAPS ALONG WASATCH FAULT ZONE

WITH SUPPLEMENTARY CONTOURS AT 5 AND 10 FOOT INTERVALS

NATIONAL GEODETIC VERTICAL DATUM OF 1929

CORRELATION OF MAP UNITS [This map is one of a series of surficial geologic maps of the Wasatch fault zone, Utah. Colored map units in the correlation appear on this map; uncolored map units are included to aid correlation with other maps in this series.] deposits deposits Alluvial deposits sand and silty sand; poorly sorted; clasts subangular to

round. Thin to thick, parallel bedding and crossbedding;

locally massive. Forms small fans and fan remnants topo-

graphically above or cut by the Bonneville shoreline.

Correlative deposits probably underlie much of the map

area and are buried by younger deposits downslope from

the Bonneville shoreline. Typical soil profile, A-Bt(moderate-

and cobble gravel, locally bouldery, in a matrix of sand and

silty sand; poorly sorted; clasts subangular to round. Thin to

thick, parallel bedding and crossbedding; locally massively

bedded. Forms high fan remnants on ridge tops near front of

Wasatch Range. Some remnants may be deposits of old till

that lack morainal morphology. Typical soil profile,

dates the Bonneville lake cycle; mapped near the Salt Lake

salient, where old fan deposits have not been differentiated.

utwash of Bells Canyon age (upper Pleistocene)—Clast-

supported cobble and pebble gravel, locally bouldery, in a

minor matrix of sand and silt; poorly to moderately sorted;

clasts subangular to round. Thin to thick, parallel bedding

and crossbedding. Deposits grade into alluvial gravel graded

to Provo shoreline (alp) below Big and Little Cottonwood

matrix; very poorly sorted; clasts subangular to subround;

massive. Forms large moraines at mouths of Little Cotton-

wood and Bells Canyons and smaller moraines in cirque

valleys in Wasatch Mountains. Exposed thickness 1-10 m

supported cobble and pebble gravel, locally bouldery, in

minor matrix of sand and silt; poorly to moderately sorted;

clasts subangular to round. Thin to thick, parallel bedding

and crossbedding. Exposed in large gravel pit north of

mouth of Big Cottonwood Canyon and along Dry Creek

downstream from Bells Canyon. Soil profile: A-Bt(moderate-

boulder, cobble, and pebble gravel in sandy silt to silty sand

matrix; very poorly sorted; clasts subangular to subround;

massive. Surface of deposit contains abundant grus derived

from weathering of quartz monzonite (Ti) boulders. Exposed

near mouths of Little Cottonwood and Bells Canyons. Soil

profile: A-Bt(moderate-strong)-Cox-Cn. Exposed thickness

coarse sand and minor silty sand; moderately to well sorted.

Thin to medium bedding; usually crossbedded, locally

longitudinal dunes; deposit derived from reworked sandy

deposits of the Bonneville lake cycle. Thickness 1-3 m

Debris-flow deposits 1 (upper Holocene)—Clast-supported

pebble, cobble, and boulder gravel in a matrix of sand, silt,

and clay; boulders are as much as several meters in diameter

massive. Deposited by rapidly moving flows of rock debris,

sand, mud, and water. Forms fan-shaped to lobate deposits

at mouths of several canyons south of Big Cottonwood

Canyon. Typical soil profiles range from A-Cn to A-Bw-

Pleistocene)—Clast-supported pebble, cobble, and boulder

gravel in a matrix of sand, silt, and clay; boulders are as much

as several meters in diameter and are angular to subround.

Very poorly sorted; massive to crude parallel bedding. Some

deposits are hummocky. Deposited by rapidly moving flows

lobate deposits at mouths of several canyons south of Bells

Canyon. Typical soils range from A-Bw-Cox-Cn to

cobble, and boulder gravel, usually clast supported, in a

but unit contains some recycled lacustrine gravel of the

matrix of sand and silt; clasts usually angular to subangular,

Bonneville lake cycle. Very poorly sorted; massive to crude

parallel bedding. Forms small fans, cones, and debris aprons

at the mouths of small canyons and at the bases of bedrock

slopes. Deposited by mass-wasting processes, sheetwash,

Sand, silt, clay, and minor pebble gravel of the Bonneville

lake cycle and younger lacustrine, marsh, and alluvial

deposits redeposited by lateral spreading as a result of

liquefaction, probably during major earthquakes. Bedding

deposits at north end of map area were first recognized on

aerial photographs by Van Horn (1982). The northern

dot contact between the two is based on changes in

spread appears to truncate the southern spread; the dash-

vegetation and preservation of hummocky topography.

cls Landslide deposits (Holocene to middle Pleistocene)—Grain

Thickness > 1 m

Thickness 1 to >10 m

Thickness 1 to >10 m

FILL DEPOSITS

Both deposits incompletely truncate the Gilbert shoreline

and a topographically lower undesignated shoreline, indi-

size and texture reflects character of deposits in source area;

usually unsorted, unstratified. Deposited as slides and

slump-earthflows on relatively steep slopes in mountains.

Pleistocene)—Gravel, sand, silt, and clay; grain size and

texture reflect character of deposits directly upslope.

Generally poorly sorted, with parallel bedding and cross-

bedding; commonly massive. Deposited by intermittent

streams and mass-wasting processes; forms small fans and

debris aprons at base of slopes in unconsolidated deposits.

Also mapped in some grabens along Wasatch fault zone.

Manmade fill (historic)—Most consist of locally derived surficial

Precambrian metamorphic rocks (Proterozoic and Archean)-

deposits of variable grain size; used as engineered fills for

highways, railways, and buildings; also includes assorted

materials in landfills and tailing piles and ponds. Thickness

Colluvium and alluvium, undivided (Holocene to middle

usually contorted or the deposit is unstratified. Two large

and small debris flows. Thickness 1 to >10 m

Lateral-spread deposits (Holocene to upper Pleistocene)-

of rock debris, sand, mud, and water. Forms fan-shaped to

A-Bt(weak)-Cox-Cn. Thickness 1 to >5 m

Hillslope colluvium (Holocene to upper Pleistocene)—Pebble,

Debris-flow deposits 2 (middle Holocene to uppermost

and are angular to subround. Very poorly sorted; bedding

massive. Forms sheets of sand and low parabolic and

strong)-Cox-Cn. Exposed thickness 1–15 m

EOLIAN DEPOSITS

(windblown silt) cover most early Holocene and older surficial deposits (Shroba, 1984).

oess is weathered and mixed with upper parts of underlying sediments and soils, and

es Eolian sand (Holocene and upper Pleistocene)—Fine to

COLLUVIAL DEPOSITS

from sources directly up slope. Debris-flow deposits (cd1, cd2) differentiated by degree

[Consist of poorly sorted to unsorted, gravity-generated deposits, generally derived

of soil development, surface morphology, and relations to present stream level and

Cox-Cn. Thickness 1 to >5 m

[Consist of eolian sand deposits. However, thin (<1 m), discontinuous deposits of loes

is not mapped as separate unit]

alluvial deposits of similar age]

Till of Dry Creek age (middle Pleistocene)—Matrix-supported

Outwash of Dry Creek age (middle Pleistocene)—Clast-

A-Bt(strong)-Cox-Cn. Thickness 1 to >10 m

[Consist of variable amounts of boulder, cobble, and pebble gravel, sand, and silt

deposited by glaciers (till) or glacial meltwater streams (outwash). The nomenclature

and dating of glacial deposits used here follows the work of McCoy (1977), Madsen

and Currey (1979), and Scott (1988a). Deposits of Bells Canyon age are broadly

equivalent in age to deposits of Pinedale age mapped widely in the Rocky Mountains

most deposits at the mountain front predate the initial occupation of the Bonneville

shoreline by a few thousand years. Deposits of Dry Creek age have weathering

characteristics similar to those of deposits of Bull Lake age in the Rocky Mountains that

Canyons. Exposed thickness 1-40 m

gbct Till of Bells Canyon age (upper Pleistocene)—Matrix-supported

Exposed thickness >2 m

are thought to be about 150 ka (Pierce and others, 1976)]

Older fan alluvium, undivided (middle Pleistocene)—Pre-

Fan alluvium 5 (middle Pleistocene)—Clast-supported pebble

strong)-Cox-Cn. Thickness 1 to >10 m

Tertiary sedimentary and volcanic rocks (Neogene)—Consists of undivided sedimentary, volcanic, and volcaniclastic rocks in the Salt Lake salient and Traverse Mountains Tertiary sedimentary and volcanic rocks (Paleogene)-Consists of undivided sedimentary, volcanic, and volcaniclastic rocks in the Salt Lake salient and Traverse Mountains Tertiary intrusive igneous rocks (Oligocene)—Consists primarily of quartz monzonite of the Little Cottonwood stock of Oligocene age (Crittenden and others, 1973); some minor diorite is present near the mouth of Bells Canyon (Crittenden, 1965a) Mesozoic sedimentary rocks (Cretaceous to Triassic)-Consists of shale, siltstone, sandstone, and limestone Paleozoic sedimentary rocks (Permian to Cambrian)-Consists of shale, siltstone, sandstone, conglomerate limestone, and dolomite

> Consists of low- to high-grade metamorphic rocks Contact—Dashed where approximately located; dash-dot lines are contacts between geomorphic features in a map unit ?- Normal fault—Bar and solid ball on downdropped side along / 12(9) Wasatch and other active fault zones; bar and hollow ball along other faults in bedrock. Dashed where approximately located, dotted where concealed, 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: DC-1-4, Dry Creek trenches; LC1-4, Little Cottonwood trenches

Thrust fault—Sawteeth on overriding plate or block (mapped in bedrock only); dashed where approximately located, dotted where concealed Major shorelines related to levels of the Bonneville lake cycle—Coincide with geologic contacts in some places Bonneville shoreline ——b—— Other shorelines of the transgressive phase

——p—— Other shorelines of the regressive phase --x-- Undesignated shorelines of the Bonneville lake cycle Topographic escarpment—Escarpments along stream channels, terraces, and deltas; formed primarily by fluvial processes;

contacts in some places

coincide with geologic contacts in some places; tear drops Landslide escarpment—Major headscarps and fissures in landslides and lateral-spread deposits; coincide with geologic faulting events along much of the Wasatch fault zone is 1.5–2.5 m (Swan and the "bedrock spurs" found in several places along the Wasatch fault zone. In Paleostream channels—Preserved as abandoned channels others, 1980; Schwartz and Coppersmith, 1984; Machette and others, 1987, almost all cases these spurs are areas of reduced structural relief that are now in press); thus Gilbert's estimate of three faulting events should be viewed as a recognized as probable boundaries between fault segments (Schwartz and → Tilted geomorphic surface—Arrow points in general direction minimum number. The possibility that part of the scarp was eroded or buried Coppersmith, 1984; Machette and others, 1987, 1989, in press; Wheeler

INTRODUCTION This map shows the surficial deposits and the faults that offset them

along the Salt Lake City segment and adjacent parts of the Weber and Provo segments of the Wasatch fault zone in north-central Utah. The map area includes the central and eastern part of the Salt Lake Valley, site of metropolitan Salt Lake City and its southern suburbs. Although a major surface-faulting earthquake has not occurred on the Wasatch fault zone since the state was settled in 1847 (Arabasz and others, 1979), the geologic record contains abundant evidence of large earthquakes during Holocene and late Pleistocene time (Gilbert, 1890, 1928; Cluff and others, 1975; Swan and others, 1980; Schwartz and Coppersmith, 1984; Machette and others, 1987, 1989, in press). The size, age, and distribution of fault scarps produced by these prehistoric earthquakes can be used to determine the most likely sites for future earthquakes, and are therefore the principal focus of this map. Most long, active fault zones are thought to be composed of several seismically independent pieces or segments. Initial work on segmentation of the Wasatch fault zone, summarized in Schwartz and Coppersmith (1984), identified six discrete fault segments, but recent work by the U.S. Geological Survey has identified ten to twelve segments (Machette and others, 1987, 1989, in press). The concept of fault segmentation is critically important to paleoseismic analysis of active fault zones because during a major earthquake, surface faulting usually is restricted to a single segment of a fault zone. As used here and in other studies (Schwartz and Coppersmith, 1984; Bruhn and others, 1987; Machette and others, 1987, 1989, in press), the Salt Lake City segment consists of the Warm Springs fault, the East Bench fault, and that part of the main Wasatch fault zone from Mount Olympus south to Corner Canyon (labeled "CS" on fig. 1). Another active fault in the region, the

West Valley fault zone, appears to be seismically independent of the Wasatch

area, but the recent map by Scott and Shroba (1985) was the primary source

used to compile this map (see Sources of Geologic Data diagram). Their map

units were modified for consistency with the units of Personius (1990) to

Numerous published geologic and soils maps exist for most of the map

fault zone, and is discussed separately.

and Machette (1982).

insure continuity with the other maps in this series (see Map Area diagram). Other sources used to compile the surficial geology of this map in areas not covered by Scott and Shroba (1985) include Miller (1980, 1982) and Van Horn (1982). The trace of the West Valley fault zone and a discussion of these structures were taken from Keaton and others (1987) and J.R. Keaton (written commun., 1987, 1988, 1989). Other map data were compiled from disturbance of the upper part of the trenches has removed any colluvial Course (Machette and others, 1987, in press), from geologic mapping on the north side of the Salt Lake salient (Nelson and Personius, 1990, in press) and in the Traverse Mountains (Machette, 1989, in press), and from preliminary geologic data for the South Fork Dry Creek area (Lund and Schwartz, 1987; Schwartz and Lund, 1988). The geology in the Wasatch Range was compiled and generalized from maps by Crittenden (1965a,b), Van Horn (1981), Davis (1983a,b), Bryant (1984), and Van Horn and Crittenden (1987). The senior author mapped parts of the Salt Lake salient and the area near the mouth of Little Cottonwood Canyon on 1:6,000- and 1:12,000scale low-sun-angle aerial photographs taken for the Utah Geological and Mineral Survey in 1970; these photographs were particularly helpful in dentifying fault scarps in surficial deposits. In addition, some areas along the Jordan River in the southwestern part of the map area and on the Salt Lake salient were mapped on aerial photographs taken for the U.S. Soil Conservation Service in 1952–1953 at scales of 1:10,000 and 1:62,500. Much of the scarp-measurement data shown on the geologic map was derived from measurements made in the field with an Abney level and stadia rod; most are from Scott and Shroba (1985). A few measurements along the Warm Springs fault and the Weber segment were determined from profiles measured on aerial photographs with a computer-assisted stereoplotter (A.R. Nelson, written commun., 1988). Terminology used to describe faultscarp parameters follows that established by Bucknam and Anderson (1979)

The following discussion begins with a brief description of the Quaternary deposits in the map area, continues with a description of the distribution, age, and amount of displacement of late Quaternary faulting, and concludes with a description of segmentation of the Wasatch fault zone in the Salt Lake City area. Together, this information can be used to describe the paleoseismic history of the Salt Lake City segment and to help identify key sites for further detailed studies.

QUATERNARY DEPOSITS AND DEPOSITIONAL HISTORY This discussion of late Quaternary depositional history of the Wasatch Front is summarized from McCoy (1977, 1987), Madsen and Currey (1979), Currey (1980), Currey and others (1983, 1984), Scott and others (1983), Currey and Oviatt (1985), Scott and Shroba (1985), and Scott (1988a,b). Most surficial deposits along the north-central part of the Wasatch fault zone were deposited during the Holocene (< 10 ka, or thousands of years ago) and the last cycle of Lake Bonneville (known as the Bonneville lake cycle) between 30 and 10 ka. Lake Bonneville began rising from a low level about 30 ka and rose slowly, with several fluctuations and pauses, to the Bonneville shoreline (1,573–1,585 m (5,160–5,200 ft) above sea level in the map area) about 16 ka. After 1,000–2,000 years at or near this level, the lake dropped about 110 m (360 ft) to an altitude of about 1,465 m (4,800 ft) as a consequence of catastrophic downcutting of its outlet in southeastern Idaho. The resulting Bonneville Flood deposited debris northward into southern Idaho (Gilbert, 1890; Malde, 1968; Jarrett and Malde, 1987). In the map area, this rapid decline in lake level was accompanied and followed by rapid erosion of lacustrine transgressive-phase sand and gravel (lbg) and other glacial-outwash and alluvial-fan deposits; much of this debris was redeposited as deltas (Ipd, alp) at the Provo shoreline near the mouths of major canyons. Between 14 and 13 ka, the lake level again dropped quickly, this time in response to changing climatic conditions, further downcutting of its outlet, and isostatic rebound of shoreline areas. Lake Bonneville reached a level near that of modern Great Salt Lake (1,280 m; 4,200 ft) about 11 ka and rose briefly to the Gilbert shoreline (1,295 m; 4,250 ft) 10-10.5 ka. Since then, the ake level has remained within 10 m of the level of present Great Salt Lake. Glaciers in Little Cottonwood and Bells Canyons advanced beyond the Wasatch Range and into the eastern Salt Lake Valley 26–18 ka, while Lake Bonneville stood at a low to intermediate level during the transgressive phase that eventually reached the Bonneville shoreline. Till (gbct) deposited by these glaciers forms large end moraines that extend nearly 1 km into the valley. Meltwater from these glaciers and from glaciers in Big Cottonwood Canyon deposited gravelly outwash fans (gbco) along the range front and deltaic deposits in Lake Bonneville. Other streams, emanating from valleys in the Wasatch Range whose headwaters were at altitudes too low to support more than small glaciers, also deposited gravelly fans and deltas graded to the lake. The rising lake culminated at the Bonneville shoreline about 16 ka, several thousand years after the glaciers in Little Cottonwood and Bells Canvons had retreated some distance upvalley from their end moraines. The outwash and alluvial-fan deposits along the mountain front also were inundated by the rising lake and, except for small areas near the canyon mouths that stood above the level of the lake, are covered by a veneer of lake sediment (lbg and lbm).

As the level of Lake Bonneville receded from the Provo shoreline during the regressive phase, alluvial-fan deposits (af2) and debris-flow deposits (cd2) were emplaced at canyon mouths along the mountain front. Rates of alluvial-fan deposition appear to have declined later in the Holocene, because deposits of late Holocene age (af1, cd1) are restricted to small cating both lateral spreads formed less than 10.5 ka. deposits covering parts of the surfaces of much larger alluvial fans (af2). Urbanization probably has destroyed surface evidence of Debris flows continue to be a common phenomenon in many canyons along Pre-Bonneville-lake-cycle deposits are limited to small remnants of alluvial-fan (af4, af5) and glacial-drift deposits (gdco, gdct), and to a few

exposures of deposits of the Little Valley lake cycle that are too small to show at the scale of this map. Till of the Dry Creek advance (gdct) of Madsen and Currey (1979) is exposed at the mouths of Little Cottonwood and Bells Canyons. Although undated, the till is weathered to a degree that suggests it may be about 150 ka, and thus Dry Creek moraines roughly correlate with Bull Lake-aged moraines (Pierce and others, 1976) in the Rocky Mountains (Scott and Shroba, 1985). Outwash of probably the same age is exposed in gravel pits near the mouth of Big Cottonwood Canyon and along Dry Creek unstream from Bells Canyon, below the type Dimple Dell Soil of Morrison (1965). A uranium-trend age of 250±90 ka was obtained on a deposit of unit af4 near South Fork Dry Creek (J.N. Rosholt, written commun., 1984, in Scott and Shroba, 1985); the lithologic and soil-development characteristics of this deposit suggest that it may be outwash of Dry Creek age. Thus, glacial deposits of Dry Creek age are probably at least 150 ka, and some may be Deposits of the Little Valley lake cycle (Scott and others, 1983; McCoy,

1987; Scott, 1988b.c) are exposed in a few places in the map area, but not extensively enough to show at the scale of this map. Small exposures have been located in an abandoned gravel pit near the University of Utah, at several places along the south side of Parleys Creek near Interstate Highway 215, below outwash of Dry Creek age in a gravel pit north of the mouth of Big Cottonwood Canyon, and in gravel pits on the Salt Lake salient and Point of the Mountain in the southern part of the map area (Scott, 1981; Scott and others, 1983; Scott, 1988b,c). On the basis of stratigraphic, soil-development, and amino-acid data, the Little Valley lake cycle appears to correlate with the later part of marine oxygen-isotope stage 6, which ended about 130 ka (Scott and others, 1983; Scott, 1988b).

DESCRIPTIONS OF QUATERNARY FAULTS

The relatively well dated sequence of Quaternary deposits in the map area greatly aids in the interpretation of Quaternary faulting along the Wasatch fault zone. The age of offset of these surficial deposits and the size of fault scarps can be used to calculate slip rates and average recurrence intervals at various places along the Salt Lake City segment. The ages of scarps formed by surface displacements along Quaternary faults in the map area have been estimated by stratigraphic techniques and fault-scarp morphology. Limits on the ages of fault scarps have been determined by the ages of stratigraphic units in which the scarps formed and by younger units that cross the scarps but are not offset. Two parameters used on the map to describe amount of vertical offset along a fault zone are faultscarp height and net vertical tectonic displacement, or surface offset. Scarp height is simply the vertical distance from the base to the crest of the scarp. As defined by Bucknam and Anderson (1979), surface offset is the net vertical offset of a geomorphic surface across a fault zone. Surface offset is typically less than scarp height because most fault scarps are formed on sloping surfaces. Where the fault zone consists of a broad zone of deformation that

along the Granger fault pre-date the Gilbert shoreline, but show evidence of at least two post-Gilbert shoreline surface-faulting events. Taken together, the entire West Valley fault zone has a post-Provo shoreline (<13.5 ka) slip rate of 0.5-0.6 mm/yr, and an average recurrence interval of 1,800-2,200 yr, includes fault scarps, grabens, and surfaces that are backtilted toward the based on six or seven surface-faulting events. Unfortunately, Keaton and main scarp, the surface offset, or net vertical tectonic displacement, may be others (1987) did not find evidence of the age of the most recent event. We less than half the height of the highest scarp in the zone. concur with them and with Keaton (written commun., 1989) that the West The following discussion contains brief descriptions of known and Valley fault zone probably is seismically independent of the Wasatch fault suspected latest Quaternary faults in the Salt Lake Valley, including the zone, but that sympathetic movement on the fault zone from earthquakes Varm Springs fault, the East Bench fault, the active trace of the Wasatch fault along the Wasatch fault zone is a distinct possibility. zone from Mount Olympus to Corner Canyon (herein informally named the Cottonwood section), and the West Valley fault zone (fig. 1). The apparently SEGMENTATION inactive part of the Wasatch fault zone north of Mount Olympus also is briefly The trace of the Salt Lake City segment is clearly the most complex of WARM SPRINGS FAULT The Warm Springs fault represents the northernmost extent of late Quaternary faulting in the Salt Lake City area, forming the western flank of

any segment of the Wasatch fault zone (Schwartz and Coppersmith, 1984; Machette and others, 1987, 1989, in press). From north to south, the segment consists of three active branches, the Warm Springs fault, the East Bench fault, and the Cottonwood section of the Wasatch fault zone (fig. 1). the Salt Lake salient. The fault is named after the thermal springs (Becks hot We will describe some of the significant features along the Salt Lake City springs and Wasatch warm springs) along the fault. Unfortunately, much of segment, including its northern and southern boundaries and the bifurcation the evidence of surface faulting along the Warm Springs fault has been zone at the intersection of the East Bench fault and the Cottonwood section. destroyed by gravel quarrying and highway construction, but evidence from Bruhn and others (1987) described all three of these areas as "nonold photographs and observations made by G.K. Gilbert in the late 1800's conservative barriers" to fault-rupture propagation. Non-conservative barrier (Gilbert, 1890, 1928, in Hunt, 1982) were used by Scott and Shroba (1985) are regions along a fault where the orientation of the slip vector changes and Scott (1988d) to evaluate recurrent Holocene faulting. Gilbert described between adjacent parts of a fault; these regions commonly mark the location ault scarps 10–14 m high on alluvial-fan deposits post-dating the Bonneville of the initiation and termination of fault ruptures (King and Yielding, 1984; lake cycle at the mouths of two canyons southeast of Becks hot springs King and Nabelek, 1985). As such, these features may have controlled the (Gilbert, 1890, p. 348–349, in Hunt, 1982, p. 27–29). At Jones Canyon, geometry of surface ruptures in the past and may do so in the future. strath terraces upstream from the scarp and variations in size of the scarp in NORTHERN SEGMENT BOUNDARY inset parts of the fans suggested to Gilbert that the scarp resulted from three The Salt Lake salient marks the boundary between the northern end of faulting events. Gilbert measured terraces 4.5, 1.5, and 3 m above stream evel in the footwall block at the fault scarp on the Jones Canyon fan and the Salt Lake City segment and the southern end of the Weber segment (fig. 1) Machette and others, 1987, in press), previously known as the Ogden concluded that these terraces represented three surface-faulting events segment (Schwartz and Coppersmith, 1984). The structural significance of producing surface offset similar to the amount of vertical terrace separation. the salient was first recognized by Gilbert (1890, 1928), who was intrigued by We now know that the average displacement resulting from paleo-surface

think it is related seismogenically to the rest of the Salt Lake City segment. Bruhn and others (1987, p. 345) have described the Salt Lake salient as a non-conservative barrier to rupture propagation. As discussed above, the Warm Springs fault trends northward 2 km beyond Becks hot springs, and then turns northeastward before dying out on he north side of the Salt Lake salient. Several short, north-trending fault scarps are preserved in the 2-km-wide gap between the northern end of the Warm Springs fault and the southern end of the Weber segment. The southernmost end of the Weber segment is marked by a single scarp that trends southwest across the drainage of North Canyon and then trends south, offsetting the Bonneville shoreline before dying out in bedrock. The amount of surface offset along this scarp decreases from 11.6 m in Bonneville-lakecycle gravels (lbg) to 3.7 m in alluvial-fan deposits post-dating the Bonneville lake cycle (af2); these changes in surface offset clearly indicate recurrent latest Pleistocene and Holocene faulting. The numerous fault scarps on the northwest flank of the salient appear to form a network of subsidiary faults hat may have diffused the energy of earthquake ruptures propagating into the salient from the Salt Lake City and (or) Weber segments.

and Krystinik, 1988). The active part of the Warm Springs fault is probably

too short (about 7 km) for it to be a seismically independent structure, so we

Another indicator of structural complexity at the northern segment boundary may be the location of Becks and Wasatch thermal springs. These springs may be localized by increased permeability associated with faulting and fracturing in the subsurface near the Salt Lake salient (Murphy and Gwynn, 1979a). Although it may be coincidental, thermal springs along the Salt Lake City segment are found only near the segment boundaries (Mundorff, 1970; Klauk, 1984). Hot springs on the Brigham City segment of the Wasatch fault zone (Personius, 1990) are similarly localized at the The eastern flank of the Salt Lake salient is also bounded by a normal

fault, the Rudys Flat fault of Van Horn and Crittenden (1987), that places Tertiary sedimentary and volcanic rock against Precambrian metamorphic rock. Although this fault appears to connect the southern end of the Weber segment with the northern end of the East Bench fault, we have observed no evidence of Quaternary movement on this structure. Therefore, latest Quaternary fault activity on the northern end of the Salt Lake City segment appears to be restricted to the Warm Springs fault on the northwest side of the SOUTHERN SEGMENT BOUNDARY

The Traverse Mountains salient marks the boundary between the

South. The height of these larger scarps along the East Bench fault suggests southern end of the Salt Lake City segment and the northern end of the surface faulting along the East Bench fault during much of the middle and rovo segment (fig. 1; Schwartz and Coppersmith, 1984; Machette and late Quaternary. However, Scott and Shroba (1985) suggested that perhaps others, 1987, 1989, in press). Scott and Shroba (1985) ended their mapping only about 11 m of offset occurred during latest Pleistocene and Holocene of latest Quaternary faulting on the Cottonwood section of the Salt Lake City time; this estimate yields a slip rate of about 1 mm/yr. A shallow seismicsegment near the mouth of Corner Canyon, but Machette and others (1987, reflection profile across the East Bench fault along Interstate Highway 80 n press) discussed evidence that extends Quaternary faulting across the between 1300 East and 700 East suggested to Crone and Harding (1984) raverse Mountains salient along the Fort Canyon fault of Bruhn and others that there has been about 85 m of vertical offset on the East Bench fault (1987). However, the rate of Quaternary movement on the Fort Canyon fault during Quaternary time. They used this estimate of offset and an age of appears to be much lower than on the adjoining segments. The reduced rate 600–2,000 ka to determine a long-term slip rate of 0.04–0.14 mm/yr. This of Quaternary slip is consistent with the lower structural relief apparent across slip rate is substantially less than the estimated latest Quaternary rate of about his part of the Wasatch fault zone. 1 mm/yr, and suggests that the latest Quaternary slip rates may not be Gravity data suggest that the steep northwest flank of the Traverse representative of average longer term slip on the East Bench fault. This Mountains is bounded by northeast-trending normal faults (Cook and Berg, phenomenon has been recognized at several other locations along the 1961; Zoback, 1983), but Scott and Shroba (1985) and photogeologic Wasatch fault zone (Machette and others, 1987, in press). reconnaissance by the senior author found no evidence of latest Quaternary Machette and others (1987, in press) described preliminary results of isplacement on these structures. Bruhn and others (1987, p. 345) described two trenches dug across the East Bench fault at the Dresden Place site near the Traverse Mountains as a non-conservative barrier, consisting of three 550 South Street (trench locations are shown on the map). The exposures arge normal faults that intersect in a "triple junction" at the sharp bend in the revealed evidence of a minimum of 7 m of deformation in deposits of the Wasatch fault zone near the mouth of Corner Canyon. The northeasttransgressive phase of the Bonneville lake cycle. This deformation appears to trending faults on the northwest flank of the salient form a presently inactive have occurred in two distinct phases. The first phase consisted of plastic arm of this triple junction. Crystal (hot) Springs may be localized by increased deformation expressed as 3 m of monoclinal warping, thought to have ermeability in the subsurface associated with these faults (Mundorff, 1970; occurred during a single faulting event while the site lay under the waters of Murphy and Gwynn, 1979b; Klauk, 1984). Lake Bonneville. The altitude of the Dresden Place site (about 1,326 m; Analysis of structural data by Bruhn and others (1987) suggested that 4,350 ft) and hydrographs of Lake Bonneville (Scott and others, 1983; future ruptures on the Salt Lake City segment may begin at the Traverse Currey and Oviatt, 1985) suggest that this event probably occurred 12.5-25 ka. Mountains salient and propagate northward along the Cottonwood section The absence of colluvial deposits and unconformities within the plastically and the rest of the Salt Lake City segment. The distribution and size of fault deformed lake sediments suggests that the deformation occurred as a single scarps on the Cottonwood section near the bifurcation zone (see discussion event. The second phase of deformation at the Dresden Place site consisted below) support this suggestion. of a minimum of 4 m of brittle deformation expressed as planar fault ruptures BIFURCATION ZONE that extend to the top of the in-place sediment in the trenches. The

during deposition of the fan also suggests that three Holocene surface-

aulting events should be considered a minimum (Scott, 1988d). Topographic

profiles measured by A.R. Nelson (written commun., 1988) across the Warm

Springs fault on aerial photographs taken in 1952, before much of the gravel

mining, yielded surface offsets of 13.7-15.8 m in Bonneville-lake-cycle

gravels. Given these scarp measurements, perhaps as many as six to eight

surface-faulting events have occurred on the Warm Springs fault during latest

the north, our mapping from the 1952 aerial photographs clearly shows that

he fault continues northward about 2 km beyond Becks hot springs and then

turns northeastward and dies out on the northern flank of the Salt Lake

salient. Van Horn (1982) shows the Warm Springs fault trending directly

northward from Becks hot springs along a scarp that we have interpreted as

the Gilbert shoreline. To the south, urbanization has obscured evidence of

surface faulting, but Scott and Shroba (1985) and Scott (1988d) concluded

that there probably has been no significant late Quaternary surface faulting

south of 600 North Street. The active part of the Warm Springs fault thus

springs (unit ly, Hot Spring Lake of Van Horn, 1982). Gilbert (in Hunt, 1982.

p. 27) noted that the low area occupied by this lake is anomalous because it

was not filled by deposits of the Jordan River and suggested the lake

represented an area of local subsidence related to the Warm Springs fault.

Recent local or regional tectonic activity probably has backtilted this area

toward the Warm Springs fault, although alternatively this low area may have

formed behind a levee of the Jordan River and not be related to tectonism

EAST BENCH FAULT

fault zone diverges from the mountain front near Tolcats Canyon and trends

north across much of Salt Lake City before intersecting the range front at the

mouth of Dry Creek, near the University of Utah. This fault zone is known as

the East Bench fault, a structure that has clearly been more active in

Quaternary time than faults along the range front directly to the east (Marsell,

data show a double scarp almost 40 m high near 3900 South, and Scott and

Shroba (1985, p. 8, 9) discuss scarps as much as 50 m high north of 2100

deformation associated with these structures probably post-dates 12.5 ka.

and was formed by one or more surface-faulting events during latest

age of these events cannot be determined more precisely because manmade

the eastern part of Salt Lake Valley has prevented further trenching studies

on the East Bench fault, and will make future investigations of this important

COTTONWOOD SECTION OF THE WASATCH FAULT ZONE

the Salt Lake City area lies in a relatively narrow zone along the base of the

Wasatch Range from near Mount Olympus south to Corner Canyon. For ease

of discussion this part of the fault zone is herein informally named the

The northernmost extent of the Cottonwood section is marked by a single

small (1-2 m high) scarp that extends about 3 km from its intersection with

the East Bench fault near the mouth of Tolcats Canyon (the "bifurcation

zone" on fig. 1) to near Casto Spring (Scott and Shroba, 1985); from the

bifurcation zone southward, scarps along the Cottonwood section show

about 10–15 m of surface offset. These changes in scarp size suggest that

most late Quaternary faulting was restricted to the East Bench fault and that

part of the Cottonwood section south of the bifurcation zone. Only small,

scattered faults that mostly pre-date the end of the Bonneville lake cycle have

been mapped along the Wasatch Range north of the termination of the

the Cottonwood section (figs. 2, 3). The fault zone may be as wide as 500 m,

and backtilting and graben formation associated with faulting have created

scarps as high as 30-40 m, although surface offset post-dating the Bonneville

lake cycle is probably no more than about 15 m along this part of the Salt

South of Little Willow Creek, scarps along the fault zone decrease in

surface offset from 10–14 m near Little Willow Creek to about 6 m near

orner Canyon (Scott and Shroba, 1985). The height of late Quaternary

fault scarps appears to decrease rapidly near Corner Canyon, where the

Wasatch fault zone turns sharply to the east and divides the Traverse

investigations. In 1979, geologists with Woodward-Clyde Consultants

conducted a comprehensive investigation of Quaternary faulting near the

mouth of Little Cottonwood Canyon (trenches LC-1-4; see fig. 2). Data from

this investigation is included in Swan and others (1981); summaries of the

and Coppersmith (1984), Machette and others (1987, in press), and

Schwartz and Lund (1988). The fault zone is extremely complex in the trench

area, but studies indicate a slip rate of 0.76 (+0.6, -0.2) mm/yr over the past

19,000±2,000 yrs, average displacement per event of 2 m, and an average

recurrence interval of 2,400–3,000 yrs. In addition, the trenches exposed

evidence of two surface-faulting events within the main graben in the past

8,000–9,000 yrs. The older of the two events occurred just prior to 8–9 ka,

but the age of the most recent event could not be determined. Because of the

width of the fault zone near Little Cottonwood Canyon, not all fault splays in

the area could be trenched; Schwartz and Lund (1988) concluded that

because of this complexity, the youngest event affecting the Cottonwood

conducted by the Utah Geological and Mineral Survey and U.S. Geological

Survey in 1985 near the mouth of South Fork Dry Creek (fig. 3), about 1.5 km

south of Bells Canyon (not to be confused with the other Dry Creek in the

map area north of the University of Utah). Four trenches (trenches DC-1-4;

see fig. 3) were excavated across three strands in a 300-m-wide fault zone

deposits. Preliminary results of this investigation include evidence for two

large surface-faulting events with offsets of 4–5 m each in the past 5.5 ka, and

a slip rate greater than 1 mm/yr. The age of the most recent event is still

uncertain, but preliminary radiocarbon ages on soil organic matter suggest

that the last event occurred about 1.1-1.8 ka. In addition, diffusion modeling

of a single-event fault scarp (trench DC-3) suggests an age of about 900 yr

(Lund and Schwartz, 1987; Machette and others, 1987, 1989, in press;

analysis of the Little Cottonwood and South Fork Dry Creek trench sites that

the Cottonwood section has been the site of at least three Holocene surface-

faulting events; these occurred just prior to 8-9 ka, shortly after 5.5-6 ka, and

the most recent about 1.1-1.8 ka. These data yield an average recurrence

interval of 3,000-4,000 yrs between major earthquakes on this part of the

RANGE FRONT FAULTING NORTH OF MOUNT OLYMPUS

The geomorphology of the northeastern part of the Salt Lake Valley

uggests that late Quaternary faulting on the Wasatch fault zone has shifted

he more subdued geomorphology of the range front north of the bifurcation

one near Mount Olympus (Marsell, 1964, 1969; Hamblin and Best, 1980;

Scott and Shroba, 1985), the presence of bedrock at shallow depths beneath

he surficial cover on the piedmont east of the East Bench fault (Marsell,

1964, 1969), and the lack of significant movement on the range front faults

following the Bonneville lake cycle (Van Horn, 1972b; Scott and Shroba,

985). One fault that may have some latest Quaternary movement is the

irginia Street fault (City Cemetery fault of Van Horn and Crittenden, 1987),

about 2 km northwest of the University of Utah. Evidence of recent movement

on this fault has been destroyed by gravel mining, but Scott and Shroba

1985) concluded that if this structure had been recently active, the amount

of displacement is small. Scott and Shroba (1985) also concluded that no

movement post-dating the Bonneville lake cycle had occurred on several

other faults along this section of the Salt Lake City segment. These faults

cluded the University Hospital fault (Everitt, 1979), on the University of

Utah campus, and a short fault just south of the mouth of Parleys Canyon

Bench fault is unknown, but because Scott and Shroba (1985) found no

evidence of significant faulting along the range front younger than the

ansgressive phase of the Bonneville lake cycle, the minimum age of this shift

Although not a part of the Wasatch fault zone, the proximity of the West

WEST VALLEY FAULT ZONE

Valley fault zone to much of the Salt Lake City metropolitan area and a recent

paleoseismic investigation (Keaton and others, 1987) have heightened

awareness of this active fault zone. The two main traces of the West Valley

fault zone, the Taylorsville and Granger faults, were first recognized by

Marsell and Threet (1960) and later named by Marine and Price (1964), who

used the term "Jordan Valley fault zone" for these structures. Van Horn

(1979, 1982) attributed these features to alluvial erosion and did not show

Keaton and others (1987) renamed the zone the "West Valley fault zone"

after nearby West Valley City, but retained the names "Granger and Taylors-

by Keaton and others (1987) are labelled on the geologic map.

them on his surficial geologic maps of the region. In a more recent study,

ville faults" for the two main fault traces. The locations of trenches excavated

Although urbanization has destroyed much of the surface evidence of

the West Valley fault zone, Keaton and others (1987) used surface, borehole,

topographic maps to delineate the fault zone and determine some of its

faulting history. They recognized two distinct fault patterns. South of about

2100 South Street, the fault zone consists of two subparallel, east-facing

scarps that mark the traces of the Taylorsville and Granger faults. North of

about 2100 South Street, the fault zone consists of numerous small scarps in

a zone as much as 7 km wide. In total, the West Valley fault zone is as much as

7 km wide and 16 km long. The Granger fault extends 1.5 km west and 3.5 km

On the northern part of the West Valley fault zone, Keaton and others

1987) found evidence for a minimum of four surface-faulting events that

post-date lacustrine deposits associated with the Gilbert shoreline (10-10.5 ka).

At least two of these events formed scarps on the Taylorsville fault. Scarps

north of the map area margin (see fig. 1).

and trench data, and studied pre-urbanization aerial photographs and

The time when faulting shifted from along the range front to the East

om the base of the range front to the East Bench fault. This is evident from

Schwartz and Lund, 1988). Schwartz and Lund (1988) concluded from

consisting of at least six fault scarps formed in late Quaternary surficial

The other major trench investigation on the Cottonwood section was

section may well have been missed at the Little Cottonwood trench site.

conclusions of this study are included in Swan and others (1980), Schwartz

The Cottonwood section has been the site of two extensive trenching

Fault scarps are consistently large and complex along the central part of

Cottonwood section (Scott and Shroba, 1985).

Lake City segment (Scott and Shroba, 1985).

Mountains from the Wasatch Range.

tonwood section of the Salt Lake City segment of the Wasatch fault zone.

Latest Quaternary faulting on the main trace of the Wasatch fault zone in

structure very difficult.

Pleistocene and Holocene time (Machette and others, 1987, in press). The

The trace of the East Bench fault is marked by very large fault scarps; our

1964, 1969; Van Horn, 1972b; Scott and Shroba, 1985).

Marsell (1964, 1969) first recognized that the active part of the Wasatch

A shallow lake and marsh, now drained, formerly lay west of Becks hot

appears to be about 7 km long.

(Scott and Shroba, 1985; Scott, 1988d).

The north and south extents of the Warm Springs fault are uncertain. To

the Salt Lake City area, at the bifurcation zone between the Cottonwood section of the Salt Lake City segment and the East Bench fault. However, this barrier does not appear to be as resistant to ruptures as the two segment boundaries previously discussed. The distribution of late Quaternary faulting southern segment boundary and the Cottonwood section northward into the East Bench fault, with only rare or very small displacements occurring on the cottonwood section north of its intersection with the East Bench fault. Scarps north of the bifurcation zone are only 1-2 m high, whereas scarps in deposits of similar age on the Cottonwood section to the south and on the East Bench fault to the east are at least 10-15 m high. The small scarps north of the bifurcation zone may represent extension of minor fault displacements into this otherwise inactive part of the Wasatch fault zone. This pattern may be similar to the pattern of surface rupture that accompanied the 1983 Borah Peak, Idaho, earthquake, during which a small amount of displacement 'jumped" across the segment boundary at the north end of the rupture (Crone and others, 1987). Unfortunately, this idea cannot be tested at present because trench data from the East Bench fault is not detailed enough o correlate individual surface ruptures from the Cottonwood section across Bruhn and others (1987) noted several structural features that may be

nfluencing the behavior of the Salt Lake City segment near the bifurcation zone. These features include a west-trending Mesozoic thrust fault system that intersects the Wasatch fault zone west of Neffs Canyon, and a westtrending gravity gradient (Zoback, 1983, fig. 4) that extends across the Salt Lake Valley at about the same latitude. J.R. Keaton (written commun., 1989) has noted that the southern end of the West Valley fault zone also terminates at this latitude, suggesting that a major west-trending structure may be controlling both the geometry of the West Valley fault zone and the bifurcation zone of the Salt Lake City segment. SEGMENTATION SUMMARY

Paleoseismic analysis of fault scarps and limited trench data suggest that the active parts of the Salt Lake City segment consist of the Warm Springs fault, the East Bench fault, and the Cottonwood section of the Wasatch fault zone. Bedrock salients at the Salt Lake salient and Traverse Mountains probably are non-conservative barriers that form the northern and southern boundaries, respectively, of the Salt Lake City segment. The bifurcation zone that marks the intersection between the East Bench fault and the Cottonwood section may be a less resistant non-conservative barrier that directs ruptures from the Cottonwood section into the East Bench fault. Unfortunately, correlation of surface-faulting events along the length of the Salt Lake City segment is impossible at the present time because data on the timing of individual events is available only for the Cottonwood section. Additional paleoseismic data will be especially difficult to obtain along the heavily urbanized Warm Springs and East Bench faults.

Mapping of Quaternary deposits and measurement of fault scarps in deposits of various ages have helped us identify some of the paleoseismic characteristics of the Salt Lake City segment and parts of the adjacent segments of the Wasatch fault zone. The Salt Lake City segment has clearly been active during Holocene time: fault scarps in Holocene alluvial deposits attest to several surface-faulting events during the past 10,000 yrs. Trench studies at several sites on the Salt Lake City segment have documented Holocene surface faulting having average recurrence intervals of 3,000-

CONCLUSION

4,000 yrs and slip rates of at least 0.75-1 mm/yr. The age of the most recent surface-faulting event has not been well constrained, but preliminary ages from the South Fork Dry Creek trench studies suggest that the youngest event on the Cottonwood section of the Salt Lake City segment occurred The Salt Lake City segment exhibits the most complex pattern of surface faulting of any segment of the Wasatch fault zone. The branched nature of the segment complicates paleoseismic studies in the Salt Lake City area because insufficient trench data are available to correlate individual faulting events on the various fault strands. However, fault scarp and trench data indicate that all three active branches of the Salt Lake City segment have experienced recurrent Holocene faulting and that these structures probably are seismically independent of the Weber segment to the north and the Provo segment to the south. The Salt Lake salient and the Traverse Mountains form the northern and southern boundaries, respectively, of the Salt Lake City egment and exhibit most of the geologic features characteristic of such boundaries, including reduced structural relief, sharp fault bends, thermal springs, and changes in rate and timing of Quaternary slip. he nearby West Valley fault zone has also undergone recurrent faulting in latest Pleistocene and Holocene time, but this structure probably is seismically independent of the Wasatch fault zone. Therefore, the West

Valley fault zone constitutes an additional potential source of seismic hazard

to the Salt Lake City area.

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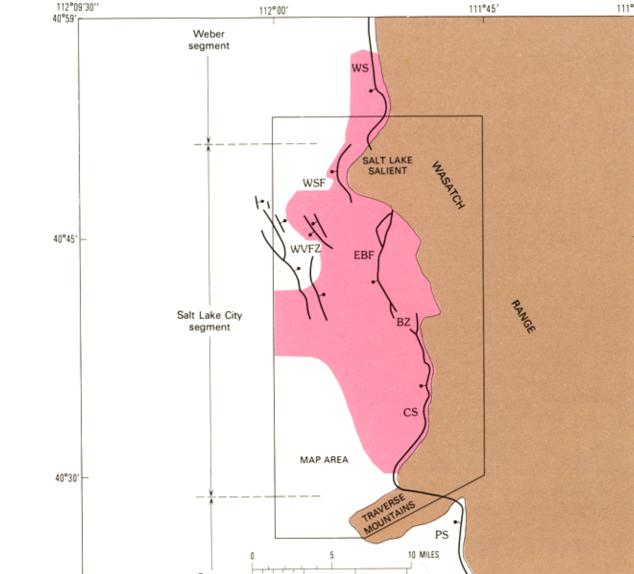


Figure 1.—Index map showing active trace (heavy line, bar and ball on downthrown side) of the Wasatch and West Valley fault zones in the Salt Lake City area. The extent of the Salt Lake City segment, and the southern part of the Weber and northern part of the Provo segments, is from Machette and others (1987, 1989, in press); this nomenclature differs from that of Schwartz and Coppersmith (1984) only in the name of the Weber (Ogden) segment. Extent of heavily urbanized area shown in pink. Abbreviations used: BZ, bifurcation zone between the East Bench fault and the Cottonwood section; CS, Cottonwood section of the Wasatch fault zone; EBF, East Bench fault; PS, Provo segment; WS, Weber segment; WSF, Warm Springs fault; WVFZ, West Valley fault zone. In this study, the West Valley fault zone is not considered part of the Salt Lake City

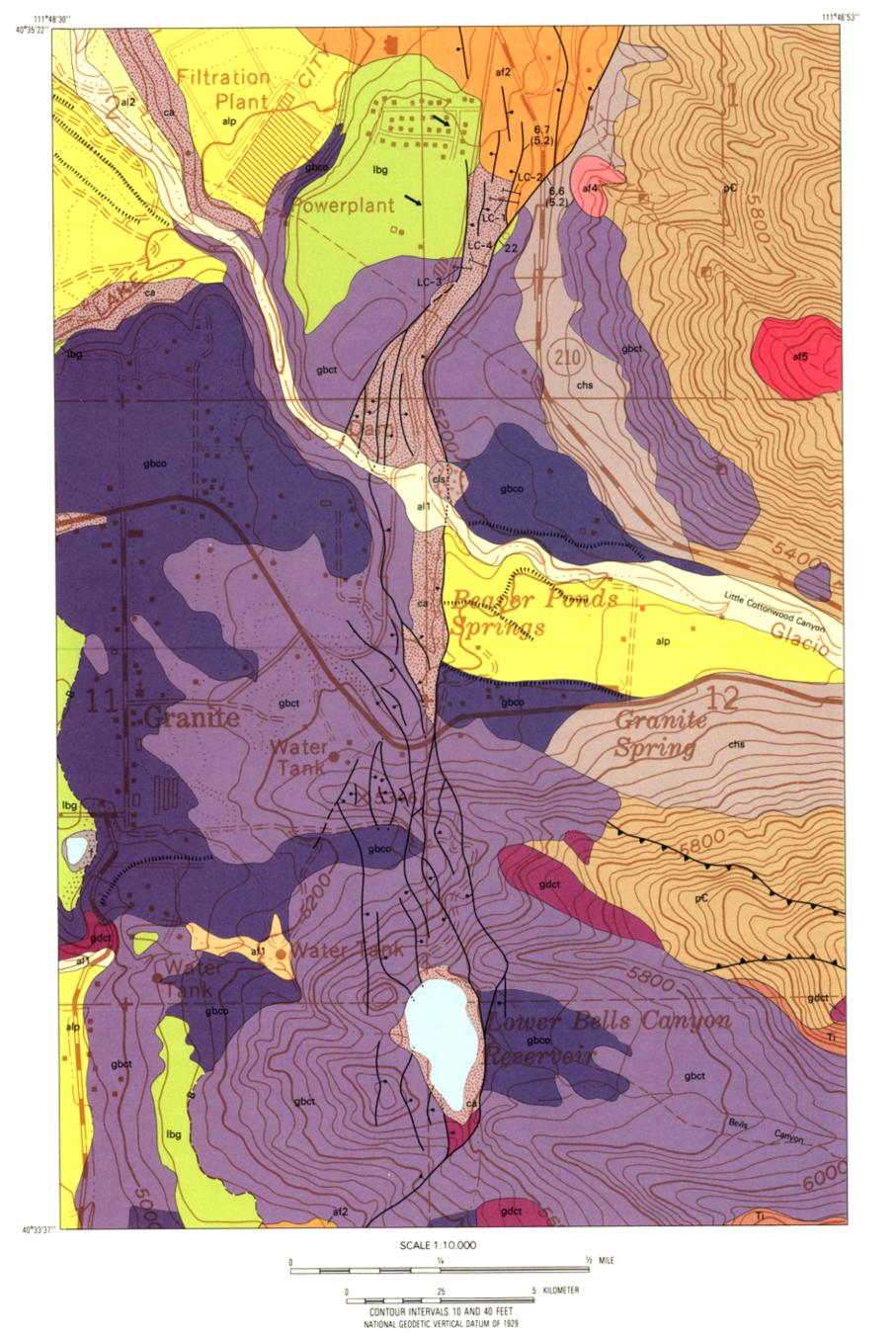
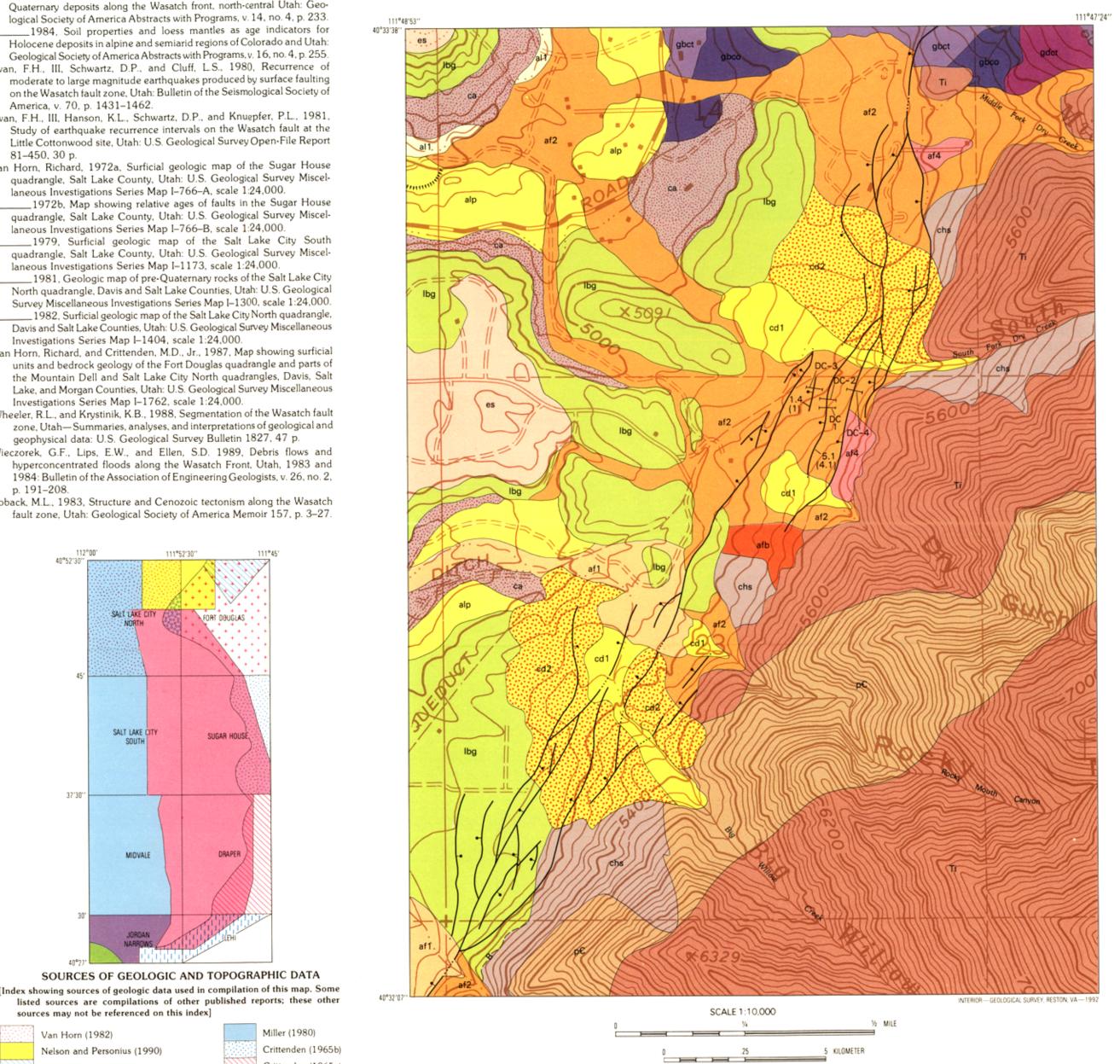


Figure 2. Detailed surficial geologic map of an area of complex faulting near the mouths of Little Cottonwood and Bells Canyons. Outline of figure shown on geologic map. Geologic units and symbols are explained in the Description of Map Units.



CONTOUR INTERVALS 10 AND 40 FEET

Figure 3. Detailed surficial geologic map of an area of complex faulting near the mouth of South Fork Dry Creek. Outline of figure

shown on geologic map. Geologic units and symbols are explained in the Description of Map Units.

NATIONAL GEODETIC VERTICAL DATUM OF 1929

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