QUATERNARY TECTONICS OF UTAH WITH EMPHASIS ON EARTHQUAKE-HAZARD CHARACTERIZATION

by
Suzanne Hecker
Utah Geological Survey

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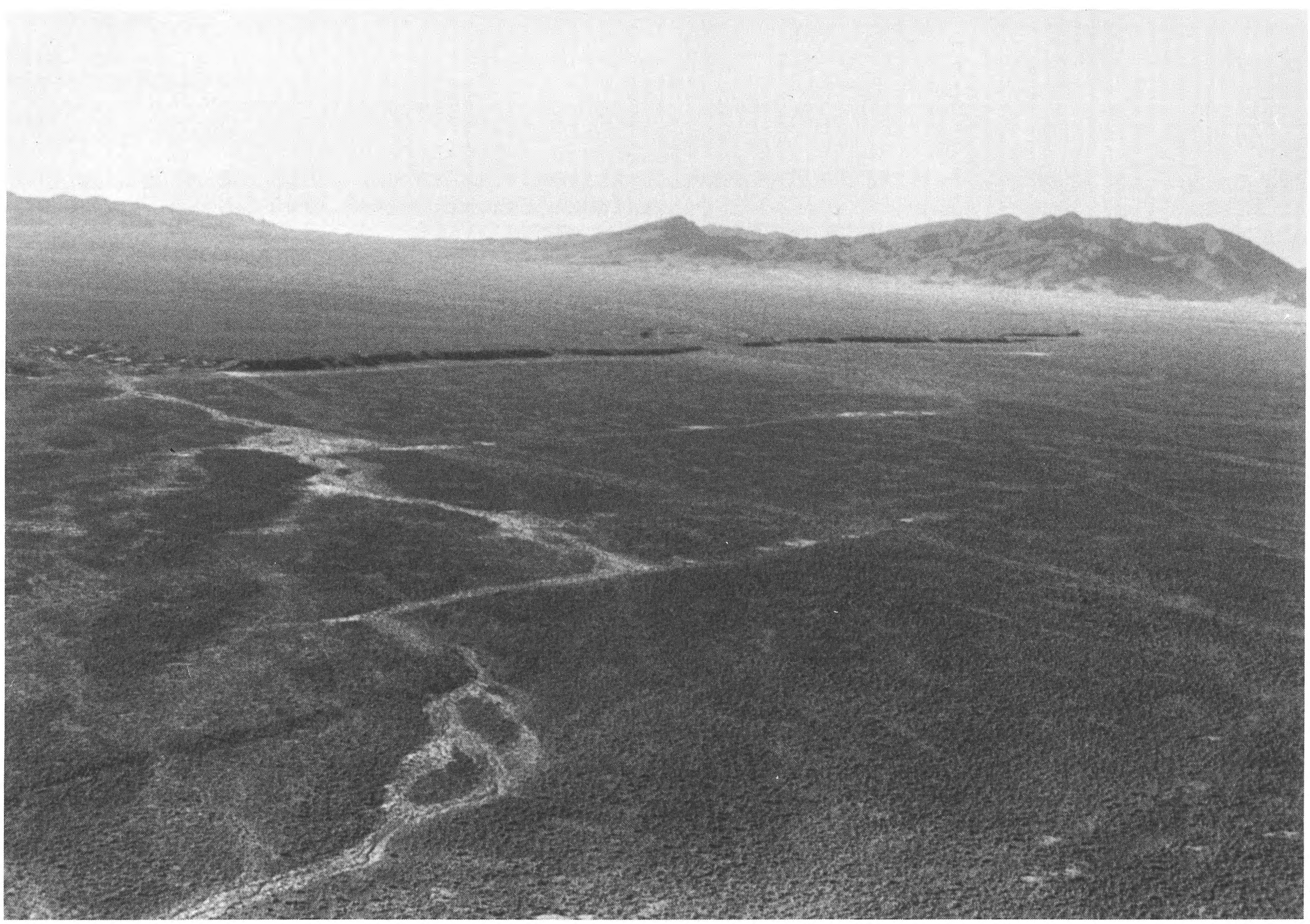

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QUATERNARY TECTONICS OF UTAH WITH EMPHASIS ON EARTHQUAKE-HAZARD CHARACTERIZATION

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ABSTRACT

This report consolidates and synthesizes information on Quaternary faulting, folding, and volcanism in Utah and characterizes recent tectonic activity throughout the state. The primary purpose is to provide a comprehensive reference on fault-specific seismic sources and surface rupture to facilitate the evaluation of earthquake hazards in Utah. Two 1:500,000-scale maps show Quaternary tectonic features categorized according to probable ages of most recent surface deformation (plate 1) and ages of volcanic rocks (plate 2). Two appendix tables summarize significant data on the activity of mapped features, including ages of surface displacements and volcanism, slip rates, recurrence intervals, displacement amounts, and lengths of surface ruptures. Good age control and quantitative activity data are available for relatively few tectonic features in Utah and detailed work is needed in many areas of the state.

Existing information is adequate to demonstrate that Quaternary crustal deformation, principally normal faulting, is concentrated within a broad, north-trending zone coincident with the Intermountain seismic belt and the transitional tectonic boundary between the Basin and Range and Middle Rocky Mountains-Colorado Plateau physiographic provinces. Large, regionally significant structures with evidence of relatively high late-Quaternary slip rates include the Wasatch fault zone in the northern half of the state and, to the south, the Hurricane and Sevier faults. Tectonic activity during the Holocene has been concentrated on the Wasatch fault zone and, to a lesser extent, on other faults and folds in the broader Wasatch Front region and in west-central Utah. The average regional recurrence interval for large-magnitude earthquakes in the Wasatch Front region during the Holocene appears to be 125 to 300 years or less, although events have been non-uniformly distributed in time. Most notably, the composite recurrence interval for the particularly active, segmented Wasatch fault zone is roughly 400 years for the middle to late Holocene, but only 220 years for the past 1,500 years. Other patterns of spatially and temporally clustered tectonic activity in northern and west-central Utah appear to be related to persistent structural controls or to tectonic perturbations, such as crustal loading from deep-lake cycles.

Most normal faults with evidence of geologically young surface displacements (or faults which may be expressed at the surface as large-scale folds) are inferred to be moderate- to high-angle structures extending down to mid-crustal levels and capable of producing large (magnitude ~6.5 to 7.5) earthquakes. However, the seismogenic potential of faults associated with shallow, low-angle geometries (identified mainly in west-central Utah, the High Plateaus, and the Middle Rocky Mountains) is poorly understood. Some faults and folds in the state may be associated with relatively aseismic processes, such as magmatism, salt diapirism, or shallow, secondary deformation arising from activity on major structures. It is hoped that the broad scope of compiled information and text discussion will yield new insights and help direct future research into Quaternary tectonics and earthquake hazards in Utah.

INTRODUCTION

This report presents a compilation of information on tectonic features in Utah that have been active during the Quaternary (the past 1.65 million years), especially information relevant to evaluating earthquake hazards. The compilation builds upon Anderson and Miller's (1979) Quaternary Fault Map of Utah, incorporating the results of numerous paleoseismic and mapping studies from the succeeding twelve years, adding information on Quaternary folds and volcanic rocks, and summarizing regional aspects of Utah's tectonic environment.

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Utah is located in a tectonically active region and, consequently, is subject to earthquakes and related hazards. A north-trending zone of historical seismicity and Quaternary crustal deformation bisects the state and coincides with the broad, transitional eastern margin of the Basin and Range Province (figure 1). Over time, the style and distribution of extensional crustal deformation has shaped the physiography of this region. Contemporary seismotectonics presents the threat of damaging earthquakes, including the effects of strong ground shaking, surface fault rupture, ground failure, and tectonic subsidence.

Geologic observations indicate that many faults in Utah have produced large, surface-rupturing earthquakes in the Quaternary. These faults are likely to be sources for large and potentially damaging earthquakes in the future. The 340-kilometer-(211-mi-) long Wasatch fault zone, which marks the physiographic boundary of the Basin and Range Province in the northern half of the state (figure 1B), is one of the most tectonically active and best studied normal faults in North America. Results of trenching, geomorphic analysis, and detailed mapping document that the most active, central segments of the Wasatch fault zone have experienced repeated earthquakes having surface-wave magnitudes (M_S) of up to 7.5 to 7.7 during the Holocene (past 10,000 years) (Machette and others, 1991; Arabasz and others, 1992). Most major, north-trending faults close to the Wasatch fault zone have also experienced large (greater than about magnitude 6.5) earthquakes during late Pleistocene and Holocene time (<130,000 years). Utah's largest population centers lie within the Wasatch Front region, adjacent to the Wasatch fault and other active structures, and thus face the greatest risk from future earthquake activity. Unless otherwise specified, the term "Wasatch Front region" herein refers to the geographical area from latitude 38°55'N. to 42°30'N., and from longitude 110°25'W. to 113°10'W. (for consistency with established usage elsewhere, such as Arabasz and others [1992]; see Wasatch Front region shown in figure 8). Other populated areas of the state are located near potentially active, but generally poorly characterized, faults and may also be exposed to significant earthquake hazards.

This compilation of the Quaternary tectonic activity of Utah combines the results of recent studies with previous work. The earthquake potential of faults in Utah has been the subject of an increasing number of studies, following important advances in paleoseismology (formalized by Wallace, 1981) and a concomitant growth in awareness of the threat posed by moderate to large earthquakes in the state. Recent detailed work along the Wasatch Front has been accomplished largely under the National Earthquake Hazards Reduction Program, through research and funding by the U.S. Geological Survey and other participating federal agencies. The compilation is the product of a comprehensive review of published as well as available unpublished sources of information, including geologic quadrangle maps and other reports in which Quaternary tectonics are not necessarily emphasized. The compiled information also includes the results of some original reconnaissance field work and aerial-photograph mapping.

The plates and appendices that accompany this report depict and summarize geologic data on individual faults, folds, and volcanic rocks that are known or suspected to have been active during the Quaternary. The main body of the report describes regional patterns of crustal deformation and discusses seismogenic potential associated with various types of tectonic features throughout the state.

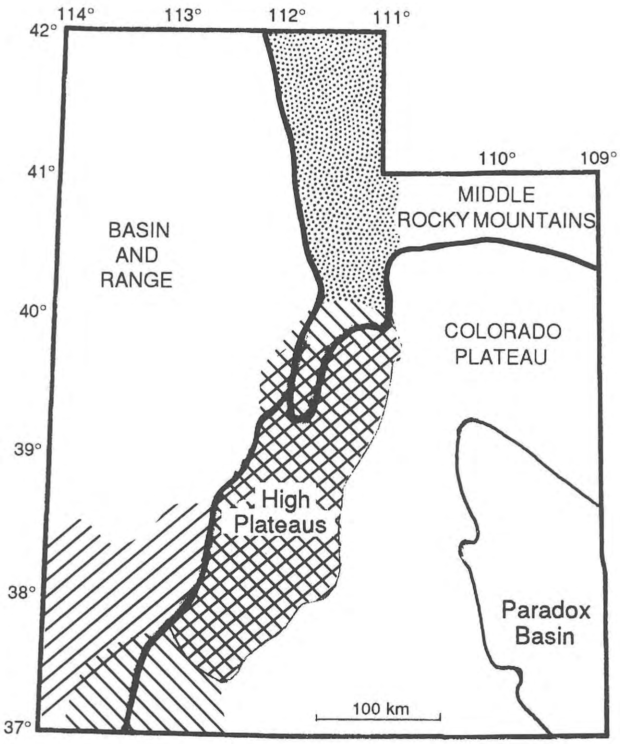
The primary purpose of this report is to provide a convenient reference for seismic-source and fault-rupture information on a statewide basis. The compilation contains the type of information necessary to assess space-time distributions of large-magnitude paleoearthquakes and to estimate regional probabilities of future earthquake occurrence. Geologic information used to characterize fault-related hazards includes: (1) timing of the most recent surface-rupturing event on a fault, (2) the length of time between successive events, (3) the amount of displacement during individual events, (4) the length of surface fault ruptures, and (5) fault slip rates.

Tectonic elements that do not produce discrete surface offset may nonetheless have relevance to earthquake-hazard evaluations and are therefore included in the compilation. Some folds (for example, the Cedar City-Parowan monocline in southwestern Utah) may overlie and be genetically related to buried faults capable of generating earthquakes. In addition, folds may control the development of spatially associated faults that are discontinuous and have small displacements, presumably terminate at shallow depths, and have uncertain seismogenic potential.

Quaternary volcanic rocks and vents are included in the compilation to indicate where surface faulting may be caused or influenced by magmatic processes, as opposed to primary tectonic processes. Clusters of short, intrabasin faults preserved in association with Quaternary volcanic rocks in west-central Utah may be related, in part, to volcanic activity and, like some fold-related faults, have uncertain seismogenic histories and potential. Information on locations and ages of volcanic rocks also provides a basis for evaluating volcanic hazards in the state.

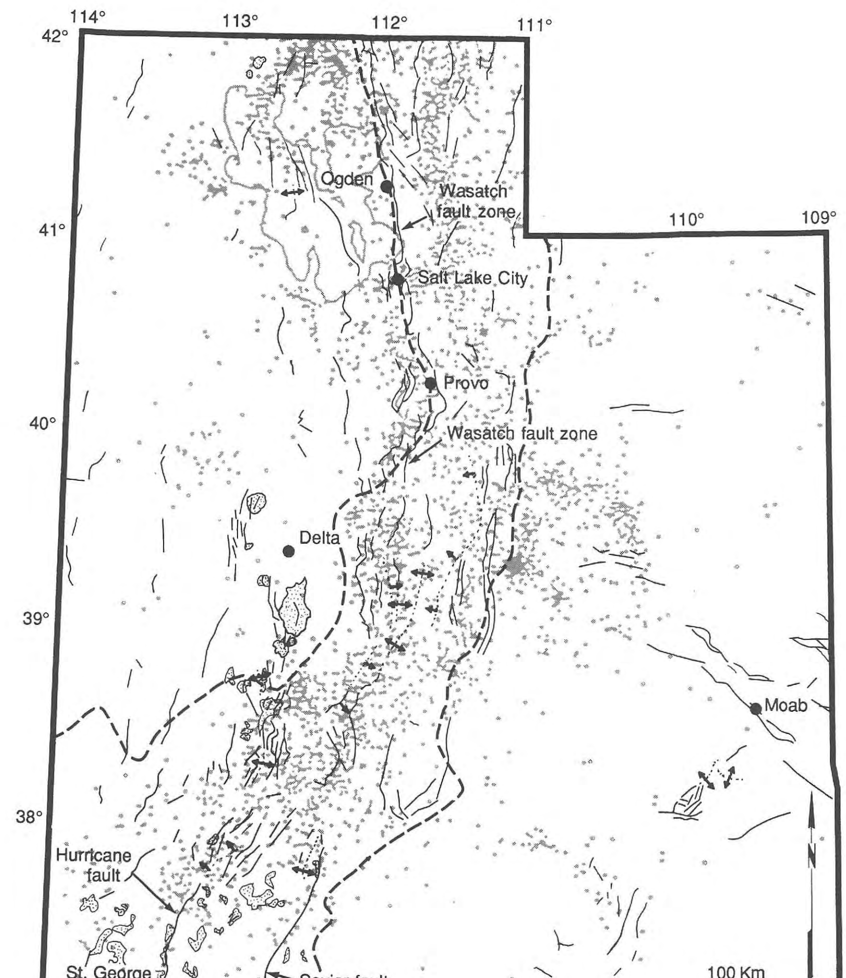
In some areas, deformation (in the form of faulting, folding, and warping) is known or suspected to be the result of mobilization or dissolution of evaporites (dominantly salt) at shallow depths and has probably not been accompanied by large-magnitude earthquakes. Although major, block-bounding faults within these areas of salt tectonics are generally regarded as potentially seismogenic, some or all of the recent movement on these structures may have been caused by the collapse of evaporite-cored anticlines or diapirs. Similar uncertainties regarding earthquake potential exist for faults whose depths and subsurface geometries appear to be incompatible with current theories on how surface-faulting earthquakes and strong ground shaking are generated. The topic of seismogenic potential is discussed at length in the next-to-last section of this report (Styles of faulting and tectonic processes) and is addressed in appendix A for particular tectonic features.

With the completion of some recent regional studies, most of the state has been surveyed for Quaternary faults and, less comprehensively, for folds. Areas that have not been studied lie mainly in eastern Utah, a region mostly undeformed by basin-range extension. On this basis, it is likely that virtually all major Quaternary structures with prominent surface expression have been identified in the state. However, many areas have been assessed at only regional scales, and, consequently, tectonic



A.

Figure 1. *(A) Major physiographic boundaries in Utah (bold lines) with respect to the transition zone between the Basin and Range Province and (1) the Middle Rocky Mountains Province (stippled area) and (2) Colorado Plateau Province (hachured areas). Alternative interpretations of the Basin and Range - Colorado Plateau transition zone are indicated by hachure patterns (northeast-trending, after Stokes, 1977; northwest-trending, after Anderson and Barnhard, 1992). Area of overlap (cross-hachure pattern pattern) coincides with the High Plateaus region. The Paradox Basin is a major region of the Colorado Plateau. (B) Quaternary tectonic features (simplified from plates 1 and 2) and seismicity (1962-1989; magnitude > 2) of Utah with respect to the Basin and Range - Colorado Plateau - Middle Rocky Mountains transition zone (area between dashed lines). Seismicity from the University of Utah Seismograph Stations catalog (Susan J. Nava, written communication, 1990)*



B.

features with subdued surface expression may remain undetected. For instance, faults with scarps less than about a meter (3 ft) high in unconsolidated deposits may not have been identified from the regional, reconnaissance studies done for western Utah (Anderson and Bucknam, 1979; Bucknam and Anderson, 1979). In addition to problems of mapping scale, small scarps in certain environments degrade rapidly. For example, the maximum 0.5 meter- (1.6 ft-) high scarp formed in salt-flat terrain during the 1934 Hansel Valley earthquake (M_L 6.6) is now difficult to detect (J.P. McCalpin, written communication, 1991). Likewise, surface evidence for some long-recurrence-time faults and folds may have been obscured by surficial processes and may be overlooked even by detailed studies. The variable quality of the Quaternary tectonic record is discussed further in a later section (Completeness of the Quaternary tectonic record) of this report.

TECTONIC-ACTIVITY PARAMETERS AND COMPILATION TECHNIQUES

Parameters commonly used to characterize fault activity and seismic-source potential (referred to herein as "tectonic-activity parameters") are tabulated in appendix A. These are: (1) age of the most recent surface-faulting event, (2) average inter-event time (recurrence interval), (3) slip rate, (4) amount of surface displacement per event, and (5) the length of surface rupture. Information for folds, although generally limited to recency of deformation, is also included in appendix A. These parameters and their relevance to the assessment of earthquake potential are discussed briefly in subsequent paragraphs. A comprehensive review of the principles and techniques involved in paleoseismology and earthquake-hazard evaluation is beyond the scope of this report, but the reader may refer to review papers by Allen (1986), Schwartz and Coppersmith (1986), Crone (1987), and Schwartz (1988).

Evidence from historical surface-faulting earthquakes indicates that the amount of surface displacement and the length of ground rupture can be correlated with earthquake size (Slemmons, 1977; Bonilla and others, 1984). Thus, measurements of coseismic rupture length and displacement, commonly obtained from fault-scarp dimensions, can provide empirical evidence for the magnitude of past earthquakes. Other magnitude relations involve fault-plane area (computed from estimates of fault dip, depth, and length) and seismic-moment calculations (Hanks and Kanamori, 1979; Wyss, 1979). The depth and subsurface geometry of faulting are key parameters in determining earthquake potential and will be addressed in a later section (Styles of faulting and tectonic processes: implications for earthquake-hazard characterization) of this report.

The time history of movement on individual faults or fault segments is expressed by estimates of slip rate, recurrence interval, and the age of the most recent event. A slip rate is usually derived from the net tectonic displacement that has occurred over a measurable period of time, providing an intermediate- to long-term measure of fault activity. Combined with information on single-event displacements, slip rates can be used to infer average intervals between successive surface-faulting events. Although actual inter-event time periods may vary substantially (Wallace, 1987), average slip-rate and recurrence-interval estimates provide a guide to the relative activity of individual faults and, when combined with constraints on the timing of one or more recent events, provide a guide to the short-term likelihood of future earthquakes.

Specific tectonic-activity information is available for few Quaternary structures in Utah. Age estimates, although commonly qualitative and broad, have been made for all structures listed in appendix A. However, approximately 75 percent of the entries in the appendix do not contain estimates of any of the other four parameters that were tabulated for this report.

Dating methods used to constrain the ages of surface faulting and other forms of tectonic deformation can yield either numeric ages, such as those commonly produced by radiocarbon, potassium-argon, and thermoluminescence dating, or relative- (and correlative-) age results, such as those produced by tephrochronology and the evaluation of stratigraphic relations, soil-profile development, geomorphic position, and fault-scarp morphology. In addition, many relative-age methods can be calibrated by independent chronologic control to yield calibrated ages (Colman and others, 1987; see Easterbrook, 1988 and Forman, 1989 for reviews of Quaternary dating techniques). Most age estimates for faulting pertain to the age of deposits that have been faulted or that bury a fault and therefore provide limiting ages for one or more surface-faulting events. Alternatively, age estimates based on fault-scarp morphology pertain directly, although often with considerable uncertainty, to the timing of faulting. Thus, the most effective studies of fault age and fault displacement have generally involved a combination of methods, such as mapping surficial geology, profiling fault scarps, interpreting the stratigraphy and soils exposed in natural cuts or trenches, and radiocarbon dating of organic material.

Broad, qualitative age estimates, based on loosely defined divisions of the Quaternary, have been assigned to many structures in appendix A using age estimates provided by earlier workers or my age interpretations of geologic and physiographic characteristics. Some of the guidelines followed in assigning ages were: (1) most fault scarps on unconsolidated deposits probably formed during the late Quaternary (past 500,000 years) (2) faulted deposits of unknown but possibly Quaternary age and faulted bedrock with preserved tectonic landforms define features suspected of being active during Quaternary time, and (3) prominent range fronts suggest a history of Quaternary tectonism on range-bounding faults or folds. A Quaternary(?) age has been applied both to poorly known, but possibly quite young, features and to better-known features thought to have had little or no late Quaternary activity.

Age information on Quaternary volcanic rocks is tabulated in appendix B. This table contains isotopic and geochemical-based ages, together with relative-age information derived from geomorphic and stratigraphic analyses of the rocks.

Each entry in appendices A and B pertains to a tectonic feature (or group of features) that appears on plates 1 and 2, respectively. Entries are shown on index maps and cross-referenced in alphabetical listings of features (appendix C) using location numbers. Entries in appendices A and B are also annotated with comments that provide relevant supplementary information, including conflicting interpretations by various workers and important assumptions regarding the data. However, no attempt has been made to systematically evaluate conflicting information or the quality of data.

Faults, folds, and volcanic rocks shown on plates 1 and 2 are grouped into one of five overlapping age categories, indicating probable age of most recent movement (or extrusive magmatic activity): Quaternary(?) (<1.65 million years), early to middle Pleistocene (130,000-1.65 million years), middle to late Pleistocene (10,000-750,000 years), late Pleistocene (10,000-130,000 years), and latest Pleistocene to Holocene (<30,000 years). The variable lengths of the time intervals reflect decreasing resolution with increasing age, whereas the overlap in age categories reflects the ambiguity inherent in most of the age estimates. In addition to providing a gross scheme for differentiating structures according to recency of movement (plate 1), the age divisions provide an approximation of tectonic activity. Structures in all but the youngest category would appear to have recurrence intervals on the order of 10,000 years or longer, whereas structures that have moved during the latest Pleistocene or Holocene may have shorter repeat times.

Plates 1 and 2 were digitally compiled using the public-domain software GSMap and GSDraw (Selner and Taylor, 1989). These graphics programs store geodetic coordinates (latitude/longitude) and handle variations in map scale and projection. Regional-scale (generally 1:100,000 or 1:250,000) maps on stable base were preferred for digitizing, although readily available maps that show features of interest were generally limited to paper copies, with scales ranging from 1:24,000 to 1:500,000. Sources used to digitize plates 1 and 2 are listed by location number (with a cross-reference to tectonic feature) in appendix C. Differences among features in the level of detail shown on plates 1 and 2 are mainly a function of original map scale. However, differences in map detail are also dependent on how structures are expressed at the ground surface, generally either as fault scarps, which reflect actual surface fault-rupture patterns, or as range fronts, which indicate the general, long-term trace of subjacent faults.

Plate 1 is intended to show, where possible, complete surface lengths of Quaternary structures without regard to the effects of surficial processes on preservation of geomorphic features. To that end, fault traces have been interpreted to be continuous where scarps or mapped faults are aligned and closely spaced (judged according to original map scale), especially where faults bound range blocks. Likewise, concealed faults inferred from topographic or geophysical data to lie near the base of range fronts are typically shown as single, continuous lines, undoubtedly oversimplifying actual surface fault-rupture patterns. Faults are not shown as interconnected where the continuity of surface faulting is in doubt, based on available mapping. However, areas beyond the end portions of mapped faults and between on-strike faults (notably along range fronts) may have experienced surface rupture during the Quaternary, a possibility that should be considered when evaluating earthquake hazards.

Many volcanic rocks in the state have been dated, but little work has been done to establish the timing of multiple extrusive events within volcanic fields. Some volcanic centers are represented by a single flow or series of flows, whereas others record long histories of episodic late Tertiary and Quaternary activity and consist of thick sequences of flows of apparent diverse ages (for example, Hamblin, 1970; Clark, 1977). As a whole, dated flows are relatively few in number and their stratigraphic contexts are not well documented. Reported ages on individual flows (appendix B) may be neither representative of nearby undated flows nor representative of the youngest flow in a given sequence. Careful mapping and intensive isotopic and geochemical work would be necessary to construct detailed flow chronologies and to confidently evaluate volcanic hazards. However, numeric ages, in combination with relative and correlative ages derived from geomorphic, stratigraphic, and map relations, are sufficient to ascribe general ages to most areas of volcanic rocks in the state. While acknowledging inadequacies in age information for some areas, volcanic rocks on plate 2 have been tentatively grouped into the same age categories as faults and folds on plate 1.

Plates 1 and 2, supplemented with additional spatial information from appendices A and B, are intended to serve as guides to the distribution of Quaternary structures and volcanic rocks in the state and not as substitutes for detailed, site-specific studies of the potential for surface faulting, volcanic eruptions, or other forms of tectonic deformation. Much of the information presented in this report is from regional, preliminary, or incomplete studies, and much remains to be learned about the nature and location of active tectonism in the state.

PREVIOUS WORK: REGIONAL STUDIES

This study builds upon a decade-old map compilation, at a scale of 1:500,000, and age classification of Quaternary faults in Utah by Anderson and Miller (1979). Paleoseismic investigations and general geologic mapping subsequent to this initial statewide compilation have substantially increased the amount of fault-activity information available for Utah. Additional Quaternary faults have been identified; fault ages have been estimated, refined, or reinterpreted; previously known faults have been remapped; and the origins or ages of some features previously identified as Quaternary faults have been questioned. Nakata and others (1982) incorporated some of this newer information in a 1:2,500,000-scale Quaternary fault map of the Basin and Range and Rio Grande Rift Provinces of the western United States. Several faults mapped as possibly being Quaternary in age by Anderson and Miller (1979) have especially questionable ages and therefore have been excluded from the present compilation. Such faults include those along the east sides of Curlew Valley, Blue Creek Valley, the West Hills, and the Newfoundland Mountains in northern Utah.

The most intensive paleoseismic work in the state has been done on the Wasatch fault zone in connection with a five-year program of earthquake-hazard research and implementation begun in 1983 under the auspices of the National Earthquake Hazards Reduction Program (NEHRP). Studies under this program have yielded much detailed information on the Wasatch fault zone (see summary papers by Machette and others, 1991, 1992) and important advances in the knowledge of normal-slip surface faulting in general. These studies build upon earlier studies of the fault by Woodward-Clyde Consultants in the late 1970s and early 1980s (Swan and others, 1980; Schwartz and Coppersmith, 1984) and pioneering observations made a century earlier by G.K. Gilbert (see Machette, 1988 for an overview of Gilbert's contributions). Although the Wasatch fault zone was the focus of research efforts under the NEHRP, neighboring faults such as the Hansel Valley, West Valley, and East Cache fault zones were also studied.

The Quaternary tectonics west of the Wasatch fault zone have been documented in several 1:250,000-scale maps of fault scarps on unconsolidated deposits for the Tooele, Delta, and Richfield 1° x 2° sheets, and Quaternary faults and folds for the Cedar City 1° x 2° sheet (Anderson and Bucknam, 1979; Bucknam and Anderson, 1979; Barnhard and Dodge, 1988; Anderson and Christenson, 1989). Ertec Western, Inc. (1981) produced Quaternary fault maps at the same scale within an overlapping portion of west-central Utah as part of a regional siting study for the MX missile program. Although these studies differed in scope and purpose, they generated similar types of information on relative or approximate ages of last movement and dimensions of surface offset. Ertec Western, Inc. (1981) sought to identify and characterize all young faults in their study region; U.S. Geological Survey workers generally used a more restrictive data set (scarps on alluvium) to indicate regional characteristics of earthquakes of about magnitude 7 or greater, as averaged over thousands of years (Bucknam and others, 1980).

Fault-bounded basins east of the Wasatch fault zone in north-central Utah have been the subject of a regional seismotectonic evaluation for dams by the U.S. Bureau of Reclamation (summarized in Sullivan and others, 1988). These workers identified a number of faults with documented or inferred late Quaternary displacements in a region where few potential sources of large-magnitude earthquakes had previously been recognized.

The recency of tectonism and salt-related deformation in the Paradox Basin of southeastern Utah has been studied by Woodward-Clyde Consultants (Woodward-Clyde Consultants, 1982; Biggar, 1985; Harden and others, 1985), as one aspect of a regional geologic assessment for nuclear waste storage, and by several other workers in the region (for example, Colman and others, 1986; Huntoon, 1988; Oviatt, 1988). Evidence of recent deformation related to movement or dissolution of salt has been found within collapse valleys formed along the crests of salt anticlines. However, the ages and seismogenic character of surface faulting in the region remain ambiguous.

The regional pattern of late Cenozoic volcanism within the Basin and Range - Colorado Plateau transition zone, where Quaternary volcanic rocks in the state are concentrated, has been documented by Best and others (1980) using original and previously available geochemical analyses and isotopic ages. In a comparable study, Nash (1986) described late Cenozoic volcanism for the northern portion of the transition zone in west-central Utah.

PHYSIOGRAPHIC AND TECTONIC SETTING

Utah is subdivided into three major physiographic and tectonic provinces: the Basin and Range, Middle Rocky Mountains, and Colorado Plateau (Hunt, 1967; figure 1A). The boundary between the Basin and Range and the other two provinces is a zone of transitional physio-tectonic characteristics. Major elements of these domains are described herein because of their relevance to later discussions concerning creation and preservation of tectonic landforms, spatial variations in Quaternary tectonism, and the effect of older tectonic patterns on Quaternary faulting styles and seismotectonics.

Western Utah lies within the northern Basin and Range Province. The province is noted for its regularly spaced (20- to 50-kilometers [12-31-mi] apart), north-trending, elongate mountain ranges and intervening broad, sediment-filled basins (figure 2). The ranges are bounded on one or, less commonly, both sides

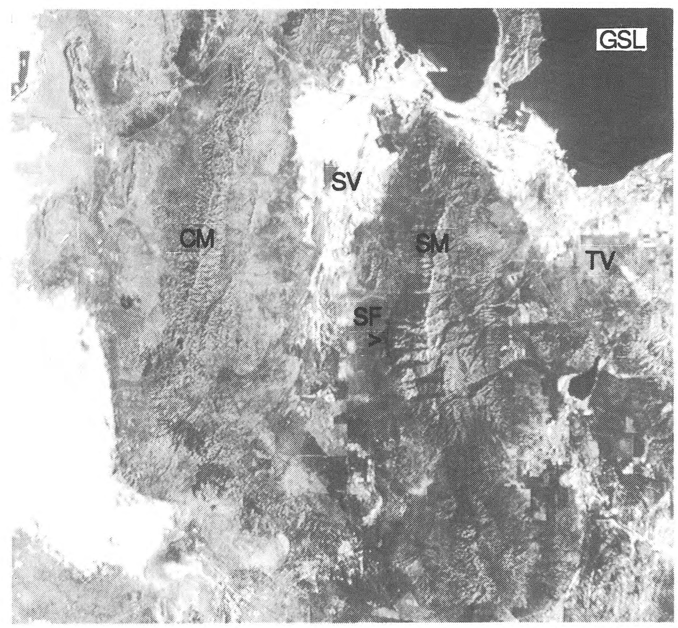


Figure 2. Landsat image showing an example of basin-and-range topography at the south end of the Great Salt Lake. The range-bounding Stansbury fault (SF), the Great Salt Lake (GSL), Tooele Valley (TV), Stansbury Mountains (SM), Skull Valley (SV), and Cedar Mountains (CM) are labeled. Landsat data provided by EOSAT Corp.; processed by the Department of Geography and Earth Resources, Utah State University (approximate scale 1:950,000).

by major normal faults that have moderate to steep dips at the surface. Much of the region, known also as the Great Basin, is internally drained. The northeast corner of Utah lies within the Middle Rocky Mountains Province, a region of mountainous terrain, stream valleys, and alluviated structural basins. Principal geographic features of the Middle Rocky Mountains in Utah are the geologically dissimilar north-trending Wasatch Range and east-trending Uinta Mountains. The northern Colorado Plateau of southeastern Utah is distinguished by its relatively high, generally flat topography and deeply incised canyons. Bedrock of the Plateau is spectacularly exposed, whereas surficial deposits characteristically are thin, localized, or absent.

The distinctive physiography of the Basin and Range Province is the product of roughly east-west horizontal extension during the late Cenozoic (Zoback and Zoback, 1989). This latest landscape-shaping period of tectonic deformation is part of an ill-defined, extensively debated history of middle and late Cenozoic crustal rifting. One view maintains that extensional faulting has had a distinct two-part history: block-faulting on widely spaced, mainly high-angle normal faults, which is responsible for the existing topography and continues to the present; and an earlier phase (post ~30 million years; pre-10 to -15 million years) of intense deformation associated with closely spaced, low-angle faults (Zoback and others, 1981; Eaton, 1982). A quite different perspective is that low- and high-angle faults have formed concurrently as part of the process of extension on large-displacement, low-angle shear zones which penetrate deep into the lithosphere (Wernicke, 1981). These and other models of extension (for example, Hamilton, 1987) in part reflect actual differences in ages, modes, and rates of deformation throughout the province (Anderson, 1989; Thompson and others, 1989), which may be controlled to some extent by the pre-existing structural fabric of the crust (Allmendinger and others, 1987). Cenozoic extension has been widely accompanied by igneous activity, which underwent a dramatic change from calc-alkalic volcanism to predominantly basaltic or bimodal basalt-rhyolite volcanism about 17 million years ago (Christiansen and Lipman, 1972). With time, both faulting and predominately basaltic volcanism have tended to become concentrated in relatively narrow zones along the margins of the province (Christiansen and McKee, 1978). In contrast to the interiors of the Middle Rocky Mountains and Colorado Plateau Provinces, where crustal thicknesses are about 40 to 50 kilometers (25-31 mi), the central Basin and Range Province has an attenuated crust that is about 30 kilometers (19 mi) thick (Smith and others, 1989). Basin-range extension has been superimposed on broadly coeval uplift, which has affected provinces adjacent to the Basin and Range as well (Stewart, 1978; Morgan and Swanberg, 1985).

Block faulting, which is the hallmark of the Basin and Range Province, extends tens of kilometers into the Middle Rocky Mountains and Colorado Plateau Provinces, forming a 100-kilometer- (62-mi-) wide zone of transitional tectonics and physiography (figure 1A). This north-trending boundary zone coincides with the southern portion of the Intermountain seismic belt, a broad zone of diffusely distributed earthquake epicenters (figures 1B and 3; Smith and Sbar, 1974; Smith and Arabasz, 1991), and it is associated with geophysical characteristics that are consistent with active extension (Smith and others, 1989). The zone is also spatially related to and may be inherited from older crustal boundary zones: namely, the eastern margin of a Late Proterozoic continental rift, the hingeline of a subsequent Paleozoic passive margin, and the leading edge of the Cretaceous to early Tertiary Sevier fold and thrust belt (Stokes, 1976; Allmendinger and others, 1987). Much of the transition zone lies beyond the regime of strongest basin-range deformation and, as a result, extensional structures overprint relatively intact compressional features formed during the Sevier orogeny. The

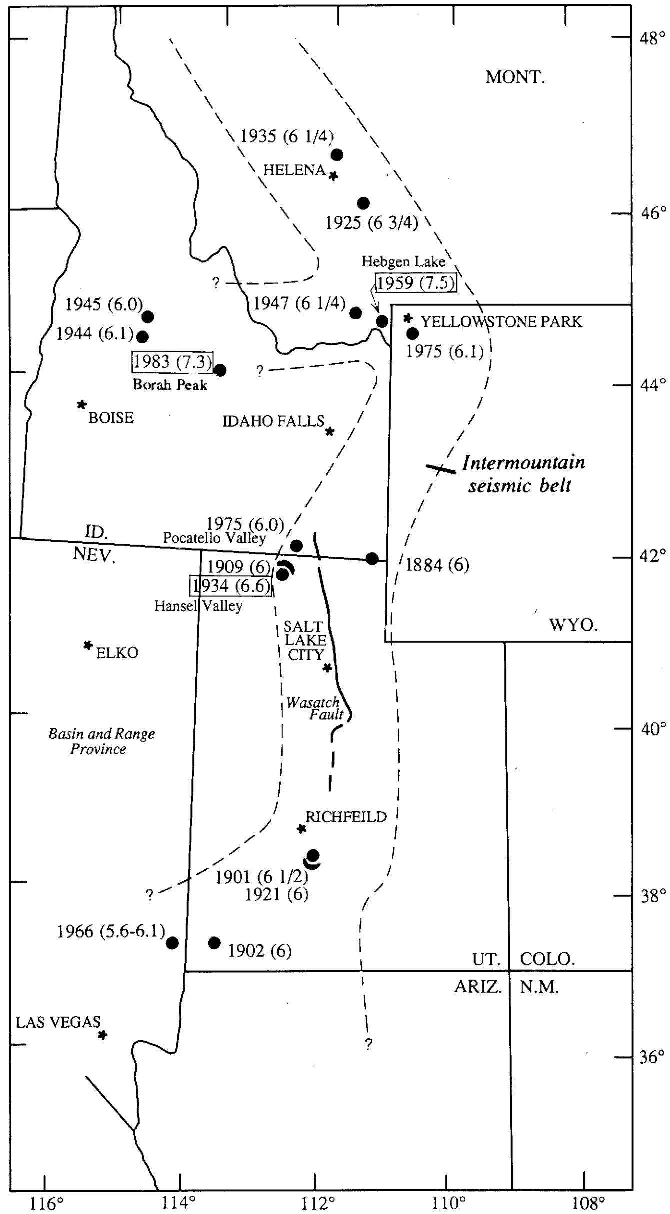


Figure 3. *Index map of the Intermountain seismic belt and historical earthquakes of magnitude 6.0 and greater (solid circles). The three events associated with surface faulting in the region are indicated by boxes (from Arabasz and others, 1992).*

structural fabric of the zone is largely a relict of eastward-directed, thin-skinned thrust sheets, portions of which appear to have accommodated movement in the reverse direction during basin-range extension (for example, Royse and others, 1975).

The physiographic boundary between the Basin and Range and Middle Rocky Mountains Provinces in Utah is considered to be the Wasatch Front, the prominent west-facing escarpment that follows the 340-kilometer- (211-mi-) long Wasatch fault zone (figure 1). However, this boundary is indistinct north of about 41.5 degrees north latitude, where displacement on the Wasatch fault zone diminishes and is at least partially supplanted by displacements farther east on other north-trending, range-bounding faults (notably, the East and West Cache fault zones and the eastern Bear Lake fault; figure 4). Normal faults similar to faults in the Basin and Range, but generally with shorter lengths and less total displacements, also lie directly east of the most active, central segments of the Wasatch fault zone and help to define a region of transitional tectonics and physiography east of the relatively abrupt, classic physiographic boundary (figures 1B and 4; Sullivan and others, 1988).

The Basin and Range - Colorado Plateau transition zone is a region of hybrid topography, basaltic volcanism, and complex crustal structure. The northern portion of the zone, known as the High Plateaus (figure 1A), consists of high-elevation tablelands separated by generally narrower, north-trending structural valleys (figure 5). The first-order physiographic development of the High Plateaus and much of the transition zone farther south (a less clearly defined region, figure 1A) can be ascribed to block faulting superimposed on plateau uplift. However, geologic and seismologic evidence indicates a complicated pattern of late Cenozoic and contemporary crustal deformation involving the coeval development of folds and faults and mixed modes of tectonic slip (Arabasz and Julander, 1986; Anderson and Christenson, 1989; Anderson and Barnhard, 1992). This deformation has been accompanied by mafic and generally older silicic volcanism within and adjacent to the transition zone (Best and others, 1980). Interpretation of the late Cenozoic tectonic history of the northern High Plateaus is complicated by the structural effects of Sevier-age thrusting (for example, Standlee, 1982) and possibly episodic diapirism of the Jurassic Arapien Shale, an evaporite-rich, structurally weak unit in central Utah (for example, Witkind, 1982). The areal distribution of Tertiary ash-flow tuffs within the southern High Plateaus indicates that structural differentiation between the Basin and Range and Colorado Plateau Provinces began along the present primary physiographic boundary at the end of Oligocene time (Rowley and others, 1978). The presence of young faulting and volcanism east of this boundary (figure 1) suggests that zones of extension have expanded, encroaching into more stable areas to the east (Best and Hamblin, 1978; Keller and others, 1979; Thompson and Zoback, 1979; Morgan and Swanberg, 1985).

East of the transition zone, the Colorado Plateau is a relatively coherent and tectonically stable block which has experienced 2 kilometers (1.2 mi) of epeirogenic uplift during the Cenozoic (Morgan and Swanberg, 1985). The region is underlain by generally horizontal sedimentary strata, disrupted locally by early Tertiary Laramide basement-block uplifts and Oligocene igneous intrusions. The domal, fault-bounded uplifts have variable trends and include the east-trending Uinta Mountains north of the Colorado Plateau. The modern stress field of the Plateau interior was originally thought to be compressive (Thompson and Zoback, 1979; Zoback and Zoback, 1980). However, recent evidence from small-magnitude earthquakes indicates that, although differential stresses are apparently low and variable in magnitude, most of the region may be characterized by horizontal northeast-oriented extension occurring on a combination of normal and strike-slip faults (Wong and Humphrey, 1989; Zoback and Zoback, 1989). Outside of a subregion known as the Paradox Basin, the interior of the Colorado Plateau in Utah appears to be virtually unaffected by recent crustal deformation. Only a few areas have evidence, generally subtle or ambiguous, of minor amounts of possible Quaternary faulting (plate 1; appendix A).

A zone of late Paleozoic and younger deformation within the Paradox Basin, a late Paleozoic depositional trough interior to the Colorado Plateau (figure 1A), is related to the mobility and solubility of evaporites. Major structures of the Paradox Basin include large salt anticlines and faults related both to late Cenozoic dissolutional collapse along the crests of the anticlines (figure 6) and to older, deep-seated tectonics. The structural grain of this subprovince has a northwest orientation, distinct from the western margin of the Colorado Plateau, where most faults trend north to northeast.

EARTHQUAKE MAGNITUDES AND SURFACE FAULT-RUPTURE DIMENSIONS

Based on the record of historical seismicity in the Intermountain seismic belt and the Basin and Range Province, the magnitude threshold for surface fault rupture in Utah appears to be about 6 to 6.5 (Arabasz and others, 1992). Bucknam and others (1980) noted that all historical earthquakes in the Great Basin with magnitudes (M_L) larger than 6.3 (seven earthquakes) produced normal-fault displacements at the earth's surface. Most of those earthquakes were in the central Nevada - eastern California seismic belt. One event in the eastern Great Basin, the 1934 magnitude 6.6 Hansel Valley earthquake, was the smallest of three historical surface-faulting events in the Intermountain seismic belt and the only one in Utah (figure 3).

Other historical earthquakes in the Utah portion of the Intermountain seismic belt with magnitudes of 6 to 6.5 (eight earthquakes, including two in 1921 with identical estimated location and size; figure 3) occurred without identified surface rupture, suggesting a relatively high threshold for surface faulting in this region (Arabasz and Julander, 1986). However, because of variations in earthquake-source parameters and geologic setting, and difficulties in identifying minor displacements, actual minimum magnitudes for surface faulting may be expected to vary and to be smaller than recognized (Arabasz and Julander, 1986; also see Bonilla, 1988 for general discussion).

Additionally, earthquakes slightly smaller than the threshold for surface faulting may produce surface folding or warping. Surface deformation along portions of the West Valley fault zone in the Salt Lake Valley is expressed as monoclinal flexuring and minor step faulting, implying earthquakes that are near the surface-rupture threshold (Keaton and others, 1987; appendix A, location no. 12-7). A study of the neotectonics of Pocatello Valley in southern Idaho (McCalpin and others, 1992) found that the 1975 magnitude (M_L) 6.0 earthquake (figure 3), which was associated with valley-floor subsidence of up to 0.13 meters (0.43 ft) (Bucknam, 1976), may be typical of the size of events that have resulted in substantial cumulative warping but no faulting of late Quaternary deposits along the eastern range front.

Dimensions of surface fault rupture are likewise related to earthquake magnitude (see Slemmons, 1977 and Bonilla and others, 1984 for empirical relations). All historical surface-faulting earthquakes less than magnitude 6.8 in the Basin and

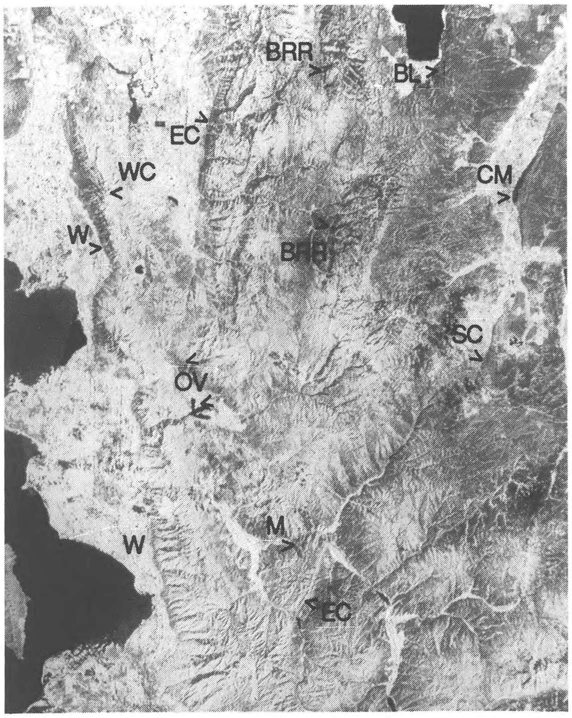


Figure 4. Landsat image of the Basin and Range - Middle Rocky Mountains transition zone (figure 1A) north of about 40°45' north latitude in Utah. Some of the more prominent faults with known or suspected Quaternary movement are labeled: Wasatch (W), West Cache (WC), East Cache (EC), Bear River Range (BRR), Bear Lake (BL), Crawford Mountains (CM), Saleratus Creek (SC), Ogden Valley (OV), Morgan (M), East Canyon (EC). Landsat data provided by EOSAT Corp.; processed by the Department of Geography and Earth Resources, Utah State University (approximate scale 1:1,430,000).

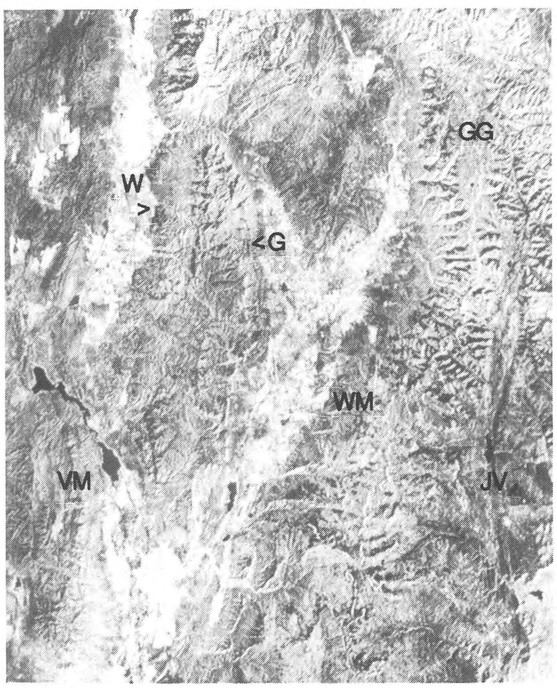


Figure 5. Landsat image of the northern High Plateaus in the Basin and Range - Colorado Plateau transition zone (figure 1A), between about 39° and 39°50' north latitude. Some of the more prominent faults and folds with known or suspected Quaternary movement are labeled: Wasatch fault zone (W), Gunnison fault (G), Gooseberry graben (GG), Joes Valley fault zone (JV), Wasatch monocline (WM), Valley Mountains monocline (VM). Landstat data provided by EOSAT Corp.; processed by the Department of Geography and Earth Resources, Utah State University (approximate scale 1:1,000,000).

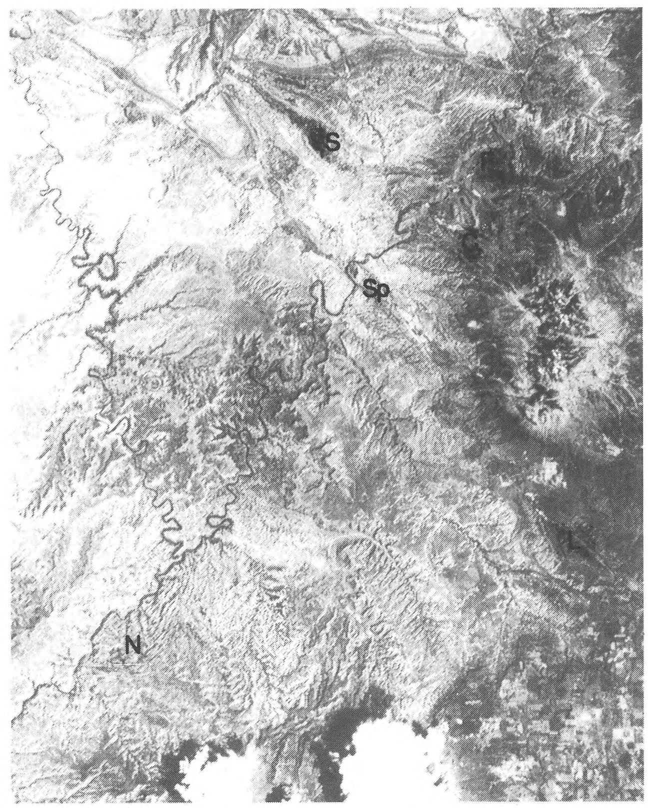


Figure 6. Landsat image of the Paradox Basin in the Colorado Plateau (figure 1A) north of about 38° north latitude. The Needles fault zone (N) and major late Cenozoic collapse valleys formed along the crests of salt anticlines are labeled: Salt Valley (S), Fisher Valley (F), Castle Valley (C), Spanish Valley (Sp), Lisbon Valley (L). Landsat data provided by EOSAT Corp.; processed by the Department of Geography and Earth Resources, Utah State University (approximate scale 1:1,150,000).

Range Province have resulted in maximum displacements of less than a meter (3 ft), whereas most earthquakes greater than magnitude 7 have been associated with more than a few meters of maximum displacement (Bucknam and others, 1980). Observations made from historical earthquakes in the Intermountain seismic belt and throughout the extensional western interior of the United States similarly indicate that magnitude 7 or greater earthquakes are accompanied by surface displacements of more than a meter (3 ft), and by surface-rupture lengths of more than 15-20 kilometers (9-12 mi) (Doser, 1985a; Doser and Smith, 1989).

The 1934 magnitude (M_L) 6.6 Hansel Valley, Utah, earthquake produced vertical displacements of less than 0.2 meters (0.7 ft) (estimated average) to 0.5 meters (1.6 ft) (maximum) along a rupture about 11.5 kilometers (7.1 mi) long (figure 7; Slemmons, 1977; Machette and others, 1991). An analysis of first-motion data for this earthquake suggests that strike-slip motion occurred on the fault (Doser, 1989), although there is equivocal evidence of only minor amounts (up to 0.25 meters [0.82 ft]) of strike-slip displacement at the surface (Walter, 1934; dePolo and others, 1989).

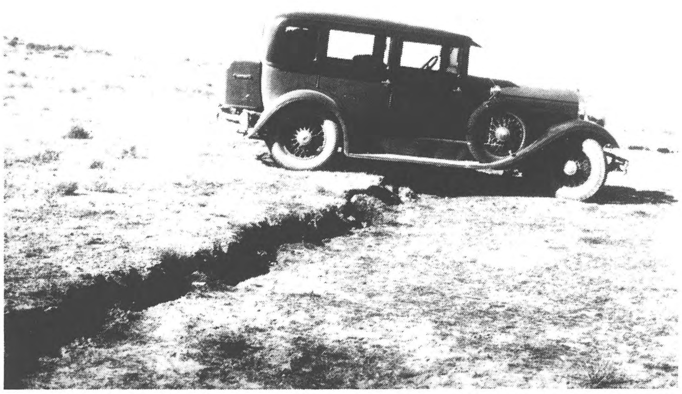


Figure 7. *Fault scarp formed during the 1934 Hansel Valley earthquake, magnitude 6.6 (photo courtesy of Robert B. Smith, University of Utah Seismograph Stations).*

The largest historical earthquake with dominantly normal-slip movement in the Basin and Range Province was the 1915 Pleasant Valley, Nevada, earthquake, with an estimated magnitude of about 7.8 (Abe, 1981; Doser, 1988), a surface-rupture length of about 59 kilometers (37 mi), and surface displacements of 2 meters (6.6 ft) (average) to 5.8 meters (19 ft) (maximum) (Wallace, 1984a). The largest two events in the eastern Basin and Range/Intermountain seismic belt were the 1959 M_S 7.5 Hebgen Lake, Montana, and the 1983 M_S 7.3 Borah Peak, Idaho, earthquakes (figure 3; Doser, 1985b; Doser and Smith, 1985; Smith and others, 1985). The Hebgen Lake earthquake produced a combined surface-rupture length of about 35 kilometers (22 mi) along two faults and surface displacements of about 2.0 meters (6.6 ft) (average) to 6.7 meters (22 ft) (maximum) (Witkind and others, 1962; U.S. Geological Survey, 1964; Witkind, 1964; Hall and Sablock, 1985; summarized in Machette and others, 1991). The Borah Peak earthquake had a rupture length of about 36 kilometers (22 mi) and displacements of 0.8 meters (2.6 ft) (average) to 2.7 meters (8.9 ft) (maximum) (Crone and others, 1987; Machette and others, 1991). These three historical events serve as models for the maximum earthquake size to be expected in the Utah region (Smith and Richins, 1984; Doser, 1985a; Arabasz and others, 1992).

Earthquakes below the magnitude threshold for surface faulting but still capable of producing damaging ground motions are relatively common in Utah. On the basis of a 25-year instrumental record of seismicity, Arabasz and others (1992) estimated an average return period of about 10 years for events of magnitude (M_L) 5.0 or greater in the Wasatch Front region. Moderate-size earthquakes of about magnitude 5 have the potential to cause damage to structures (Hopper, 1988, in press) and to initiate landslides, rock falls, and liquefaction (Youd and Perkins, 1978; Keefer, 1984). Since the beginning of Utah's historical earthquake record in 1850, there have been an estimated fifteen independent earthquakes with magnitudes of about 5.5 or greater (an average inter-event time since 1884 of 6-7 years) in the entire Utah region; eight events have had magnitudes of about 6 or greater (Arabasz and others, 1992; figure 3). The locations of these relatively abundant, moderate-size earthquakes could not have been predicted from surface geology alone. These and smaller events do not appear to be directly associated with mapped Quaternary faults, but may instead be related to slip on secondary, buried faults that have no simple surface expression (Arabasz, 1984; Smith and Bruhn, 1984; Arabasz and Julander, 1986).

The historical earthquake record in Utah may be sufficient to estimate regional rates of earthquake activity below the threshold for surface fault rupture, but the record is too short relative to the seismic flux to adequately characterize the occurrence of infrequent, large-magnitude earthquakes (Arabasz and Smith, 1981; Arabasz and others, 1992). The seismic cycle of major faults is long; geologic evidence indicates that the recurrence interval for large earthquakes on individual faults or fault segments is on the order of thousands of years or more (Wallace, 1981). Thus, although dozens of potential earthquake sources are recognized in the geologic record, earthquakes large enough to produce surface faulting are rare in the historical record of the Utah region. To properly characterize seismic-source zones and estimate probabilities of damaging earthquakes, the brief historical record of mainly small-to-moderate events must be supplemented with long-term, geologic information on the space-time distribution of large, surface-faulting earthquakes (Youngs and others, 1987, in press; Arabasz and others, 1992).

COMPLETENESS OF THE QUATERNARY TECTONIC RECORD

Geomorphic setting and surficial processes set conditions for preservation of surface fault ruptures and other types of surface deformation. These factors also determine how well the timing of past tectonic events can be resolved. Hence, it is important to consider the geomorphic and stratigraphic framework when interpreting the record of Quaternary tectonism in Utah.

Information on Quaternary deformation is relatively scarce in bedrock areas because erosion is the dominant surficial process. Quaternary deposits are generally thin, localized, very young, or landslide-prone within the deeply incised Colorado Plateau Province and within range blocks and mountainous areas elsewhere in the state, making it difficult to assess the recency of tectonic activity. The freshness of tectonic landforms, such as the steepness and linearity of fault-controlled bedrock escarpments, provides approximate age control for faulting in areas that lack surficial deposits. In the Basin and Range - Colorado Plateau transition zone, volcanic rocks serve as discrete, erosionally resistant datums, but are frequently too young to date using conventional potassium-argon methods or provide only maximum limiting ages for younger deformation. In the Basin and Range Province, tectonic deformation is concentrated on major, range-bounding faults. Recurrent surface-faulting activity in this region is indicated by prominent range fronts and, at least locally, by scarps in Quaternary basin fill.

Even in areas where unconsolidated deposits are relatively thick and continuous, the record of recent faulting can be difficult to decipher and is rarely complete. Surface faulting is most easily identified from fault scarps, but scarps degrade over time and are commonly destroyed by stream erosion, lacustrine and alluvial-fan deposition, and other surficial processes. Geomorphic activity is greatest along tectonically active range fronts, where steep bedrock slopes abut gently sloping piedmonts. In this geomorphic environment, where faulting occurs at or near the bedrock-alluvium contact, scarps may persist for less than the interval of time between surface-faulting events. Even so, the coarseness of material deposited along range fronts enhances scarp preservation, relative to more erodible, finer grained deposits in the center of basins.

The size and frequency of surface-faulting events also affects the completeness of the fault-scarp record, because large scarps are preferentially preserved. Faults with long recurrence intervals and consistently small displacements in unconsolidated deposits may not be evidenced by scarps. Approximately one-meter- (3-ft-) high, hundred-thousand-year-old alluvial scarps are rare to absent in the Basin and Range Province (Machette, referenced in Hanks and others, 1984). In contrast, faults that experience a succession of closely spaced and/or large surface displacements may produce steep, high scarps capable of persisting for several hundreds of thousands of years. Also, larger scarps are easier to identify and map. All scarps included in regional mapping by the U.S. Geological Survey are the result of at least a meter (3 ft) of vertical displacement, providing a record of earthquakes greater than about magnitude 7 (Bucknam and others, 1980).

Once identified, surface fault ruptures are often difficult to date because most faulting environments in Utah lack the types of deposits amenable to Quaternary dating methods. In particular, organic material necessary for radiocarbon dating is commonly oxidized and removed from the alluvial record as a result of the semi-arid climate that has characterized most of Utah throughout the Holocene.

An exception to the general lack of dating opportunities in the state is provided by pluvial lake datums in western Utah. Lake Bonneville covered much of the eastern Great Basin during the latest Pleistocene (about 10,000 to 30,000 years ago) and left an extensive record of deposits and landforms. This record includes well-preserved evidence of a highstand shoreline (the Bonneville shoreline), which formed at an elevation of 1,552 meters (5,092 ft) between about 15,000 and 16,000 years ago, and another threshold-controlled level (the Provo shoreline), which existed at 1,444 meters (4,738 ft) between about 14,000 and 15,000 years ago (Curry, 1982; Currey and Oviatt, 1985). Detailed information on the chronology and morphostratigraphy of this lake cycle provides excellent region-wide age control for identifying latest Pleistocene and Holocene tectonism in western Utah (for example, Currey, 1982). The age of Lake Bonneville and broadly synchronous glaciation of mountainous areas is the basis for defining the youngest age category (<30,000 years) of tectonic features on plates 1 and 2. Although lake processes created pervasive time and elevation lines for subsequent deformation in much of western Utah, they also obscured evidence of older Pleistocene deformation and may have hampered identification of some Quaternary structures.

DISTRIBUTION AND PATTERNS OF QUATERNARY TECTONIC FEATURES

Temporal and spatial grouping and migration of faulting events, whether between individual faults or across subprovinces, appear to characterize tectonic activity in the Basin and Range Province (Wallace, 1984b, 1987). Recognizing regional space-time patterns of Quaternary tectonism is important for improving our understanding of surface faulting and earthquake hazards, especially in areas where individual fault histories are not well defined. Regional differences in recency of fault movement in Utah have been used by the U.S. Geological Survey to define regional seismic-source zones and prepare national ground-motion hazard maps (Algermissen and others, 1982, 1990; Thenhaus, 1983). Additions to and refinements in the tectonic-activity data, such as encompassed by this report, continue to clarify patterns of activity and enable more accurate modeling of seismic-source zones across the state. This section describes regional trends in tectonic behavior during the Quaternary, as recognized both in previous studies and from the results of this latest compilation.

Tectonic activity has been nonuniform throughout Utah during the Quaternary, being concentrated along the transitional eastern boundary of the Basin and Range Province (figure 1B; plate 1). In contrast, active features are relatively sparse along much of the state line with Nevada and in the northwestern corner and most of the eastern third of Utah. Subpatterns of tectonic activity are evident for certain time frames. During the late Quaternary, and perhaps earlier, the Wasatch fault zone and the Hurricane and Sevier faults to the south (figure 1B) may have been among the most active tectonic features in the state. During the Holocene, the central segments of the Wasatch fault zone clearly have been the most recurrently active (appendix A). Many other faults in the Wasatch Front region have also experienced latest Pleistocene or Holocene surface displacements (plate 1), and faults in an area of west-central Utah have each had a displacement event during the last 15,000 years.

Deformation has been manifest as folding and warping, as well as faulting, in the Paradox Basin of the Colorado Plateau and in a region of central Utah (the High Plateaus) between the southern segments of the Wasatch fault zone and the northern end of the Hurricane and Sevier faults (figure 1; plate 1). Mechanisms for folding appear to vary and may include salt diapirism and dissolution, plateau-block uplift, and local adjustments to faulting.

Quaternary volcanic rocks are abundant in west-central and southwestern Utah (figure 1; plate 2). The northern group of basaltic and rhyolitic rocks in west-central Utah has a north-south alignment along the eastern boundary of the Basin and Range and a close association with intrabasin faults. Basaltic flows in southwestern Utah have a less well defined distribution oblique to the province boundary, and vents do not generally coincide with mapped faults.

Wasatch Front Region

Quaternary tectonic features in northern Utah are concentrated within about a 200-kilometer- (124-mi-) wide zone centered on the Wasatch fault zone (figure 8) and coincident with the Intermountain seismic belt (figure 3). The Wasatch fault zone is by far the longest (340 kilometers [211 mi]) and most tectonically active structure in Utah, with abundant evidence of recurrent surface rupture during the Holocene (for example, figure 9; Schwartz and Coppersmith, 1984; Machette and others, 1991, 1992). More than two dozen other faults (or zones of faulting, as identified in appendix A) in the Wasatch Front region show evidence of one or more latest Pleistocene to Holocene surface-faulting events (figure 8; plate 1). The East Cache, eastern Bear Lake, Bear River, West Valley, and East Great Salt Lake fault zones, among others, have evidence documenting or suggesting multiple latest Quaternary displacements. These faults appear to be second only to the Wasatch fault zone in levels of recent activity. Although the displacement histories of most faults are not known in detail, sufficient documentation on ages of faulting exists to provide an estimate of the total number and average regional recurrence interval for large-magnitude, surface-faulting earthquakes within the Wasatch Front.

In the past 15,000 years (slightly longer or shorter for some faulting records), an estimated 50 to 120 large-magnitude earthquakes (with a preferred value of 85) have occurred in the 85,000-square-kilometer (82,833-mi^2) Wasatch Front region (as earlier defined; figure 8) on as many as 37 faults (table 1). Normalized for area, this amounts to an average recurrence rate of 3.9 to 9.4 events per 10,000 years per 10,000 square kilometers (3,863 mi^2). The range in estimates reflects uncertainties in the number and timing of surface-faulting events on individual faults and, in part, an assumption that some faults may not be the nucleation source of large earthquakes (appendix A). Some faults may rupture in response to events on nearby faults, whereas other faults may rupture in the absence of large earthquakes owing to their association with volcanic processes or poorly understood seismogenic properties associated with their subsurface geometries (as discussed in the next section on Styles of faulting and tectonic processes). However, the range in estimates does not reflect probable undercounting of events near the minimum magnitude for surface faulting; for this reason, the estimated range should be regarded as a minimum for earthquakes larger than about magnitude 6.5 in the region.

Based on a (minimum) count of 50 to 120 events in the past 15,000 years, the (maximum) average regional recurrence interval for surface-faulting earthquakes within the Wasatch Front region is 125 to 300 years. The preferred, single-value estimate (based on 85 events) is 176 years (table 1). For comparison, Arabasz and others (1992) obtained a slightly lower, but similar range of recurrence-interval estimates (60 to 250 years, with a preferred value of 120 years) for earthquakes of magnitude 6.5 or greater in the same region by extrapolating recurrence relations for historical (1962-1985) earthquakes (figure 10). Doser and Smith (1982) used seismic moment rates to predict a recurrence interval of about 140 to 310 years for magnitude 7.0-7.5 earthquakes in the identical Wasatch Front region. Thus, there appears to be approximate agreement between recurrence-interval estimates derived using both geologic and historical data sets.

Half of the estimated 50 to 120 post-Bonneville surface-faulting earthquakes in the Wasatch Front region have been on the Wasatch fault zone (table 1). Average Holocene slip rates of about 1 to 2 mm/yr (0.04-0.08 in/yr) along the central portion of the fault zone (the five segments between Brigham City and Nephi; Machette and others, 1991) are as much as one or two orders of magnitude greater than slip rates estimated for other faults in the state (which commonly range from about 0.01 to 0.5 mm/yr [0.0004-0.02 in/yr]; appendix A) and for the Wasatch fault zone since the middle Pleistocene (a rate of 0.1-0.3 mm/yr [0.004-0.012 in/yr] for the past 150,000-250,000 years; Machette and others, 1992). A notable exception is the Bear River fault zone, at the eastern margin of the tectonic transition zone north of the Uinta Mountains, which has had a similarly high slip rate (about 0.8 - 2.7 mm/yr [0.0032-0.011 in/yr]) during late Holocene time. This feature is unique, however, because it appears to be a very young zone of normal faulting superimposed on a system of ancient thrust faults. The entire displacement history of the Bear River fault zone consists of two movements during the late Holocene (appendix A, location no. 12-18).

Paleoseismic data for the middle to late Holocene (past 6,000 years) indicate that recurrence intervals for surface-faulting earthquakes on individual segments of the central Wasatch fault zone have varied from about 500 to 4,000 years (figure 11). The average composite recurrence interval (average time between faulting events anywhere in the central Wasatch fault zone) for this time period is 395 ± 60 years, although the actual timing of events during much of this period appears to be randomly distributed (Machette and others, 1991).

An exception to the general randomness of the earthquake record for the past 6,000 years is an episode of clustering between about 400 and 1,500 years ago, when almost the entire central portion of the fault zone (excluding the Brigham City segment and including the Levan segment) ruptured in a sequence of six(?) large earthquakes (figure 11). This activity yields an average composite recurrence interval of 220 years, about half the longer term (middle to late Holocene) composite value (Machette and others, 1991). In this context, the apparent lack of faulting on the Brigham City segment in the past 3,600

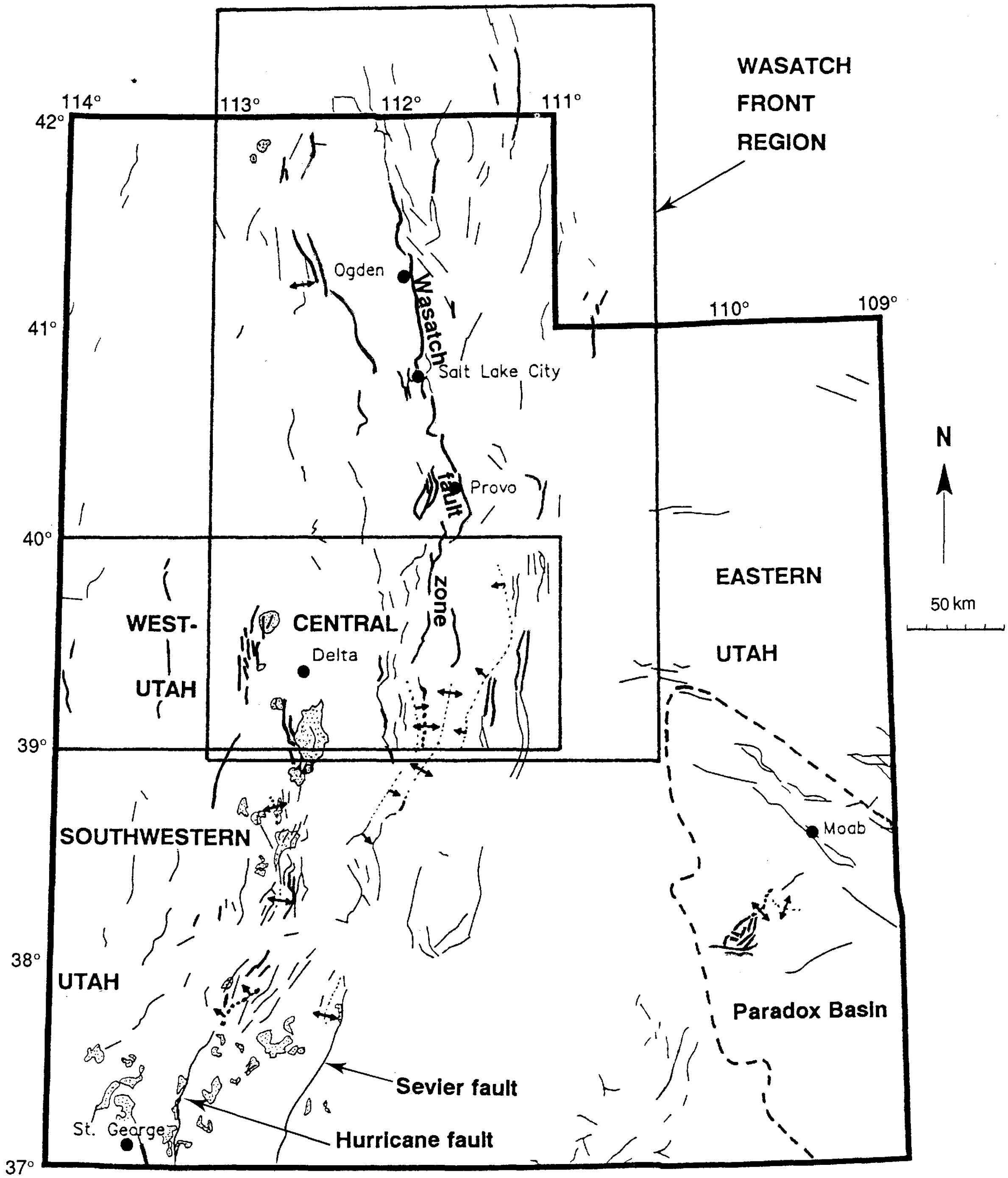


Figure 8. Quaternary tectonic map (generalized from plates 1 and 2) showing regions used to organize text discussion on the distribution and patterns of Quaternary tectonism. Darker lines indicate faults and folds with probable latest Pleistocene to Holocene activity. Stippled areas are volcanic rocks. The Wasatch Front region is shown as defined by Arabasz and others (1992); the west-central Utah region is modified from Bucknam and others (1980).

A.

B.

Figure 9. Oblique aerial views of the Wasatch fault zone: (A) Salt Lake City segment (location no. 12-6), where the fault displaces late Pleistocene glacial moraines (courtesy of William R. Lund) and stream alluvium at the mouths of Little Cottonwood Canyon (left) and Bells Canyon (right). Individual scarps are tens of meters high and are the result of recurrent faulting. (B) Nephi segment (location no. 13-21), near Mona, where the most-recent-event scarp displaces the apices of alluvial fans (arrows) and colluvial slopes along the base of the range.

Table 1. *Surface-faulting earthquakes in the past 15,000 years in the Wasatch Front region*

Location Number	Fault	Time Interval ($x10^3$ yr B.P.)	Number of Earthquakes+ Minimum/Maximum/Preferred		
6-1	Hansel Valley	<15	2	3	3
6-2	North Promontory	<15 ?	1	4	2 ?
6-6	Brigham City segment, Wasatch	<13-14	6	10	8
6-7	Big Pass	<15 ?	0	1 ?	1
6-8	East Great Salt Lake	<15	4 ?	8 ?	6 ?
6-13	West Cache	<15 ?	0	1 ?	1 ?
7-7	Topliff Hill	<15 ?	0	1 ?	0
7-10	Stansbury	<15 ?	0	1 ?	0
7-14	Mercur	<15 ?	0	1 ?	0
7-15	northern Oquirrh	<15	1	1	1
7-16	Puddle Valley	<15	1	1 ?	1
8-1	Drum Mountains	<13.5	0*	1 ?	1
8-5	Clear Lake	<15 ?	0*	2 ?	1
8-19	Scipio Valley	<15 ?	1	2	1
8-21	Pavant Range	<10 ?	1	1 ?	1
9-20	Tabernacle	<14	0*	2 ?	1
9-28	Cricket Mountains	<15 ?	0	1 ?	1 ?
9-33	Red Canyon	<10 ?	1	1 ?	1
11-2	East Cache	<15	2	2	2
11-8	south segment, eastern Bear Lake	<13	2	2 ?	2
NA	central segment, eastern Bear Lake	<13 ?	1	2 ?	2 ?
NA (see 11-5)	western Bear Lake	<11	0*	1	1
11-10	Mantua area	<10 ?	0	1 ?	0 ?
11-18	Morgan	<8-9	1	1	1
11-22	Weber segment, Wasatch	<15	7	15	10
12-3	Provo segment, Wasatch	<15	7 ?	10 ?	9 ?
12-4	Strawberry	<15-30	2	3	2 ?
12-6	Salt Lake City segment, Wasatch	<19	6 ?	10 ?	7
12-(7-8)	West Valley	<13	0*	7 ?	3* ?
12-18	Bear River	<15	0*	2	2
12-19	Utah Lake	<13 ?	0*	3 ?	2 ?
13-(5-7)	Joes Valley	<14-30	0*	3 ?	2 ?
13-13	Snow Lake	<10 ?	0*	2 ?	1 ?
13-18	Gunnison	<10 ?	0*	2 ?	1 ?
13-21	Nephi segment, Wasatch	<15 ?	3 ?	9 ?	6 ?
13-22	Levan segment, Wasatch	<15 ?	1	2 ?	1
13-23	Fayette segment, Wasatch	<15 ?	0 ?	1 ?	1
	Total Number of Earthquakes		**50**	**120**	**85**
	Regional Recurrence Interval		**300 years**	**125 years**	**176 years**

+ Values are based on information contained in appendix A and references cited therein.
* Value assumes some surface-faulting events do not correspond directly to generation of large earthquakes.
NA = Not Applicable. Fault is in Idaho.

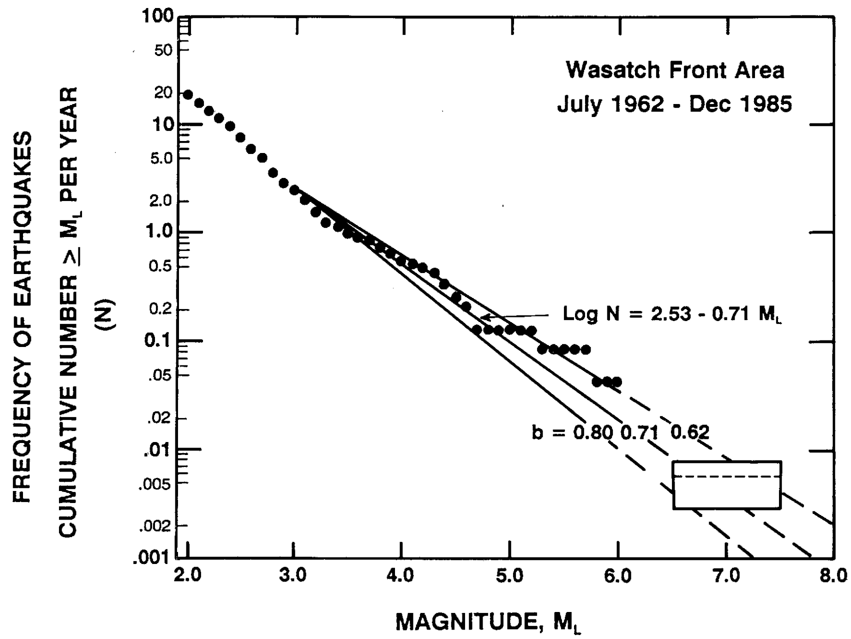


Figure 10. *Cumulative frequency - magnitude plot for independent main shocks in the Wasatch Front region from July 1962 through December 1985 (from Arabasz and others, 1992). The recurrence relations (a best-fit and two bounding lines) are for earthquakes above M_L3.0, but are extrapolated (dashed portions of lines) for earthquakes above M_L6.0. The box represents the range in recurrence-interval estimates for large-magnitude earthquakes (125-300 years, with a preferred value of 176 years represented by dashed line within box) determined in the present study using paleoseismic data.*

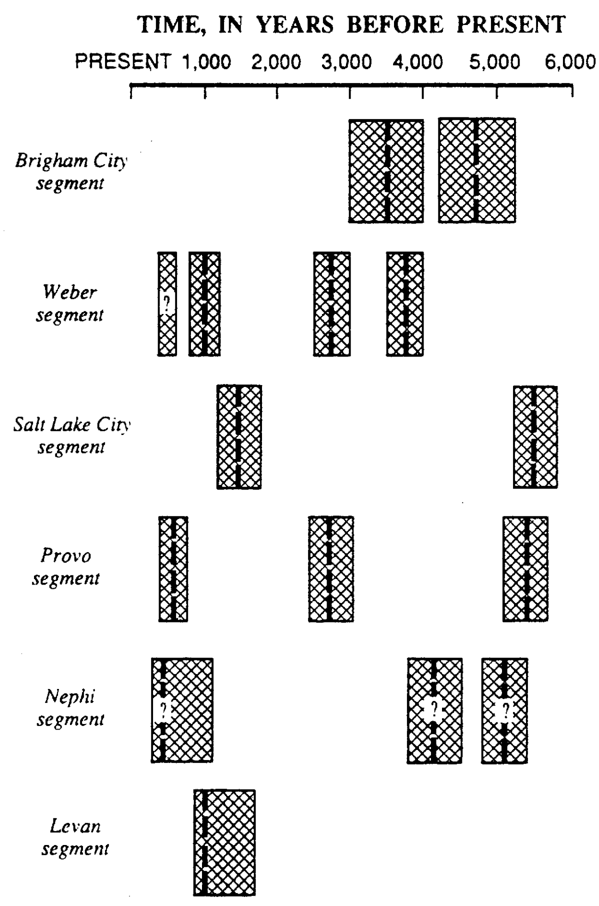


Figure 11. *Timing of surface-faulting events on segments of the Wasatch fault zone during the past 6,000 years. Heavy dashed lines indicate best estimates for timing of events; cross-hachure pattern indicates likely time limits, based on radiocarbon and thermoluminescence age estimates (from Machette and others, 1991).*

years may indicate a relatively higher probability of faulting for that segment (Nishenko and Schwartz, 1990; appendix A, location no. 6-6). The pattern of temporal clustering of earthquakes on the Wasatch fault zone may be analogous, although on a longer time scale, to a sequence of eleven large-magnitude earthquakes that occurred after 1860 in the central Nevada - eastern California seismic belt (Machette and others, 1991).

Evidence for the timing and magnitude of latest Quaternary surface faulting from several faults in the Lake Bonneville basin suggests that a causal relation may exist between the loading from deep-lake cycles and patterns of strain release. The movement histories of the Hansel Valley fault and the central segment of the East Cache fault zone appear to be characterized by relatively large events during Bonneville time and smaller, less frequent events during the Holocene (appendix A, location nos. 6-1 and 11-2). Rapid changes in crustal stresses caused by rapid filling and draining of the lake (especially the large, geologically instantaneous drop from the Bonneville shoreline to the Provo shoreline) may have been a regional triggering mechanism for events on these and other faults in the Bonneville basin (McCalpin and others, 1992). Evidence of small, infrequent events during interpluvial time, together with the substantial amounts of strike-slip motion detected for the Hansel Valley and some other Basin and Range earthquakes, suggested to Doser (1989) that in some parts of the province, localized tectonic processes may be currently more important than processes associated with classic basin-range extension.

The opposite faulting behavior with respect to deep-lake cycles has also been noted in the Bonneville basin. On the West Valley fault zone, evidence suggests an absence of faulting during Bonneville time (13,000-26,000 years ago) and as many as six or seven faulting events in the last 13,000 years (appendix A, location nos. 12-7 and 12-8). This alternate pattern of strain release may also reflect a response to changes in crustal loading, as it suggests a causal relation between increased faulting activity in the Holocene and isostatic rebound following the regression of Lake Bonneville (Keaton and others, 1987). Isostatic rebound has also been invoked to explain why post-Bonneville slip rates on the Wasatch fault zone are substantially higher than long-term (late Quaternary) rates (Machette and others, 1986, 1992).

The central segment of the East Cache fault zone and the southern segment of the eastern Bear Lake fault, both of which have experienced recurrent latest Pleistocene to Holocene movement, are part of a regional V-shaped belt of latest Quaternary faulting that extends northward in a right-stepping en echelon pattern from the Brigham City segment of the Wasatch fault zone to the Yellowstone area and from there trends westward into southwestern Montana and central Idaho. This pattern of young faulting activity, which includes the 1959 Hebgen Lake and 1983 Borah Peak surface-rupturing earthquakes, may be related in part to the northeastward migration of the Yellowstone hotspot (Scott and others, 1985; Smith and others, 1985; Anders and others, 1989; Machette and others, 1991).

Proposed segment lengths for late Quaternary faults in valleys east of the Wasatch fault zone (in the Basin and Range - Middle Rocky Mountains transition zone), including the East Cache and eastern Bear Lake faults, are typically between 10 and 30 kilometers (6 and 19 mi) (appendix A). Machette and others (1991) similarly found that fault segments in the aforementioned V-shaped belt of young tectonism have an average length between about 20 and 25 kilometers (12 and 16 mi). For comparison, the central, most active segments of the Wasatch fault zone have an average length of about 50 kilometers (31 mi), about twice that of other late Quaternary fault segments in the region. The distal, less active segments of the Wasatch fault zone have an average length of about 20 kilometers (12 mi), consistent with the regional average (Machette and others, 1991).

Southwestern Utah

The Hurricane fault, along with its northward continuation as the Cedar City - Parowan monocline and Paragonah fault, lies along the physiographic boundary between the Basin and Range and Colorado Plateau Provinces, southwest of the Wasatch fault zone (figure 1). The Hurricane fault and related structures are subparallel to and roughly 50 kilometers (31 mi) west of the Sevier fault, another major tectonic feature in southwestern Utah. Both sets of structures show evidence of vigorous late Quaternary activity (for example, figure 12). Average slip rates since the early to middle Pleistocene, estimated from various fault-displaced basalts, are 0.3-0.5 mm/yr (0.012-0.02 in/yr) and 0.4 mm/yr (0.016 in/yr) for the Hurricane and Sevier faults, respectively (Anderson and Christenson, 1989; appendix A, location nos. 10-1, 10-7, 10-21, and 10-22). These values are comparable to or greater than an average slip rate of about 0.1-0.3 mm/yr (0.004-0.012 in/yr) estimated for the Wasatch fault zone since middle Pleistocene time (Machette and others, 1992) and comparable to or less than an average Quaternary slip rate of 0.4-0.7 mm/yr (0.016-0.028 in/yr) estimated for the East Great Salt Lake fault zone, a major structure just to the west of the Wasatch fault zone (Pechmann and others, 1987).

The zone of young tectonic activity defined by the Hurricane fault, the Sevier fault, and less prominent nearby structures can be envisioned as the southern continuation of the Wasatch Front zone of extension (as identified by Wallace, 1984b, on the basis of faulting density). Whereas long-term (late Quaternary) slip rates appear to be broadly comparable between the two structurally aligned zones, there is a markedly uneven distribution of more recent faulting activity. Holocene surface faulting is common within the Wasatch Front region, especially on the central Wasatch fault zone where Holocene slip rates have greatly outpaced (by a factor of ten) longer term rates of slip for the late Quaternary. In contrast, evidence of Holocene tectonic activity is relatively sparse within the southern zone and indeed within the entire southwestern corner of the state (figure 8; plate 1).

The sparseness of Holocene surface faulting in southwestern Utah is not inconsistent with the long-term rate of late Quaternary tectonism in the region. In a study which examined patterns of late Quaternary faulting in the Basin and Range of western Utah for the purpose of defining seismic-source zones, Bucknam and others (1980) estimated an average recurrence interval of

Figure 12. View of the Hurricane fault (marked by double-shafted arrows) at the base of the Hurricane Cliffs near Pintura. A steep bedrock scarp crosses a minor transverse drainage and separates a remnant of pedimented bedrock (marked by single-shafted arrow) from its downthrown equivalent west of the fault (covered by juniper trees) (from Anderson and Christenson, 1989).

about 5,000 years (half the length of the Holocene) for magnitude 7.0-7.6 earthquakes in a region mostly south of 39° north latitude and west of the Hurricane fault. A recurrence interval similar to or shorter than this regional value may characterize the long-term history of the Hurricane fault alone, given the computed slip rate of 0.3-0.5 mm/yr (0.012-0.02 in/yr) and an assumption that surface displacements occur in increments of two meters or less per event.

West-Central Utah

The part of west-central Utah that lies in the Basin and Range Province, between about 38.5 degrees and 40 degrees north latitude and west of the Wasatch fault zone (the western three-quarters of the region as defined in figure 8), has a unique pattern of single-event latest Pleistocene to Holocene displacements distributed across a series of fault zones semi-evenly spaced about 50 kilometers (31 mi) apart. Bucknam and others (1980) made use of these distinctions to outline a discrete seismic-source region in west-central Utah with a recurrence rate from geologic data of 2.4 events per 10,000 years per 10,000 square kilometers (3,863 mi^2). This rate is several times greater than the longer term rate computed for the source region to the south which, when normalized for area, is about 0.7 events per 10,000 years per 10,000 square kilometers (3,863 mi^2) (Bucknam and Thenhaus, 1983). At the same time, however, the west-central Utah rate may be several times less than the Holocene rate for the (overlapping) Wasatch Front region (with an upper-range estimate of 9.4 or more events per 10,000 years per 10,000 square kilometers [3,863 mi^2]). Based on the recognized extent of latest Pleistocene to Holocene faulting (plate 1) and on similarities in apparent subsurface styles of faulting (discussed in section titled: Styles of faulting and tectonic processes), the west-central Utah source region may be extended eastward to include the Gunnison, Snow Lake, and Joes Valley fault zones, all east of the Wasatch fault zone (figure 8).

The spatial grouping of latest Pleistocene to Holocene faulting in west-central Utah is broadly analogous to the spatial-temporal clustering of surface fault ruptures on the Wasatch fault zone during the last 1,500 years and within the central Nevada - eastern California seismic belt during the last century (Wallace, 1984b). However, the pattern of faulting in west-central Utah has developed over a much longer time span, at least 10,000 years, and ages of faulting appear to comprise two subgroups separated by a gap of several thousand years (figure 13). The most recent surface-rupturing movement on the Fish Springs fault, the Levan segment of the Wasatch fault zone, the Gunnison fault, and the faults in Scipio Valley appears to have occurred in late Holocene time (after about 4,000 years ago; appendix A), whereas probable ages of most recent movement on the Fayette segment of the Wasatch fault zone, the Drum Mountains fault zone, faults along the House Range and the Cricket Mountains, and faults in Little Valley occurred before about 8,000 years ago in latest Pleistocene or early Holocene time (appendix A). Age resolution for possible prior Holocene events on these faults (such as the Gunnison fault) and for events on other faults in the region (such as the Joes Valley, Pavant Range, and Snake Valley faults) is insufficient to evaluate whether these two intervals of time encompass all of the latest Pleistocene to Holocene faulting events in west-central Utah.

The two periods of faulting activity together encompass the timing of recent volcanic eruptions within a north-trending zone of Quaternary volcanic rocks in west-central Utah (figures 8 and 13). The Ice Springs flow was extruded during late Holocene time (perhaps less than about 660 years ago) and the next-youngest volcanic deposits in the region, at Tabernacle Hill and Pavant Butte, were erupted about 14,500 and 15,500 years ago, respectively (appendix B).

Assuming that this observed clustering of faulting and volcanic events is real, the implication that levels of tectonic activity in the region have varied during the Holocene has significance for estimating regional recurrence and future probabilities of large earthquakes. The distribution of events shown in figure

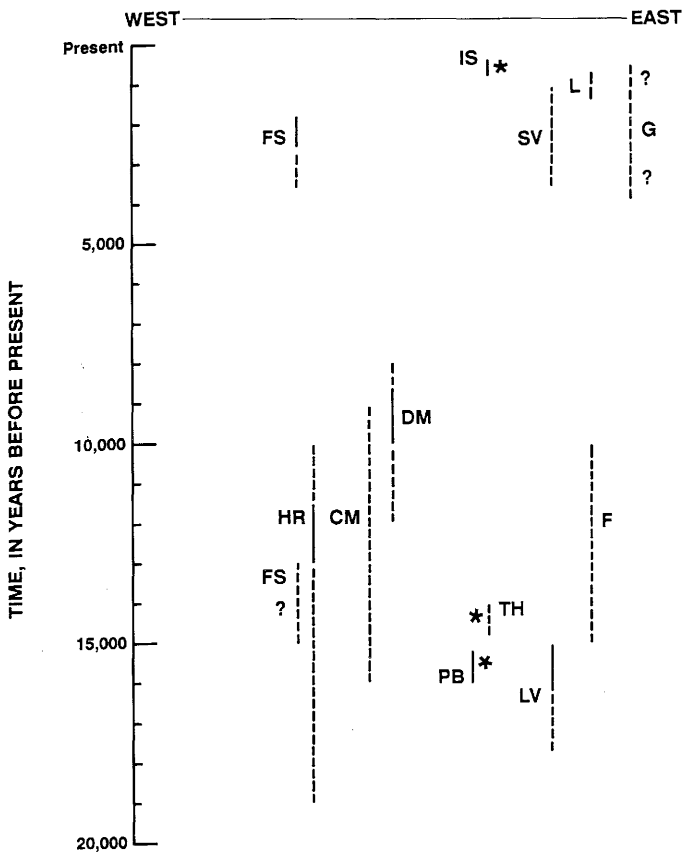


Figure 13. *Timing of some latest Pleistocene to Holocene tectonic events in west-central Utah. Vertical lines indicate likely time intervals (with dashes and question marks indicating less certainty) for surface faulting and volcanic eruptions (denoted by *) from west to east across the region. The following faults are represented: Fish Springs (FS), House Range (HR), Cricket Mountains (CM), Drum Mountains (DM), Scipio Valley (SV), Little Valley (LV), Levan (L) and Fayette (F) segments of the Wasatch, and Gunnison (G). The volcanic features are the Ice Springs flow (IS), Tabernacle Hill (TH), and Pavant Butte (PB).*

13, although based on incomplete data, suggests that the late Holocene period of faulting and volcanism may be unfinished; an episode of heightened tectonic activity may be presently occurring in west-central Utah.

Faulting patterns in western Utah may reflect persistent structural controls on the regional distribution of faulting. The group of coeval faults in west-central Utah is bordered on the north and south by east-trending zones of extensional accommodation that cross much of the Great Basin and generally separate domains of opposite range tilts (Stewart, 1980; Thenhaus and Barnhard, 1989). Temporal patterns of faulting in west-central Utah and elsewhere in the province suggest that the accommodation zones are barriers to rupture and limit the north-south lengths of individual belts of faulting (Thenhaus and Barnhard, 1989). Little is known about possible causes for clustering of faulting and volcanic events in west-central Utah, but the phenomenon may reflect widespread movement along extensive, low-angle detachment surfaces thought to underlie the region (refer to the section on Styles of faulting and tectonic processes).

The behavior of faults as a group in west-central Utah is markedly different from faults in regions to the north (generally west of the East Great Salt Lake fault zone) and south, where Holocene ruptures appear to be short and widely scattered (figure 8). The northwestern corner of the state not only lacks evidence of substantial Holocene faulting, but has little evidence of recurrent Quaternary faulting of any age. Lake Bonneville may have obscured evidence of older faulting in the Great Salt Lake Desert, but regardless, the flatness of the terrain suggests that fault-displacement rates during the Quaternary have been low, relative to adjacent regions. For the purpose of evaluating seismicity relevant to a proposed project site, Arabasz and others (1989) characterized fault-specific seismic sources in a large region of northwestern Utah, generally north of the west-central Utah region.

Eastern Utah

Quaternary tectonism has been largely absent from eastern Utah (figure 8), including the Uinta Mountains portion of the Middle Rocky Mountains and much of the interior of the Colorado Plateau. A significant exception is the Paradox Basin, where late Tertiary to Quaternary dissolutional collapse of large salt anticlines and additional salt flowage have continued locally into the late Quaternary. Several widely scattered locations elsewhere in the Colorado Plateau have tenuous evidence of small amounts of early to middle Pleistocene and Quaternary(?) faulting. Young tectonic features in eastern Utah commonly have uncertain seismotectonic significance (appendix A and section titled: Styles of faulting and tectonic processes) and orientations that are oblique to the structural fabric of the Basin and Range Province. Regions of eastern Utah may lie east of significant extensional forces or, alternatively, may simply be underlain by stronger, more coherent crust.

Areas of Folding and Distributive Faulting

Crustal extension in most regions of the state is characteristically expressed at the surface as narrow zones of semi-continuous faults that show mainly normal separation and dip away from adjacent range fronts or bedrock escarpments. However, more complex distributions of faults and other expressions of tectonism dominate in some areas, notably within a zone between the Wasatch and Hurricane-Sevier fault zones and in valleys of the Paradox Basin (figure 8; plate 1). Along the general structural trend between the southern Wasatch fault zone and the Hurricane and Sevier faults, clusters of short, discontinuous faults commonly are in basin areas and are associated with Quaternary folds, volcanic rocks, or both. Anticlinal, synclinal, and east- and west-facing monoclinal folds occupy several distinct structural settings in this region and have been attributed to various deformational processes. In the Paradox Basin, faulting related to collapse of salt structures has been concentrated along the margins of valleys, although more diffuse deformation, in the form of warping, tilting, and faulting, has affected central valley-fill deposits as well.

The Wasatch, Valley Mountains, Elsinore, and Cedar City-Parowan monoclines (location nos. 13-25, 13-26, 9-7, and 10-21, respectively) all bound plateau or range blocks that generally contain late Quaternary faults. These block-interior faults, typically arranged as narrow grabens with little net displacement across them, may be secondary extensional features resulting from major uplift across the monoclines (Foley and others, 1986; Anderson and Christenson, 1989). A major, normal-slip fault, identified from seismic-reflection profiles, underlies the Wasatch monocline (Standlee, 1982). Similar blind faults, perhaps with significant seismogenic potential, may lie beneath other mountain-front monoclines as well (Anderson and Christenson, 1989; Anderson and Barnhard, 1992). Part of the structural relief across the Wasatch and Valley Mountains monoclines, which rim opposite sides of Sevier and Sanpete Valleys, has been attributed by Witkind and Page (1984) to differential subsidence caused by dissolution of salt diapirs beneath the valley floors.

Upward movement of salt is suggested as a cause of Quaternary deformation along the Sanpete-Sevier Valley and Redmond Hills anticlines (figure 14; appendix A, location nos. 13-16 and 13-17), which form low hills subparallel to and between the Wasatch and Valley Mountains monoclines. Diapiric upwelling of salt is also called upon to explain evidence of growth of the Meander anticline and Gibson dome in the Paradox Basin (Huntoon, 1982, 1988; location nos. 18-9 and 18-10).

Three other areas of folding between the southern Wasatch and Hurricane-Sevier faults are near the base of the Tushar Mountains in Beaver Basin (location no. 9-4), near the base of the Hurricane Cliffs in Cedar Valley (location no. 10-8), and near the base of the Paunsaugunt and Sevier Plateaus in the central Sevier Valley (location no. 10-17). All three sets of structures lie within the hanging wall of range-bounding faults. The folds near Panguitch are thought to have formed aseismically in response to movement on the subparallel Sevier fault (Anderson and Christenson, 1989). Folds in all three areas are cut by clusters of short, closely spaced faults which appear to be shallow structures related to fold development (Machette, 1985; Anderson and Christenson, 1989).

Areas of Volcanism

Except for a small volcanic field in northernmost Utah, Quaternary volcanism appears to be confined to two closely spaced areas in the west-central and southwestern regions of the state (figure 8; plate 2). One group, consisting of basalt and lesser quantities of rhyolite, forms a narrow belt that is aligned north-south along the eastern boundary of the Basin and Range Province between 38 degrees and 40 degrees north latitude. The other group, of fundamentally basaltic rocks, is oriented northeast-southwest, transverse to the province boundary between 37 degrees and 38 degrees north latitude (Best and others, 1980).

The northern volcanic belt has formed in an intra-graben area between the Pavant Range and Tushar Mountains to the east and the Cricket Mountains and Mineral Mountains to the west. Volcanism in this belt appears to be concurrent with east-west extension across numerous, small-scale intrabasin faults (Hoover, 1974; Clark, 1977). Vents and cones generally lie along high-angle normal faults (for example, figure 15), which have controlled the surface expression of the volcanism (Nash, 1986) and may have served as conduits for the ascending mantle-derived magma (Hoover, 1974).

Eruptions of basaltic magma within the belt began about 2 million years ago and have continued intermittently. The most recent eruptions occurred during two broadly defined, regional episodes of faulting (figure 13): (1) in the latest Pleistocene to early Holocene (with the eruption of Pavant Butte and Tabernacle Hill during Bonneville time, figure 16), and (2) in the late Holocene (with the eruption of the Ice Springs flow less than about 1,000 years ago). The volcanic belt includes White Mountain, which at ~400,000 years old is the youngest known exposure of rhyolite in Utah (Nash, 1986). A group of high-silica rhyolites along the crest and western flank of the Mineral Mountains at the south end of the belt (location nos. 9 - 38-41) erupted between about 500,000 and 800,000 years ago, a time interval encompassed by more mafic volcanic activity just to the east (Lipman and others, 1978; Nash, 1986).

The southern group of volcanic rocks (which dates from the latest Tertiary, less than about 5 million years) trends to the northeast, oblique to the physiographic boundary between the Basin and Range and Colorado Plateau and generally coincident with the southern limit of middle Cenozoic arc volcanic rocks (Best and others, 1980). Volcanic vents in this group do not generally coincide with mapped faults (plate 2; Anderson, 1988; Anderson and Christenson, 1989), in contrast to vents in the group to the north. Some vents in the southern group lie adjacent to major faults (such as the Hurricane and Sevier faults), where they tend to be localized on the footwall block, but do not appear to exploit faults as conduits for magma. Cinder cones and mounds generally form alignments parallel to the trends of faults in the region, but these alignments appear to reflect structural control by steep joints rather than by faults (Anderson, 1988; Anderson and Christenson, 1989). An absence of synvolcanic faulting or significant permanent dilatation (indicated by a lack of dike-filled joints) suggests that volcanic eruptions during the Quaternary were not accompanied by significant levels of seismogenic faulting (Anderson, 1988; Anderson and Christenson, 1989).

STYLES OF FAULTING AND TECTONIC PROCESSES: IMPLICATIONS FOR EARTHQUAKE-HAZARD CHARACTERIZATION

Geologic and geophysical data from various areas of the state reveal structural styles of faulting that appear to be at odds with the basic model (described below) for generating large-magnitude, normal-faulting earthquakes. Some major, block-bounding faults seem to have downward-flattening (listric) geometries and some faults appear to intersect, but not cut, subhorizontal detachments within a few kilometers of the surface (for example, Royse and others, 1975; Smith and Bruhn, 1984). Scarps in

Figure 14. *Oblique aerial view of the Redmond Hills diapiric salt anticline (location no. 13-17) within the cultivated flood plain of the Sevier River. The town of Redmond appears on the left side of the photo.*

Figure 15. *Oblique aerial view of Fumarole Butte, a probable volcanic neck, on Crater Bench at the northern end of the Drum Mountains fault zone (location nos. 8-4 and 8-27). Arrow points to one of many faults (with ≤ 7-m [23-ft]-high scarps) that cut the 900,000-year-old basalts.*

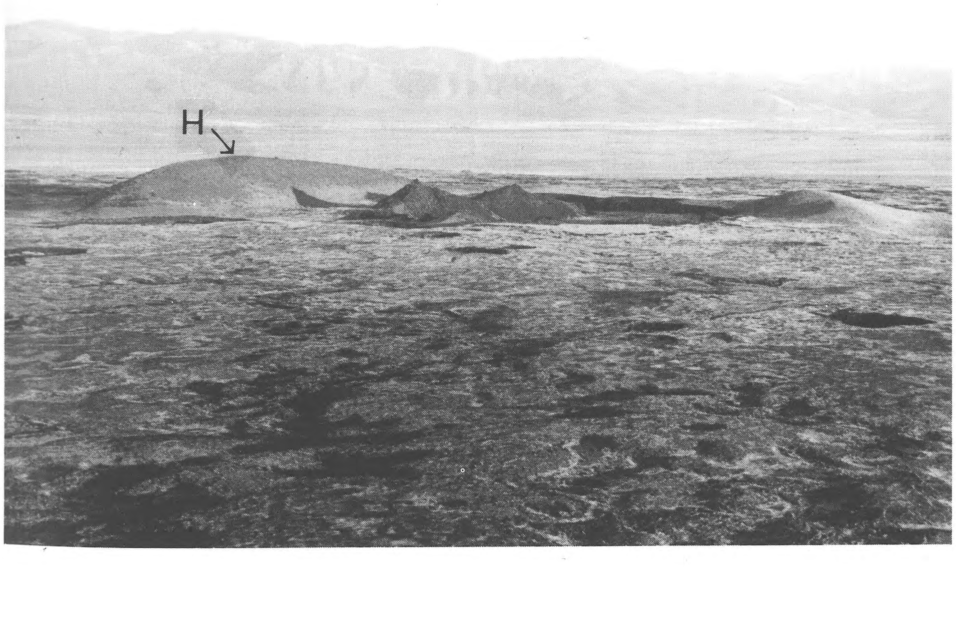


Figure 16. *Oblique aerial view of Tabernacle Hill (H) basalt flow and tuff ring (location no. 9-48), which erupted into Lake Bonneville ~14,500 years ago. The Pavant Range forms the skyline.*

Quaternary deposits commonly lie along the traces of these faults, indicating recent surface-rupturing movement. However, potential rupture pathways between these near-surface faults and the mid-crustal levels where large-magnitude earthquakes are observed to nucleate have not been identified (Arabasz and Julander, 1986).

Seismologic and geodetic evidence associated with three well-studied magnitude 7 earthquakes in the Basin and Range Province and Intermountain seismic belt suggests that large-magnitude, normal-faulting earthquakes in the Utah region are high strain-energy events with hypocenters at or near the base of the seismogenic crust (about 15 kilometers [9 mi] deep) on moderate-to-steep (about 40-60 degrees) planar faults (Smith and Richins, 1984; Doser, 1985a; Smith and others, 1989). This faulting configuration agrees with conclusions drawn from studies of magnitude 5.5+ normal-faulting earthquakes in the western interior of the United States (Doser and Smith, 1989) and throughout the world (Jackson, 1987; Jackson and White, 1989). This configuration is also consistent with theoretical requirements for the nucleation of large normal-faulting earthquakes. Classic fault mechanics predicts that a normal fault must be steep enough (ideally about 60 degrees) to allow gravitational forces to overcome frictional forces (Anderson, 1951). Additionally, ruptures must nucleate in deep, high stress-drop regions to have the potential to propagate over the entire fault plane and produce a large-magnitude earthquake (Das and Scholz, 1983).

Pre-existing crustal structure appears to play an important role in the location and geometry of normal faults in the boundary region of the Basin and Range Province. In a broad sense, the eastern tectonic boundary of the northern Basin and Range coincides with the alignment of Late Proterozoic to Paleozoic continental rifting and sedimentation and the leading edge of eastward-directed Cretaceous to early Tertiary Sevier thrusting (Stokes, 1976). On a more detailed scale, individual basin-range structures appear to be related, spatially and presumably genetically, to discontinuities inherited from these older tectonic episodes. For example, the northern end of the Hurricane fault appears to terminate along the Paragonah lineament, one of a series of northeast-trending lineaments that influenced deformation during both compressional and extensional tectonic regimes in Utah (Picha and Gibson, 1985; Picha, 1986). Similarly, segment boundaries proposed for the Wasatch fault zone coincide with these (specifically, the Leamington lineament) and other tectonic elements farther north that served as displacement transfer structures within the Sevier thrust belt (Smith and Bruhn, 1984; Zoback, 1992).

Particularly noteworthy from an earthquake-hazards perspective is that the shallow listric geometry recognized for a number of active normal faults in Utah, Wyoming, and Idaho has been interpreted as resulting from extensional backsliding on low-angle thrusts (for example, Royse, 1983; Royse and others, 1975). The thin-skinned structures that formed in the foreland of the Sevier thrust belt are presumably zones of weakness that may have been exploited during basin-range extension. Alternatively, some major low-angle normal faults may have formed without fundamental regard to pre-existing compressional structures, as shown in the Mormon Mountains of Nevada where an exhumed low-angle normal fault cross-cuts Mesozoic Sevier thrusts and involves Precambrian basement rocks (Wernicke, 1981; Wernicke and others, 1985).

Basin and Range - Middle Rocky Mountains Transition Zone

The characteristics of extensional tectonics superimposed on a thrust-faulted terrain are perhaps best seen in the Middle Rocky Mountains, where block-faulting has not extensively masked the pre-existing thrust-belt structure. Subsurface information indicates that many major normal faults in the thrust-belt province of northern Utah, Wyoming, and Idaho may be listric structures restricted to the upper plates of thin (several kilometers thick), subhorizontal thrust sheets (Royse and others, 1975; Corbett, 1982). The younger, extensional faults appear to be localized above steeply dipping thrust-plane ramps and have surface traces that are parallel to or coincident with the traces of associated major thrusts. The subsurface geometry of parts of the Wasatch fault zone appears to be controlled by pre-existing thrust faults, but other parts of the fault zone appear to cut thrusts at high angles (Smith and Bruhn, 1984; Zoback, 1992). The East Great Salt Lake fault zone, which lies just west of the Basin and Range - Middle Rocky Mountains transition zone, may be listric, appearing to decrease in dip from about 60 degrees near the surface to less than 10 degrees at a depth of 5 kilometers (3 mi) (Viveiros, 1986).

Normal-slip reactivation of thrust planes is viewed by West (1988, 1989, in press) as the initial stage of extensional tectonic development in this thrust-belt terrain. Later stages involve upward propagation of blind faults, which cut through the thin-skinned structures and eventually form major planar faults capable of producing large-magnitude, surface-rupturing earthquakes. The spatial distribution of normal faults with different geometries and amounts of slip appears to support this model of evolving extension for northern Utah (Evans, 1991). To the east of the Wasatch fault zone, the East Cache fault zone appears to be steeply dipping and planar to significant depths; farther east, the eastern Bear Lake, Crawford, and Bear River fault zones appear to be listric and to merge with underlying thrusts (figure 17; West, 1986, 1989, in press; Evans, 1991). Net slip across these major normal faults decreases to the east, consistent with an eastward decrease in tectonic maturity.

Focal mechanisms for small- to moderate-magnitude earthquakes in the Wasatch Front region do not support an interpretation of seismic slip on low-angle, listric fault surfaces. Rather, earthquakes are occurring almost exclusively on moderate- to high-angle (>30 degree) faults (Zoback, 1983; Bjarnason and Pechmann, 1989). In addition, maximum depths of earthquake foci are everywhere greater than about 12 kilometers (7 mi) (Arabasz and others, 1992), indicating that seismogenic crust is present below the thrust sheets (Zoback, 1983). The distribution of earthquake depths is apparently influenced by thrust-belt structure, however, as indicated by evidence from an earthquake swarm sequence in southern Idaho (Arabasz and Julander, 1986). In view of the uncertainties in assessing seismic potential in the Basin and Range - Middle

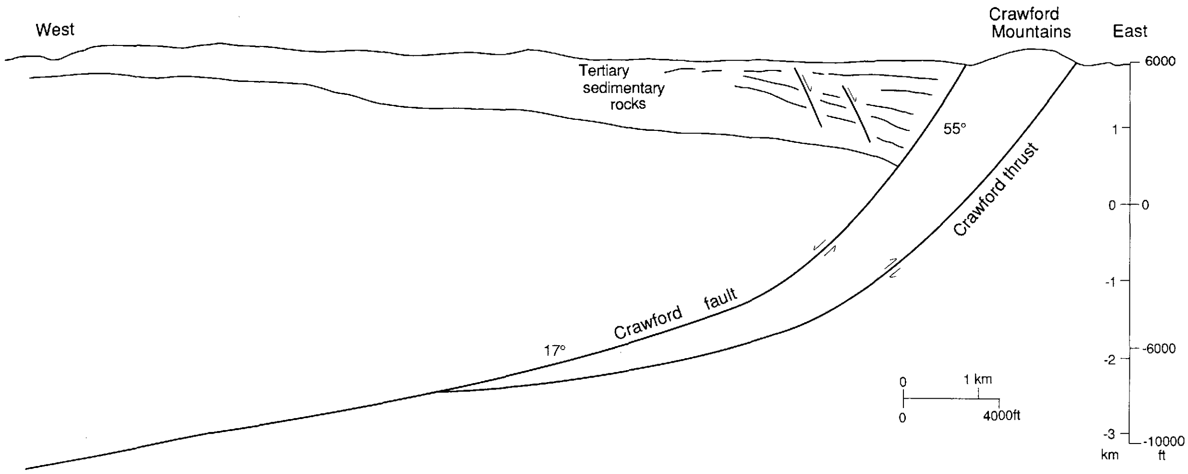


Figure 17. Generalized east-west cross section showing how the normal fault on the west side of the Crawford Mountains appears to sole into the Crawford thrust fault (from Evans, 1991).

Rocky Mountains transition zone, the U.S. Bureau of Reclamation in their regional seismotectonic studies (Sullivan and others, 1988) chose to consider the largest historical earthquakes of the Intermountain seismic belt as representative of maximum-magnitude events on late Quaternary faults in the transition zone.

Basin and Range of West-Central Utah

Detailed subsurface information is lacking for much of the Basin and Range Province. The best-studied region in western Utah lies between about 38 degrees and 40 degrees north latitude, where a series of vertically stacked, low-angle detachment surfaces, expressed as prominent seismic reflectors, dominates the structure of the upper 15 kilometers (9 mi) of crust and appears to have accommodated recent extension (figures 18 and 19; Allmendinger and others, 1983; Smith and Bruhn, 1984). The location and general character of the detachment surfaces may have been controlled by features associated with Late Proterozoic continental rifting (Allmendinger and others, 1986), and at least some of the detachments may have originated as Sevier thrust sheets, although other interpretations are possible (Allmendinger and others, 1983; Smith and Bruhn, 1984). In some instances, crustal extension may be accommodated on new low-angle fault planes that are unrelated to older thrusts, as observed in the Mormon Mountains of southeastern Nevada (Wernicke, 1981; Wernicke and others, 1985).

A prominent detachment fault, referred to as the Sevier Desert detachment, slopes gently (about 5-15 degrees) westward, away from the west side of the Canyon Range (figure 19, profile A-A′). The detachment appears to extend virtually unbroken for at least 70 kilometers (44 mi) perpendicular to strike, directly beneath complexly faulted sub-basins in the Sevier and Black Rock Deserts and reaches depths of at least 12-15 kilometers (7-9 mi) close to the Utah - Nevada border (figure 19, profile A-A′; Allmendinger and others, 1983; Smith and Bruhn, 1984; Planke and Smith, 1991). However, there is some evidence from modeling of seismic-reflection data that the detachment is offset across a zone of high-angle normal faults (with individual throws of about 500 meters [1,640 ft]) in the Sevier Desert (Picha, 1986; Smithson and Johnson, 1989). A

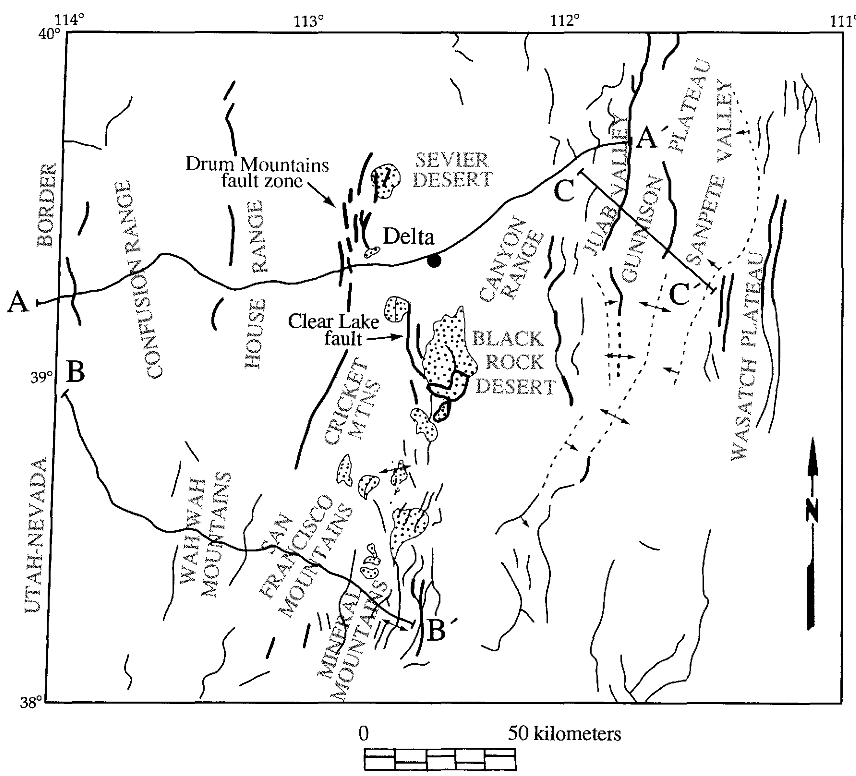


Figure 18. The region of west-central and southwestern Utah where detachment geometries have been identified within the upper crust from various studies, including McDonald (1976), Standlee (1982), Allmendinger and others (1983), Smith and Bruhn (1984), Arabasz and Julander (1986), and Planke and Smith (1991). Quaternary faults, folds, and volcanic rocks are shown simplified from plates 1 and 2 and darkened where most recent activity is probably latest Pleistocene to Holocene. Lines A-A′, B-B′, and C-C′ correspond to geologic cross sections in figure 19.

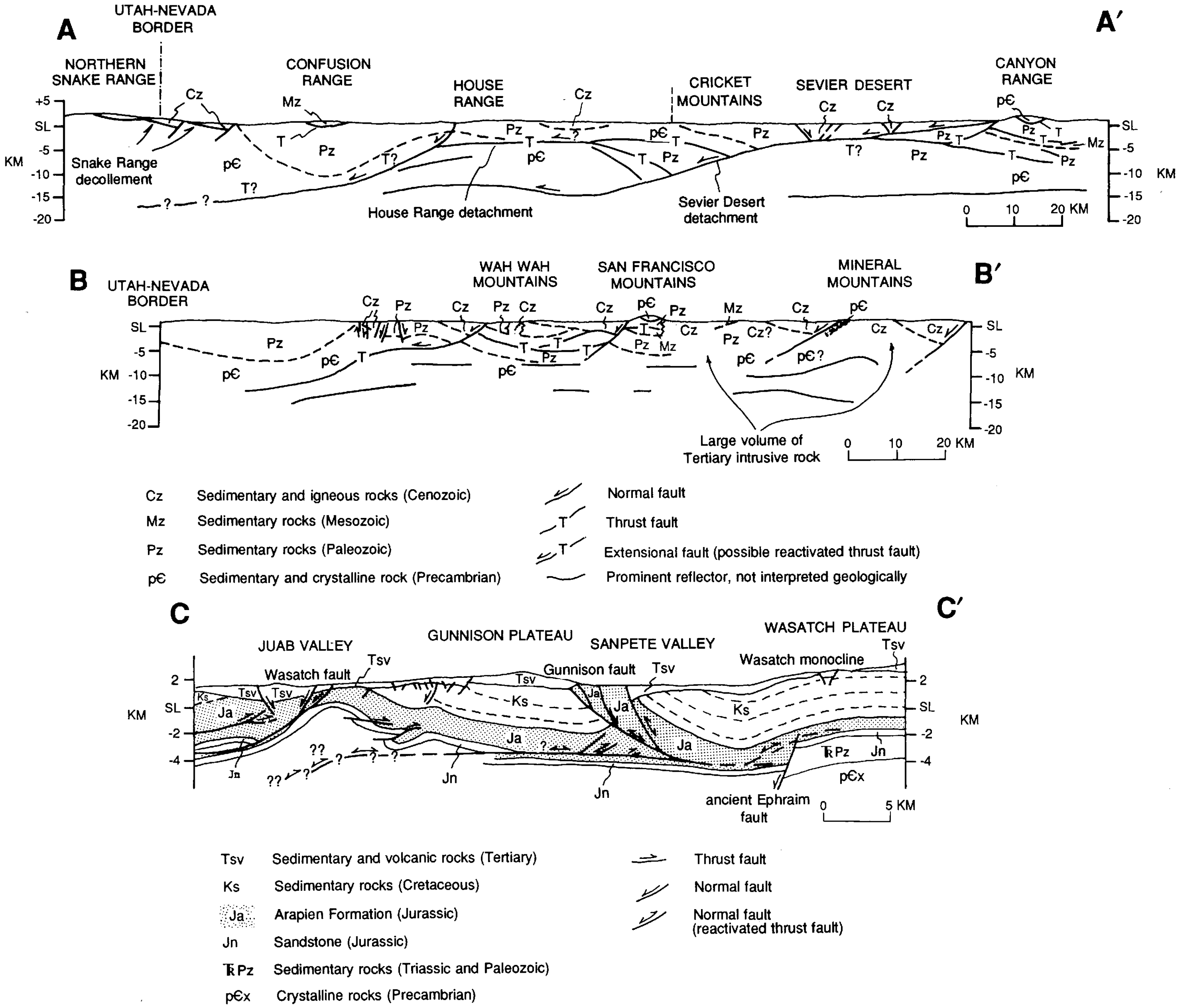


Figure 19. *Cross sections (locations shown in figure 18) showing interpretations of regional crustal structure, western Utah. Profiles A-A′ and B-B′ are modified from Smith and Bruhn (1984) and are based mainly on seismic-reflection data. Profile C-C′, modified from Standlee (1982), is based on surface and drill-hole data, seismic profiles, and gravity surveys.*

buried 4.2 million year old basalt layer appears to be faulted by greater amounts than the subjacent detachment, suggesting that during an earlier phase of movement these faults soled into or were truncated by the detachment (Smithson and Johnson, 1989). The high-angle faults crossed by the reflection lines lie on-trend with an alignment of Quaternary volcanic vents and rocks to the south. If faults within the volcanic field serve as conduits for the mantle-derived magma (as inferred by Hoover, 1974), they indeed are likely to penetrate below shallow detachment surfaces. Many of these faults record tens of meters of vertical displacement and may have generated hazardous levels of seismicity during volcanic eruptions.

Away from the zone of volcanic rocks and associated faults, high-angle normal faults in the Sevier and Black Rock Deserts appear to terminate at the Sevier Desert detachment at depths less than 4 kilometers (2.5 mi) and appear to have both planar and downward-curving geometries (McDonald, 1976; Allmendinger and others, 1983; Anderson and others, 1983; Smith and Bruhn, 1984). Some of the faults are buried beneath uncut strata (Anderson and others, 1983), but the Clear Lake fault, which has been traced down to its intersection with the Sevier Desert detachment in seismic-reflection profiles, has had post-Bonneville surface displacement (Crone and Harding, 1984). A direct connection between surface faulting and deformation on the Sevier Desert detachment is supported by the association of the Clear Lake fault zone with irregularities in the geometry of the detachment surface (figure 20). A complex deformational history for the detachment is suggested both by complexities in

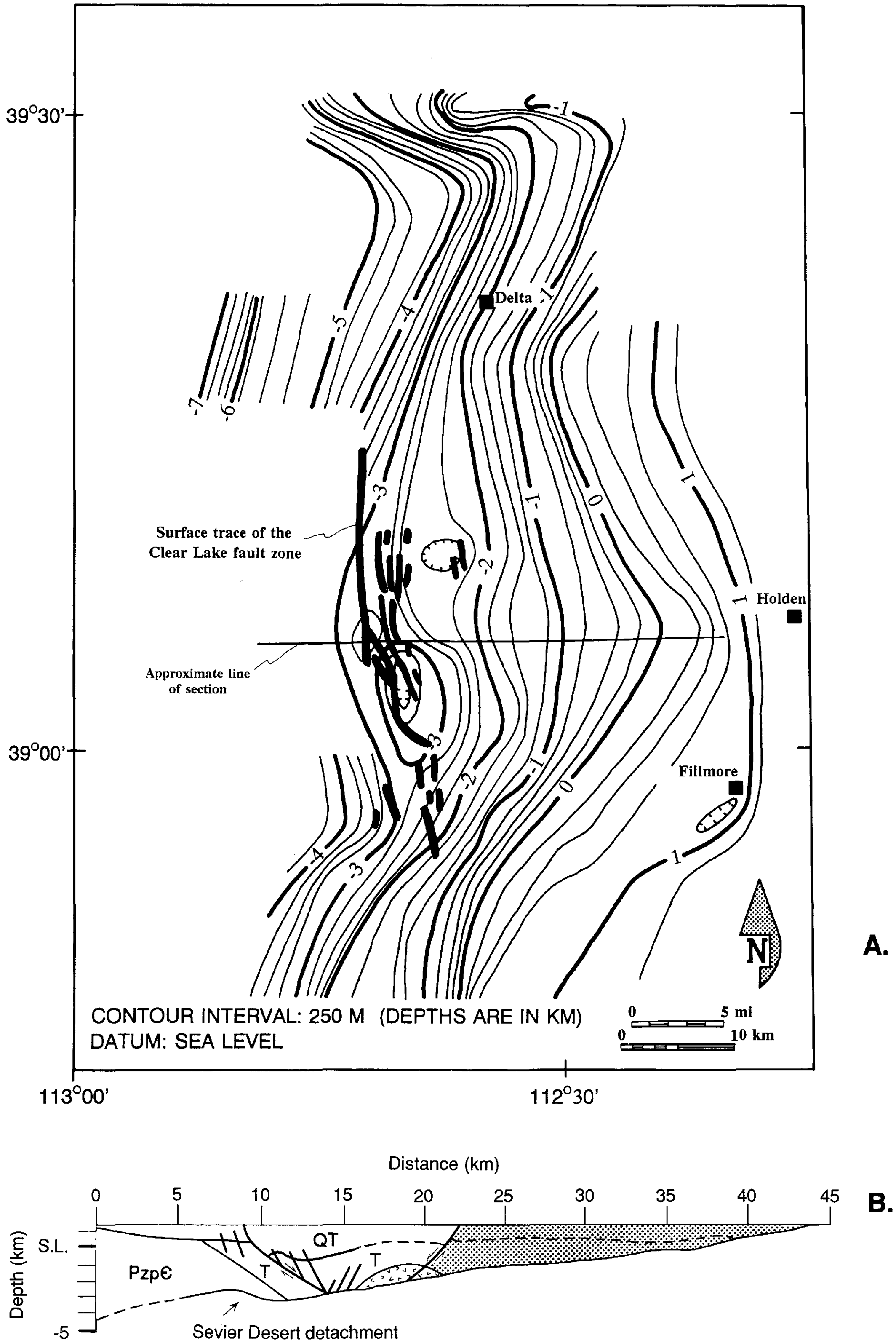


Figure 20. *(A) Generalized surface ruptures of the Clear Lake fault zone superimposed on a depth contour map of the Sevier Desert detachment made from seismic-reflection data (modified from Planke and Smith, 1991). (B) Generalized geologic cross section of the Sevier Desert basin (location shown on A) interpreted from seismic-reflection data (from Planke and Smith, 1991). Dotted area is poorly resolved on seismic section; pluses indicate a possible salt dome. Other symbols are Precambrian and Paleozoic basement (PzpC); Tertiary units (T); middle Pliocene to Quaternary units (QT).*

the pattern of the Clear Lake fault zone and by the geometry and variable displacement of a prominent reflector (interpreted as the 4.2 million year old basalt layer) that overlies the detachment (Planke and Smith, 1991, who refer to the Clear Lake fault as the western basin-bounding fault). Using geologic and geometric information from the Sevier and Black Rock Desert basins, Planke and Smith (1991) estimated a minimum post-middle Pliocene extension rate of 0.6-0.8 mm/yr (0.02-0.03 in/yr) for the Sevier Desert detachment. The presence of a thick body of Tertiary-age salt encountered in a drill hole and identified on a seismic-reflection profile in the northern Sevier Desert, and similar evidence for the presence of subsurface salt and possible salt structures elsewhere in the Sevier Desert (Planke and Smith, 1991; figure 20B) suggest the possibility that mobilization of salt deposits may influence tectonism in the region (Anderson and others, 1983).

The eastern portion of a detachment surface that lies above the Sevier Desert detachment (the House Range detachment, figure 19, profile A-A′) is interpreted by Wernicke and others (1985) to be inactive on the basis of its domal geometry, structural position, and the Pliocene age of strata that appear to overlap a hanging-wall, growth-fault basin. However, continued activity is suggested by the presence of the Holocene Drum Mountains fault zone (on the western margin of the Sevier Desert, figures 18 and 21), which lies along a possible surface projection of the House Range detachment (as the geometry of the detachment is interpreted by Allmendinger and others, 1983 and Wernicke and others, 1985). At the southern end of the Drum Mountains fault zone, the channel pattern of a 35-kilometer (22-mi) section of the Sevier River suggests a broad uplift (Anderson and Barnhard, 1992). Perhaps uplift near the breakaway zone of the House Range detachment reflects isostatic rebound accompanying tectonic unloading of the detachment footwall, as envisioned by Wernicke and Axen (1988) in their model of evolving extensional terrains. Alternatively, the uplift may be the result of reverse-drag flexing owing to movement on the subjacent Sevier Desert detachment, as postulated by Wernicke and others (1985) to explain doming of the House Range detachment west of the Drum Mountains fault zone.

Range-front faults that lie west and south of the low-relief Sevier and Black Rock Deserts may likewise be confined to the upper plate of regional, subhorizontal detachment surfaces (figures 18 and 19, profiles A-A′ and B-B′). The high-angle, range-bounding faults appear to terminate against or sole into detachments at depths that vary from less than 5 kilometers (3 mi), on the west side of the House Range, to about 10 kilometers (6 mi), on the west side of the Mineral Mountains (Allmendinger and others, 1983; Smith and Bruhn, 1984). A low-angle structure beneath Snake Valley, interpreted as the subsurface continuation of the Snake Range decollement, has a dip and sense of displacement that are opposite to those of the detachments farther east (figure 19, profile A-A′). The subsurface extent of the east-dipping Snake Range decollement and its relation to other structures is unclear (Allmendinger and others, 1983; Smith and Bruhn, 1984). As discussed later, detachment geometries may also characterize the region east of the Sevier Desert, beneath the northern High Plateaus portion of the Basin and Range - Colorado Plateau transition zone.

Evidence of recent surface faulting is widespread in the regions of Utah where detachments have been identified (figure 18). Fault scarps that are known or inferred to lie above the Sevier Desert detachment and related low-angle structures to the east and west are mostly younger than or comparable in age to Bonneville shoreline scarps (and are the basis for defining the extent of the west-central Utah region shown in figure 8). These fault scarps, together with the youngest volcanic rocks in the Sevier and Black Rock Deserts, appear divisible into two age groups: latest Pleistocene to early Holocene, and late Holocene, with an intervening period of little or no activity (figure 13). Evidence of widespread, coeval surface faulting is consistent with extension on a controlling system of regional detachments.

Figure 21. *Oblique aerial view looking northward along the Drum Mountains fault zone (location no. 8-1). Scarps are less than about 7 meters (23 ft) high.*

South of where the Sevier Desert detachment has been identified, three detachment-floored, range-front faults within an east-west transect (figures 18 and 19, profile B-B′) are marked by degraded, pre-Bonneville fault scarps or by an absence of identified scarps. This spatial variation in the ages of most recent fault movement suggests that range-front faults and subjacent detachments just south of the west-central Utah region (as defined in figure 8) may form a system that is decoupled from the system to the north. Thenhaus and Barnhard (1989) recognized that these domains of pre-Bonneville and post-Bonneville faulting are separated by a transverse structural zone, defined primarily on the basis of regional basin-range tilt patterns (Stewart, 1980), that presumably accommodates differences in the rate, direction, or magnitude of strain between the two domains.

Accurate assessment of earthquake hazards in and adjacent to west-central Utah is problematic because the mechanics of movement on low-angle faults are poorly understood and the seismogenic potential of these and overlying steeper faults is unknown (Crone and Harding, 1984; Smith and Bruhn, 1984; Arabasz and Julander, 1986). Late Quaternary slip on moderate- to high-angle faults appears to have occurred as discrete scarp-forming events of about 1 to 3 meters (3-10 ft) of vertical displacement, indicating that a surface-rupture hazard exists in this region of detachment geometries. However, classic brittle-failure theory for normal faulting argues against frictional sliding on low-angle structures (Sibson, 1985) and, consequently, the earthquake potential of low-angle detachments is suspect. In addition, regional microseismicity data from the Intermountain seismic belt, which lies mainly east of the relatively aseismic Sevier Desert, suggest that seismic slip is occurring predominantly on moderate- to high-angle faults (Zoback, 1983; Arabasz and Julander, 1986). Results of a worldwide study of large normal-faulting earthquakes led Jackson (1987) to argue that if large-scale, low-angle faults are active, then they likely move aseismically and are located in areas of low seismicity apart from areas characterized by seismogenic high-angle faulting.

Perhaps discrete, incremental slip associated with surface faulting in this tectonic domain is restricted to the higher angle portions of faults in the thin wedges of crust above the detachments (Smith, 1981). It is doubtful, however, whether faulting within low-strength Cenozoic rocks, which appear to comprise the shallow strata above the Sevier Desert detachment, would produce strong seismic shaking (Anderson and others, 1983).

An alternative possibility is that faulting may involve high-strength rocks at deeper crustal levels along the gently dipping detachments, which appear to extend down at least to depths of 10 to 15 kilometers (6-9 mi). Although the low resolved shear stresses associated with low-angle structures argue against significant seismogenic potential, the large down-dip extent of the detachments is consistent with theoretical requirements for the generation of large earthquakes (Smith and Bruhn, 1984). If such earthquakes are possible, the epicenters and the loci of strongest ground motion may be located many tens of kilometers from the site of associated surface rupture (Anderson and others, 1983). This disparity would have important implications for the evaluation of seismic-source zones and seismic shaking in the region.

One way to explain the conflicting observations in west-central Utah is to conclude, despite evidence to the contrary, that the regional detachments are in fact cut by all young, high-angle faults. This explanation implies that displacements across the high-angle faults are either too small to be resolved by reflection data or are masked by the low-angle geometries of inactive structures.

Basin and Range - Colorado Plateau Transition Zone

The record of crustal deformation in the Basin and Range-Colorado Plateau transition zone is marked by moderately to complexly deformed rocks with generally poor exposure, setting the stage for diverse interpretations of the region's tectonic development. Hypotheses advanced to explain the complex structural geometry of the northern High Plateaus region have differed mainly on the amount of deformation attributed to upward mobility of the Jurassic evaporite-rich Arapien Shale. Understanding the influence on tectonics of this mechanically weak, low-density unit is important to the assessment of earthquake sources and hazards in the region.

Some workers (Moulton, 1975; Baer, 1976; Stokes, 1982; Witkind, 1982, 1983; Witkind and Marvin, 1989) have proposed large-scale, widespread salt diapirism as the mechanism responsible for the geologic complexity of the northern High Plateaus. Witkind (1982) has postulated recurrent episodes of diapiric folding (which may have been controlled spatially and temporally by periodic reactivation of deep-seated faults) and intervening periods dominated by salt removal (through dissolution or outward flowage), structural collapse, and erosion of the fold structures. Movement along high-angle normal faults and plateau-bounding monoclines is thought to be partly the result of near-surface collapse of the diapiric folds (Witkind, 1982; Witkind and Page, 1984). While representing a potential surface-faulting hazard, displacement caused by collapse of rocks above the Arapien Shale may not contribute significantly to the ground-shaking hazard in the region.

Although individual interpretations differ, other workers (for example, Spieker, 1946; Gilliland, 1951, 1952; Standlee, 1982, 1983) have ascribed the pattern of geologic relations in central Utah to multiple compressional and extensional events. Within this tectonic framework, diapirism either is not invoked or is viewed as a secondary and relatively minor phenomenon. Using subsurface data (drill holes, seismic profiles, and gravity surveys) together with surface geology, Standlee (1982, 1983) interpreted the structural configuration of the region to be generally the product of complex thrust-fault deformation (dominated by westward-directed "back-thrusting") along the leading edge of the Sevier thrust belt. During this compressional episode, the low-strength Arapien Shale underwent intense deformation and tectonic thickening. Subsequent basin-range extension, which appears to have been at least partly accommodated by backsliding along thrust planes, has added to the structural complexity of the region. Diapirism of salt-bearing strata is thought to have occurred only locally (for example, within the Redmond Hills) during these orogenic episodes.

Range-bounding normal faults in the northern High Plateaus, which are steeply dipping in the near-surface, appear from seismic-reflection profiles to bottom in shallow (4- to 6-kilometers [3-4-mi] deep) detachment faults within or at the base of the Arapien Shale (figure 19, profile C-C′; Standlee, 1982; Smith and Bruhn, 1984; Arabasz and Julander, 1986). The detachment structures are interpreted as following the Pavant and subjacent thrusts (Standlee, 1982; Smith and Bruhn, 1984) and may be correlative with similarly identified structures beneath the eastern Sevier Desert (Allmendinger and others, 1983; Arabasz and Julander, 1986). The northern limits of detachment-controlled extension may cross the Wasatch fault zone in the boundary zone between the Nephi and Levan segments. Seismic-reflection data near Nephi indicate that the Wasatch fault zone is a relatively steep planar feature that truncates all structures to depths of 9 to 10 kilometers (6 mi) (Zoback, 1992); 20 kilometers (12 mi) to the south near Levan, the fault can be traced to depths of only about 5 kilometers (3 mi), where it merges with an inferred detachment (figure 19, profile C-C′; Standlee, 1982; Smith and Bruhn, 1984).

Although detachment faulting has been inferred to extend as far east as the Wasatch Plateau (figure 19, profile C-C′; Standlee, 1982), it is uncertain whether the numerous en echelon plateau faults penetrate below or merge with the Jurassic (Arapien Shale) section and the postulated detachment (Allmendinger and others, 1986; Foley and others, 1986). The graben structures on the plateau (for example, the Joes Valley fault zone, figures 5 and 22) are unlike late Cenozoic basins to the west in that they are relatively narrow, are bounded by faults with near-vertical dips, and are associated with little or no net vertical displacement. The nature of these faults suggests they may have formed in response to uplift across the Wasatch monocline (Foley and others, 1986). A blind, steeply dipping normal fault (the "ancient Ephraim fault") lies subparallel to and just east of the Wasatch monocline and cuts upsection as high as the structurally thickened and synclinally folded Arapien Shale (figure 19, profile C-C′; Standlee, 1982; Allmendinger and others, 1986). Possible basin-range extension across this fault may be transferred along the detachment horizon to the faults on the Wasatch Plateau (Allmendinger and others, 1986). If this blind fault is active, it may be capable of producing large-magnitude earthquakes.

Fault rupture that fails to reach the ground surface during a large earthquake has been known to occur where a mechanically weak layer (such as overpressured shale or evaporites) decouples a thick sequence of sediments from the underlying "basement" (Jackson and White, 1989). Investigations of two recent moderate-magnitude earthquakes beneath and east of the Wasatch Plateau indicate that left-lateral shear is occurring on north-northeast-striking Precambrian basement faults in the region (Pechmann and others, 1990). This sense of shear at depth is consistent with the right-stepping, en echelon pattern of grabens on the plateau (Pechmann and others, 1990).

Detailed earthquake studies in the High Plateaus region indicate that the layered structure of the upper crust may strongly influence the distribution of earthquake foci. Small to moderate earthquakes, which occur predominantly on moderate- to high-angle faults, appear to be markedly less abundant below the level of the detachment surfaces (Arabasz and Julander, 1986) and, likewise, below an hypothesized shallow brittle-ductile transition zone (Smith and Bruhn, 1984). As previously discussed, the idea of structural layering of the upper crust and downward flattening or truncation of range-bounding faults has implications, although not well understood, for assessing maximum earthquake magnitudes and regional ground-shaking hazards.

Earthquake focal mechanisms and detailed geologic data within and adjacent to a zone of late Quaternary deformation in the central Sevier Valley (faults in the Annabella and Joseph Flats areas, location nos. 9-8 and 9-32) reveal a variable and complex style of shallow deformation, involving significant

Figure 22. *Oblique aerial view looking northward up the axis of the Joes Valley graben (location nos. 13-5 - 13-7) from just south of Joes Valley reservoir.*

components of folding and strike-slip faulting (Arabasz and Julander, 1986; Anderson and Barnhard, 1992). The intense, thin-skinned deformation in this area of the central High Plateaus appears to be localized, however. Major range-front structures which trend away from the area (notably the Sevier fault) bound wide, uniformly tilted plateau blocks and thus probably extend below the shallow detachments and penetrate the seismogenic part of the crust (Anderson and Barnhard, 1992).

Within the southern portion of the Basin and Range - Colorado Plateau transition zone in Utah (including the southern High Plateaus), reconnaissance studies of neotectonic deformation and local structure indicate complex structural relations involving left-lateral normal-slip faulting and folding (Anderson and Christenson, 1989). Some groups of features appear to be secondary structures related to large-scale folding and faulting, particularly sets of faulted folds west of the Sevier and Hurricane faults (location nos. 10-8 and 10-17) and systems of small structures on the flank of the Cedar City-Parowan monocline and possibly on the adjacent Markagunt Plateau (location nos. 10-21 and 10-23). With the exception of these features, which are ascribed to nonseismogenic surficial deformation, Quaternary structures in the region are regarded as potential sources of large-magnitude earthquakes (Anderson and Christenson, 1989). The largest structures, plateau- and range-bounding faults (including a possible blind fault beneath the Cedar City-Parowan monocline), are thought to be capable of generating the largest seismic events.

Quaternary volcanic rocks are widespread in this region of the Basin and Range-Colorado Plateau transition; however, vents do not generally coincide with mapped faults. A lack of evidence to indicate synvolcanic faulting suggests that eruptions in this region are probably not accompanied by hazardous levels of seismicity (Anderson, 1988; Anderson and Christenson, 1989).

Colorado Plateau

In a broad sense, the interior of the Colorado Plateau is tectonically stable and has simple crustal structure. Much of the region shows little or no evidence of tectonism during the Quaternary. However, the 1988 M_L 5.3 San Rafael Swell earthquake, which occurred on a buried fault, demonstrates a potential for moderate-size earthquakes in the Colorado Plateau (Nava and others, 1988).

Unlike the regional picture, the Paradox Basin contains complex structural relations and a number of faults known or suspected to have had Quaternary movement. A conspicuous northwest-trending group of high-angle, valley-bounding faults is associated with dissolutional collapse along the crests of large salt anticlines, cored by evaporite-rich strata of the Pennsylvanian Paradox Formation. These normal-slip faults may be favorably oriented with respect to the regional stress field, which on the basis of low-level seismicity appears to be characterized by northeast-oriented extension (Wong and Humphrey, 1989; Zoback and Zoback, 1989). From a study of relative fluvial-incision rates during the late Cenozoic, Ely (1988) recognized a regional northwest-trending downwarp axis between Castle-Sinbad-Paradox Valleys and the Uncompagre uplift, which he attributed to extensional reactivation of deep-seated faults beneath the Paradox Basin. Major Quaternary(?) faults that appear to extend below the evaporite sequence (for example, the Moab fault and possibly the Lisbon Valley fault zone) or that intersect the trend of the salt anticline belt along pre-existing structures (for example, the Shay graben) can be regarded as potentially active faults that may experience significant tectonic displacements (Woodward-Clyde Consultants, 1982).

Surface faulting related strictly to salt dissolution and collapse represents an unknown, although probably low, seismic hazard. Youthful salt-related deformation along the Colorado River (in particular, the Needles graben and Meander anticline) is a local, shallow-seated response to canyon cutting and associated topographic relief (appendix A, location no. 18-11) and thus probably occurs aseismically. Much of the most recent deformation in the Paradox Basin is due to continued collapse of salt-cored structures or remobilization of salt within the anticline-collapse valleys and is expressed as tilted and warped surficial deposits, rather than as discrete surface fault ruptures. This type of deformation may occur gradually and not as a succession of instantaneous events.

SUMMARY

Geologic and seismologic observations reveal that most Utahns live in a tectonically active environment susceptible to large (magnitude ~6.5 to 7.5) surface-faulting earthquakes. Earthquake potential in the state is not apparent from the short historical record, during which only one event (the 1934 magnitude 6.6 Hansel Valley earthquake in northernmost Utah) was large enough to cause rupture of the ground surface. However, data on geologically young faults and other related tectonic features, combined with information on the rupture characteristics of large, historical normal-faulting earthquakes in the western United States, show the extent of the earthquake hazard in Utah and provide a sound basis for identifying and characterizing seismic-source zones in the state.

Seismogenic normal-slip faults that rupture up to the surface are understood to be planar and moderately to steeply dipping (40-60 degree) features to depths of about 12-15 kilometers (7-9 mi). A significant minority of Quaternary faults and fault-related folds in Utah have surface patterns, structural settings, or apparent subsurface geometries that indicate they may be relatively shallow structures without independent potential for generating large earthquakes.

Most tectonic deformation in Utah during the Quaternary has occurred along a broad north-trending zone through the center of the state, where historical seismicity has been most abundant (the Intermountain seismic belt) and where the late Cenozoic extensional terrain of the Basin and Range Province gives way to the more stable terrain of the Middle Rocky Mountains and Colorado Plateaus Provinces to the east. This zone of seismic and tectonic activity has been a major tectonic boundary for much of geologic time. In addition to marking the transitional eastern boundary of the Basin and Range Province, it also approximates the leading eastern edge of the Mesozoic to early Cenozoic Sevier fold and thrust belt and the eastern margin of a Precambrian to Paleozoic continental rift zone. Structural elements that may have been inherited from these earlier tectonic settings appear to have influenced the development and seismogenic character of present-day tectonic features. In particular, extensional backsliding on shallow, low-angle thrust planes appears to account for the position and subsurface geometry of a number of Quaternary faults in the region. These thrust planes do not extend to significant seismogenic depths, raising questions about the seismic potential of these and related faults. Furthermore, evidence indicates that virtually all small to moderate earthquakes in Utah occur on moderate- to high-angle faults, arguing against seismic slip on low-angle structures.

Approximately three dozen faults in the Wasatch Front region of north-central Utah have evidence of one or more surface-rupturing event(s) in latest Pleistocene to Holocene time, in contrast to faults within the tectonic transition zone farther south which generally lack evidence of recent activity. During the past 15,000 years, faults in the Wasatch Front region have produced a minimum of 50 to 120 (with a preferred estimate of 85) large-magnitude earthquakes. This estimate converts to a minimum average regional recurrence interval for magnitude ~6.5 + earthquakes of 125 to 300 years.

Roughly half of the events during the past 15,000 years in the Wasatch Front region have occurred on the Wasatch fault zone, the longest and most active single structure in the state. In particular, the central portion of the fault zone has individual segment lengths and Holocene rates of activity that are substantially greater than those for other late Quaternary faults. With lengths that average about 50 kilometers (31 mi) (more than twice that for many other faults), segments of the central Wasatch fault zone have collectively produced large (up to magnitude 7.5-7.7) earthquakes an average of once every 400 years during the middle to late Holocene. During the past 1,500 years, these segments have experienced a cluster of more closely spaced events, defining a shorter term composite recurrence interval of only 220 years. Slip rates for the central Wasatch fault zone during the Holocene (generally 1-2 mm/yr [0.04-0.08 in/yr]) are substantially greater (in many cases one to two orders of magnitude greater) than rates estimated for most other faults in the state.

Some latest Quaternary faulting patterns recognized in the vicinity of the Wasatch Front may be due to perturbations in the regional stress field. Specifically, several faults within the Lake Bonneville basin have evidence of large and/or frequent surface-faulting events during or following Lake Bonneville time juxtaposed with periods of relative quiescence. The timing of high- versus low-activity periods appears to differ among faults, however, obscuring the connection between changes in crustal loading and changes in faulting activity. Latest Quaternary and historical surface fault ruptures mainly north and east of the Bonneville basin (in states north of Utah) form a distinctive spatial pattern that may be related to migration of the Yellowstone hotspot.

Latest Quaternary faulting in the southern Wasatch Front region is part of an east-west-oriented grouping of recent faulting and volcanism in west-central Utah. The ages of surface-faulting and eruptive events in the zone appear to separate into two time intervals: latest Pleistocene to early Holocene, and the late Holocene. This space-time pattern of tectonic activity may be somehow related to intervals of movement on a system of shallow, low-angle detachment faults identified beneath west-central Utah. The mechanics of extension across detachment faults are poorly understood and consequently the earthquake-generating potential of surface-rupturing faults in this domain is open to speculation. Faults within a north-trending belt of Quaternary volcanic activity in the Sevier - Black Rock Deserts appear to be deeper-seated structures that offset shallow detachment surfaces and may provide pathways for upwelling magma. The northern and southern extent of young faulting in west-central Utah coincides with, and may be controlled by, narrow east-west oriented structural zones that cross much of the Basin and Range Province and appear to accommodate regional variations in extension.

Understanding seismotectonics in the eastern portion of the west-central Utah domain is made more difficult by the uncertain role of salt flowage and dissolution in the tectonic evolution of the region. The presence of evaporite-cored anticlines with evidence of Quaternary activity indicates that diapirism may be important locally. If it is presumed that salt movements have been a long-term, dominant tectonic process in the region, then the down-dropping of valley basins along high-angle faults and plateau-bounding monoclines may involve the near-surface collapse of diapiric folds. Regardless of whether salt movements have been important, the mechanically weak, evaporite-rich Arapien Shale is postulated to form a detachment horizon, perhaps connecting young plateau-top grabens to deeper, seismogenic(?) faults responsible for uplift of the Wasatch Plateau and other tablelands in the region.

In the Basin and Range - Colorado Plateau transition zone of southern Utah, where evidence of latest Quaternary tectonism is sparse relative to regions farther north, folds and clusters of short, distributive faults have developed adjacent to major, plateau-bounding structures. Some of these small-scale faults and folds are interpreted to be shallow, secondary features with little or no potential for generating large earthquakes. The Hurricane and Sevier faults, which dominate the tectonic landscape of southern Utah, have late Quaternary vertical slip rates of 0.3 to 0.5 mm/yr (0.01-0.02 in/yr). These values are substantially less than Holocene slip rates of 1 to 2 mm/yr (0.04-0.08 in/yr) estimated for the central segments of the Wasatch fault zone, but are comparable to rates estimated for other relatively active faults in Utah and to longer term (late Quaternary) rates estimated for the Wasatch fault zone.

The interior of the Colorado Plateau has generally scattered, subdued evidence of tectonism during the Quaternary. Although the province has experienced epeirogenic uplift, it is basically a coherent, stable crustal block beyond the regime of basin-range extension. The Paradox Basin is unlike the rest of the plateau in that it has experienced extensive deformation, owing to a long history of salt tectonics. Faulting and folding attributed mainly to near-surface movement and dissolution of salt rather than to seismic-strain release have been locally important in the Paradox Basin during the late Quaternary.

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REFERENCES

Abe, Katsuyuki, 1981, Magnitudes of large shallow earthquakes from 1904 to 1980: Physics of the Earth and Planetary Interiors, v. 27, no. 1, p. 72-92.

Algermissen, S.T., Perkins, D.M., Thenhaus, P.C., Hanson, S.L., and Bender, B.L., 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U.S. Geological Survey Open-File Report 82-1033, 99 p.

——1990, Probabilistic earthquake acceleration and velocity maps for the United States and Puerto Rico: U.S. Geological Survey Miscellaneous Field Studies Map MF-2120, scale 1:7,500,000.

Allen, C.R., 1986, Seismological and paleoseismological techniques of research in active tectonics, *in* Geophysics Research Forum, and the National Research Council, Active tectonics: Washington D.C., National Academy Press, p. 148-154.

Allmendinger, R.W., Farmer, Harlow, Hauser, E.C., Sharp, J.W., Von Tish, Douglas, Oliver, Jack, and Kaufman, Sidney, 1986, Phanerozoic tectonics of the Basin and Range - Colorado Plateau transition from COCORP data and geologic data — a review, *in* Barazangi, Muawia, and Brown, Larry, editors, Reflection seismology — the continental crust: American Geophysical Union, Geodynamics Series volume 14, p. 257-267.

Allmendinger, R.W., Hauge, T.A., Hauser, E.C., Potter, C.J., and Oliver, Jack, 1987, Tectonic heredity and the layered lower crust in the Basin and Range Province, western United States, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Geological Society of America Special Publication No. 28, p. 223-246.

Allmendinger, R.W., Sharp, J.W., Von Tish, Douglas, Serpa, Laura, Brown, Larry, Kaufman, Sidney, Oliver, Jack, and Smith, R.B., 1983, Cenozoic and Mesozoic structure of the eastern Basin and Range Province, Utah, from COCORP seismic-reflection data: Geology, v. 11, no. 9, p. 532-536.

Anders, M.H., Geissman, J.W., Piety, L.A., and Sullivan, J.T., 1989, Parabolic distribution of circumeastern Snake River Plain seismicity and latest Quaternary faulting—migratory pattern and association with the Yellowstone hotspot: Journal of Geophysical Research, v. 94, no. B4, p. 1589-1621.

Anderson, E.M., 1951, The dynamics of faulting and dyke formation with applications to Britain: Edinburgh, Oliver and Boyd, 206 p.

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Long Beach, California, Fugro Incorporated, 35 p., scale 1:500,000.

Anderson, R.E., 1988, Hazard implications of joint-controlled basaltic volcanism in southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A115.

——1989, Tectonic evolution of the intermontane system—Basin and Range, Colorado Plateau, and High Lava Plains, *in* Pakiser, L.C., and Mooney, W.D., editors, Geophysical framework of the continental United States: Geological Society of America Memoir 172, p. 163-176.

Anderson, R.E., and Barnhard, T.P., 1992, Neotectonic framework of the central Sevier Valley area, Utah, and its relationship to seismicity, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-F, 47 p.

Anderson, R.E., and Bucknam, R.C., 1979, Map of fault scarps in unconsolidated sediments, Richfield 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-1236, 15 p., scale: 250,000.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p., scale 1:250,000.

Anderson, R.E., Zoback, M.L., and Thompson, G.A., 1983, Implications of selected subsurface data on the structural form and evolution of some basins in the northern Basin and Range Province, Nevada and Utah: Geological Society of America Bulletin, v. 94, no. 9, p. 1055-1072.

Arabasz, W.J., 1984, Earthquake behavior in the Wasatch Front area—association with geologic structure, space-time occurrence, and stress state, *in* Hays, W.W., and Gori, P.L., editors, A workshop on evaluation of regional and urban earthquake hazards and risk in Utah: U.S. Geological Survey Open-File Report 84-763, p. 310-339.

Arabasz, W.J., and Julander, D.R., 1986, Geometry of seismically active faults and crustal deformation within the Basin and Range-Colorado Plateau transition in Utah, *in* Mayer, Larry, editor, Extensional tectonics of the southwestern United States—a perspective on processes and kinematics: Geological Society of America Special Paper 208, p.43-74.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1989, Evaluation of seismicity relevant to the proposed siting of a Superconducting Supercollider (SSC) in Tooele County, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-1, 107 p.

——1992, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-D, 36 p.

Arabasz, W.J., and Smith, R.B., 1981, Earthquake prediction in the Intermountain seismic belt—an intraplate extensional regime, *in* Simpson, D.W., and Richards, P.G., editors, Earthquake prediction—an international review: American Geophysical Union Maurice Ewing Series 4, p. 248-258.

Baer, J.L., 1976, Structural evolution of central Utah—Late Permian to Recent, *in* Hill, J.G., editor, Symposium on geology of the Cordilleran hingeline: Rocky Mountain Association of Geologists, p. 37-45.

Barnhard, T.P., and Dodge, R.L., 1988, Map of fault scarps formed on unconsolidated sediments, Tooele 1° x 2° quadrangle, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1990, scale 1:250,000.

Best, M.G., and Hamblin, W.K., 1978, Origin of the northern Basin and Range Province—implications from the geology of its eastern boundary: Geological Society of America Memoir 152, p. 313-340.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, no. 10, p. 1035-1050.

Biggar, Norma, 1985, Quaternary studies in the Paradox Basin, southeastern Utah: Walnut Creek, California, Woodward-Clyde Consultants Topical Report, 284 p.

Bjarnason, I.T., and Pechmann, J.C., 1989, Contemporary tectonics of the Wasatch Front region, Utah, from earthquake focal mechanisms: Bulletin of the Seismological Society of America, v. 79, no. 3, p. 731-755.

Bonilla, M.G., 1988, Minimum earthquake magnitude associated with coseismic surface faulting: Bulletin of the Association of Engineering Geologists, v. 25, no. 1, p. 17-29.

Bonilla, M.G., Mark, R.K., and Lienkaemper, J.J., 1984, Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement: Bulletin of the Seismological Society of America, v. 74, no. 6, p. 2379-2411.

Bucknam, R.C., 1976, Leveling data from the epicentral area of the March 27, 1975, earthquake in Pocatello Valley, Idaho: U.S. Geological Survey Open-File Report 76-52, 6 p.

Bucknam, R.C., Algermissen, S.T., and Anderson, R.E., 1980, Patterns of late Quaternary faulting in western Utah and an application in earthquake hazard evaluation, *in* Andriese, P.D., compiler, Earthquake hazards along the Wasatch and Sierra-Nevada frontal fault zones: U.S. Geological Survey Open-File Report 80-801, p. 299-314.

Bucknam, R.C., and Anderson, R.E., 1979, Map of fault scarps on unconsolidated sediments, Delta 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-366, 21 p., scale 1:250,000.

Bucknam, R.C., and Thenhaus, P.C., 1983, Great Basin seismic source zones; summary of workshop convened October 10-11, 1979, *in* Thenhaus, P.C., editor, Summary of workshops concerning regional seismic source zones of parts of the conterminous United States, convened by the U.S. Geological Survey, 1979-1980, Golden Colorado: U.S. Geological Survey Circular 898, p. 4-9.

Christiansen, R.L., and Lipman, P.W., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States, II. late Cenozoic: Philosophical Transactions of the Royal Society of London, Series A, v. 271, p. 249-284.

Christiansen, R.L., and McKee, E.H., 1978, Late Cenozoic volcanic and tectonic evolution of the Great Basin and Columbia intermountane regions: Geological Society of America Memoir 152, p. 283-311.

Clark, E.E., 1977, Late Cenozoic volcanic and tectonic activity along the eastern margin of the Great Basin, in the proximity of Cove Fort, Utah: Brigham Young University Geology Studies, v. 24, pt. 1, p. 87-114.

Colman, S.M., Choquette, A.F., Rosholt, J.N., Miller, G.H., and Huntley, D.J., 1986, Dating the upper Cenozoic sediments in Fisher Valley, southeastern Utah: Geological Society of America Bulletin, v. 97, no. 12, p. 1422-1431.

Colman, S.M., Pierce, K.L, and Birkeland, P.W., 1987, Suggested terminology for Quaternary dating methods: Quaternary Research, v. 28, no. 2, p. 314-319.

Corbett, M.K., 1982, Superposed tectonism in the Idaho-Wyoming thrust belt, *in* Powers, R.B., editor, Geologic studies of the Cordilleran thrust belt, Volume I: Rocky Mountain Association of Geologists, p. 341-356.

Crone, A.J., 1987, Introduction to directions in paleoseismology, *in* Crone, A.J., and Omdahl, E.M., editors, Proceedings of Conference XXXIX, Directions in paleoseismology: U.S. Geological Survey Open-File Report 87-673, p. 1-6.

Crone, A.J., and Harding S.T., 1984, Relationship of late Quaternary fault scarps to subjacent faults, eastern Great Basin, Utah: Geology, v. 12, no. 5, p. 292-295.

Crone, A.J., Machette, M.N., Bonilla, M.G., Leinkaemper, J.J., Pierce, K.L., Scott, W.E., and Bucknam, R.C., 1987, Surface faulting accompanying the Borah Peak earthquake and segmentation of the Lost River fault, central Idaho: Bulletin of the Seismological Society of America, v. 77, no. 3, p. 739-770.

Currey, D.R., 1982, Lake Bonneville—selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p.

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—papers from a conference held in Salt Lake City, March 26-28, 1985: Salt Lake City, University of Utah, Center for Public Affairs and Administration, p. 9-24.

Das, Shamita, and Scholz, C.H., 1983, Why large earthquakes do not nucleate at shallow depths: Nature, v. 305, no. 5935, p. 621-623.

dePolo, C.M., Clark, D.G., Slemmons, D.B., and Aymard, W.H., 1989, Historical Basin and Range Province surface faulting and fault segmentation, *in* Schwartz, D.P., and Sibson, R.H., editors, Fault segmentation and controls of rupture initiation and termination—proceedings of conference XLV: U.S. Geological Survey Open-File Report 89-315, p. 131-162.

Doser, D.I., 1985a, The 1983 Borah Peak, Idaho and 1959 Hebgen Lake, Montana earthquakes—models for normal fault earthquakes in the Intermountain seismic belt, *in* Stein, R.S., and Bucknam, R.C., editors, Proceedings of workshop XXVII on the Borah Peak, Idaho, earthquake: U.S. Geological Survey Open-File Report 85-290, p. 368-384.

——1985b, Source parameters and faulting processes of the 1959 Hegben Lake, Montana, earthquake sequence: Journal of Geophysical Research, v. 90, no. B6, p. 4537-4555.

——1988, Source parameters of earthquakes in the Nevada seismic zone, 1915-1943: Journal of Geophysical Research, v. 93, no. B12, p. 15,001-15,016.

——1989, Extensional tectonics in northern Utah-southern Idaho, U.S.A., and the 1934 Hansel Valley sequence: Physics of the Earth and Planetary Interiors, v. 54, no. 1-2, p. 120-134.

Doser, D.I., and Smith, R.B., 1982, Seismic moment rates in the Utah region: Seismological Society of America Bulletin, v. 72, no. 2, p. 525-551.

——1985, Source parameters of the 28 October 1983, Borah Peak, Idaho, earthquake from body wave analysis: Bulletin of the Seismological Society of America, v. 75, no. 4, p. 1041-1051.

——1989, An assessment of source parameters of earthquakes in the cordillera of the western United States: Bulletin of the Seismological Society of America, v. 79, no. 5, p. 1383-1409.

Easterbrook, D.J., editor, 1988, Dating Quaternary sediments: Geological Society of America Special Paper 227, 165 p.

Eaton, G.P., 1982, The Basin and Range Province—origin and tectonic significance: Annual Review of the Earth and Planetary Sciences, v. 10, p. 409-440.

Ely, R.W., 1988, Late Cenozoic crustal warping in the central Colorado Plateau [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A233.

Ertec Western, Inc., 1981, MX siting investigation, faults and lineaments in the MX siting region, Nevada and Utah: Long Beach, California, unpublished consultant's report no. E-TR-54 for U.S. Air Force, volume I, 77 p.; volume II, variously paginated.

Evans, J.P., 1991, Structural setting of seismicity in northern Utah: Utah Geological Survey Contract Report 91-15, 37 p.

Foley, L.L., Martin, R.A., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 86-7, 132 p.

Forman, S.L., editor, 1989, Dating methods applicable to Quaternary geologic studies in the western United States: Utah Geological and Mineral Survey Miscellaneous Publication 89-7, 80 p.

Gilliland, W.N., 1951, Geology of the Gunnison quadrangle, Utah: Lincoln, University of Nebraska Studies, New Series No. 8, 101 p.

----1952, Another Tertiary crustal disturbance in central Utah: American Association of Petroleum Geologists Bulletin, v. 36, no. 7, p. 1461-1464.

Hall, W.B., and Sablock, P.E., 1985, Comparisons of the geomorphic and surficial fracturing effects of the 1983 Borah Peak, Idaho, earthquake with those of the 1959 Hebgen Lake, Montana earthquake, *in* Stein, R.S., and Bucknam, R.C., editors, Proceedings of workshop XXVII on the Borah Peak, Idaho, earthquake: U.S. Geological Survey Open-File Report 85-290, p. 141-152.

Hamblin, W.K., 1970, Late Cenozoic basalt flows of the western Grand Canyon region, *in* Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Utah Geological Society, Guidebook to the Geology of Utah No. 23, p. 21-37.

Hamilton, Warren, 1987, Crustal extension in the Basin and Range Province, southwestern United States, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Oxford, Blackwell Scientific Publications, Geological Society Special Publication No. 28, p. 155-176.

Hanks, T.C., Bucknam, R.C., Lajoie, K.R., and Wallace, R.E., 1984, Modification of wave-cut and faulting-controlled landforms: Journal of Geophysical Research, v. 89, no. B7, p. 5771-5790.

Hanks, T.C., and Kanamori, Hiroo, 1979, A moment magnitude scale: Journal of Geophysical Research, v. 84, no. B5, p. 2348-2350.

Harden, D.R., Biggar, N.E., and Gillam, M.L., 1985, Quaternary deposits and soils in and around Spanish Valley, Utah, *in* Weide, D.L., editor, Soils and Quaternary geology of the southwestern United States: Geological Society of American Special Paper 203, p. 43-64.

Hopper, M.G., 1988, Isoseismals of some historical earthquakes affecting the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, Volume III: U.S. Geological Survey Open-File Report 88-680, p. Y-1-28.

---in press, Isoseismals of some historical earthquakes affecting the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-K-Z.

Hoover, J.D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 3-72.

Hunt, C.B., 1967, Physiography of the United States: San Francisco, W.H. Freeman and Company, 480 p.

Huntoon, P.W., 1982, The Meander anticline, Canyonlands, Utah, an unloading structure resulting from horizontal gliding on salt: Geological Society of America Bulletin, v. 93, no. 10, p. 941-950.

----1988, Late Cenozoic gravity tectonic deformation related to the Paradox salts in the Canyonlands area of Utah, *in* Doelling, H.H., Oviatt, C.G., and Huntoon, P.W., editors, Salt deformation in the Paradox region: Utah Geological and Mineral Survey Bulletin 122, p. 81-93.

Jackson, J.A., 1987, Active normal faulting and crustal extension, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Geological Society of America Special Publication No. 28, p. 3-17.

Jackson, J.A., and White N.J., 1989, Normal faulting in the upper continental crust--observations from regions of active extension: Journal of Structural Geology, v. 11, no. 1/2, p. 15-36.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1987, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for the U.S. Geological Survey, Contract No. 14-08-0001-22048, 55 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

Keller, G.R., Braille, L.W., and Morgan, P., 1979, Crustal structure, geophysical models, and contemporary tectonism of the Colorado Plateau: Tectonophysics, v. 61, no. 1-3, p. 131-147.

Lipman, P.W., Rowley, P.D., Mehnert, H.H., Evans, S.H., Jr., Nash, W.P., and Brown, F.H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah--geothermal and archeological significance: U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 133-147.

Machette, M.N., 1985, Late Cenozoic geology of the Beaver Basin, southwestern Utah: Brigham Young University Geology Studies, v. 32, pt. 1, p. 19-37.

----editor, 1988, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, 120 p.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1986, Late Quaternary segmentation and slip-rate history of the Wasatch fault zone, Utah [abs.]: EOS Transactions of the American Geophysical Union, v. 76, no. 44, p. 1107.

----1992, Paleoseismology of the Wasatch fault zone--a summary of recent investigations, interpretations, and conclusions, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

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.

McCalpin, J.P., Robison, R.M., and Garr, J.D., 1992, Neotectonics of the Hansel Valley-Pocatello Valley corridor, northern Utah and southern Idaho, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-G, 18 p.

McDonald, R.E., 1976, Tertiary tectonics and sedimentary rocks along the transition--Basin and Range Province to plateau and thrust belt province, Utah, *in* Hill, J.G., editor, Geology of the Cordilleran hingeline: Rocky Mountain Association of Geologists, p. 281-317.

Morgan, P., and Swanberg, C.A., 1985, On the Cenozoic uplift and tectonic stability of the Colorado Plateau: Journal of Geodynamics, v. 3, p. 39-63.

Moulton, F.C., 1975, Lower Mesozoic and upper Paleozoic petroleum potential of the hingeline area, central Utah, *in* Bolyard, D.W., editor, Symposium on deep drilling frontiers in the central Rocky Mountains: Rocky Mountains Association of Geologists, p. 87-97; reprinted *in* Hill, J.G., editor, Symposium on geology of the Cordilleran hingeline: Rocky Mountain Association of Geologists, p. 219-229.

Nakata, J.K., Wentworth, C.M., and Machette, M.N., 1982, Quaternary fault map of the Basin and Range and Rio Grande Rift provinces, western United States: U.S. Geological Survey Open-File Report 82-579, scale 1: 2,500,000.

Nash, W.P., 1986, Distribution, lithology, and ages of late Cenozoic volcanism on the eastern margin of the Great Basin, west-central Utah: Salt Lake City, University of Utah Research Institute, Earth Science Laboratory Final Report prepared for U.S. Department of Energy, contract DEAC0780 ID 12079, DOE/ID/12079-131, 82 p.

Nava, S.J., Pechmann, J.C., and Arabasz, W.J., 1988, The magnitude 5.3 San Rafael Swell, Utah, earthquake of August 14, 1988--a preliminary seismological summary: Utah Geological and Mineral Survey, Survey Notes, v. 22, no. 1,2, p. 16-19.

Nishenko, S.P. and Schwartz, D.P., 1990, Preliminary estimates of large earthquake probabilities along the Wasatch fault zone, Utah [abs.]: EOS Transactions of the American Geophysical Union, v. 71, no. 43, p. 1448.

Oviatt, C,G., 1988, Evidence for Quaternary deformation in the Salt Valley anticline, southeastern Utah, *in* Doelling, H.H., Oviatt, C.G., and Huntoon, P.W., editors, Salt deformation in the Paradox region: Utah Geological and Mineral Survey Bulletin 122, p. 63-76.

Pechmann, J.C., Nash, W.P., Viveiros, J.J., and Smith, R.B., 1987, Slip rate and earthquake potential of the East Great Salt Lake fault, Utah [abs.]: EOS Transactions of the American Geophysical Union, v. 68, no. 44, p. 1369.

Pechmann, J.C., Nava, S.J., and Arabasz, W.J., 1990, Left-lateral shear beneath the NW Colorado Plateau--the 1988 San Rafael Swell and 1989 southern Wasatch Plateau earthquakes: Seismological Research Letters, v. 61, no. 1, p. 44.

Picha, Frank, 1986, The influence of pre-existing tectonic trends on geometries of the Sevier orogenic belt and its foreland in Utah: American Association of Petroleum Geologists Memoir 41, p. 309-320.

Picha, Frank, and Gibson, R.I., 1985, Cordilleran hingeline--late Precambrian rifted margin of the North American craton and its impact on the depositional and structural history, Utah and Nevada: Geology, v. 13, no. 7, p. 465-468.

Planke, Sverre, and Smith, R.B., 1991, Cenozoic extension and evolution of the Sevier Desert basin, Utah, from seismic reflection, gravity, and well log data: Tectonics, v. 10, no. 2, p. 345-365.

Rowley, P.D., Anderson, J.J., Williams, P.L., and Fleck, R.J., 1978, Age of structural differentiation between the Colorado Plateaus and Basin and Range provinces in southwestern Utah: Geology, v. 6, no. 1, p. 51-55.

Royse, Frank, 1983, Extension faults and folds in the foreland thrust belt, Utah, Wyoming, Idaho [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 295.

Royse, Frank, Warner, M.A., and Reese, D.L., 1975, Thrust belt structural geometry and related stratigraphic problems, Wyoming-Idaho-northern Utah, *in* Boyland, D.W., editor, Deep drilling frontiers of the central Rocky Mountains: Rocky Mountain Association of Geologists Symposium, p. 41-54.

Schwartz, D.P., 1988, Geological characterization of seismic sources--moving into the 1990s, *in* Von Thun, J.L., editor, Earthquake engineering and soil dynamics II--recent advances in ground-motion evaluation: American Society of Civil Engineers Geotechnical Special Publication No. 20, p. 1-42.

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.

----1986, Seismic hazards--new trends in analysis using geologic data, *in* Geophysics Research Forum, and the National Research Council, Active tectonics: Washington, D.C., National Academy Press, p. 215-230.

Scott, W.E., Pierce, K.L, and Hait, M.H., Jr., 1985, Quaternary tectonic setting of the 1983 Borah Peak earthquake, central Idaho: Bulletin of the Seismological Society of America, v. 75, no. 4, p. 1053-1066.

Selner, G.I., and Taylor, R.B., 1989, GSDraw and GSMap Version 6.0--graphics programs and utility programs for the IBM PC and compatible microcomputers to assist compilation and publication of geologic maps and illustrations: U.S. Geological Survey Open-File Report 89-373A (Documentation and tutorial), 144 p., and 89-373 B (Executable program disks).

Sibson, R.H., 1985, A note on fault reactivation: Journal of Structural Geology, v. 7, no. 6, p. 751-754.

Slemmons, D.B., 1977, State-of-the-art for assessing earthquake hazards in the United States; Report 6, faults and earthquake magnitude: U.S. Army Corp of Engineers Waterways Experiment Station, Miscellaneous Paper S-73-1, 129 p.

Smith, R.B., 1981, Listric faults and earthquakes, what evidence? [abs.]: EOS Transactions of the American Geophysical Union, v. 62, no. 45, p. 961.

Smith, R.B., and Arabasz, W.J., 1991, Seismicity of the Intermountain seismic belt, *in* Slemmons, D.B., Engdahl, E.R., Zoback, M.D., and Blackwell, D.D., editors, Neotectonics of North America: Geological Society of America, Decade of North American Geology Map Volume 1, p. 185-228.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the western U.S. Cordillera--inferences on structural style from seismic reflection data, regional tectonics, and thermal-mechanical models of brittle-ductile deformation: Journal of Geophysical Research, v. 89, no. B7, p. 5733-5762.

Smith, R.B., Nagy, W.C., Julander, K.A., Viveiros, J.J., Barker, C.A., and Gants, D.G., 1989, Geophysical and tectonic framework of the eastern Basin and Range-Colorado Plateau-Rocky Mountain transition, *in* Pakiser, L.C., and Mooney, W.D., editors, Geophysical framework of the continental United States: Geological Society of America Memoir 172, p. 205-233.

Smith, R.B., and Richins, W.D., 1984, Seismicity and earthquake hazards of Utah and the Wasatch Front--paradigm and paradox, *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. 73-112.

Smith, R.B., Richins, W.D., and Doser, D.I., 1985, The 1983 Borah Peak earthquake--regional seismicity, kinematics, and tectonic mechanism, *in* Stein, R.S., and Bucknam, R.C., editors, Proceedings of workshop XXVII on the Borah Peak, Idaho, earthquake: U.S. Geological Survey Open-File Report 85-290, p. 236-263.

Smith, R.B., and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the Intermountain seismic belt: Geological Society of America Bulletin, v. 85, no. 8, p. 1205-1218.

Smithson, S.B., and Johnson, R.A., 1989, Crustal structure of the western U.S. based on reflection seismology *in* Pakiser, L.C., and Mooney, W.D., editors, Geophysical framework of the continental United States: Geological Society of America Memoir 172, p. 577-612.

Spieker, E.M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, 161 p.

Standlee, L.A., 1982, Structure and stratigraphy of Jurassic rocks in central Utah—their influence on tectonic development of the Cordilleran foreland thrust belt, *in* Powers, R.B., editor, Geologic studies of the Cordilleran thrust belt, Volume I: Rocky Mountain Association of Geologists, p. 357-382.

——1983, Structural controls on the Mesozoic-Tertiary tectonic evolution of central Utah [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 295.

Stewart, J.H., 1978, Basin-range structure in western North America, a review, *in* Smith, R.B., and Eaton, G.P., editors, Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 341-367.

——1980, Regional tilt patterns of late Cenozoic basin-range fault blocks, western United States: Geological Society of America Bulletin, v. 91, no. 8, p. 460-464.

Stokes, W.L., 1976, What is the Wasatch Line?, *in* Hill, J.G., editor, Geology of the Cordilleran hingeline: Rocky Mountain Association of Geologists, p. 11-25.

——1977, Subdivisions of the major physiographic provinces in Utah: Utah Geology, v. 4, no. 1, p. 1-17.

——1982, Geologic comparisons and contrasts, Paradox and Arapien basins, *in* Nielson, D.L., editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 1-11.

Sullivan, T.J., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p.

Swan, F.H., III, Schwartz, D.P., and Cluff, L.S., 1980, Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah: Bulletin of the Seismological Society of America, v. 70, no. 5, p. 1431-1462.

Thenhaus, P.C., editor, 1983, Summary of workshops concerning regional seismic source zones of parts of the conterminous United States convened by the U.S. Geological Survey 1979-1980, Golden, Colorado: U.S. Geological Survey Circular 898, 36 p.

Thenhaus, P.C., and Barnhard, T.P., 1989, Regional termination and segmentation of Quaternary fault belts in the Great Basin, Nevada and Utah: Bulletin of the Seismological Society of America, v. 79, no. 5, p. 1426-1438.

Thompson, G.A., Catchings, Rufus, Goodwin, Erik, Holbrook, Steve, Jarchow, Craig, Mann, Carol, McCarthy, Jill, and Okaya, David, 1989, Geophysics of the western Basin and Range Province, *in* Pakiser, L.C., and Mooney, W.D., editors, Geophysical framework of the continental United States: Geological Society of America Memoir 172, p. 177-203.

Thompson, G.A., and Zoback, M.L., 1979, Regional geophysics of the Colorado Plateau: Tectonophysics, v. 61, no. 1-3, p. 149-181.

U.S. Geological Survey, 1964, The Hegben Lake, Montana earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435, 242 p.

Viveiros, J.J., 1986, Cenozoic tectonics of the Great Salt Lake from seismic reflection data: Salt Lake City, University of Utah, M.S. thesis, 81 p.

Wallace, R.E., 1981, Active faults, paleoseismology and earthquake hazards in the western United States, *in* Simpson, D.W., and Richards, P.G., editors, Earthquake prediction—an international review: Washington, D.C., American Geophysical Union, Maurice Ewing Series 4, p. 209-216.

——1984a, Fault scarps formed during the earthquakes of October 2, 1915, in Pleasant Valley, Nevada, and some tectonic implications: U.S. Geological Survey Professional Paper 1274-A, p. A1-A33.

——1984b, Patterns and timing of late Quaternary faulting in the Great Basin Province and relation to some regional tectonic features: Journal of Geophysical Research, v. 89, no. B7, p. 5763-5769.

——1987, Grouping and migration of surface faulting and variations in slip rates on faults in the Great Basin Province: Bulletin of the Seismological Society of America, v. 77, no. 3, p. 868-876.

Walter, H.G., 1934, Hansel Valley, Utah, earthquake: The Compass of Sigma Gamma Epsilon, v. 14, no. 4, p. 178-181.

Wernicke, Brian, 1981, Low-angle normal faults in the Basin and Range Province—nappe tectonics in an extending orogen: Nature, v. 291, no. 5817, p. 645-648.

Wernicke, Brian, and Axen, G.J., 1988, On the role of isostasy in the evolution of normal fault systems: Geology, v. 16, no. 9, p. 848-851.

Wernicke, Brian, Walker, J.D., and Beaufait, M.S., 1985, Structural discordance between Neogene detachments and frontal Sevier thrusts, central Mormon Mountains, southern Nevada: Tectonics, v. 4, no. 2, p. 213-246.

West, M.W., 1986, Quaternary extensional reactivation of the Darby and Absaroka thrusts, southwestern Wyoming and north-central Utah [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 5, p. 422.

——1988, An integrated geological-seismological model for seismogenesis in the Intermountain seismic belt [abs.]: Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A14.

——1989, Neotectonics of the Darby-Hogsback and Absaroka thrust plates, Uinta County, Wyoming and Summit County, Utah, with applications to earthquake hazard assessment: Golden, Colorado, Colorado School of Mines, Ph.D. dissertation, 2 volumes, 450 p.

——in press, Paleoseismology of Utah, volume 4 — Seismotectonics of north-central Utah and southwestern Wyoming: Utah Geological Survey Special Studies.

Witkind, I.J., 1964, Reactivated faults north of Hebgen Lake: U.S. Geological Survey Professional Paper 435-G, p. 37-50.

——1982, Salt diapirism in central Utah, *in* Nielson, D.L., editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 13-30.

——1983, Overthrusts and salt diapirs, central Utah: Geological Society of America Memoir 157, p. 45-59.

Witkind, I.J., and Marvin, R.F., 1989, Significance of new potassium-argon ages from the Goldens Ranch and Moroni Formations, Sanpete-Sevier Valley area, central Utah: Geological Society of America Bulletin, v. 101, no. 4, p. 534-548.

Witkind, I.J., Myers, W.B., Hadley, J.B., Hamilton, Warren, and Fraser, G.D., 1962, Geologic features of the earthquake at Hegben Lake, Montana, August 17, 1959: Bulletin of the Seismological Society of America, v. 52, no. 2, p. 163-180.

Witkind, I.J, and Page, W.R., 1984, Origin and significance of the Wasatch and Valley Mountains monoclines, Sanpete-Sevier Valley area, central Utah: The Mountain Geologist, v. 212, no. 4, p. 143-156.

Woodward-Clyde Consultants, 1982, Geologic characterization report for the Paradox Basin study region, Utah study areas, volumes I-IV: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, variously paginated.

Wong, I.V., and Humphrey, J.R., 1989, Contemporary seismicity, faulting, and the state of stress in the Colorado Plateau: Geological Society of America Bulletin, v. 101, no. 9, p. 1127-1146.

Wyss, Mat, 1979, Estimating maximum expectable magnitude of earthquakes from fault dimensions: Geology, v. 7, no. 7, p. 336-340.

Youd, T.L., and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: American Society of Civil Engineers, Journal of the Geotechnical Engineering Division, v. 104, no. GT4, p. 433-446.

Youngs, R.R., Swan, F.H., Power, M.S., Schwartz, D.P., and Green, R.K., 1987, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, Volume II: U.S. Geological Survey Open-File Report 87-585, p. M-1-110.

----in press, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-K-Z.

Zoback, M.L., 1983, Structure and Cenozoic tectonism along the Wasatch fault zone, Utah, *in* Miller, D.M., Todd, V.R., and Howard, K.A., editors, Tectonic and stratigraphic studies in the eastern Great Basin: Geological Society of America, Memoir 157, p. 3-27.

----1992, Superimposed late Cenozoic, Mesozoic, and possible Proterozoic deformation along the Wasatch fault zone in central Utah, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-E, 20 p.

Zoback, M.L., Anderson, R.E., and Thompson, G.A., 1981, Cenozoic evolution of the state of stress and style of tectonism of the Basin and Range Province of the western United States: Philosophical Transactions of the Royal Society of London, series A, v. 300, p. 407-434.

Zoback, M.L., and Zoback, M.D., 1980, State of stress in the conterminous United States: Journal of Geophysical Research, v. 85, no. B11, p. 6113-6156.

----1989, Tectonic stress field of the continental United States, *in* Pakiser, L.C., and Mooney, W.D., editors, Geophysical framework of the continental United States: Geological Society of America Memoir 172, p. 523-539.

APPENDIX A
Tectonic-Activity Information for Quaternary Faults and Folds in Utah

This table presents information pertaining to the activity and seismic potential of Quaternary faults and folds in Utah (shown on plate 1). Surface-rupture (or surface-fold) parameters arranged in columns across each page provide information on the recency, frequency, and magnitude of large paleoearthquakes (see text for further discussion).

Tectonic features are identified in the first column of the table by: (1) a name used in the literature or a brief geographic description, and (2) a "location number." Structure types (generally faults or folds) are indicated parenthetically for unnamed structures. Entries in the table are organized by location number, which consists of two individual numbers separated by a dash. An exception is the last entry in the table, which contains composite information on several segments of the Wasatch fault zone and is presented without a location number. The first part of each number refers to the 1° x 2° quadrangle in which most of the feature is located; the second part reflects the sequence in which the feature was digitally compiled within that 1° x 2° quadrangle and does not reflect location within the quadrangle. Index maps and an alphabetical listing of tectonic features with location numbers are included in appendix C.

Individual entries in the table may pertain to a single fault, fault segment, or fold or to a group of structures. Estimates of the age of most recent movement may vary between portions of a structure or between structures within a group, as shown on plate 1. However, only the age of most recent movement for each entry as a whole is listed in the table (in the second column).

Slip-rate and recurrence-interval estimates (third and fourth columns) are generally average or representative values for the time period indicated in parentheses. Ideally, slip rates and recurrence intervals should be derived from the timing of individual events. However, in practice, the time period used to calculate these parameters is commonly defined by the present day ("time zero") and the age of an offset datum, which may be considerably older than the offsetting event. This arbitrary time window may provide useful slip-rate and recurrence-interval information if it incorporates several displacement events. If instead the time window covers an interval which is substantially shorter than the actual recurrence interval of faulting, it may lead to significant over-estimation of parameter values.

Numeric values for ages or time intervals given in the various columns of the table are written in terms of thousands of years (X 10^3 years). It should be noted that the proper designation for uncalibrated radiocarbon ages is "radiocarbon years before present" (abbreviated ^{14}C yr B.P.) rather than actual years. Direct radiocarbon age control for faulting in Utah is rare, and most applicable ages have been calendar-corrected (in particular, for the Wasatch fault zone) or combined with the results of other dating techniques to yield composite ages. However, the regional Lake Bonneville chronology (discussed in text under "Completeness of the Quaternary tectonic record"), which has been used widely to constrain ages of faulting, is based on uncalibrated radiocarbon ages (M.N. Machette, written communication, 1991) and is older than the upper limit of existing calibration curves. Recent work to extend calibration of the radiocarbon time scale back to 30,000 years shows that prior to 9,000 years ago, radiocarbon ages from an oceanic reservoir are systematically younger than probable true ages, with a maximum difference of ~3,500 years at ~20,000 years ago (Bard and others, 1990). This sort of age divergence can introduce significant errors into slip-rate and recurrence-interval calculations, and, consequently, parameter values that may be affected (in the third and fourth columns of the table) have been noted with an asterisk (*).

Age estimates that are semi-quantitative in nature are expressed as subdivisions of the Quaternary (0-1,650,000 years ago): early Pleistocene (750,000-1,650,000 years ago), middle Pleistocene (130,000-750,000 years ago), late Pleistocene (10,000-130,000 years ago), and Holocene (0-10,000 years ago). Two additional age terms which appear in the table are the latest Pleistocene (~10,000-30,000 years ago) and the late Quaternary (roughly the last third of the Quaternary , ~0-500,000 years ago). Ages of most recent movement (second column of table) are portrayed on plate 1 according to prescribed age categories (discussed in text under "Tectonic activity parameters and compilation techniques") that are generally less precise than those ages in the table that are derived from numeric constraints, but are too narrowly defined for some ages that are estimated from relative or qualitative criteria.

The table identifies the general criteria used to estimate ages of deformation for each feature. Several dating methods are abbreviated using standard symbols: "^{14}C" for radiocarbon, "K-Ar" for potassium-argon, "TL" for thermoluminescence, and "U-trend" for uranium-trend dating (see text for brief overview of dating methods). Unless otherwise noted, terms such as "shoreline relations" and "lacustrine stratigraphy" refer specifically to the chronology and morphostratigraphy of the Bonneville lake cycle.

Preference has been given to the most recent or most detailed studies as citations (labeled as "References" and listed alphabetically) for the parameter values presented for each entry in the table. No attempt has been made to identify all early sources of information that may have been superseded by the results of more detailed studies or incorporated into more comprehensive reports. However, conflicting interpretations that indicate significant uncertainty in the age or activity of structures are presented in the comments section. As a rule, information given as "Comments" can be attributed to one or more of the listed references unless other sources are given.

Estimates of tectonic-activity parameters may be coded with one or more trailing characters to indicate additional or qualifying information. The use of an asterisk (*) is described above. Seven other "activity codes" appear in the table:

1) "d" notes values that have been derived for this compilation.
2) "?" queries values judged to have significant uncertainty.
3) "i" notes values that are based substantially on inference or assumed characteristics rather than direct evidence.
4) "h" indicates scarp-height measurements, which are used as a proxy for, but are typically greater than, net vertical tectonic displacements.
5) "n" denotes displacement values identified as "net vertical tectonic displacement," whereby the effects of antithetic faulting and back-tilting adjacent to the main fault have been removed from the estimate.
6) "m" indicates values that are maxima, as opposed to average or typical values.
7) "e" signals the elapsed time since the most recent surface-faulting event. Elapsed time is used in conjunction with recurrence intervals to assess the likelihood of future earthquake occurrence.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Hansel Valley fault
(6-1)

Parameter values:					
	0.05 e	0.06 - 0.12 *d (<26)	1, 12 ? * (<26) 46+ ? * (26-72)	0.5 - 2.6	10

Age Criteria : historical record; lacustrine stratigraphy; shoreline chronology; scarp morphology; TL
References : McCalpin, 1985; McCalpin and others, 1992
Comments : The scarps are several kilometers from the range front. The most recent event, which occurred in 1934, had a maximum vertical surface displacement of 0.5 meters and a magnitude (M_L) of about 6.6. The event appears to have had a strike-slip focal mechanism (Doser, 1989), although only secondary amounts of strike-slip motion (0.25 meters at one location) were observed at the surface (dePolo and others, 1989; Walter, 1934). Scarp morphology suggests the most recent prehistoric event(s), associated with a total displacement of 2.2-2.6 meters, occurred 10,000-15,000 years ago (although there's uncertainty in dating scarps that formed subaqueously). Radiocarbon, TL, and amino acid dating of deformed lake deposits, interpreted as probable lateral spreads, suggest these events occurred 13,000 and 14,000-15,000 years ago. Another event occurred shortly before deposition of Bonneville transgressive gravels (~26,000 years ago) as evidenced by a filled tectonic fissure. It's unclear whether any events occurred between 26,000 and 58,000 years ago. There's evidence of no events between about 58,000 and 72,000 years ago. Recurrence and displacement data suggest clustering of large events during times when deep lakes occupied the basin. Less frequent, smaller events (as typified by the 1934 event) occurred during times of shallow or no lakes.

North Promontory fault
(6-2)

Parameter values:					
	<15	0.53 *d (<15) 0.15 d (<65)	3.7 - 5 i? * (<15) 16 - 35 i? (<65)	2 - 2.5 i?	

Age Criteria : lacustrine stratigraphy; scarp morphology
References : McCalpin, 1985; McCalpin and others, 1992
Comments : Fault scarps occur at only two locations along the northern portion of the range front. The fault scarps are unbeveled, but are likely the result of more than one event. Single-event displacement is inferred from an antithetic subsidiary fault. The inferred post-Bonneville recurrence interval (computed from a cumulative displacement of 8 meters) seems too short relative to faults associated with more youthful range fronts (such as the Wasatch Range). An antithetic fault 100 meters east of the north end of the main fault has evidence for a single-event displacement that occurred ~10,000-15,000 years ago (based on soil development) and cuts deposits as old as 100,000+ years. Slip and recurrence data for the last 65,000 years are taken from a valley-ward splay off of the range-front fault. Some events on the range-front fault may not have occurred on the splay. The faulted alluvial-fan deposits may correlate with oxygen isotope stage 4 (~65,000 years ago) or 6 (~140,000 years ago). The longer recurrence interval (35,000 years) assumes the greater deposit age. The southern portion of the North Promontory fault is expressed as a prominent range front, although upper Pleistocene deposits are unfaulted. Faults in this area cut Pliocene to Pleistocene deposits and may have last moved in the early or middle Pleistocene (Miller and Schneyer, 1990).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Hansel Valley - valley floor (faults) (6-3)					
Parameter values:	50 - 740 ?				

Age Criteria : tephrochronology; lacustrine stratigraphy
References : McCalpin, 1985; McCalpin and others, 1992
Comments : Age data are from two different faults. Multiple faults displace early Pleistocene(?) deposits, but not overlying Bonneville deposits. Lineaments defined by stream channels are suspected of having a tectonic origin and have been mapped as Quaternary(?) faults on plate 1. Cumulative displacement on individual faults is <5 meters.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Hansel Mountains - east side (faults) (6-4)					
Parameter values:	late Quaternary				

Age Criteria : range-front morphology
References : McCalpin, 1985; McCalpin and others, 1992

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Wasatch fault zone - Collinston segment (6-5)					
Parameter values:	late Pleistocene				30

Age Criteria : range-front morphology; lacustrine stratigraphy
References : Machette and others, 1991, 1992; Personius, 1990
Comments : Faulting along most of the segment predates the transgressive phase of Lake Bonneville (~30,000 years ago). At the south end of the segment, 12 meters of displacement occurs in alluvium estimated from soil development to be several hundred thousand years old. A 2-kilometer-long scarp in Provo-equivalent alluvium at the south end is probably related to faulting on the Brigham City segment (location no. 6-6). The location of the Wasatch fault zone north of the Wellsville Mountains is poorly constrained and subject to interpretation. Gravity data and topography suggested to Machette and others (1992) that the segment lies west of the low hills north of the Wellsville Mountains and ends where it intersects the prominent east-trending fault at the south end of Clarkston Mountain (see plate 1). Cluff and others (1974) mapped the Wasatch fault zone as continuous around the south end of Clarkston Mountain, whereas Machette and others (1992) recognized a 7-kilometer left step and gap in late Pleistocene faulting between the Collinston and Clarkston Mountain segments and interpreted Cluff and other's supposed connecting fault as a shoreline.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Wasatch fault zone
- Brigham City segment
(6-6)

Parameter values:	3.6 e	0.75 (<4.7) 1.0 - 1.3 *d (<15)	1.1 - 3.6+ (<4.7)	1.0 - 2.5 n	40.0

Age Criteria : ^{14}C; lacustrine stratigraphy
References : Machette and others, 1991, 1992; Personius, 1988, 1990, 1991
Comments : Scarps on the valley floor between Willard and Brigham City may be associated with incipient lateral spreads, but have orientations and relief consistent with a faulting origin. The time elapsed since the most recent event (3,600 years) is considerably longer than the previous recurrence interval (1,100 years) and is probably also longer than the next-earlier interval (constrained by a poorly dated 5,000-7,000-year-old event). This suggests that the segment is overdue for a surface-faulting earthquake. Another possibility is that strain-accumulation rates may have declined during the late Holocene. A probabilistic analysis based on segment-specific recurrence times indicates that an event may be three times as likely as on other segments of the Wasatch fault zone (a 100-year conditional probability of 0.07, versus 0.02 for other segments) (Nishenko and Schwartz, 1990). Brigham City is the only Holocene segment of the Wasatch fault zone that has not had an event during the recent temporal cluster of faulting activity (see final entry of table for composite information on Wasatch fault zone). Only a few short discontinuous scarps near the southern boundary probably formed in latest Holocene time. The middle to late Holocene slip-rate estimate is based on trench-site data from near the center of the segment at Brigham City. However, net slip in deposits of a given age gradually decreases to the north. The central part of the segment may have had as many as 6-10 events since Provo time (14,000 years ago).

Big Pass fault
(6-7)

Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology
References : Stifel, 1964
Comments : Several kilometers south of the Big Pass fault, Bonneville deposits are reportedly cut by a southwest-trending fault (shown on plate 1).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
East Great Salt Lake fault zone (6-8)					
Parameter values:	Holocene(?)	0.4 - 0.7 (Quaternary)			50 - 100 ?

Age Criteria : thickness of unfaulted lacustrine sediments; scarp preservation; scarp-controlled stratigraphy; palynology; tephrochronology

References : Arabasz and others, 1992; Pechmann, 1987; Pechmann and others, 1987

Comments : Fault locations in the northern Great Salt Lake basin (plate 1) are less accurate than to the south because they are based on less detailed reflection data. A zone of subsidiary faults (not shown on plate 1) lies within about 5 kilometers west of the main fault in the southern Great Salt Lake, and small-displacement faults (not shown on plate 1) are found elsewhere beneath the lake. Interpretation of seismic-reflection data indicates faulting to within 10-20 meters or less of the lake bottom. A 1.5-kilometer-long zone of ten or more en echelon fractures beneath the lake west of Antelope Island appears on aerial photos to have slight down-to-the-west displacement and to be unmodified by coastal processes, and thus may date from the latest Holocene (Currey, 1980). Restricted basins adjacent to the north end of the fault existed prior to deposition of a 11,600 ^{14}C yr B.P. calcareous clay that overlies deposits of mirabilite salt (Eardley, 1962; Mikulich and Smith, 1974). The mapped Quaternary(?) fault and fold (plate 1) pre-date salt deposition but deform deeper near-surface sediments (Mikulich and Smith, 1974). Diapiric domes and lake-bottom piercement structures, identified from seismic data, developed at least partly from flowage of the salt deposits during construction of the Southern Pacific Causeway in 1957-1959 (Mikulich and Smith, 1974). Slip-rate estimates are based on vertical subsidence rates near the fault of 0.3-0.5 mm/yr. The total length of the fault is 100 kilometers, but a left step in the fault suggests two segments of about equal length. These segment lengths are comparable to those of the Wasatch fault zone (see last entry of table), suggesting earthquake magnitudes that are also comparable. Based on the assumption of similar earthquake magnitudes and a long-term slip rate that appears to be about half the rate calculated for the Wasatch fault zone during the Holocene, recurrence intervals for segments of the East Great Salt Lake fault zone may be roughly twice the average value for segments of the Wasatch fault zone. Interpretation of seismic-reflection profiles suggests that the main fault may flatten with depth (Smith and Bruhn, 1984) and merge into a horizontal detachment at depth of about 6 kilometers (Viveiros, 1986) and thus may not be seismogenic, but the evidence is equivocal.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Dolphin Island fracture zone (6-9)					
Parameter values:	late Quaternary				

Age Criteria : presence of lineaments

References : Currey, 1980

Comments : Based on air photo interpretation, two prominent parallel lineaments are roughly paralleled by sinkholes(?) produced by dissolution or springs. The features have been modified by, and thus predate, Holocene shore-zone processes.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
North Promontory Range - east-trending (fault) (6-10)					
Parameter values:	Quaternary(?)				

Age Criteria : spatial change in Quaternary activity
References : Jordon and others, 1988
Comments : Apparent differences in Quaternary activity along the North Promontory fault (location no. 6-2) north and south of the east-trending fault suggest that movement occurs on and is hinged across the east-trending fault. A preliminary correlation of erosional Provo-level shorelines on the west side of Blue Creek Valley suggests that the shorelines are about 3 meters lower to the north than to the south of the fault, although the apparent displacement may be a result of differences in geomorphic expression in different lithologies across the fault and not the result of faulting. Bonneville deposits appear to be displaced down-to-the-east across a short north-northwest-trending scarp at the east end of the fault, although well-developed soils and evidence for pediments shallowly buried beneath Quaternary deposits argue against substantial Quaternary faulting on the west side of Blue Creek Valley. Along the range front near the south end of the valley, several short faults (not shown on plate 1) cut Pliocene loess deposits but not overlying Holocene colluvium, and are probably no younger than early Pleistocene (Miller and others, 1991).

Pilot Range (faults) (6-11)					
Parameter values:	late Quaternary				

Age Criteria : presence of scarps on alluvium; geomorphic position
References : Miller and Lush, 1991; Miller and others, 1990
Comments : Scarps on Pleistocene alluvium are rounded and barely recognizable. One of the southern faults on the west side of the range displaces alluvium in dry washes (forming 2-3 meter-high scarps) and may be Holocene in age. To the north of the scarps, a probable buried Quaternary(?) fault, evidenced by aligned springs and topographic lineaments, may form the western margin of elevated Tertiary and Quaternary deposits. Evidence for Quaternary faulting extends into Nevada. On the east side of the range, springs and topographic lineaments in old alluvial-fan deposits mark early Pleistocene or older faults.

Blue Spring Hills (faults) (6-12)					
Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact
References : Everitt, 1982
Comments : The faults intersect the Bonneville shoreline, but age relations are uncertain. An aerial photo check for the present study found the surface expression of the faults to be subdued. A short fault in Holocene(?) alluvium (not shown on plate 1) has been identified in a canyon on the west side of the Blue Spring Hills at the south end of Blue Creek Valley (Miller and others, 1991)

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

West Cache fault zone
- Cache Butte area
(6-13)

Parameter values:	<25	<0.1 ? *d (<25)			

Age Criteria : lacustrine stratigraphy
References : Oviatt, 1986a
Comments : The basal transgressive gravel of the Bonneville lake cycle is faulted. Below the gravel on the downthrown side, Quaternary alluvial deposits with multiple calcic soil horizons record multiple displacements totaling more than 6 meters.

East Lakeside Mountains fault zone
(6-14)

Parameter values:	Quaternary(?)				

Age Criteria : depth to faulted sediments; geophysical expression
References : Cook and others, 1980; Mikulich and Smith, 1974
Comments : Gravity and seismic data indicate that the fault zone is a major structure that bounds the west side of the complexly faulted Great Salt Lake graben. Gravity data suggest that the fault lies along the Lakeside Mountains, extending farther south than shown on plate 1. Seismic-reflection profiles indicate that faulting penetrates up into the Quaternary section.

West Cache fault zone
- Clarkston fault
(6-15)

Parameter values:	late Quaternary				

Age Criteria : range-front morphology
References : Cluff and others, 1974
Comments : If the faults to the south near Cache Butte (location no. 6-13) are associated with the Clarkston fault, then movement along this fault zone may have occurred less than 25,000 years ago.

Wasatch fault zone
- Clarkston Mountain segment
(6-16)

Parameter values:	late Pleistocene				19

Age Criteria : range-front morphology; lacustrine stratigraphy; shoreline relations
References : Machette and others, 1991, 1992
Comments : Part of the segment is in Idaho. Segment boundaries are based on structural and geomorphic relations only and are more tenuous than the boundaries of Wasatch fault segments to the south. Regressional shorelines below the Provo level wrap around, and thus postdate, a probable fault escarpment, and deep-water sediments of Lake Bonneville are not faulted.

Raft River Mountains (fault)
(6-17)

Parameter values:	middle to late Pleistocene(?)				

Age Criteria : faulted alluvium
References : Compton, 1975

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Goose Creek Mountains (faults)
(6-18)

Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact
References : Doelling and others, 1980

Grouse Creek and Dove Creek Mountains (faults)
(6-19)

Parameter values:	middle to late Pleistocene(?)				

Age Criteria : faulted colluvium
References : Compton, 1972
Comments : Faults are mapped as Quaternary(?) (plate 1) where faulting has uplifted Pliocene to early Pleistocene gravels, and where lineaments and aligned springs suggest active faulting (Todd, 1973; this study).

Sheeprock fault zone
(7-1)

Parameter values:	late Pleistocene(?)				

Age Criteria : scarp morphology
References : Barnhard and Dodge, 1988
Comments : From scarp-profile data, the Sheeprock scarps appear to be older than the Topliff Hill, Stansbury, and Mercur scarps (location nos. 7-7, 7-10, and 7-14). Diffusion-equation modeling of the scarps, which probably represent multiple events (with a cumulative displacement of <11.5 meters), yielded an age of about 53,000 years (Hanks and others, 1984). In contrast, Everitt and Kaliser (1980) concluded that scarp morphology suggests a possible Holocene age for latest faulting. The embayed character of the range front suggests a long period of inactivity preceding the recent episode of faulting (Everitt and Kaliser, 1980).

Silver Island Mountains
- southeast side (fault)
(7-2)

Parameter values:	3 - 5 ?			0.6 ?	

Age Criteria : artifacts
References : D.B. Madsen, written and verbal communication, 1987, 1988
Comments : Lake Bonneville deposits are vertically displaced 0.6 meters across the fault. Diagnostic artifacts in faulted sediments near fault-line springs and correlations between basal spring-related peat layers and Holocene lake levels provide an estimate of the time of origin of the springs and, presumably, the time of faulting.

Cedar Valley
- south end (fault)
(7-3)

Parameter values:	late Quaternary(?)				

Age Criteria : range-front morphology
References : Anderson and Miller, 1979
Comments : Anderson and Miller (1979) indicated that Quaternary(?) alluvium may be displaced, and they mapped the fault as late Pleistocene (<500,000 years old), although an aerial photo check for this study yielded no clear evidence of faulted alluvium.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Silver Island Mountains
- west side (fault)
(7-4)

Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact
References : Moore and Sorensen, 1979

Lakeside Mountains
- west side (fault)
(7-5)

Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact
References : Moore and Sorensen, 1979; Young, 1955
Comments : Arabasz and others (1989) included the fault (queried as to state of activity) in a compilation of seismic sources in the region. They reference T.P. Barnhard as having identified the feature as a lineament that he feels is probably not related to faulting because it parallels topographic contours, and thus may be a shoreline feature.

Lookout Pass
- south side (fault)
(7-6)

Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact
References : Moore and Sorensen, 1979

Topliff Hill fault zone
(7-7)

Parameter values:	late Pleistocene(?)				

Age Criteria : scarp morphology; shoreline relations
References : Barnhard and Dodge, 1988
Comments : Everitt and Kaliser (1980) interpreted a faulted alluvial fan as younger than the Bonneville shoreline, whereas Barnhard and Dodge (1988) mapped the same surface as wave-etched and older than the Bonneville shoreline. From scarp-profile data, the Topliff Hill scarps appear to be younger than the Sheeprock, Stansbury, and Mercur fault scarps (location nos. 7-1, 7-10, and 7-14). The Topliff Hill scarps show evidence for recurrent movement, with a cumulative maximum displacement of 5.8 meters. South of the scarps, the range-front (mapped as a Quaternary(?) fault, plate 1) rises in elevation, is linear and faceted, and has an active alluvial apron (Everitt and Kaliser, 1980).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Deep Creek fault zone (7-8)					
Parameter values:	late Pleistocene				

Age Criteria : scarp morphology
References : Barnhard and Dodge, 1988
Comments : Scarps at the north end of the fault are short, highly dissected remnants and appear to be older than scarps to the south. All scarps show evidence for multiple ages of movement, with measured cumulative displacements between 1.7 and 3.4 meters. South of the scarps, the fault zone is expressed as an alignment of vegetation and springs (not shown on plate 1).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Cedar Mountains - east side (faults) (7-9)					
Parameter values:	Quaternary(?)				

Age Criteria : presence of lineaments
References : Arabasz and others, 1989
Comments : T.P. Barnhard (in Arabasz and others, 1989) identified but did not field check photo lineaments which may represent fault scarps.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Stansbury fault zone (7-10)					
Parameter values:	late Pleistocene(?)				

Age Criteria : scarp morphology
References : Barnhard and Dodge, 1988
Comments : On the basis of scarp morphology, together with an observation of stream knickpoints a short distance from the scarps, Everitt and Kaliser (1980) concluded that the most recent movement on the scarps occurred during the Holocene. However, in two stream channels inspected by Barnhard and Dodge (1988), knickpoints appear to be held up by an old exhumed bedrock fault plane and thus are not indicators of recent faulting. From scarp-profile data, the Stansbury scarps appear to be younger than the Sheeprock fault scarps (location no. 7-1), but older than the Topliff Hill and Mercur fault scarps (location nos. 7-7 and 7-14). Net tectonic displacements may be considerably less than measured scarp heights of 4.9-25.1 meters because of displacements on antithetic faults.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Clover fault zone (7-11)					
Parameter values:	late Pleistocene to Holocene(?)				

Age Criteria : presence of scarps on alluvium
References : Barnhard and Dodge, 1988
Comments : The scarps have been modified by agricultural activities and therefore can not be used to estimate the age of faulting. The graded profiles of streams that cross the fault zone suggest that faulting occurred more than several thousand years ago.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Vernon Hills fault zone (7-12)					
Parameter values:	late Pleistocene				

Age Criteria : scarp morphology; shoreline relations
References : Barnhard and Dodge, 1988
Comments : Along most of the zone, bedrock occurs on both sides of the fault or juxtaposes alluvium.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Saint John Station fault zone
(7-13)

Parameter values:	late Pleistocene				

Age Criteria : presence of scarps on alluvium; relations to lacustrine features
References : Barnhard and Dodge, 1988; Everitt and Kaliser, 1980
Comments : Small-displacement faults in alluvium (not shown on plate 1) lie several kilometers southeast of the Saint John Station fault zone within a portion of the Tooele Army Depot and are buried beneath an unfaulted soil estimated to be older than 125,000 years (Krinitzsky, 1989: U.S. Department of the Army, 1989).

Mercur fault zone
(7-14)

Parameter values:	late Pleistocene(?)				

Age Criteria : scarp morphology; lacustrine stratigraphy
References : Barnhard and Dodge, 1988
Comments : Reinterpretation of a trench log that was presented by Everitt and Kaliser (1980) as evidence for post-Bonneville faulting shows a pre-existing fault scarp buried by Bonneville transgressive deposits. A shallow trench excavated across a feature identified by Everitt and Kaliser (1980) as a fault scarp in a post-lake terrace likewise revealed a buried pre-Bonneville fault scarp. From scarp profile data, the Mercur scarps record displacements of 1.8-5.6 meters and appear to be younger than the Sheeprock and Stansbury scarps (location nos. 7-1 and 7-10), but older than the Topliff Hill scarps (location no. 7-7). Faulted alluvium exposed in a mining shaft, together with an uplifted bedrock pediment, suggest a minimum of 60 meters of Quaternary displacement on the fault (Everitt and Kaliser, 1980).

northern Oquirrh fault zone
(7-15)

Parameter values:	9 - 13.5	0.21 - 0.53 *dm (<9 - 13.5)		2.9 - 4.8 h	

Age Criteria : scarp morphology; shoreline relations
References : Barnhard and Dodge, 1988; Everitt and Kaliser, 1980
Comments : Scarp morphology is more similar to the Bonneville shoreline scarps than to the Drum Mountains fault scarps (location no. 8-1), which have been dated at about 9,000 years old. This suggests an age close to but not greater than the Provo shoreline, which has been offset across the fault. Compound scarps, with as much as twice the height of the single-event scarps (and with surface displacements of up to 7.3 meters), record an older, pre-Bonneville displacement modified by lacustrine erosion. Hanks and others (1984) considered the Oquirrh Mountain fault scarps to be older than the Bonneville shoreline and tentatively assigned them a poorly constrained diffusion-model age of 32,000 years. The southern half of the mapped fault is expressed as a prominent break in slope at the base of the range front, where Barnhard and Dodge (1988) found no direct evidence of post-Bonneville faulting. However, Tooker and Roberts (1988) mapped several short faults in Bonneville and post-Bonneville(?) deposits at the north end of the range-front embayment. Because the calculated slip rate is based on scarp height rather than displacement, the values may be too high by a factor of two. Youngs and others (1987, in press) inferred a slip rate of 0.1-0.2 mm/yr for the fault.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Puddle Valley fault zone (7-16) Parameter values:	9 - 15 ?	0.05 - 0.26 *dm (<9 - 15)		0.7 - 2.3 ?	

Age Criteria : scarp morphology
References : Barnhard and Dodge, 1988
Comments : A group of fault scarps may represent two spatially distinct surface-rupturing events. Scarps at the north end appear to be older than the Bonneville shoreline; those at the south end appear to be younger than the Bonneville shoreline but older than the Drum Mountains fault scarps (location no. 8-1), which have been dated at 9,000 years old. All the scarps are topographically below the Bonneville and Provo shorelines.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Deep Creek (faults) (7-17) Parameter values:	Quaternary(?)				

Age Criteria : bedrock scarp morphology
References : Dohrenwend and others, 1991a

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Drum Mountains fault zone (8-1) Parameter values:	9 ?				36

Age Criteria : scarp morphology
References : Bucknam and Anderson, 1979a; Crone, 1983; Pierce and Colman, 1986
Comments : Morphometric analysis by Pierce and Colman (1986) yielded a scarp age of 9,000 years. Earlier modeling, uncorrected for height-dependency in age estimates, yielded scarp ages of about 5,000 and 5,600 years (Colman and Watson, 1983; Hanks and others, 1984). Empirical studies of scarp morphology as a function of age by Bucknam and Anderson (1979b) and Sterr (1985) and a study of scarp-related soil development and stratigraphy by Crone (1983) indicate an early Holocene age for the scarps. Faulted Provo-level shoreline features provide a maximum age for the scarps of 13,500 years (Crone, 1983). The rupture-length value is the straight-line distance between the end points of the scarps and is considered a minimum for the source-zone length. Net displacement is difficult to determine because major faults across the zone are down-dropped both to the east and west (Oviatt, 1989). Scarps range in height from 0.7 to 7.3 meters and average 2.4 meters. A channel pattern anomaly suggestive of uplift affects a broad (35 kilometers-long) reach of the Sevier River south of the scarps (Anderson and Barnhard, 1992). A shallow seismic-reflection profile across the scarps shows a complex of steeply dipping faults (many of which are not associated with scarps) with substantial, recurrent displacement of prominent reflectors (volcanic rocks?) (Crone and Harding, 1984a). The surface projection of a west-dipping, low-angle detachment (Allmendinger and others, 1983) coincides with scarps at the south end of the zone.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Deseret faults (8-2) Parameter values:	middle to late Pleistocene(?)				

Age Criteria : K-Ar; basalt-flow morphology; lacustrine stratigraphy
References : Oviatt, 1989
Comments : Scarps pre-date Bonneville deposits, but post-date the early to middle Pleistocene basalt near Deseret (location no. 8-26, appendix B). The abrupt, linear eastern boundary of the flows may mark the northern extension of the Clear Lake fault (location no. 8-5). Individual faults have displacements ranging from about 3 to 15 meters.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Cricket Mountains
- north end (faults)
(8-3)

Parameter values:	middle to late Pleistocene(?)				

Age Criteria : shoreline relations
References : Bucknam and Anderson, 1979a; Oviatt, 1989
Comments : The scarps, which show a maximum surface offset of 15 meters, are formed in coarse, erosion-resistent gravel and may be old fault-line scarps.

Crater Bench (faults)
(8-4)

Parameter values:	latest Pleistocene to Holocene(?)				

Age Criteria : shoreline relations(?); alluvial-fan characteristics(?); association with Holocene faults
References : Ertec Western, Inc., 1981a
Comments : Faults with scarps up to 7 meters high displace 900,000-year-old basalts (location no. 8-27, appendix B). The faults appear to be related to the Drum Mountains fault zone (location no. 8-1); faults entirely within the basalts are known only to post-date 900,000 years, but their continuation and alignment with faults in post-Bonneville deposits implies post-Bonneville movement. Mapping by Galyhardt and Rush (1981) shows some of the faults to be partly covered by Lake Bonneville deposits.

Clear Lake fault zone
(8-5)

Parameter values:	Holocene				

Age Criteria : lacustrine stratigraphy; association with Holocene volcanics; shoreline relations
References : Bucknam and Anderson, 1979a; Currey, 1982; Oviatt, 1989
Comments : To the east of the Clear Lake fault, which is the largest (with at least 3 meters of displacement) and most continuous feature in the zone, lies a swarm of fractures in lake and playa deposits with unknown, but probably small, displacements. At least some of the displacement in the fault zone may be related to subsidence into a magma chamber beneath the Pavant, Ice Springs, and Tabernacle Hill volcanic fields, which have been active in Bonneville and post-Bonneville time (location nos. 8-29, 9-36, and 9-48, appendix B). The Bonneville and Provo shorelines on Pavant Butte are anomalously low (17 meters and 10 meters too low, respectively, from interpolation of regional shoreline mapping), but the highest shoreline on Pavant Butte may not be equivalent to the main Bonneville shoreline elsewhere. In addition, the isostatic load of the volcanic pile probably suppressed post-Bonneville crustal rebound. Seismic-reflection data indicate that the high-angle Clear Lake fault intersects, but does not cut, the Sevier Desert detachment at a shallow depth (about 3.5 kilometers), raising questions about the seismic potential of the fault (Crone and Harding, 1984a).

Pavant faults
(8-6)

Parameter values:	middle to late Pleistocene				

Age Criteria : K-Ar; basalt-flow morphology; lacustrine stratigraphy
References : Oviatt, 1989
Comments : Hoover (1974) mapped faults north of Pavant Butte (not shown on plate 1), but the features he identified might be eolian dunes (Oviatt, 1989). The Pavant scarps are locally covered by and thus pre-date Bonneville deposits and the late Holocene basalt of Ice Springs (location no. 9-55, appendix B). However, it is not known whether faults shown to extend beyond the margins of the Pavant lavas (location no. 8-28, appendix B) cut Bonneville deposits. Hoover (1974) measured 18.3 meters of displacement across the main fault (the Devils Kitchen fault of Condie and Barsky, 1972). Faults in the Black Rock-Sevier Desert basin intersect the Sevier Desert detachment at depths of 2-4 kilometers and may cut the detachment surface (Picha, 1986; Smithson and Johnson, 1989) or may terminate against it (Allmendinger and others, 1983; Anderson and others, 1983).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Sheeprock Mountains
- west side (fault)
(8-7)

Parameter values:	early Pleistocene (?)				

Age Criteria : alluvial-fan characteristics
References : Ertec Western, Inc., 1981a
Comments : The age of movement is based primarily on the age of faulted deposits and is considered a maximum estimate.

southwest of Simpson Mountains (faults)
(8-8)

Parameter values:	late Quaternary(?)				

Age Criteria : presence of scarps on alluvium
References : Ertec Western, Inc., 1981a; B.A. Schell, written communication, 1991

Swasey Mountain
- east side (faults)
(8-9)

Parameter values:	late Quaternary(?)				

Age Criteria : presence of scarps on alluvium
References : Ertec Western, Inc., 1981a; B.A. Schell, written communication, 1991

House Range
- west side (fault)
(8-10)

Parameter values:	12 - 19	0.07 - 0.12 *dm (<12-19)		1.4	

Age Criteria : shoreline relations; scarp morphology
References : Ertec Western, Inc., 1981a; Piekarski, 1980; Sack, 1990
Comments : An estimated maximum-limiting age for faulting is provided by faulted transgressive shorelines above the level of the Provo shoreline (Sack, 1990). Based on general slope-age considerations, a minimum-limiting age of 12,000 years seems reasonable (Piekarski, 1980; Sack, 1990), although Ertec Western, Inc. (1981a) classified the fault as Holocene based on the presence of scarps on post-Bonneville alluvial fans. Seismic-reflection data suggest that the fault merges with or is truncated by a low-angle detachment fault at a depth less than about 5 kilometers (Allmendinger and others, 1983; Smith and Bruhn, 1984).

Foote Range (fault)
(8-11)

Parameter values:	late Quaternary(?)				

Age Criteria : presence of scarps on alluvium
References : Ertec Western, Inc., 1981a; B.A. Schell, written communication, 1991

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Snake Valley (faults) (8-12)					
Parameter values:	<15				

Age Criteria : relations to lacustrine features
References : Ertec Western, Inc., 1981a
Comments : Scarps have maximum slope angles less than 7 degrees. The faults are not shown on U.S. Geological Survey mapping of fault scarps in the region (Bucknam and Anderson, 1979a), but do appear on a generalized hydrogeologic map of Snake Valley (Hood and Rush, 1965).

Lime Mountain (fault) (8-13)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front and bedrock scarp morphology
References : Ertec Western, Inc., 1981a

Deep Creek Range - east side (faults) (8-14)					
Parameter values:	middle to late Pleistocene				

Age Criteria : alluvial-fan characteristics; scarp morphology
References : Bucknam and Anderson, 1979a; Ertec Western, Inc., 1981a
Comments : Fault scarps, which are up to 13.4 meters high, appear on aerial photos as highly dissected remnants surrounded by several different ages of unfaulted alluvium and look to be among the oldest in western Utah. However, some of these scarps appear to extend across young (Holocene?) alluvial-fan surfaces (B.A. Schell, written communication, 1991).

Fish Springs fault (8-15)					
Parameter values:	2 - 3			3.3 m	12.1

Age Criteria : ^{14}C; scarp morphology
References : Bucknam and Anderson, 1979b; Bucknam and others, 1989; Hanks and others, 1984
Comments : A date from soil organics buried by fault-scarp colluvium suggests that faulting occurred about 2,000 years ago (Bucknam and others, 1989). Extreme youth is suggested by the lack of scarp dissection and by sharply defined knickpoints in small washes within several tens of meters of the scarp. However, the absence of a free face suggests that the scarps are greater than hundreds to thousands of years old. The scarps appear to be distinctly younger than the Drum Mountains fault scarps, dated at about 9,000 years, and they have a diffusion-based morphologic age of 3,000 years (Hanks and others, 1984). Quantitative morphometric indices used by Sterr (1985) yielded a scarp age of 4,800 years. Faulted post-Provo alluvial fans provide an upper limit for scarp age. Stratigraphic relations exposed by trenching suggest a temporal clustering of surface-faulting events shortly after the catastrophic fall of Lake Bonneville from its highstand (Machette, 1990). The rupture length is the straight-line distance between the end points of the scarps and is considered a minimum for the source-zone length. An exposure of Holocene alluvium overlying older, more steeply dipping alluvium on the east side of Fish Springs Flat, across from the Fish Springs fault, suggests that about 6.5° of pre-Holocene westward tilting occurred at this location (Oviatt, 1991a).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

East Tintic Mountains
- west side (faults)
(8-16)

Parameter values: middle to late Pleistocene | | |

Age Criteria : scarp morphology
References : Bucknam and Anderson, 1979a
Comments : Alluvial scarps appear on aerial photos as isolated, highly dissected remnants surrounded by several different ages of unfaulted alluvium and appear to be among the oldest in western Utah. Steep faceted bedrock spurs north and south of Silver City (Goode, 1959) suggest active uplift north of the scarps. In addition, faults in alluvium (not shown on plate 1) were observed northwest of Eureka, about 2 kilometers east of the range front (Goode, 1959). Anderson and Miller (1979) mapped buried Quaternary(?) faults extending to the north and south of the alluvial scarps. These faults and faults that form bedrock-alluvium contacts at the south end of the East Tintic Mountains (Morris, 1987) are mapped as Quaternary(?) on plate 1. On the east side of the mountain range, faults in pre-Bonneville alluvium (not shown on plate 1) were recognized in a tunnel at the south end of Goshen Valley (Goode, 1959).

Maple Grove (faults)
(8-17)

Parameter values: late Pleistocene(?) | | |

Age Criteria : scarp morphology; fault control of bedrock-alluvium contact
References : Bucknam and Anderson, 1979a; Oviatt, 1992
Comments : Crestal rounding and dissection suggest that fault scarps are older than the Bonneville shoreline. The steepness of scarp slopes (up to 47°) is attributed to the coarseness of the alluvium. Evidence of Holocene faulting, present in scarps to the north and south, was not noted for the Maple Grove scarps. The scarps represent displacements of up to 12 meters.

Scipio (faults)
(8-18)

Parameter values: late Pleistocene | | |

Age Criteria : scarp morphology
References : Bucknam and Anderson, 1979a; Oviatt, 1992
Comments : Evidence of Holocene faulting, present in scarps to the north and south, is not seen in the subdued morphology of the Scipio fault scarps. Faults mapped as Quaternary(?) in age on plate 1 are concealed valley-fill structures.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Scipio Valley (faults)
(8-19)

Parameter values:	late Holocene(?)			2.7 m	

Age Criteria : scarp morphology
References : Bucknam and Anderson, 1979a; Oviatt, 1992
Comments : Holocene scarps are superimposed on less steep, pre-Holocene scarps to form composite profiles with cumulative displacements of more than 11 meters. The morphology and degree of dissection of the younger scarps are similar to the Fish Springs fault scarps (location no. 8-15), which are thought to have formed 2,000-3,000 years ago. The scarp profile data are insufficient to determine whether the pre-Holocene scarps are similar in age to the Little Valley scarps (location no. 8-20), separated from the north end of Scipio Valley by small bedrock hills. Zones of elongate sinkholes, some having formed in recent years, are aligned along the faults and may be the result of subsidence above solution cavities in the carbonate bedrock (Bjorklund and Robinson, 1968). The sinkholes form lineaments (with no apparent offset) visible on aerial photos (Oviatt, 1992). A seismic-reflection profile across one of the scarps indicates that the subjacent fault is steep (~70°) and continuous to at least a depth of 400 meters; one reflector has a vertical displacement of about 70 meters across a strand of the fault. This geometry and evidence for recurrent movement argues against ground-water dissolution as the causal mechanism for faulting (Crone and Harding, 1984b).

Little Valley (faults)
(8-20)

Parameter values:	latest Pleistocene				

Age Criteria : scarp morphology
References : Bucknam and Anderson, 1979a; Oviatt, 1992
Comments : Fault scarps, which represent displacements of up to 8.2 meters, appear morphologically to be about the same age as the Bonneville shoreline scarps, but are truncated by and thus are older than the shoreline. Faults mapped as Quaternary(?) in age on plate 1 are either scarps in Pliocene and Pleistocene deposits or concealed valley-fill structures.

Pavant Range (faults)
(8-21)

Parameter values:	Holocene				

Age Criteria : scarp morphology
References : Bucknam and Anderson, 1979a; Oviatt, 1992
Comments : Scarps in colluvium-veneered bedrock appear very fresh, although scarps in alluvium at canyon mouths appear more subdued.

Sugarville area (faults)
(8-22)

Parameter values:	late Quaternary				4.3 - 6.4 ?

Age Criteria : lacustrine stratigraphy
References : Dames and Moore, 1978; Oviatt, 1989
Comments : There is subtle relief across a group of lineaments. Trenching revealed underlying faults, but their relation to deeper structures is unknown. Oviatt (1989) mapped the faults as cutting Pliocene and Pleistocene lake deposits and pre-Bonneville alluvium, but other workers (Dames and Moore, 1978; Ertec Western, Inc., 1981a) indicated that the faulted deposits may be Bonneville or post-Bonneville in age. Crosscutting stratigraphic relations indicate that at least two events have occurred along the fault zone. A minimum throw of 3.8 meters across one of the faults, together with the short apparent rupture length, suggests that numerous small-displacement events have occurred along the zone. Parallel tonal lineaments 10 kilometers to the north of the zone may be related faults (not shown on plate 1).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

faults of Cove Creek dome
(9-1)

Parameter values:	Quaternary(?)				

Age Criteria : K-Ar and amount of displacement; association with Quaternary deformation

References : Anderson and Bucknam, 1979a; Oviatt, 1991b

Comments : The faults displace late Tertiary (2.5 to 2.6 million-year-old) volcanic flows by greater amounts (some by an order of magnitude more; Clark, 1977) than the faults (location no. 9-2) that cut the 500,000-year-old Cove Fort flows (location no. 9-42, appendix B). Although Quaternary movement has not been demonstrated for the faults of Cove Creek dome, the dome itself (location no. 9-5) and nearby faults show evidence for late Quaternary deformation.

Cove Fort fault zone
(9-2)

Parameter values:	<500				

Age Criteria : K-Ar

References : Best and others, 1980; Steven and Morris, 1983

Comments : An alluvial scarp southeast of the Cove Fort flows (location no. 9-42, appendix B) is probably pre-Holocene in age and is 4.3 meters high (Anderson and others, 1978). Scarps within the volcanic field generally have 5-20 meters and locally up to 60 meters of vertical displacement (Clark, 1977, figure 24). Middle Pleistocene tephras displaced across a subdued scarp along the eastern boundary of the Cove Fort graben show at least 18-20 meters of middle to late Pleistocene vertical stratigraphic separation (Anderson, 1980). Faults on trend with those in the lava field are likely part of the same zone and are inferred to date from <500,000 years ago (Anderson and Barnhard, 1992). Faults in the Oligocene bedrock northeast of the Cove Fort flows show evidence for a mixture of left- and right-lateral strike slip, as well as dip slip, with a predominance of left-lateral displacement (of at least 150 meters on one fault). This pattern of slip is similar to that in the area of the Clear Creek downwarp and Dry Wash fault to the east (location no. 9-9; Anderson and Barnhard, 1992). Assuming fault-plane dips of 60°, Clark (1977) calculated 7.5 meters per kilometer of east-west extension across the Cove Fort lava field. The intragraben structural patterns recorded in the volcanics of the Cove Fort area may be similar to deformation within other, generally alluvial-filled, basins of the Great Basin (Clark, 1977). Alternatively, the faults may be the result of local forces related to eruption of the volcanics (Steven and Morris, 1983).

Beaver Basin (faults and a fold)
(9-3, 9-4)

Parameter values:	see following entries for substructure parameters				

References : Machette, 1985; M.N. Machette, written communication, 1988; Machette and others, 1984

Comments : Faults along the eastern margin of Beaver Basin are considered tectonic. Central basin faults appear to be related to development of a north-trending horst and antiform. Differences in fault ages shown on plate 1 generally reflect the distribution of different ages of faulted deposits and not necessarily differences in recency of movement. Sterr (1980) divided scarps in Beaver Basin into age groups on the basis of the scarp morphology associated with different-age surfaces and defined three "independent fault systems," each associated with different recurrence intervals. However, surface-age estimates, which provided the basis for determining fault histories, have been revised (Machette, 1985), and the older scarps may not be suitable for morphologic age analysis due to the effects of stream erosion, calcic soil development (Anderson and Bucknam, 1979a), and multiple episodes of movement.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Beaver Basin
- eastern margin faults
(9-3)

Parameter values:	early Holocene	0.04 d	50 i	1 - 3 h	
		(<250)	(<250)		
		0.05 d	50 i		
		(<500)	(<500)		

Age Criteria : soil development; scarp morphology; U-trend; ^{14}C; tephrochronology

References : Anderson and others, 1990b; Anderson and Bucknam, 1979a; Machette, 1985; Machette and others, 1984

Comments : Individual scarps formed in Pinedale-age (12,000-15,000-year-old) alluvium are 1-3 meters high. The scarps appear only slightly less degraded than Bonneville shoreline scarps and more degraded than the Drum Mountains fault scarps, estimated to be ~9,000 years old (location no. 8-1). However, morphometric scarp analyses by Sterr (1985) yielded an age estimate of about 18,000 years for one of the faults (the Beaver fault, which trends through the town of Beaver). Several faults that cut the east end of the Last Chance Bench (north-northeast of Beaver) and the Table Grounds surface (east of Beaver) appear to be buried by middle to late Pleistocene or Pinedale-age alluvium. The recurrence-interval and slip-rate values pertain to the Beaver fault (Machette, 1985). The recurrence intervals are based on scarp heights of 11 meters (on <250,000-year-old deposits) and 25 meters (on <500,000-year-old deposits) and on an assumed displacement of 2 meters per event. Sterr (1980) determined average displacements to be about 1.5 meters per event. As a group, the basin-margin faults have produced about 100 meters of net, down-to-the-west displacement on the 500,000-year-old Last Chance Bench (yielding a net slip rate of 0.2 mm/yr and a 2-meter-per-event composite recurrence of 10,000 years). Seismic-reflection data suggest that the fault zone intersects a subhorizontal detachment at a depth of 10 kilometers (Smith and Bruhn, 1984).

Beaver Basin
- Last Chance Bench antiform, Maple Flat horst, and central basin faults
(9-4)

Parameter values:	late Pleistocene to Holocene				

Age Criteria : soil development; U-trend

References : Anderson and others, 1990b; Machette, 1985; M.N. Machette, written communication, 1988; Machette and others, 1984

Comments : More than a hundred closely spaced normal faults cut the limbs and dip toward the axis of a broad, low-amplitude antiform on the Last Chance Bench (LCB), a pediment estimated to be about 500,000 years old. The axial trace of the antiform, which steps westward across several northeast-trending normal faults, is aligned with the Maple Flats horst to the north. The northeast-trending valley of Indian Creek is probably fault controlled, as suggested by a 30-100 meter altitude difference between LCB gravels on either side of the creek. Individual faults on the LCB have displacements ranging from 1 to 25 meters (Anderson and Bucknam, 1979a). Faults at the north end of the antiform, north of Indian Creek, displace the LCB gravels up to 5 meters. On the south margin of the antiform, west of Greenville, 0.5- to 3.0-meter-high scarps are on 140,000-250,000-year-old terraces. The 2-million-year-old Huckleberry Ridge ash bed has been rotated 10-15° away from the Maple Flat horst, although its altitude records almost no structural relief across most of the LCB antiform. Upper Pliocene lake beds are tilted as much as 20° away from the axial trend of the horst-antiform structure. Faults (not shown on plate 1) that are antithetic to the west-bounding fault of the horst displace the 1.1-million-year-old basalt of Cunningham Hill (location no. 9-43, appendix B) at least 100 meters, but do not displace on-trend upper Pleistocene deposits. Faults associated with the eastern margin of the horst and those that cut Tertiary to Quaternary deposits are suspected of being Quaternary in age.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Cove Creek dome
(9-5)

Parameter values: <15 ?

Age Criteria : shoreline relations
References : Crecraft and others, 1981; Oviatt, 1991b
Comments : The Bonneville shoreline is deflected 6-9 meters along an east-west profile on the east side of the Cove Creek dome (area of local deformation, plate 1). The deflection is attributed to post-Bonneville uplift, but the cause of the uplift is unknown. Cove Creek dome is a doubly plunging anticline associated with approximately 300 to 400 meters of uplift in Pliocene basalts and lake deposits. Most of the doming probably occurred during the late Tertiary, but an apparent diversion of Cove Creek and deformation of the Bonneville shoreline suggest that uplift has continued into the Quaternary. A remnant of Cove Creek(?) alluvium north of the modern drainage divide lies within an apparent paleochannel of Cove Creek and pre-dates the apparent southwest diversion of the creek off the western flank of the dome. The remnant appears to underlie the basalt of Black Rock, dated at about 1 million years old (location no. 9-51, appendix B). Uplift of the dome and resulting piracy by a westward-flowing stream is a likely cause of the diversion, although other contributing factors may include damming of the drainage by the basalt flow and/or faulting-induced headward erosion and resulting stream piracy.

Sevier Valley
- Marysvale-Circleville area (faults)
(9-6)

Parameter values: middle to late Pleistocene

Age Criteria : scarp morphology; fault control of bedrock-alluvium contact
References : Anderson and others, 1986; Anderson and Bucknam, 1979a; Anderson and others, 1978; Rowley and others, 1988
Comments : This area of faulting, which lies between and to the west of main valley-margin structures (the Tushar and Sevier faults, location nos. 9-10 and 9-35) south of Marysvale and north of Circleville, incorporates several different fault zones of likely different ages. Faults categorized as Quaternary(?) on plate 1 either cut Tertiary to Quaternary deposits (west of Alunite) or form sharp boundaries between bedrock and alluvium. The latter type were photo-mapped or photo-checked for this study. Alluvial fault scarps associated with individual structures are too poorly preserved for detailed morphologic age analysis. Scarps west of Circleville appear to be formed in pre-Holocene deposits, although a lineament in Holocene deposits may represent a fault with more recent movement (Anderson and others, 1986). Several small intermontane valleys west and south of Circleville are bounded by faults (not shown on plate 1) concealed beneath Quaternary alluvium (Anderson and others, 1990a). Southwest of Circleville Mountain, a pair of structural lineaments in Quaternary deposits (not represented on plate 1) may express underlying bedrock faults or joints (Anderson, 1986). Northwest of the mountain, small scarps that cut Quaternary landslide deposits (not represented on plate 1) may be related to mass movements (Anderson, 1986). Scarp heights in the Marysvale-Circleville area range from 1 to 15 meters and include low scarps northeast of Piute Reservoir, scarps 3-5 meters high near Circleville, a scarp 3.5 meters high northwest of Junction, and a 12-meter-high scarp southwest of Marysvale.

Elsinore "fault" (fold)
(9-7)

Parameter values: Quaternary(?)

Age Criteria : range-front morphology; association with Quaternary deformation
References : Anderson and Barnhard, 1992; Willis, 1988
Comments : Orientations and slip directions of bedrock faults along the Pavant Range front between Joseph and Richfield are incompatible with the existence, as has been inferred from physiography and geology, of a major range-front fault (identified as the Elsinore fault by Callaghan and Parker, 1961). Instead, a mapped southeast-facing monocline (which may overlie a major buried fault) appears to be the principal range-front structure (Anderson and Barnhard, 1992). A short, 12-meter-high fault scarp at the south end of the monoclinal structure (Anderson and others, 1978) is within an area of local late Quaternary deformation (location no. 9-8) at the juncture with the Dry Wash fault. On trend with the north end of the structure (which has been identified primarily as a fault by Willis, 1988), Tertiary to Quaternary and Quaternary(?) pediments appear to be unfaulted, but appear to be tilted (up to 20-25°) eastward, showing progressively more tilt with age (Willis, 1988).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Joseph Flats area (folds and faults)
(9-8)

Parameter values: late Quaternary | | |

Age Criteria : landform modification and geomorphic position; stream-pattern anomaly
References : Anderson and Miller, 1980; Anderson and Barnhard, 1992
Comments : The alluvial basin beneath Joseph Flats, adjacent to the northern end of the Dry Wash fault (location no. 9-9), may be related to the southward projection of a syncline mapped at the south end of the Pavant Range and may represent sagging adjacent to the terminus of the left-lateral Dry Wash fault. A gravity profile shows a low beneath the central portion of the basin and no anomaly at the fault, consistent with a synclinal origin for the basin and a predominately strike-slip origin for the fault. The northern end of the Dry Wash fault shows a significant component of dip-slip displacement as well, although the fault lies on-strike with the Elsinore fault (location no. 9-7), which has the opposite sense of vertical displacement. Accommodation of deformation within the juncture between the two incompatible structures implies the presence of a transverse structure, buried beneath the alluvial gap between Joseph Flats and the Sevier Valley. In this area, tilted remnants of a flight of four stream terraces (area of local deformation, plate 1; Callaghan and Parker, 1961), which show increasing eastward tilts with age, and an anomalous channel pattern (abrupt change from reticular to sinuous/braided) where the Sevier River crosses the projection of the fault indicate recent uplift, perhaps related to compression at the terminus of the left-lateral fault. A 3-meter-high scarp a half-kilometer southeast of the Dry Wash fault is formed in the youngest terrace. By assigning a range of ages to the tilted terraces and the underlying tilted Miocene to Pleistocene Sevier River Formation and by assigning dimensions to the rotated block, Anderson and Barnhard (1992) computed uplift rates ranging from 0.1 to 1.0 mm/yr, with values near the low end assumed to be most reasonable. The seismically active Elsinore area has had five magnitude 5+ earthquakes (in 1910 and 1921), and is one of the few areas in Utah where seismicity coincides with mapped Quaternary structures. A 1981 cluster of microearthquakes centered in the area of Quaternary deformation had focal mechanisms associated with predominately dip-slip faulting and a depth distribution consistent with seismic-reflection evidence of a shallow (5-kilometers deep) zone of detachment beneath the area (Arabasz and Julander, 1986). Thin-skinned deformation argues against the potential for large earthquakes on faults within the upper plate. The deformational history and earthquake potential of the postulated transverse zone may have little relevance for major structures (the Elsinore and Dry Wash faults) that extend to the north and south.

Dry Wash fault
(9-9)

Parameter values: Quaternary(?) | | |

Age Criteria : association with Quaternary deformation
References : Anderson and Miller, 1980; Anderson and Barnhard, 1992
Comments : The Dry Wash fault and adjacent folds and faults record a complex deformational history. The southern portion of the Dry Wash fault and parallel faults to the northwest have evidence for significant left-lateral, strike-slip displacement. The Clear Creek downwarp and parallel subsidiary folds terminate against the Dry Wash fault, suggesting a genetic relationship between folding and faulting. Sevier River Formation sediments, dated as young as 5.6 million years in this area, are involved in the downwarping. Numerous northeast- and northwest-striking left- and right-lateral faults form conjugate sets that cut the east-trending folds, indicating north-south compression. The northern end of the Dry Wash fault is within an area of local late Quaternary deformation (location no. 9-8) at the juncture with the Elsinore fault.

Tushar Mountains
- east side (fault)
(9-10)

Parameter values: Quaternary(?) | | |

Age Criteria : range-front morphology; association with Quaternary deformation
References : Anderson and Miller, 1979; Rowley, 1968
Comments : Exposure of the Miocene, Pliocene, and Pleistocene Sevier River Formation on the downthrown side of the fault (Cunningham and others, 1983) argues against substantial Quaternary displacement. Late Quaternary fault scarps are recognized south and east of the fault (location no. 9-6).

E OR LOCATION F FEATURE Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

vier Valley
east of Marysvale (fault)
(9-11)

Parameter values: Quaternary(?) | | |

Age Criteria : valley asymmetry
References : Anderson and others, 1978
Comments : The Sevier River is located on the east side of the valley, adjacent to the low hills which define the fault; to the west, alluvial fans descend from the base of the Tushar Range and have smooth, uniform profiles.

ıck Mountains (faults)
(9-12)

Parameter values: late Quaternary(?) | | |

Age Criteria : presence of faulted alluvium
References : Anderson and Miller, 1979; Rowley, 1978
Comments : Two of the faults on plate 1 are mapped as Quaternary(?). One occurs in Tertiary to Quaternary deposits and is on trend with scarps in Quaternary alluvium; the other is categorized as Pleistocene in age by Ertec Western, Inc. (1981a).

calante Desert
north end, near Thermo (faults)
(9-13)

Parameter values: Holocene(?) | | | |

Age Criteria : deposit characteristics and shoreline relations
References : Fugro National, Inc., 1981a; Rowley, 1978
Comments : Rowley (1978) mapped the faults as cutting alluvium below the Bonneville shoreline, but also as covered by (reworked?) Bonneville deposits. Fugro National, Inc. (1981a) mapped two of the faults, defined in part by mounds of hot spring deposits, as cutting a mixed unit comprised of Bonneville deposits and young alluvium. The faults appear as lineaments without relief on Ertec Western, Inc.'s (1981a) map and weren't included in mapping of fault scarps by Anderson and Bucknam (1979a). Indeed, these lineaments may be liquefaction-related features rather than faults (B.A. Schell, written communication, 1991).

neral Mountains
west side (faults)
(9-14)

Parameter values: middle to late Pleistocene | | |

Age Criteria : scarp morphology; alluvial-fan characteristics
References : Anderson and Bucknam, 1979a; Ertec Western, Inc., 1981a; Petersen, 1973
Comments : Fault scarps are highly dissected and discontinuous; limited profile data for scarps in variable lithologies suggest an age greater than the Last Chance Bench scarps in the Beaver Basin (location no. 9-4). Surface offset at one location is 5.5 meters. The westernmost fault of the zone (shown as latest Pleistocene to Holocene on plate 1) is mapped as cutting deposits associated with post-Bonneville drainage development on the valley floor (Rowley, 1978). Ertec Western, Inc. (1981a) mapped all the faults west of Minersville as post-Bonneville, but referred to them in their fault-data table as late Pleistocene in age. The range-bounding fault is inferred from seismic-reflection data to have variable dip (~15-29° west) and to intersect a subhorizontal detachment at a depth of 10 kilometers (Smith and Bruhn, 1984).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Spry area (faults)
(9-15)

Parameter values: middle to late Pleistocene(?) | | |

Age Criteria : presence of alluvial scarps; deposit characteristics; geomorphic position
References : Anderson and Grant, 1986
Comments : Small fault scarps occur on "older piedmont slope deposits" which are graded to a base level a few hundred meters higher than the present level of the Sevier River.

Black Rock area (faults)
(9-16)

Parameter values: middle to late Pleistocene | | |

Age Criteria : association with middle to late Pleistocene faulting; relation to lacustrine features
References : Oviatt, 1991b
Comments : The faults are on-trend with the middle to late Pleistocene Mineral Mountains fault. They cut the approximately 1-million-year-old Black Rock flows (location no. 9-51, appendix B), but are covered in places by pre-Bonneville alluvial fans.

White Sage Flat (faults)
(9-17)

Parameter values: middle to late Pleistocene | | |

Age Criteria : lacustrine stratigraphy and shoreline relations; fan-surface morphology
References : Anderson and Bucknam, 1979a; Oviatt, 1991b
Comments : Faults scarps, which show up to 13.2 meters of displacement, appear to be part of the Cove Fort fault zone (location no. 9-2).

Meadow-Hatton area (faults)
(9-18)

Parameter values: Holocene | | | |

Age Criteria : deposit characteristics; lacustrine stratigraphy
References : Oviatt, 1991b
Comments : The faults are west of and parallel to a large spring tufa mound that developed along a linear fracture system when ground-water discharge was greater, probably during Lake Bonneville (mainly Provo or post-Provo) time.

Beaver Ridge faults
(9-19)

Parameter values: middle to late Pleistocene | | |

Age Criteria : K-Ar; lacustrine stratigraphy
References : Hoover, 1974; Oviatt, 1991b
Comments : Faults with up to 70 meters of displacement cut lava flows dated at 0.5, 0.9, and 1.5 million years (location nos. 9-45 - 9-47, appendix B). Lake Bonneville deposits overlie and are not cut by the faults. Faults that cut the oldest basalt flow in the area are shown as early to middle Pleistocene in age on plate 1, but late Pleistocene movement on these faults cannot be precluded. Faults in the Black Rock-Sevier Desert basin intersect the Sevier Desert detachment at depths of 2-4 kilometers and may cut the detachment surface (Picha, 1986; Smithson and Johnson, 1989), or may terminate against it (Allmendinger and others, 1983; Anderson and others, 1983).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Tabernacle faults (9-20)					
Parameter values:	<14				

Age Criteria : ^{14}C; ash and lacustrine stratigraphy; basalt-flow morphology and geomorphic position
References : Oviatt, 1991b
Comments : The basalt of Tabernacle Hill (location no. 9-48, appendix B) was extruded into Lake Bonneville at or near the level of the Provo shoreline. Faults that cut the flow include fractures with minor offset. Hoover (1974) measured 15.2 meters of vertical displacement of the flow surface. However, the flow appears to be draped over pre-existing scarps (C.G. Oviatt, verbal communication, 1988). Faults in the Black Rock-Sevier Desert basin intersect the Sevier Desert detachment at depths of 2-4 kilometers and may cut the detachment surface (Picha, 1986; Smithson and Johnson, 1989) or may terminate against it (Allmendinger and others, 1983; Anderson and others, 1983).

Pine Valley - south end (faults) (9-21)					
Parameter values:	early to middle Pleistocene(?)				

Age Criteria : alluvial-fan characteristics
References : Fugro National, Inc., 1981b
Comments : The Quaternary(?) faults shown on plate 1 are bedrock faults that appear to be associated with an alluvial scarp. Numerous short bedrock scarps of indeterminate but Quaternary(?) age occur along the western margin of Pine Valley (not shown on plate 1).

Pine Valley (faults) (9-22)					
Parameter values:	middle to late Pleistocene				

Age Criteria : alluvial-fan characteristics
References : Fugro National, Inc., 1981b
Comments : Faults shown on plate 1 are part of a small cluster of tectonic lineaments.

Little Rough Range (faults) (9-23)					
Parameter values:	middle to late Pleistocene				

Age Criteria : alluvial-fan characteristics
References : Ertec Western, Inc., 1981a
Comments : Indeterminate age (Quaternary(?) to late Tertiary) faults have also been mapped by Ertec Western, Inc. (1981a) at the north end of Pine Valley on the margins of the Tunnel Spring Mountains and Middle Mountain (not shown on plate 1).

north of Wah Wah Mountains (faults) (9-24)					
Parameter values:	late Quaternary(?)				

Age Criteria : presence of scarps on alluvium
References : Ertec Western, Inc., 1981a; B.A. Schell, written communication, 1991
Comments : The faults are shown by Ertec Western, Inc. (1981a) as Pleistocene in age.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Wah Wah Mountains (faults)
(9-25)

Parameter values: Quaternary(?)

Age Criteria : morphology of bedrock scarps
References : Ertec Western, Inc., 1981a
Comments : A concealed range-bounding fault, interpreted from seismic-reflection data, lies along the west side of the Wah Wah Mountains (not shown on plate 1; Smith and Bruhn, 1984).

Wah Wah Valley
- west side (faults)
(9-26)

Parameter values: middle to late Pleistocene

Age Criteria : presence of scarps on alluvium
References : Ertec Western, Inc., 1981b
Comments : Springs coincide with the fault zone. A height of 6 meters was measured for one of the scarps. The scarps were not included in mapping by Anderson and Bucknam (1979a), and they may be the result of liquefaction and lateral spreading rather than faulting (B.A. Schell, written communication, 1991).

San Francisco Mountains
- west side (fault)
(9-27)

Parameter values: middle to late Pleistocene

Age Criteria : scarp morphology; alluvial-fan characteristics
References : Anderson and Bucknam, 1979a; Ertec Western, Inc., 1981a, 1981b
Comments : Short, discontinuous scarps that are as high as 13 meters and occur in old dissected fan surfaces appear on aerial photos to be among the oldest in the Richfield 1° x 2° quadrangle. Shorelines to the north of the mapped fault are unfaulted. The fault is inferred from seismic-reflection data to intersect a subhorizontal detachment at a depth of 10 kilometers (Smith and Bruhn, 1984).

Cricket Mountains
- west side (fault)
(9-28)

Parameter values: latest Pleistocene to Holocene

Age Criteria : scarp morphology; shoreline relations
References : Anderson and Bucknam, 1979a; Ertec Western, Inc., 1981a; Oviatt, 1989
Comments : Oviatt (1989) mapped the north end of the fault as cutting alluvial-fan surfaces modified by wave erosion in Lake Bonneville, and Ertec Western, Inc. (1981a) indicated that the fault displaces post-Bonneville alluvium. In contrast, Anderson and Bucknam (1979a) observed a fault scarp with a wave-etched bench and also beach terraces with no apparent displacement across the fault. Thus, they interpreted a pre-Bonneville-highstand age for the fault scarps, despite a morphology that appears younger than adjacent wave-cut scarps and similar to the Drum Mountain fault scarps (location no. 8-1). The Cricket Mountains scarps have a maximum measured displacement of 1.3 meters.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Mineral Mountains
- northeast side (fault)
(9-29)

Parameter values:	Quaternary(?)			

Age Criteria : presence of scarps on unconsolidated deposits and Quaternary (?) volcanics
References : Anderson and Miller, 1979; Anderson and Bucknam, 1979a
Comments : Gravity data indicate a buried range-front fault (Steven and others, 1990).

Buckskin Valley (faults)
(9-30)

Parameter values:	middle to late Pleistocene			

Age Criteria : presence of scarps on alluvium
References : Anderson and others, 1990b; Anderson and Bucknam, 1979a
Comments : Scarps are dissected and subdued and may actually be erosional, fault-line features.

Fremont Wash (faults)
(9-31)

Parameter values:	late Quaternary			

Age Criteria : presence of scarps on alluvium
References : Anderson and others, 1990b; Anderson, 1980; Anderson and Bucknam, 1979a
Comments : Radiocarbon ages of about 3,800 yr B.P. were obtained for alluvium that post-dates faulting. Alluvial deposits mapped as late Pleistocene to Holocene in age are faulted.

Annabella graben
(9-32)

Parameter values:	latest Pleistocene to early Holocene		4.7 - 5.2 ?	

Age Criteria : scarp morphology
References : Anderson and Barnhard, 1992; Anderson and Bucknam, 1979a
Comments : The Annabella faults, which compose a wide graben, are in a structurally complex bend at the north end of the Sevier fault (location no. 9-35) and separate a weakly deformed, east-tilted Sevier Plateau block bounded by the Sevier fault from a highly deformed series of west-tilted blocks downfaulted toward the plateau. The deformation appears to be younger than the Sevier River Formation, dated as young as 5.6 million years old in this area. Faults within the upthrown and downthrown blocks have diverse orientations and slip directions, although dip- and oblique-slip faults predominate over strike-slip faults. Normal-fault dip directions are mostly incompatible with the presence of a major, range-front fault system. Late Quaternary faulting and historical seismicity are concentrated within the Annabella graben, indicating high stress accumulation within a possible structural juncture. The deformation may also be related to flowage of the Arapien Shale, exposed northeast of the graben, and growth of the south end of the Sanpete-Sevier Valley anticline (location no. 13-16). In addition to faulting, youthful tectonism takes the form of closed basins on mountain flanks, deflections of major drainages, and aligned inflections of parallel ridge crests. Individual fault scarps within the graben are less than 5 kilometers long and record spatial differences in rates of late Quaternary faulting. The highest scarp, which is on the main strand of the Sevier fault, has a cumulative displacement of about 109 meters in late(?) Quaternary deposits and may be the highest alluvial scarp in Utah. The 90-meter-long, 35° midslope of the scarp implies numerous faulting events closely spaced in time. The morphology of a single-event(?) scarp suggests an age comparable to the Bonneville shoreline. The short lengths of both the zone of young faulting and of individual faults argue against causative earthquakes with large magnitudes. The age and rate of deformation within the structural juncture is likely not characteristic of deformation along the rest of the Sevier fault, where larger, longer return-period earthquakes are likely. A 1982 magnitude 4.0 earthquake and aftershock sequence, associated with internally inconsistent faulting kinematics, was centered in the Annabella graben in an historically rare association of seismicity with mapped Quaternary faults.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Red Canyon fault scarps (9-33)					
Parameter values:	Holocene(?)				

Age Criteria : scarp morphology
References : Anderson and Bucknam, 1979a
Comments : Most scarps cross steep colluvial and bedrock slopes and, as a result, are steep (35-40°) and sparsely vegetated, in comparison to a scarp formed where the fault crosses a gently sloping stream terrace. The maximum measured displacement is 2.2 meters.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Wah Wah Mountains - south end near Lund (fault) (9-34)					
Parameter values:	late Pleistocene(?)				31 ?

Age Criteria : scarp morphology; alluvial-fan characteristics
References : Anderson and Bucknam, 1979a; Anderson and Christenson, 1989; Ertec Western, Inc., 1981a
Comments : Anderson and Bucknam (1979a) and Anderson and Christenson (1989) described the scarps, which record at least 5.5 meters of displacement, as highly dissected, similar to the scarps along the west side of the Mineral Mountains (location no. 9-14). An unfaulted alluvial fan northwest of Lund appears to be etched by the Bonneville(?) shoreline (Anderson and Bucknam, 1979a). Ertec Western, Inc. (1981a) indicated a middle to late Pleistocene(?) age of last movement on the fault. An apparent displacement in modern stream alluvium may represent more recent faulting or may be the expression of an exhumed fault in water-saturated deposits (Ertec Western, Inc., 1981a). Alternatively, the feature may be related to liquefaction and lateral spreading (B.A. Schell, written communication, 1991). Fugro National, Inc. (1981a) discussed and mapped small displacements (0.3 meters) in Holocene alluvium, and Currey (1982) suggested that the bed of Lake Bonneville may have been deformed by Holocene movement on the fault. A magnitude of about 6.5 has been estimated for surface-rupturing earthquakes on the fault.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Sevier fault - northern portion (9-35)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology; association with Quaternary deformation
References : Anderson and Miller, 1979; Anderson and Barnhard, 1992
Comments : The north end of the fault zone, which geophysical data indicate is comprised of a series of step faults, appears to be predominantly dip slip, but has some component of strike-slip displacement. The fault lies on-trend and south of the late Quaternary Annabella faults (location no. 9-32).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Mountain Home Range - west side (faults) (9-36)					
Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact
References : Dohrenwend and others, 1991b

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Sevier fault - southern portion (10-1)					
Parameter values:	late Pleistocene	0.36 (<560)			

Age Criteria : amount of displacement in middle Pleistocene deposits; basin closure; range-front morphology; alluvial-fan characteristics; K-Ar

References : Anderson and Christenson, 1989

Comments : Striations with a southerly component of rake indicate that the Sevier fault has left-lateral oblique slip. A small closed basin adjacent to a left step at the south end of the fault is consistent with dilation due to left-lateral slip and indicates that subsidence and fault activity (due either to surface-faulting earthquakes or low-level seismicity/aseismic creep) are likely late Pleistocene in age. Farther north on the fault, southeast of Panguitch, 200 meters of offset in the 560,000-year-old flow in Red Canyon (which yields a vertical slip rate of 0.36 mm/yr; location no. 10-42, appendix B) also suggests that faulting occurred during late Pleistocene time. Basalts of Quaternary age at Black Mountain, northeast of Glendale (location no. 10-43, appendix B) have probably been faulted (23 meters according to Cashion, 1961), but the amount of displacement is difficult to determine due to uncertainties in distinguishing scarps related to landslides, preflow topography, and faults. Range-front steepness and linearity along the fault suggest recent movement, although in places these are likely fault-line characteristics resulting from juxtaposition of resistent and nonresistant rocks. Near Alton, differential erosion of indurated Quaternary deposits and relatively weak Cretaceous rocks have resulted in a southeast-facing fault-line scarp. A small (up to 5 meters high), continuous west- (uphill-) facing scarp 2 kilometers long is on the face of the fault-line scarp along the main trace of the Sevier fault. An unfilled sediment trap formed against the scarp suggests that it is only a few thousand years old. The scarp is believed to be related to subsidence caused by gravity-driven movement of weak rocks east of the fault and not related to earthquake surface faulting, as ridgelines cut by the scarp show little or no tectonic throw. Also, it seems unlikely that 5 meters of seismogenic surface displacement on a major block-bounding fault would be restricted to such a short segment. East of Panguitch, where the Sevier fault dies out in bedrock, Anderson and Miller (1979) and Carpenter and others (1967) show a number of dashed Quaternary faults (not shown on plate 1). An air-photo study by Anderson and Christenson (1989) in this area indicate that short fault traces are expressed only as aligned drainages in bedrock and that no through-going scarps occur in the irregular mass of Quaternary deposits. A possible en echelon left step at the north end of the fault is expressed as a youthful range front (shown as Quaternary(?) on plate 1).

Kolob Terrace (faults) (10-2)					
Parameter values:	middle to late Pleistocene				

Age Criteria : K-Ar; scarp morphology

References : Anderson and Christenson, 1989

Comments : The relation between dated basalt flows, ranging in age from 0.36 to 1.4 million years (location no. 10-38, appendix B), and faulting has not been established. The maximum displacement in the basalt is about 15 meters (Cashion, 1961).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Washington fault
(10-3)

Parameter values: latest Pleistocene to Holocene(?) | | |

Age Criteria : scarp morphology; deposit characteristics
References : Anderson and Christenson, 1989; Earth Science Associates, 1982
Comments : Slip on the main and subsidiary faults ranges from pure dip slip to left-lateral, oblique slip. The recency of movement appears to vary along the fault. North of Washington, a Pleistocene pediment deposit (tentatively estimated to be roughly 300,000 years old), which underlies a 8-meter-high scarp, appears not to be displaced. Here, and along much of the fault, scarp development is largely the result of differential erosion of contrasting lithologies on the upthrown and downthrown blocks (Petersen, 1983). Near Washington, an early Pleistocene basalt flow (the Washington flow, location no. 10-28, appendix B) is displaced up to 4.5 meters by a subsidiary fault. Along the central portion of the main fault, subsurface investigations by Earth Science Associates (1982) indicated more than a meter of displacement in undated "older" alluvium (estimated based on uncertain evidence to be 10,000-25,000 years old). Small (up to 5 centimeters) displacements in "younger" alluvium may be due to differential compaction rather than coseismic surface faulting (Earth Science Associates, 1982). Farther south, a single profile of a scarp on a highly dissected pediment indicates a morphologic age comparable to the Bonneville shoreline (Anderson and Christenson, 1989). At the south end of the fault in Utah, Menges and Pearthree (1983) estimated a late Pleistocene to early Holocene age range for faulting based on scarp morphlogy, and Scarborough and others (1986) placed the fault in an age category of <30,000 years for most recent rupture. Anderson and Christenson (1989) considered the age uncertainty to be greater and recommended a middle to late Pleistocene age for this part of the fault.

Washington dome
(10-4)

Parameter values: middle to late Pleistocene(?) | | |

Age Criteria : stratigraphic thickness; geomorphic position
References : Anderson and Christenson, 1989
Comments : A thick sequence of sands and gravels, containing 1.3- and 1.6-million-year-old basalt clasts, are faulted and tilted an average of 20° and as much as 80° near faults. The deposits are many tens of meters thick, have variable dips, and appear to be highly localized. It is postulated that deposition of the gravels was related to subsidence accompanying dissolution of subsurface evaporites.

Volcano Mountain (faults)
(10-5)

Parameter values: middle to late Pleistocene(?) | | |

Age Criteria : basalt-flow morphology
References : Hamblin, 1970; W.K. Hamblin, unpublished mapping, 1989
Comments : The faults are in undated Pleistocene basalts that have retained much of their flow morphology (location no. 10-29, appendix B).

Gunlock fault
(10-6)

Parameter values: <1600 | 0.005 (<1600) | | |

Age Criteria : K-Ar
References : Anderson and Christenson, 1989
Comments : A splay and several faults parallel to the Gunlock fault show evidence for predominantly left-lateral slip, although it is not known whether strike-slip displacement occurred during the Quaternary. Total stratigraphic throw on the fault is less than on the Hurricane fault (location no. 10-7) and is probably less than 300 meters. A cumulative displacement of 8 meters in a 1.6-million-year-old basalt (location no. 10-26, appendix B) argues against displacement during the late Pleistocene.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Hurricane fault
(10-7)

Parameter values:	latest Pleistocene(?)	0.4 m (<50) 0.3 - 0.47 m (<1000)			

Age Criteria : scarp morphology; range-front morphology; stream knickpoint development; K-Ar; TL; soil development
References : Anderson, 1980; Anderson and Christenson, 1989
Comments : The shorter-term slip rate is based on a minimum age estimate of 50,000 years for a soil developed on an alluvial surface displaced across a 20-meter-high scarp at the north end of the fault (at Shurtz Creek). The profile of the scarp, which lacks clear evidence of recurrent movement, suggests that the most recent event is pre-Holocene, but probably close to the Pleistocene-Holocene boundary. At several locations, the steep range front is formed in relatively nonresistant rocks, and in areas of resistent rocks, sharp knickpoints coincide with the base of the cliffs. Small alluvial fans adjacent to the cliffs are probably Holocene in age and appear to be unfaulted. West of the fault and southwest of Pintura, fault scarps as high as 15 meters cross dissected Pine Valley Mountain fan surfaces and appear to represent recurrent late Pleistocene(?) antithetic faulting that is mechanically linked to the Hurricane fault. Scarborough and others (1986) categorized most recent surface rupture on the fault in Arizona and southern Utah as <30,000 years old. The range in longer-term slip rates encompasses calculations from various dated basalts (W.K. Hamblin and M.G. Best, written and verbal communication in Anderson and Christenson, 1989; Anderson and Mehnert, 1979), and the values may be greater than the actual tectonic displacement rate adjusted to exclude throw from fault-related flexing. Given the high rate of displacement and an estimated total tectonic displacement across the fault of 1,100-1,500 meters (latest estimate, calculated to exclude apparent throw due to fault-related flexing and pre-existing folding), the Hurricane fault appears to be mainly a Pliocene to Pleistocene structure. Several swarms of historical seismicity have occurred adjacent to, but cannot be correlated directly with, the north end of the Hurricane fault. The earliest of these swarms (in 1942) included two approximately magnitude 5 earthquakes (Arabasz and Smith, 1979; Richins and others, 1981).

North Hills (fold and faults)
(10-8)

Parameter values:	<1000				

Age Criteria : K-Ar
References : Anderson and Christenson, 1989; Anderson and Mehnert, 1979
Comments : An uplifted and faulted Quaternary basalt (not shown on plate 2) has dips up to 30°, significantly less than dips in older rocks, and a structural form that resembles the faulted folds near Panguitch. The deformation that produced the current physiographic expression of the North Hills post-dates the basalt and most likely extended into middle to late Pleistocene time.

Cross Hollow Hills (faults)
(10-9)

Parameter values:	<1200				

Age Criteria : K-Ar; basalt-flow morphology
References : Anderson and Christenson, 1989
Comments : Faulted Quaternary basalts (location no. 10-36, appendix B) are similar to basalts of the nearby North Hills. Several short scarps represent displacements of less than about 10 meters. It is not known whether the faults were active during the late Pleistocene. However, Earth Science Associates (1982) estimated a late Pleistocene age for a meter of displacement on one fault, based on a general assessment of carbonate development in faulted alluvium. Bedding attitudes in Quaternary basalt, particularly at the south end of the Cross Hollow Hills (Averitt and Threet, 1973), indicate a possible north-trending anticline with flank dips generally less than 10°.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Enterprise (faults)
(10-10)

Parameter values:	middle to late Pleistocene				

Age Criteria : scarp continuity and morphology
References : Anderson and Christenson, 1989
Comments : Faulting is mainly expressed as concordant faceted spurs on ridges of dissected alluvium. Strata with a ^{14}C age of about 5,000 yr B.P. post-dates faulting (Anderson, 1980).

Antelope Range fault
(10-11)

Parameter values:	middle to late Pleistocene				

Age Criteria : range-front morphology; scarp morphology; alluvial-fan characteristics
References : Anderson and Christenson, 1989; Ertec Western, Inc., 1981a
Comments : Scarps, which are 20-30 meters high and represent multiple events, are highly degraded. Those at the north end of the range appear to be older than isolated scarps along the range front. Approximate slope-height scarp measurements suggest an age that is greater than the Bonneville shoreline. A 2-meter-high, east-facing scarp 5 kilometers west of the Antelope Range may be the result of antithetic faulting.

Escalante Desert
- near Zane (faults)
(10-12)

Parameter values:	late Pleistocene				

Age Criteria : alluvial-surface characteristics
References : Anderson and Christenson, 1989
Comments : Fault scarps are low, are parallel to drainage, and are locally modified by eolian deposits and modern drainage. Ertec Western, Inc. (1981a) indicated displacement of Holocene (or modern) deposits, but Anderson and Christenson (1989) determined, based on photogeologic work, that the faulted alluvium is more likely late Pleistocene in age.

Johns Valley (fault)
(10-13)

Parameter values:	late Pleistocene				

Age Criteria : scarp morphology
References : Anderson and Christenson, 1989
Comments : The main scarp (with ~1 meter of apparent displacement) parallels and may be part of a group of stream-terrace scarps, but it is roughly concordant with a bedrock fault and separates surfaces with similar characteristics, suggesting fault displacement. Also, a short parallel scarp dies out on both ends in a manner characteristic of fault scarps. Mapping by Rowley and others (1987) does not show any Quaternary faults in the area, and more detailed work is needed to determine if the scarps are actually related to faulting.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Escalante Desert
- east side (faults)
(10-14)

Parameter values: late Pleistocene to Holocene | | |

Age Criteria : scarp continuity; deposit characteristics; drainage disruption
References : Anderson and Christenson, 1989; Ertec Western, Inc., 1981a
Comments : Along the western of the two mapped fault scarps, only the youngest stream deposits are not displaced. Anderson and Christenson (1989) indicated a probable late Pleistocene age for faulting, whereas Ertec Western, Inc. (1981a) assigned a Holocene age to the faulted deposits. Scarps along the eastern fault are highly degraded and discontinuous and are only on the oldest (middle to late Pleistocene) deposits.

Cedar Valley
- west side (faults)
(10-15)

Parameter values: middle to late Pleistocene | | |

Age Criteria : deposit characteristics
References : Anderson and Christenson, 1989

Cedar Valley
- north end (faults)
(10-16)

Parameter values: middle to late Pleistocene | | |

Age Criteria : deposit characteristics; scarp morphology
References : Anderson and Christenson, 1989
Comments : The northernmost scarps are located on highly dissected alluvium of probable early to middle Pleistocene age. General scarp morphology and age estimates of the youngest faulted deposits at the southern end of the group (north of Rush Lake) suggest that some of the scarps may be latest Pleistocene in age.

Sevier Valley
- hills near Panguitch (folds and faults)
(10-17)

Parameter values: late Quaternary | | |

Age Criteria : soil development; erosional modification; stream-pattern anomaly; basin closure
References : Anderson and Christenson, 1989
Comments : The northernmost fold is defined by fan surfaces (probably as old as middle Pleistocene) rotated as much as a few degrees away from a central graben. Faulted folds on-trend to the south occur mostly in a 5.3-million-year-old basalt that overlies the Sevier River Formation, and they have limbs that dip an average of 5 degrees. Axial graben scarps are as high as about 25 meters, whereas most other scarps are only a few meters high. The tilted fan surfaces have mature calcic soils many tens of thousands to >100,000 years old. Streams that flow west from the Sevier Plateau bisect the surfaces and scarps, and Holocene fluvial deposits (with ^{14}C ages of 4,000-5,000 yr B.P. at one locality) locally bury the surfaces. One low-lying surface 4 kilometers north of the intersection of Highways 89 and 12 is displaced vertically less than 1 meter by surface faulting that may be as young as the late Pleistocene event on faults north of Panguitch (location no. 10-24). Geomorphic evidence in the area of deformed basalts suggests that folding and faulting may have continued into the latest Pleistocene or Holocene. Several closed basins disrupt drainages, and an anomaly in the channel pattern of the Sevier River where it crosses the southward projection of an anticline suggests active uplift. A general morphologic age (of 100,000 years) estimated for scarps within the larger Panguitch area using regression analysis of scarp-profile data (Bucknam and Anderson, 1979b) may not be meaningful because of possible erosional complications and because the available data show significant scatter and represent multiple-event scarps. The faulted folds are thought to have formed aseismically and to be genetically related to the subparallel Sevier fault. The clusters of closely spaced scarps are associated with far less structural relief than the folds and probably represent shallow, fold-related faults with little seismic potential.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Enoch graben
(10-18)

Parameter values: latest Pleistocene to Holocene | | | |

Age Criteria : ^{14}C
References : Anderson, 1980; Anderson and Christenson, 1989
Comments : In an exposure across the eastern (5-7-meters-high) scarp, which extends into Enoch, the relation to faulting of a soil with a ^{14}C age of 9,500 yr B.P. is uncertain, although subjacent strata are faulted. The morphology of the scarp suggests an age significantly greater than the Bonneville shoreline, but the scarp may degrade more rapidly than Bonneville reference scarps because it is formed on finer grained deposits. The fault on the west side of the graben, west of Enoch, crosses alluvial deposits of estimated middle to late Pleistocene age. Five kilometers north of Enoch, faults with up to 50 meters or more of throw displace a series of Quaternary basalt flows. One flow has a K-Ar age of 1.3 million years (location no. 10-34, appendix B). Some of these bedrock faults likely had movement as recently as indicated by the Enoch alluvial scarp, but are age-grouped as late Pleistocene on plate 1.

Red Hills fault
(10-19)

Parameter values: late Pleistocene | | | |

Age Criteria : range-front morphology; alluvial-fan characteristics; basin closure
References : Anderson and Christenson, 1989
Comments : Despite bedrock that is relatively nonresistant, range-front embayments are few, even along major drainages. The presence of Little Salt Lake and the broad, flat Parowan Valley suggests that subsidence of the basin accompanied uplift of the range during the late Pleistocene. V.S. Williams (written communication, 1991) believes that Holocene movement on this fault cannot be precluded.

Parowan Valley (faults)
(10-20)

Parameter values: Holocene(?) | | | | |

Age Criteria : scarp morphology; soil development; deposit characteristics
References : Anderson and Christenson, 1989; Maldonado and Williams, 1991a and b; Williams and Maldonado, 1990
Comments : The profile of a 2.0-2.5-meters-high scarp on the east side of the valley indicates a morphologic age just slightly greater than the Bonneville shoreline. The appearance of this scarp suggests that it is one of the youngest fault features in southwestern Utah. The morphologic age of a nearby 5-meter-high scarp appears somewhat greater, but this may be due to distribution of slip over a series of closely spaced faults that are exposed in a road cut. Scarps on the west side of the valley are generally higher and appear older than those to the east (Anderson and Christenson, 1989). However, most faults in the area have small (<1 meter) offsets in possible Holocene alluvial fans and alluvium (Maldonado and Williams, 1991a and b; V.S. Williams, written communication, 1991; Williams and Maldonado, 1990). A buried portion of one fault (the "Little Salt Lake fault") may extend northward for about 8 kilometers along the base of the northern Red Hills (not shown on plate 1).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Cedar City-Parowan monocline
(10-21)

Parameter values:	Holocene(?)	0.25 (<1000)			

Age Criteria : modern strain measurements; stream-dissection rates; basin closure; ^{14}C; K-Ar

References : Anderson and Bucknam, 1979b; Anderson and Christenson, 1989

Comments : The monoclinal structure, which appears to be quite complex, may form a structural bridge between the Hurricane and Paragonah faults (locations nos. 10-7 and 10-22; Threet, 1963). Both normal and strike-slip faults deform the monocline, and interrelated systems of faults and folds generally displace rocks down toward the uplift, forming numerous closed range-front basins that are only partially filled with sediment. In one area of the monocline along the West Fork of Braffits Creek, dramatic modern downcutting (possibly 20 meters in 60-70 years) has exposed faults in late Holocene deposits. The faults appear to have a significant component of strike-slip motion (and not reverse, as was reported earlier by Anderson, 1980 for the main fault). A geodetic network established across Braffits Creek in 1977 indicated significant horizontal and vertical changes during the first four years, up to 39.2 millimeters of position shift at one station. The lateral shifts, all southerly, are opposite to the topographic gradient (thus precluding gravity sliding) and suggest tectonic deformation that is consistent with geologic evidence on one fault for right-lateral slip. A displacement rate of 10 mm/yr, indicated by the geodetic survey, seems reasonable for the Holocene faults. The modern deformation has not been accompanied by seismicity above a background threshold of about M_L 3.0. This suggests that the closed basins on the flank of the plateau and possibly other tectonically youthful landforms elsewhere on the Markagunt Plateau may be due to high rates of relatively aseismic deformation. Limited depth penetration observed for some small-scale structures in the area supports a model of thin-skinned extensional response to major uplift of the plateau block. The possibility exists that a blind, plateau-bounding, normal fault zone with significant seismic potential underlies the main mountain-front monocline. The value for the long-term rate of deformation (0.25 mm/yr) is a minimum for uplift due to folding in the central part of the monocline.

Paragonah fault
(10-22)

Parameter values:	late Pleistocene	0.46 (<440)			

Age Criteria : range-front morphology; scarp morphology; K-Ar

References : Anderson and Christenson, 1989; Hamblin and others, 1981

Comments : The fault lacks recognized alluvial scarps. However, a companion fault west of the main Paragonah fault and on-trend with the Cedar City-Parowan monocline has a poorly preserved 12.5-meter-high alluvial scarp (probably representing several surface-faulting events) with a maximum slope angle (23°) suggestive of latest Pleistocene faulting. The displacement rate for the main strand of the fault is 0.30 mm/yr; the rate for the companion fault to the west is 0.16 mm/yr.

Markagunt Plateau (faults)
(10-23)

Parameter values:	middle to late Pleistocene				

Age Criteria : range-front morphology; basin closure; drainage pattern; scarp morphology and dissection

References : Anderson and Christenson, 1989

Comments : It is unclear whether the faults, which are all in bedrock, are seismogenic or whether they are the result of gravitational processes. The terrain appears generally unstable, and some of the mapped scarps may be the margins of landslides. The apparent age of the bedrock scarps (based on photogeologic study) varies considerably, and some of the scarps may date from the latest Pleistocene.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Sevier Valley
- north of Panguitch (faults)
(10-24)

Parameter values:	late Pleistocene			0.8 mh	

Age Criteria : soil development; scarp preservation

References : Anderson and Christenson, 1989

Comments : The faults bound a conspicuous horst. The youngest faulting event displaced a fan surface (by less than a meter) thought to be middle to late Pleistocene in age, based on similarities with soils near Beaver, Utah (described by Machette, 1985) dated at 120,000-140,000 years. Deposits that post-date faulting have a weakly developed soil roughly similar to Holocene soils in the Beaver area. The preservation and linearity of the small (0.88-meter-high) single-event scarp indicate youthful faulting, probably late Pleistocene in age. Vegetation lineaments in Holocene deposits were interpreted by Anderson and Rowley (1987) as evidence for Holocene faulting, but Anderson and Christenson (1989) believed that the lineaments are an expression of ground water concentrated along buried portions of the late Pleistocene faults. The next-to-last faulting event is associated with about 0.6 meters of dip separation and pre-dates the middle to late Pleistocene fan surface. Scarps as high as 12 meters occur on remnants of a surface that may be as old as middle Pleistocene. Steep midslope segments on many of these high scarps may be the result of relatively recent surface faulting or of lithologically controlled contrasts in resistance to erosion. A general morphologic age (100,000 years) estimated for scarps within the larger Panguitch area using regression analysis of scarp-profile data (Bucknam and Anderson, 1979b) may not be meaningful because of possible erosional complications and because the data show significant scatter and represent multiple-event scarps.

East Cache fault zone
- northern segment
(11-1)

Parameter values:	middle to late Pleistocene	0.1 - 0.2 ? (<100-200)			33+

Age Criteria : alluvial-surface morphology; soil development; range-front morphology

References : McCalpin, 1987, 1989; McCalpin and Forman, 1991

Comments : The fault segment consists of two parallel, range-bounding fault strands roughly 3.5 kilometers apart (shown on plate 1) and one or two other strands concealed beneath the valley floor to the west (not shown on plate 1). Activity data are from alluvial surfaces with as much as 20 meters of surface displacement at the southern end of the younger, western strand. To the north, pediment surfaces rise to 500 meters in elevation and are buried on the downthrown side. The northward rise in pediment elevation and southward steepening of the main (eastern) range front suggests progressive transfer of slip from the eastern to the western strand. The structure of faceted spurs suggests that the boundary between the northern and central segments has shifted southward several kilometers during the middle to late Quaternary, probably along with development of the younger, western strand. Tilted Bonneville shorelines in the vicinity of a large delta are attributed to depositional loading onto weak Salt Lake Formation rocks and resulting ductile bending. At one location on the western strand, a graben in Provo-level deltaic deposits below unfaulted deltaic topset beds shows a total displacement of 0.4 meters. The displacement appears to be localized and may be due to lateral spreading rather than seismogenic faulting.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

East Cache fault zone
- central segment
(11-2)

Parameter values:	4 - 7 ? e	0.16 - 0.27 * (<15.5) >0.06 ? d (<150 ?)	5.8 - 11.5 * (<15.5)	0.8 - 1.8 n	20 - 44

Age Criteria : alluvial-surface morphology; ^{14}C; soil development; lacustrine stratigraphy
References : McCalpin, 1987, 1989; McCalpin and Forman, 1991
Comments : The central segment is defined by the presence of post-Bonneville fault scarps (which are preserved over a distance of 8 kilometers in the northern half of the segment) and by range-front geomorphology. The most recent event predates alluvial fans estimated to be about 4,000-7,000 years old. Thermoluminescence dating places the event between 2,500 and 8,700 years ago. Stratigraphic and geomorphic evidence indicates that the penultimate earthquake event likely occurred between formation of the Bonneville and Provo shorelines. This event may have been influenced by loading from the water or deposits of Lake Bonneville. Measured displacements for the penultimate event (~1.8 meters) are greater than for the most recent event (~0.8-1.4 meters). There is equivocal evidence, based on a 1930s photo of a road cut which shows a 4.9-meters displacement in prodelta sands, for another event between 19,400 years ago (approximately when the lake shore reached the site) and 15,000-17,000 years ago. Unlike the northern and southern segments, the central segment (which is composed of Paleozoic rocks) does not show evidence for post-Bonneville warping, attributed to depositional loading. This may be because faulting along the central segment has decoupled the upthrown block from the loaded downthrown block. Calculated long-term slip rates for the past 150,000 years are similar along all three segments of the fault. Similarities in the structure of faceted spurs and the absence of a gravity-defined boundary between the central and southern segments suggest that they may have behaved as a single 44-kilometer-long seismogenic segment during much of the late Cenozoic. However, the last two events on the East Cache fault zone were limited to the 20-kilometer-long central segment, suggesting paleoearthquake magnitudes in the range of 6.6 to 7.1 (M_s). In a characterization of fault-specific seismic-source zones along the Wasatch Front, Youngs and others (1987, in press) calculated a maximum earthquake magnitude of 7.25 for the East Cache fault zone based on a segment length of 47 kilometers (measured from the south end of the fault to the range-front salient north of Smithfield) and single-event displacements that have been estimated for the Wasatch fault zone.

East Cache fault zone
- southern segment
(11-3)

Parameter values:	26 - 46 e	0.01 - 0.07 ? (<150-1000 ?)	7.5 - 143 i (<150-1000 ?)	0.5 - 1.5 i	24 - 34

Age Criteria : TL; alluvial-surface characteristics
References : McCalpin, 1987, 1989; McCalpin and Forman, 1991
Comments : The fault segment consists of three parallel strands within a 2.5 kilometer-wide zone. The central strand, expressed as an alignment of low hills and stream channels, is not shown on plate 1. Age data come from the youngest, eastern strand. If faulting on the southern segment extends to and includes the James Peak fault (location no. 11-12), then the rupture length may be 34 kilometers. Data from the James Peak fault suggest that two events may have occurred in the last 140,000 years on the southern segment of the East Cache fault zone, with an attendant slip rate of 0.03 mm/yr and recurrence interval of about 50,000 years or greater. Tilted Bonneville shorelines in the vicinity of a large delta are attributed to depositional loading onto weak Salt Lake Formation rocks and resulting ductile bending. Similarities in the structure of faceted spurs and the absence of a gravity-defined boundary between the central and southern segments of the East Cache fault zone suggest a common history of faulting during much of the late Cenozoic. The values for single-event displacements are inferred from values for the central segment. The range of recurrence-interval values assumes 7-20 events in displacement increments of 0.5-1.5 meters, yielding a measured cumulative displacement of 10 meters. A preferred estimate for long-term recurrence (for the eastern strand of the segment) is 15,000-50,000 years.

AME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Crawford Mountains - west side (fault) (11-4)					
Parameter values:	<70 ?				

Age Criteria : geomorphic position; soil development; glacial chronology
References : Hecker, 1987a
Comments : A faulted Bear River terrace at the south end of the fault likely dates from Pinedale time (<~70,000 years ago), as indicated by weak soil development in a thick loess deposit that overlies fluvial sand and gravel. Scarps are apparently absent from the Bear River flood plain and from young (Holocene(?)) alluvial fans. However, older alluvial scarps are preserved locally along the range front and many talus slopes appear to be truncated by faulting. Recent tectonic tilting is suggested by the position of the Bear River on the east side of the valley and by meander-bend scars adjacent to the range front. Late Pleistocene faulting likely extended north of the faulted river terrace to at least where the range front takes a prominent left step, and south for an unknown distance. The impressive steepness and linearity of the range front suggest recurrent late Quaternary faulting, but these characteristics are attributed in part to resistent rock units that dip steeply (50-70°) basinward. The range-front fault appears to have a listric subsurface geometry that may be inherited from earlier thrusting (Evans, 1991; Lamerson, 1982; F. Royse, in Sullivan, Nelson, and others, 1988).

Bear Lake - west side (fault) (11-5)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology(?)
References : Anderson and Miller, 1979; Kaliser, 1972; McCalpin, 1990
Comments : The mapped fault is on-trend with the western Bear Lake fault in Idaho, which has evidence for an event 6,500-5,900 years ago (McCalpin, 1990). However, seismic-reflection profiles on the western side of the lake (Skeen, 1975) do not show any subsurface faults on-trend with the Holocene fault in Idaho. One possibility is that the western side of the Bear Lake graben in Utah is an east-tilted hingeline rather than a discrete zone of faulting (McCalpin, 1990).

Saleratus Creek (fault) (11-6)					
Parameter values:	late Quaternary(?)				

Age Criteria : presence of scarps on alluvium(?); range-front morphology
References : Hecker, 1987a
Comments : Late Pleistocene faulting identified at the south end of the Crawford Mountains (location no. 11-4) may have also occurred on a fault which parallels Saleratus Creek. Young scarps at the north end of Saleratus Creek may be tectonic in origin, but appear to be stream-cut. The "Saleratus Creek fault" is expressed as scarps in bedrock, alluvial-scarp(?) remnants, lineaments, and linear bedrock-alluvium contacts. Ponded water adjacent to the fault suggests recent tectonic subsidence. The fault has a more subdued geomorphic expression than the fault along the Crawford Mountains, but this may be attributed to bedrock that is less resistent and to an absence of structurally controlled range-front slopes.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Bear River Range (faults) (11-7)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology
References : Sullivan, Nelson, and others, 1988; Westaway and Smith, 1989
Comments : Escarpments associated with several intermountain faults are prominent, but triangular facets are poorly preserved. The physiography suggests that late Quaternary displacements may have occurred on these faults. The Temple Ridge fault, the northernmost of the faults shown on plate 1, has only about 500 meters of Miocene to Pliocene throw, but is a likely source for the 1962 M_s 5.7 Cache Valley (Logan) earthquake which occurred at a depth of 10 kilometers. Coseismic slip involved a small component of right-lateral displacement, which may typify the sense of slip on other normal faults in the region. A left-stepping pattern in the trace of the East Cache fault zone (location nos. 11-01, 11-02, and 11-03) is consistent with right-lateral slip.

eastern Bear Lake fault - southern segment (11-8)					
Parameter values:	2.1 e	0.8 * (<12.7)	>5.3 ? *d (<12.7)	1 - 5.6+ ?	32

Age Criteria : ^{14}C
References : McCalpin, 1990; McCalpin and others, 1990
Comments : The fault zone extends north into Idaho. The zone comprises multiple strands and, as a result, the number of events and displacement during individual events are difficult to assess. Seismic-reflection data suggest that the zone of faulting extends offshore (Skeen, 1975). The age of the penultimate event is poorly constrained, but based on a weakly developed soil separating the two youngest colluvial wedges and assumed loess deposition and soil formation rates, the earlier event may have occurred about 2,600-4,600 years ago. The most recent interval between events (500-2,500 years?) may be considerably shorter than the prior recurrence interval (assuming the third-to-last event occurred before 12,700 ^{14}C yr B.P.), but the data are insufficient to demonstrate this. Minimum estimates of paleoearthquake magnitudes (M_s) vary between events (which were associated with variable surface displacements) from 6.9 to 7.4. An estimate of 7.1 can be calculated from the 32-kilometer length of the segment. Seismic-reflection data show that the fault is listric and appears to merge with the Meade thrust at depth (Evans, 1991). An alternative interpretation of the data is that the fault cuts the Meade thrust and has a subsurface dip of approximately 40° (Evans, 1991).

Dayton fault (11-9)					
Parameter values:	Quaternary(?)				

Age Criteria : stratigraphy
References : Dames and Moore, 1985
Comments : The Miocene and Pliocene Salt Lake Formation is faulted; Lake Bonneville deposits are unfaulted.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Mantua area (faults) (11-10)					
Parameter values:	late Quaternary(?)				

Age Criteria : basin closure; range-front morphology

References : Crittenden and Sorensen, 1985; Sullivan, Nelson, and others, 1988

Comments : The presence of faults is mostly inferred. Most of the basins have probably had at least tens of meters of Quaternary displacement. The central portions of some escarpments have morphologies similar to back valleys with known or inferred late Quaternary movement. One fault is expressed as a prominent lineament on aerial photos and may have had Holocene movement (S.F. Personius, verbal communication, 1991; see Goter, 1990). Karst features are present locally in the area, but karst processes are probably of secondary importance in basin development.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
southeastern Wellsville Mountains (fault) (11-11)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology (?)

References : Sullivan, Nelson, and others, 1988

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
James Peak fault (11-12)					
Parameter values:	30 - 110	0.03 (<140)	>50 ? (<140)	1.8 - 2.4	30 ?

Age Criteria : glacial chronology; scarp morphology; geomorphic position; soil development

References : Nelson and Sullivan, 1992; Sullivan, Nelson, and others, 1988

Comments : Faulting occurs in Bull Lake outwash deposits (~140,000 years old). The data are ambiguous, but lithofacies analysis of fault colluvium and the cumulative displacement (4.2 meters) suggest two events rather than a single, large event. Analyses of soil development in deposits which pre- and post-date faulting bracket the timing of movement. The lack of a soil between the two colluvial wedges suggests that time between events was short and, therefore, that recurrence intervals may be nonuniform. The short fault length (7 kilometers) suggests that surface faulting may have extended northward, rupturing the southern segment of the East Cache fault zone (location no. 11-3). If so, the 26,000-46,000-year age for most recent faulting on the southern East Cache fault applies as well to the James Peak fault. Faceted spurs at the base of James Peak, although smaller, less continuous, and less steep than those along the East Cache and Wasatch fault zones, suggest recurrent Quaternary displacements. The estimated maximum credible earthquake for the southern East Cache fault system is 7.5 (M_s).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Broadmouth Canyon (faults) (11-13)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology; presence of lineaments

References : Nelson and Sullivan, 1992; Sullivan, Nelson, and others, 1988

Comments : Most faults cannot be traced into the Tertiary Salt Lake Formation, but in two areas, faint lineaments do extend into these deposits. The morphology of the scarps in Paleozoic bedrock suggests that recurrent late Quaternary displacement has not occurred. The faults intersect and have been displaced by the James Peak fault (location no. 11-12) and may be the southernmost part of the Quaternary rupture zone encompassing the East Cache and James Peak faults.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Ogden Valley - North Fork fault (11-14)					
Parameter values:	late Quaternary(?)				18 ?

Age Criteria : range-front morphology
References : Sullivan, Nelson, and others, 1988
Comments : For the purpose of seismic-hazard assessment, values for slip rate, recurrence interval, and single-event displacement are inferred to be similar to those calculated for the Morgan fault (location no. 11-18), based on similarities in late Quaternary fault length and escarpment morphology. North of the late Quaternary(?) portion of the North Fork fault, a faceted bedrock escarpment with eroded, 22° slopes may have been produced by Quaternary faulting. Personius (1990) mapped the fault in this area as cutting Quaternary deposits within a kilometer west of the escarpment.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Ogden Valley - northeastern margin (fault) (11-15)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology
References : Sullivan, Nelson, and others, 1988
Comments : The morphology of the range front suggests an absence of late Quaternary faulting. Sorenson and Crittenden (1979) mapped fault scarps in Holocene colluvium that Sullivan, Nelson, and others (1988) interpreted as shallow landslide scarps.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Ogden Valley - southwestern margin (faults) (11-16)					
Parameter values:	late Quaternary(?)				10 ?

Age Criteria : range-front morphology; alluvial-fan morphology
References : Sullivan, Nelson, and others, 1988
Comments : Sorenson and Crittenden (1979) mapped faults in late Quaternary alluvial-fan and colluvial deposits, but Sullivan, Nelson, and others (1988) found no scarps in deposits at the base of the escarpment. Lofgren (1955) inferred "recent displacement" based on springs and the steepness (28-33°) of the escarpment. For the purpose of seismic-hazard assessment, values for slip rate, recurrence interval, and single-event displacement are inferred by Sullivan, Nelson, and others (1988) to be similar to those calculated for the Morgan fault (location no. 11-18), based on similarities in late Quaternary fault length and escarpment morphology. A short southwest-striking section of the fault south of the Ogden River is associated with a faceted escarpment and may have had Quaternary movement. The estimated maximum credible earthquake for the fault is 6.75-7.0 (M_s).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Morgan fault
- northern section
(11-17)

Parameter values:	late Quaternary	0.03 - 0.15 ? (<1000-5000)			

Age Criteria : range-front morphology; geomorphic position
References : Sullivan and Nelson, 1992; Sullivan, Nelson, and others, 1988
Comments : The escarpment morphology is similar to the central section of the fault. Undeformed Bonneville shorelines near the projection of the fault argue against, but do not preclude Holocene faulting. Tectonically tilted pediments cut into the Huntsville Fanglomerate (Eardley, 1944; estimated by Sullivan and Nelson, 1992, to be 5-35 million years old ?) are likely much older than a lower surface dated at >730,000 years. Projection of the tilted surfaces yields a minimum Quaternary displacement estimate of 150 meters. A narrow graben and eroded escarpment about 1 kilometer east of the main fault are interpreted as subsidiary faults and are suspected of having Quaternary movement on the basis of linearity and crosscutting relationship with respect to regional drainage. These faults lie along projection of, and thus may be related to, the central section of the Morgan fault.

Morgan fault
- central section
(11-18)

Parameter values:	<8.3 - 9.1	0.01 - 0.02 (<200-400)	25 - 100 (<200-400)	0.5 - 1.0	16 ?

Age Criteria : ^{14}C; soil development; correlation with amino-acid-dated deposits
References : Sullivan and Nelson, 1992; Sullivan, Nelson, and others, 1988
Comments : Although early Holocene colluvium is faulted, scarps are not preserved along the fault. This is attributed to the steepness (20-25°) of escarpment slopes and the presumably small amounts of surface displacement. Small, single-event displacements are suggested by a lack of discrete colluvial wedges. Analyses of soils developed on faulted deposits at different sites yielded age estimates that are generally between 200,000 and 400,000+ years, but which range from about 70,000 to >500,000 years. An antithetic, graben-bounding fault (shown as Quaternary(?), plate 1) is inferred to occur along the west side of a topographic low west of the main fault. The rupture length and an estimated maximum credible earthquake of 6.75-7.0 (M_s) assume simultaneous rupture on all three sections of the Morgan fault.

Morgan fault
- southern section
(11-19)

Parameter values:	late Quaternary				

Age Criteria : range-front morphology; alluvial-fan morphology
References : Sullivan and Nelson, 1992; Sullivan, Nelson, and others, 1988
Comments : The escarpment morphology is similar to the central section of the fault. A northwest-trending subsidiary fault that displaces late Quaternary (200,000-400,000+-year-old ?) colluvium appears to connect the southern and central sections, suggesting that at least some events rupture both sections of the Morgan fault.

Porcupine Mountain (faults)
(11-20)

Parameter values:	Quaternary(?)				

Age Criteria : presence of faulted alluvium
References : Bryant, 1990
Comments : Pliocene or Pleistocene gravel deposits are faulted.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

West Cache fault zone
- Wellsville fault
(11-21)

Parameter values:	late Quaternary				

Age Criteria : presence of scarps on alluvium; range-front morphology
References : Oviatt, 1986b
Comments : Scarps representing about 15 meters of displacement are present in areas where the fault is above the Bonneville shoreline. The north end of the fault is concealed beneath Bonneville deposits.

Wasatch fault zone
- Weber segment
(11-22)

Parameter values:	0.5 ? e	1 - 3 (middle to late Holocene) 0.5 - 1.9 * (<15)	1.2 ? (middle to late Holocene)	1 - 3 ?	61.0

Age Criteria : ^{14}C; TL; geomorphic position; shoreline chronology
References : Machette and others, 1991, 1992; Nelson, 1988; Nelson and Personius, 1990, 1993
Comments : The occurrence of the 500-year-old, small-displacement event is in question (Nelson, 1988). The most recent well-documented event on the segment occurred about 1,000 years ago (Forman and others, 1991). Amounts of displacement have been greatest along the central and northern portions of the segment, decreasing toward the ends. The range in post-15,000-year slip rates reflects this variation in activity along the segment. Individual faulting events may not have ruptured the entire segment, which is the longest segment of the Wasatch fault zone, although the general timing of events at three study sites up to about 20 kilometers apart appears to be similar. Three faulting events recorded at one site (East Ogden) occurred 1,000-1,400 years ago, 2,500-3,200 years ago, and 3,500-4,500 years ago, based on a synthesis of TL and ^{14}C age estimates (Forman and others, 1991). Actual recurrence intervals on the segment during the middle to late Holocene may have varied from about 300 to 2,200 years (Nelson and Personius, 1990, 1993).

Duchesne-Pleasant Valley fault system
(12-1)

Parameter values:	Quaternary ?				

Age Criteria : physiographic expression
References : Martin and others, 1985; Sullivan, 1988
Comments : The faults are expressed as prominent lineaments and escarpments in bedrock. Photogeologic mapping indicates that no scarps are present on late Quaternary (>250,000-year-old ?) deposits. This evidence, together with a fault orientation that appears to be at odds with the contemporary tectonic stress regime, indicated to Sullivan (1988) that the fault system should not be considered a potential source for large-magnitude earthquakes. A relation between variations in escarpment height and drainage incision led Sullivan (1988) to conclude that the escarpments are fault-line features, resulting from base-level lowering and erosion rather than Quaternary faulting. However, the geomorphic position of the faults suggested to Martin and others (1985) the possibility of late Quaternary faulting, and judging from scarp morphology, Osborn (1973) thought that faulting may have occurred less than a thousand years ago.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Towanta Flat graben (12-2)					
Parameter values:	130 - 500		60 (130-500)	0 n	

Age Criteria : soil development; cobble weathering

References : Martin and others, 1985; Nelson and Weisser, 1985

Comments : Some workers (Hansen, 1969a, 1969b; Utah Geological and Mineral Survey, 1977) have assigned late Pleistocene and Holocene ages to the scarps, based on estimated ages of faulted deposits and the freshness of the scarps. Nelson and Weisser (1985) concluded that there is no significant net tectonic displacement across the graben (although the throw across individual scarps has been 2.1-2.6 meters per event). This lack of net slip, together with an orientation that differs from planes defined by microseismicity, the limited extent of the scarps, and an average recurrence interval that is less than half as long as the time since the most recent event, suggests that the faults may not have a seismogenic origin and may not be capable of significant future surface-rupturing events. A reported late Pleistocene fault east of Tabiona that lies along the projected strike of the Towanta Flat faults (Ritzma, referenced in Anderson and Miller, 1979) shows no displacement in bedrock. An anomalous linear drainage used to infer the presence of the fault (Ritzma, referenced in Martin and others, 1985) is apparently a strike stream.

Wasatch fault zone - Provo segment (12-3)					
Parameter values:	0.5 - 0.6 e	1.1 - 1.3 (<5.3) 1.0 - 1.7 * (<15)	2.4 (<5.3)	1.5 - 3.0 n	69.5

Age Criteria : ^{14}C; TL; lacustrine stratigraphy

References : Lund and others, 1991; Machette, 1989, in press; Machette and others, 1991, 1992

Comments : Based on fault geometry and apparent recency of movement as indicated by scarp morphology, Machette and others (1986) tentatively subdivided the Provo segment (as originally proposed by Schwartz and Coppersmith, 1984) into three subsegments (from north to south, the American Fork, Provo "restricted sense," and Spanish Fork). However, based on the timing of the last two events deciphered from trench studies, the entire length of the Wasatch fault zone in Utah Valley appears to be a single segment (Machette, 1989, in press; Lund and others, 1991; Machette and others, 1991). The penultimate event occurred about 2,600-3,000 years ago; based on results from the northern end of the segment (at American Fork), the prior two events occurred about 5,300 and 5,500-8,000 years ago. A conflicting chronology of faulting from a site near the southern boundary of the segment (at Water Canyon, where two events have occurred in the last 1,000 years) may be explained by spatial overlap of the Nephi and Provo segments, whereby events from both segments are recorded at the site (Machette, 1989, in press; Ostenaa, 1990). The slip-rate and recurrence data are from the American Fork site, where rates of activity appear to have been constant during post-Bonneville time. However, at the Hobble Creek site (east of Spanish Fork), there is two-to-three times more displacement recorded in Bonneville transgressive deposits than in Provo-age regressive deposits. Twenty to thirty meters of displacement in just a few thousand years represents slip rates as high as 10 mm/yr and may be related to the presence of Lake Bonneville. Six or seven post-Provo events are inferred to have occurred at the site, yielding an average recurrence interval of 1,700-2,600 years. The Woodland Hills splay of the Spanish Fork subsegment has evidence for three or four events, totaling 3 meters of displacement, in about the past 130,000 years, yielding a slip rate of 0.01-0.02 mm/yr and an average recurrence interval of about 40,000-65,000 years. Movement on the splay apparently occurs during only some of the events on the main fault, although the most recent event on the splay occurred about 1,000 years ago and may be correlative with the most recent event on the main fault. Movement on a couple of short subsidiary faults at the northern end of Utah Valley appears to have occurred during, and may be related to, the recession of Lake Bonneville.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Strawberry fault (12-4)					
Parameter values:	early to middle Holocene	0.04 - 0.17+ * (<15-30) 0.03 - 0.06+ (<150-230)	5 - 15 * (<15-30)	0.1 - 1.8+ n	28 ?

Age Criteria : soil development; ^{14}C; amino-acid dating

References : Nelson and Martin, 1982; Nelson and Van Arsdale, 1986

Comments : Evidence for latest Pleistocene and Holocene activity comes from three short alluvial scarps west of the main fault trace, so that associated displacement and slip rate values are minima for the fault zone as a whole. Doubling these values (for a single-event displacement of 0.2-3.6 meters and a slip rate of 0.07-0.4 mm/yr) may provide estimates for the entire fault zone. A minimum of two-to-three events have occurred since 15,000-30,000 ^{14}C yr B.P. on the fault. Scarp height (up to 7 meters) and stratigraphic displacement are much greater than net displacement, due to backtilting and graben formation. Recency of deformation is also indicated by the asymmetry of stream channels (evidence for tectonic tilting) and the presence of knickpoints in small channels above the scarps. Long-term slip-rate values were determined from dated down-faulted sediments along the main fault. These values are also minima, because of an unknown amount of erosion on the upthrown side of the fault. The uncertainties in the data prevent resolution of differences in slip histories between the main trace of the fault and subsidiary faults, and Holocene faulting on the main fault can only be inferred. The en echelon pattern of faulting north of the Strawberry Reservoir suggests that the main Strawberry fault is segmented, although similarities in escarpment morphologies suggest a similar movement history along the entire fault. The estimate for the maximum credible earthquake is 7.0.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Stinking Springs fault (12-5)					
Parameter values:	late Quaternary				11 ?

Age Criteria : range-front morphology; presence of faulted pediment; drainage disruption

References : Nelson and Martin, 1982; Van Arsdale, 1979

Comments : Escarpment morphology and height suggest a movement history that is similar to the Strawberry fault (location no. 12-4), although the Stinking Springs fault lacks direct evidence for Holocene movement. The prominent topographic escarpment, which is one third or less as long as the entire fault, is used to estimate the rupture length. An apparent rupture length that is much less than the Strawberry fault suggests that displacement may occur in smaller (about magnitude 6.5), more frequent events.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Wasatch fault zone - Salt Lake City segment (12-6)					
Parameter values:	1.1 - 1.8 e	>1.0 (<8-9) 0.8 * (<19)	4 ? (<8-9) 2.4 - 3 i * (<19)	1.5 - 5.0 ?	46.0

Age Criteria : ^{14}C; glacial chronology

References : Machette and others, 1991, 1992; Personius and Scott, 1992; Schwartz and Lund, 1988; Scott, 1988

Comments : The most active trace of the segment can be divided into three en echelon sections: from north to south, the Warm Springs fault, the East Bench fault, and the Cottonwood section of the Wasatch fault zone (Personius and Scott, 1992). The most recent event on the segment probably occurred shortly after 1,100-1,800 years ago. Diffusion-equation modeling of scarp degradation suggests an age of 900 years for the event. Based on combined observations at two trench sites at the southern end of the segment (Little Cottonwood Canyon and Dry Creek sites), there appears to have been three events since about 8,000-9,000 years ago, spaced roughly 4,000 years apart. However, a wide, complex zone of deformation at the Little Cottonwood Canyon site complicates determination of displacement and recurrence values. Data from the main graben indicate two post-8,000-9,000-year, 2-meter-displacement events, but whether other splays of the fault at this site moved during the same or other events is not known. Net tectonic displacements associated with the last two events at the Dry Creek site (4.5-5 meters) are the largest documented on the Wasatch fault zone. The post-19,000-year recurrence interval is based on evidence from the Little Cottonwood site and assumes 2 meters of displacement per event. The East Bench fault has evidence for at least two events in the last 26,000 years (during and after the Bonneville lake cycle). The earliest documented event appears as 3 meters of monoclinally warped, deep-water sediments and probably occurred subaqueously, before the lake level dropped below the site about 12,500 years ago. Subsequent events occurred as brittle, presumably subaerial, deformation. A rough latest Quaternary slip-rate estimate of 1 mm/yr for the East Bench fault is significantly greater than a rough long-term (Quaternary) estimate of 0.04-0.14 mm/yr based on shallow seismic-reflection data (Crone and Harding, 1984b). Faulting activity in the northeastern part of Salt Lake Valley has shifted westward from the range front (whose morphology is subdued relative to the range front farther south) to the East Bench fault during the late Quaternary (Personius and Scott, 1992). Although faults in pre-Bonneville deposits have been noted at several locations along the range front, post-Bonneville movement on this portion of the Wasatch fault zone has been minimal. Pre-urbanization studies of the Warm Springs fault at Jones Canyon by G.K. Gilbert (1890, in Hunt, 1982) showed evidence for three post-Bonneville events, with displacements totaling 9 meters. However, these estimates are probably minima; perhaps six to eight latest Quaternary events with displacements totaling 14-16 meters have occurred on this section of the segment. Robison and Burr (1991) estimated a maximum displacement of about 12 meters at a site (Washington Elementary School) at the south end of the fault. A fault in bedrock east of the Warm Springs fault (shown as Quaternary(?) on plate 1) appears to connect the East Bench fault with the Weber segment of the Wasatch fault zone (location no. 11-22), but has no evidence of Quaternary movement. Based on the structural geology of the segment, distribution and size of fault scarps, and comparisons with large historic earthquakes elsewhere, surface rupture on the Salt Lake City segment may initiate at the southern end of the Cottonwood section and propagate unilaterally northward (Bruhn and others, 1987; Personius and Scott, 1992). A buried fault defined by gravity data at the south end of the segment along the steep northwest side of the Traverse Mountains (not shown on plate 1) lacks evidence for latest Quaternary activity.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

West Valley fault zone
(12-7, 12-8)

Parameter values:	<12	0.5 - 0.6 *	1.8 - 2.2 *	1.2 - 1.5 i	8 - 16
		(<13)	(<13)		

Age Criteria : lacustrine stratigraphy; geomorphic relations
References : Keaton and others, 1987; S.S. Olig, verbal communication, 1991; Personius and Scott, 1992.
Comments : The above parameter values are composites for the fault zone as a whole. The southern portion of the fault zone consists of two subparallel east-facing scarps (the Granger and Taylorsville faults), whereas the northern portion is broader and is characterized by many smaller, east- and west-facing scarps. Seismic-reflection data from an area on-trend with the fault zone at the south end of the Great Salt Lake indicate a buried, east-dipping fault (not shown on plate 1), which cuts the inferred base of the Quaternary section (Wilson and others, 1986). It is unclear whether movement on the West Valley fault zone is independent or directly tied to movement on the Salt Lake City segment of the Wasatch fault zone (location no. 12-6). Deformation includes monoclinal flexure of near-surface sediments as well as surface rupture. Single-event displacement is inferred from a post-Bonneville monoclinal flexure on the Taylorsville fault. Multiple techniques yield earthquake magnitude estimates for independent events of 5.8 (M_L) to 7.0 (M_S), with an average value of 6.7.

West Valley fault zone
- Taylorsville fault
(12-7)

Parameter values:	<12	0.1 - 0.2 *	6 - 12 ? *	1.2 - 1.5	8
		(<12)	(<12)		

Age Criteria : morphostratigraphy
References : Keaton and others, 1987; S.S. Olig, verbal communication, 1991
Comments : Geomorphic evidence suggests that at least one event and possibly two events occurred on the Taylorsville fault in post-Gilbert shoreline time (<12,000 ^{14}C yr B.P.). The near-surface expression of portions of the Taylorsville fault is characterized by monoclinal flexuring and minor step-faulting. The style of deformation suggests earthquakes near the threshold magnitude for surface-faulting events (M~6.5).

West Valley fault zone
- Granger fault
(12-8)

Parameter values:	<13	0.4 - 0.5 *	2.6 - 6.5 *	1.2 - 1.5 i	16
		(<13)	(<13)		
		0.2 - 0.4			
		(<60)			
		0.1			
		(<140)			

Age Criteria : lacustrine stratigraphy; geomorphic relations
References : Keaton and others, 1987: S.S. Olig, verbal communication, 1991
Comments : Stratigraphic evidence on the main Granger fault suggests that two events occurred in the last 13,000 ^{14}C yr B.P. Geomorphic relations within the northern West Valley fault zone suggest that four or more events occurred in the same time period and that some of the post-Bonneville faulting occurred prior to formation of the Gilbert shoreline. Bore-hole evidence associated with several traces of the northern West Valley fault zone suggests that the most recent event may have occurred 6,000-9,000 years ago and that two-to-three events may have occurred since 22,000-28,000 years ago. Single-event displacement is inferred from displacement across a monoclinal flexture on the Taylorsville fault and is consistent with the heights of apparent single-event scarps on the Granger fault. The relatively high slip rate calculated for post-Bonneville time suggests that strain release may be due to isostatic rebound within an extensional setting. Stratigraphy adjacent to the Granger fault suggests an absence of faulting during the Bonneville lake cycle (~13,000-26,000 years ago).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Frog Valley fault
(12-9)

Parameter values:	Quaternary(?)				

Age Criteria : range-front and valley morphologies; amino-acid dating
References : Sullivan, 1982; Sullivan, Nelson, and others, 1988
Comments : Drainage which formerly drained east into Keetley Valley has been cut off by the escarpment of the fault. Faulting and formation of the escarpment likely post-dates middle Quaternary deposits in Keetley Valley. No scarps were found in late Quaternary colluvium at the base of the escarpment, although if small scarps formed there, they could have been eroded in a few thousand years.

Parleys Park (faults)
(12-10)

Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology
References : Sullivan, Nelson, and others, 1988
Comments : The eastern and southern margins of the valley consist of steep dip slopes that meet at right angles. This morphology is likely due to faulting rather than fluvial erosion.

East Kamas fault
(12-11)

Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology; soil development
References : Sullivan, Nelson, and others, 1988
Comments : Alluvial deposits estimated to be 130,000-140,000 years old cross the inferred trace of the fault and appear to be unfaulted. Degraded scarps in old alluvial-fan remnants could be the result of faulting, but the presence of a parallel scarp cut by the Weber River suggests that an erosional origin is more likely.

Round Valley (faults)
(12-12)

Parameter values:	late Quaternary(?)				10 ?

Age Criteria : range-front morphology
References : Sullivan, Nelson, and others, 1988
Comments : Scarps on alluvial fans at the base of range-front escarpments are not preserved, perhaps due to the steepness of escarpment slopes. For the purpose of seismic-hazard assessment, values for slip rate, recurrence interval, and single-event displacement are inferred to be similar to those calculated for the Morgan fault (location no. 11-18), based on similarities in escarpment morphology. The estimated maximum credible earthquake for the fault is 6.5-6.75 (M_s).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Little Diamond Creek fault
(12-13)

Parameter values: late Quaternary(?) | | | | 20 ?

Age Criteria : range-front morphology; presence of lineaments
References : Sullivan and others, 1987; Sullivan, Nelson, and others, 1988
Comments : Previous workers (Baker, 1976; Young, 1978) have suggested little or no late Cenozoic displacement on the fault, yet there are striking similarities with other known or inferred late Cenozoic faults in the Wasatch Range (Sullivan, Nelson, and others, 1988). Alluvial scarps are not preserved, perhaps due to the steepness of escarpment slopes. For the purpose of seismic-hazard assessment, values for slip rate, recurrence interval, and single-event displacement are inferred to be similar to those calculated for the Morgan fault (location no. 11-18), based on similarities in fault length and escarpment morphology. The estimated maximum credible earthquake for the fault is 6.75-7.0 (M_s).

Elizabeth Ridge scarps
(12-14)

Parameter values: middle to late Pleistocene(?) | | | |

Age Criteria : scarp morphology
References : West, 1988, 1989, in press
Comments : Scarps, with apparent displacements of about 1.5-2.5 meters, are subparallel to the North Flank thrust fault and cross the south end of the Darby-Hogsback thrust fault. To the north in Wyoming, a 55+-kilometer-long, middle to late Pleistocene zone of apparent normal faulting and tectonic tilting lies along the trace of the Darby-Hogsback thrust. It is unclear how the scarps in Utah relate to this apparent extensional reactivation of the Darby-Hogsback thrust, but they may be analogous to the discordant scarps at the south end of the Bear River fault zone (location no. 12-18). Trenching revealed no direct evidence for faulting, although geomorphic evidence is more in line with a tectonic origin for the scarps than with hypothesized erosional origins. The easternmost scarp has a sense of displacement opposite to that of the other two scarps and appears to be somewhat older. The subdued expression of the scarps suggests that they are substantially older than scarps along the Bear River fault zone.

Bald Mountain fault
(12-15)

Parameter values: Quaternary(?) | | | |

Age Criteria : range-front morphology; soil development
References : Sullivan, Martin, and other, 1988; Sullivan and Nelson, 1983; Sullivan, Nelson, and others, 1988
Comments : The fault escarpment is similar to those in other valleys east of the Wasatch Front, but is more eroded. A steep-sided trough (imaged by seismic refraction) beneath the Provo River valley to the south may be fault-bounded, but late Quaternary (~125,000-year-old) deposits are unfaulted. Early to middle Quaternary faulting cannot be precluded.

East Canyon fault
- northern segment
(12-16)

Parameter values: Quaternary(?) | | | |

Age Criteria : range-front morphology; soil development; geomorphic position
References : Sullivan, Nelson, and others, 1988
Comments : At the south end of the northern fault (north of the East Canyon Dam), the bedrock escarpment is primarily a fault-line scarp that has retreated from a western trace of the fault. A parallel eastern fault trace, which is not associated with an escarpment, displaces Tertiary Norwood Tuff and is thought to be the younger of the two traces. Both traces are overlain by unfaulted deposits estimated to be >100,000-200,000 years old.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

East Canyon fault
- southern segment
(12-17)

Parameter values:	late Quaternary(?)				12 ?

Age Criteria : range-front morphology
References : Sullivan, Nelson, and others, 1988
Comments : For the purpose of seismic-hazard assessment, values for slip rate, recurrence interval, and single-event displacement are inferred to be similar to those calculated for the Morgan fault (location no. 11-18), based on similarities in fault length and escarpment morphology. The estimated maximum credible earthquake for the fault is 6.5-6.75 (M_s).

Bear River fault zone
(12-18)

Parameter values:	2.4 ? e	0.8 - 2.7 ? (<4.6)	2.3 - 2.4+ ? (<4.6)	<1 - 5+ n	34-40

Age Criteria : ^{14}C
References : West, 1988 , 1989, in press
Comments : The Bear River fault zone (BRFZ) extends from southeast of Evanston, Wyoming to the Uinta Mountains in Utah, where it ends at a complex juncture with the North Flank fault. The trend of scarps at the southern end of the zone is sharply discordant with the main, northerly trend of faulting, perhaps due to the buttressing effect of the Uinta Mountains. The fault lies between the leading edges of the Absaroka and Darby-Hogsback thrust faults and appears to be a new (Holocene) feature superimposed on older thrust-belt structure. The independent seismic potential of the Absaroka and Darby-Hogsback faults is unclear. A 5-kilometer-long Holocene scarp (the Martin Ranch scarp), together with at least 10 kilometers of related surface warping, lies west of the BRFZ in Wyoming and is coincident with the Absaroka thrust. The age of most recent movement on this fault is consistent with that on the BRFZ, suggesting that it represents movement that is simultaneous and sympathetic with that on the main fault zone. Scarp heights and tectonic displacements increase markedly from north to south along the BRFZ. The southernmost scarp, which displaces Pinedale glacial deposits, is 15+ meters high, suggesting that it may have formed from more than two Holocene events. The range in slip rates reflects the range in displacement along the fault zone. Fault-activity parameters for the BRFZ are comparable to values for the Wasatch fault zone (see location nos. 6-6, 11-22, 12-3, 12-6, and 13-21). There is no evidence to suggest that the BRFZ is segmented. Documented ages of faulting (4,600 and ~2,400 years ago) are considered to be maximum estimates because the residence times of organic matter in the dated soils have not been incorporated into the ages. The youthfulness of faulting is demonstrated by the presence of beheaded and reversed drainages, sag ponds, and displacements in the youngest flood-plain deposits. Northern portions of the BRFZ in Utah are expressed only as drainage lineaments or are obscured by recent landsliding. Assuming that it is planar and basement-penetrating, the BRFZ may be capable of producing earthquakes as large as 7.5 (M_s).

Utah Lake (faults and folds)
(12-19)

Parameter values:	latest Pleistocene to Holocene(?)				

Age Criteria : lacustrine stratigraphy; depth to faulted sediments
References : Brimhall and Merritt, 1981
Comments : Fault locations, based on widely spaced seismic-reflection transects, are uncertain. Acoustical profiles show a persistent 8-15 meter-deep layer identified as the Provo Formation that is displaced from <2 to 5 meters across individual faults and folds beneath the lake. Machette (1989, in press) interpreted the layer as lake bottom sediments probably deposited during the regressive phase of Lake Bonneville. The reflection profiles suggest that displacements decrease upward in strata above the marker horizon and occur within several meters of the lake bottom.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Salt Creek area (fold) (13-1)					
Parameter values:	Quaternary(?)				

Age Criteria : deposit characteristics
References : Witkind and Sprinkel, 1982
Comments : Pleistocene(?) deposits are tilted northwestward on the flank of a small diapiric fold.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Juab Valley - west side (faults) (13-2)					
Parameter values:	late Quaternary				

Age Criteria : presence of scarps on alluvium
References : R.M. Robison, written communication, 1989; Sullivan and Baltzer, 1986
Comments : The scarps, which show a cumulative displacement of ~1 meter, are most likely tectonic, but alternatively may be related to lateral spreading. Although not defined by a bedrock escarpment, a fault has been inferred along the east side of Juab Valley near the contact between Tertiary volcanic rocks and unconsolidated valley fill. The east-dipping fault is thought to intersect the Wasatch fault zone well above the seismogenic crust and thus to be antithetic to the Wasatch fault zone and not an independent seismic source.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Long Ridge - west side (fault) (13-3)					
Parameter values:	middle to late Pleistocene(?)				

Age Criteria : presence of scarps on alluvium
References : Meibos, 1983
Comments : The fault both cuts and is covered by "older" unconsolidated alluvium and forms the contact between bedrock and alluvium along much of its length.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Long Ridge - northwest side (fault) (13-4)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology
References : Sullivan and Baltzer, 1986

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Joes Valley fault zone
- intragraben faults
(13-5)

Parameter values:	6 - (14-30)	0.1 - 0.2 d (<14-30)	10 - 15 (<14-30)	1 - 3	

Age Criteria : ^{14}C; soil development
References : Foley and others, 1986
Comments : The intragraben faults, which include the Middle Mountain and Bald Mountain faults, appear to merge with the East Joes Valley fault. Activity data are from the Middle Mountain fault. The recurrence interval is estimated from a soil developed during the interval between the two most recent events. The displacements measured for the earlier and later events are about 3 meters and <1 meters, respectively. The Middle Mountain fault may be antithetic to the West Joes Valley fault based on similarities in movement histories. The Bald Mountain faults displace upper Pleistocene deposits, but the north and south ends of the east Bald Mountain fault appear to be covered by unfaulted late Pleistocene moraines. The estimated maximum credible earthquake for the Middle Mountain fault is 7.5 (M_s). However, this estimate assumes the existence of a rupture pathway (presently unidentified) to the base of the seismogenic crust.

Joes Valley fault zone
- West Joes Valley fault
(13-6)

Parameter values:	6.5 - 23		10 - 20 (<30)	0.5 - 5.5+ ?	42 ?

Age Criteria : ^{14}C; soil development, alluvial-surface morphology, geomorphic position
References : Foley and others, 1986
Comments : The fault consists of three segments with lengths, from north to south, of 4, 42, and 7.5 kilometers. Based on criteria similar to that for middle segment of the East Joes Valley fault, only the middle segment (which is composed of two en echelon sections) shows evidence for significant late Quaternary displacement. Activity data are from the longer of the two sections of the middle segment. One location along this section of the fault has a 9-meter-high, single-event(?) scarp and age data (faulted/unfaulted deposits correlated with glacial chronology) that indicate the most recent event may have occurred between 11,000 and 14,000 years ago. A short, en echelon portion of the fault has 12-14-meter-high scarps in latest Pinedale (11,000-14,000-year-old) deposits. Scarp heights in ~30,000-year-old deposits on the main fault vary from 8 to 12 meters. The estimate for the maximum credible earthquake on the West Joes Valley fault is 7.5 (M_s). However, this estimate assumes the existence of a rupture pathway (presently unidentified) to the base of the seismogenic crust.

Joes Valley fault zone
- East Joes Valley fault
(13-7)

Parameter values:	1.5 - (14-30)	0.1 - 0.3 d (<150-300)	<60 (<150-300)	0.5 - 2	42 ?

Age Criteria : ^{14}C; soil development; alluvial-surface morphology; geomorphic position; amino-acid dating
References : Foley and others, 1986
Comments : The fault contains three segments with lengths, from north to south, of 5, 42, and 8 kilometers. Only the central segment is inferred to have significant late Quaternary (<150,000-year-old) displacement, based on active alluvial fans, total bedrock displacements, linearity and steepness of the escarpment, and presence of scarps in Quaternary deposits. However, the scarps may actually be part of the intragraben faults. The youngest measured displacement (2.5 meters) is apparently due to monoclinal folding and may be the result of several small events. Four or more events are thought to have occurred since 150,000-300,000 years ago; two of these events predate a soil interpreted to date from >130,000 years ago. The estimate for the maximum credible earthquake is 7.5 (M_s). However, this estimate assumes the existence of a rupture pathway (presently unidentified) to the base of the seismogenic crust.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
southern Joes Valley fault zone (13-8)					
Parameter values:	middle to late Pleistocene(?)				

Age Criteria : soil development, alluvial-surface morphology, geomorphic position
References : Foley and others, 1986
Comments : The zone is composed of many grabens, but late Quaternary faulting is apparently restricted to just two short grabens, where gravels displaced about 30 meters are estimated to be at least middle Pleistocene in age. Elsewhere, the faults (mapped as Quaternary(?) on plate 1) are expressed as eroded escarpments and topographically reversed scarps. There is no net tectonic displacement across the grabens.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Pleasant Valley fault zone - Pleasant Valley graben (13-9)					
Parameter values:	middle to late Pleistocene				17 ?

Age Criteria : escarpment morphology
References : Foley and others, 1986
Comments : Alluvial fans geomorphically similar to latest Pleistocene to Holocene fans in Joe's Valley are unfaulted. For the purpose of seismic-hazard assessment, late Quaternary recurrence intervals are inferred to be comparable to intervals for Joes Valley faults (specifically, location no. 13-6). Pleasant Valley fault zone escarpments are more eroded and less steep than those in Joes Valley, although this may be due to lower scarp heights and less resistent bedrock lithologies in Pleasant Valley. A value for the maximum credible earthquake of 7.0 (M_s) is based on comparison of estimated rupture length with lengths of Joes Valley and Basin-and-Range faults.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Pleasant Valley fault zone - Dry Valley graben (13-10)					
Parameter values:	middle to late Pleistocene				12 ?

Age Criteria : escarpment morphology
References : Foley and others, 1986
Comments : For the purpose of seismic-hazard assessment, late Quaternary recurrence intervals are inferred to be comparable to intervals for faults in Joes Valley (specifically, location no. 13-6). Pleasant Valley fault zone escarpments are more eroded and less steep than those in Joes Valley, although this may be due to lower scarp heights and less resistent bedrock lithologies in Pleasant Valley.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Pleasant Valley fault zone - unnamed faults (13-11)					
Parameter values:	Quaternary(?)				

Age Criteria : escarpment morphology
References : Foley and others, 1986

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Gooseberry graben
(13-12)

Parameter values:	middle to late Pleistocene				20

Age Criteria : escarpment morphology; drainage pattern
References : Foley and others, 1986
Comments : Glacial moraines and alluvial fans are geomorphically similar to latest Pleistocene features in northern Joes Valley, but are unfaulted. Late Quaternary faulting is suggested by beheaded, incised drainages and by the prominence of the eastern escarpment. The more subdued topography of the western escarpment is attributed to less displacement and less-resistent bedrock. The Gooseberry graben is similar structurally and geomorphically to the Pleasant Valley fault zone (location nos. 13-9 and 13-10). Fault lengths (20 kilometers for the East Gooseberry fault) and bedrock displacements are less than those of the Joes Valley fault zone, suggesting a smaller value for the maximum credible earthquake.

Snow Lake graben
(13-13)

Parameter values:	Holocene(?)				25

Age Criteria : escarpment morphology; drainage disruption
References : Foley and others, 1986; Spieker and Billings, 1940
Comments : The 30-meter-high east Snow Lake fault scarp impounds Snow Lake and several other lake basins within what is inferred to be Pleistocene nivation basins. It is likely that some of the 30 meters of late(?) Quaternary displacement occurred during Holocene time. The escarpment walls of the graben are incised by streams, but they are nearly vertical and little modified by erosion.

Sage Valley fault
(13-14)

Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact; presence of faulted alluvium; range-front morphology
References : Clark, 1990
Comments : The fault forms the contact between bedrock and alluvium along much of its length; an eroded set of triangular facets forms a fault-line scarp along the southern portion of the fault. At its southern termination, the fault cuts "older" alluvial-fan deposits.

White Mountain area (faults)
(13-15)

Parameter values:	Quaternary(?)				

Age Criteria : drainage disruption
References : Witkind and others, 1987
Comments : Several lakes are impounded behind the fault-controlled escarpments.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Sanpete-Sevier Valley anticline
(13-16)

Parameter values: Quaternary(?) | | | |

Age Criteria : deposit characteristics
References : Taylor, 1980; Willis, 1986, 1988
Comments : A number of areas of deformed Quaternary(?) deposits lie adjacent to the anticline, which is cored by the deformed and structurally thickened Arapien Shale. Tilted and deformed unconsolidated deposits are found on the western flank of the fold in the vicinity of Aurora and Salina near exposures of the Arapien Shale. This deformation is attributed to diapirism and/or dissolution of evaporites and subsequent collapse (Willis, 1986, 1988). Farther north, between Redmond and Axtell, Pleistocene pediment deposits are tilted about 20° away from the northwest flank of a small diapiric dome (Witkind, 1982), which parallels the general axis of the anticline. Tilted, folded, and uplifted Quaternary gravels unconformably overlie the Arapien Shale in several areas at the south end of Sanpete Valley (in the Sterling 7.5-minute quadrangle), evidencing recent diapirism (Gilliland, 1963; Taylor, 1980). Along the east side of Gunnison Reservoir, Pleistocene(?) gravels have been rotated into a vertical position, most likely as a result of upward movement of the Arapien Shale (Witkind, 1981). Extensional deformation within the southern part of the anticline (which may be associated with the Annabella faults, location no. 9-32) is attributed to lateral flowage of the Arapien Shale from beneath the northern Sevier Plateau (Anderson and Barnhard, 1992).

Redmond Hills anticline
(13-17)

Parameter values: latest Pleistocene to Holocene (?) | | | |

Age Criteria : geomorphic position; drainage pattern
References : Gilliland, 1963; Willis, 1988, 1991
Comments : The diapiric salt anticline is defined by a linear, fault-controlled(?) chain of small hills cored by the Arapien Shale and capped by unconsolidated fluvial gravels that generally dip 30-60° away from the center of the hills. The hills, which are composed of nonresistant materials, are located in the flood plain of the Sevier River and influence the course of the river. This evidence suggests that diapirism is actively raising the hills.

Gunnison fault
(13-18)

Parameter values: late Holocene(?) | | | |

Age Criteria : alluvial-surface morphology; geomorphic position; scarp morphology; ^{14}C
References : Fong, 1991; Hecker, 1987b, 1989; Witkind and Weiss, 1991; Witkind and others, 1987
Comments : Preliminary observations at a few locations indicate that the most recent event may date from (late?) Holocene time and be associated with less than about a meter of displacement. Progressively older alluvial surfaces have greater displacements, and old Quaternary (Tertiary?) surfaces have tens of meters of displacement across steep, high scarps. A set of unusual relations characterizes the north end of the fault at Birch Canyon, where a cliff-like scarp on the order of 10-15 meters high is underlain by fluvial and debris-flow deposits ^{14}C dated at between ~2,000-4,000 years (E. Lips, verbal communication, 1989). The sequence of deposits appears to be monoclinally folded, with an apparent dip that is parallel to the face of the scarp and fairly uniform throughout the section. These relations suggest locally intense, recent deformation along this portion of the range front (Hecker, 1987b). The top of a tufa deposit that contains wood debris ^{14}C dated at 370 years is found at different elevations across the inferred trace of the fault of Birch Canyon, suggesting fault movement during the last 370 years (Fong, 1991). Witkind (1981) postulated that the Gunnison fault may be a subsidence feature related to dissolution of evaporites in the Arapien Shale. The fault appears to flatten into a detachment fault at a depth less than 5 kilometers (Standlee, 1982).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Price River area (faults)
(13-19)

Parameter values:	Quaternary(?)				

Age Criteria : geomorphic position; structural setting; presence of lineaments
References : Howard and others, 1978; Osterwald and others, 1981
Comments : Some faults within the zone displace pre-Wisconsin-age pediments less than 2 meters. Most are normal faults that dip steeply or vertically. Structural relations indicate that the fault zone forms the crest of a broad, collapsed anticline. The fault zone is similar in trend, pattern, and length to faults along the crest of the Moab-Spanish Valley anticline (primarily location no. 18-2), although it is not as strongly developed. The faults are inferred to be related to a salt anticline at the northern margin of the Paradox basin. Early to middle Pleistocene pediments north of the fault zone steepen sharply at the base of the Book Cliffs and may be warped due to elastic rebound of the Mancos Shale during erosional unloading and/or monoclinal folding (not indicated on plate 1). The ancestral course of Whitmore Canyon (near Sunnyside) also appears to be warped.

Japanese and Cal Valleys (faults)
(13-20)

Parameter values:	middle to late Pleistocene				

Age Criteria : scarp morphology; fault control of bedrock-alluvium contact; basin closure
References : Anderson and others, 1978; Oviatt, 1992; Willis, 1991; Witkind and others, 1987
Comments : Alluvial scarps are up to 4 meters high. The pattern of faulting in Japanese Valley suggested to Witkind and others (1987) that the graben-formed valley may be a collapse feature, perhaps related to dissolution of salt from the underlying Arapien Shale. However, Willis (1991) interpreted the faults as basin-range-type extensional faults.

Wasatch fault zone
- Nephi segment
(13-21)

Parameter values:	0.3 - 0.5 ? e	0.8 - 1.3 ? (<5.5 ?)	1.7 - 2.7 ? (<5.5 ?)	1.4 - 2.5 n	42.5

Age Criteria : ^{14}C; scarp morphology
References : Jackson, 1991; Machette and others, 1991, 1992; Schwartz and Coppersmith, 1984
Comments : Scarp morphology and continuity suggest very recent displacement (~300-500 years ago), although a combination of ^{14}C and TL dates suggest an age of about 1,200 years for the most recent event. Schwartz and Coppersmith (1984) determined that the penultimate event occurred before about 4,000 years ago, whereas Jackson (1991) constrained the event between about 3,000 and 3,500 years ago. The third-to-last event may have occurred between 4,000 and 4,500 years ago (Jackson, 1991). Thus, actual middle to late Holocene recurrence intervals may vary from less than 1,000 years to more than 3,000 years. Three middle to late Holocene events post-date a late Pleistocene(?) fan at the southern end of the segment (at Red Canyon), suggesting a possible hiatus in faulting activity during latest Pleistocene to early Holocene time (Jackson, 1991). The range in displacement-per-event and slip-rate values reflects a systematic decrease in slip between the middle (larger values) and southern end (smaller values) of the segment. The Benjamin fault, which extends into Utah Valley, may be the northern extension of the Nephi segment (which would then total about 50 kilometers in length). Sediments of the Provo phase of the Bonneville lake cycle are offset as much as 2 meters along this fault (Machette, 1989, in press). There is a 15-kilometer-long gap in Holocene faulting between the Nephi segment and the Levan segment to the south. Faults associated with young scarps north of the town of Nephi are probably continuous with near-surface faults in the town identified from seismic-reflection data (Crone and Harding, 1984b). A number of small faults in Quaternary deposits have been identified on the western flank of the Gunnison Plateau east of Nephi (not shown on plate 1; Biek, 1991).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Wasatch Fault zone
- Levan segment
(13-22)

Parameter values:	1.0 ? e	<0.3 d * (<7.3)	>6.3 * (<7.3)	1.8 - 2.0 n	30

Age Criteria : TL; ^{14}C

References : Jackson, 1991; Machette and others, 1991, 1992; Schwartz and Coppersmith, 1984

Comments : Stratigraphic relations indicate that the 1,000-year-old date is a close maximum limiting age for the most recent event; other TL and ^{14}C dates provide maximum ages of about 1,500 and 1,700 years. An alluvial fan dated at 7,300 ^{14}C yr B.P. is crossed by a single-event scarp (∼1,000 years old ?), providing a minimum time interval since the penultimate event of ∼6,300 years. At one site, the penultimate event, which is inferred from greater stratigraphic thicknesses on the down-thrown side of the fault, predates TL and ^{14}C dates of 3,000 to 4,000 years. The recurrence and slip-rate estimates are based on less than one complete interval between events. There is a 15-kilometer-long gap in Holocene faulting between the Levan and Nephi segments. The range front in this area is marked by old, degraded scarps on middle(?) Pleistocene surfaces, and there is little evidence for latest Pleistocene faulting. In contrast to the planar fault geometry at the southern end of the Nephi segment (Zoback, 1992), this segment of the fault appears to have a listric subsurface geometry and/or to terminate at a shallow detachment fault (Smith and Bruhn, 1984; Standlee, 1982).

Wasatch fault zone
- Fayette segment
(13-23)

Parameter values:	10 - 15				11

Age Criteria : scarp morphology

References : Machette and others, 1991, 1992

Comments : Fault scarps were compared morphologically to the Drum Mountains (location no. 8-1) and Bonneville shoreline scarps. Some antiquity is also suggested by a lack of scarp preservation at canyon mouths. Faulting is not well expressed at the northern end of the segment (mapped as middle to late Pleistocene, plate 1; M.N. Machette, verbal communication, 1991).

Big and Water Hollows (faults and warps?)
(13-24)

Parameter values:	Quaternary(?)				

Age Criteria : deposit characteristics

References : Hawks, 1980

Comments : The origin of the oval depressions is suspected to be dissolution and collapse of underlying salt diapirs, although Banks (1991) disagrees with this view because of the large amount of diapiric material that would be required. Collapse-related slumping has down-dropped Tertiary to Quaternary stream gravels into the depressions. Large-scale slumping into Sanpete Valley may be the cause of fault-controlled contacts (not shown on plate 1) between gravel deposits and Tertiary volcanic rocks along the western margin of the Cedar Hills. Circular features (not shown on plate 1) similar to Big and Water Hollows lie to the northeast, in the vicinity of Indianola (Runyon, 1977).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Wasatch monocline
(13-25)

Parameter values:	Quaternary(?)				

Age Criteria : association with Quaternary deformation
References : Foley and others, 1986
Comments : The Joes Valley fault zone (location nos. 13-5 to 13-8) and other graben structures on the Wasatch Plateau may have formed in response to movement on the Wasatch monocline, which is underlain by a buried normal fault, identified (on seismic-reflection profiles) as the "ancient Ephraim fault." Part of the structural relief of the Wasatch monocline may be due to differential subsidence of Sanpete Valley caused by dissolution of salt diapirs beneath the valley floor (Witkind and Page, 1984).

Valley Mountains monocline
(13-26)

Parameter values:	Quaternary(?)				

Age Criteria : association with Quaternary deformation
References : Witkind and Page, 1984; this study
Comments : Similar patterns of deformation in the facing Valley Mountains monocline and Wasatch monocline suggest that these structures formed contemporaneously by the same geologic processes. Although the linearity and trend of the monoclines may be attributed to block faulting, at least some of the structural relief may be due to dissolution of salt diapirs beneath the valley floors. A narrow late Quaternary graben (Japanese Valley, location no. 13-20) on the crest of the Valley Mountains has a configuration similar to grabens on the Wasatch Plateau and thus may have formed by similar processes, perhaps in response to uplift across the subjacent monocline. Two small (about 0.5 kilometer-long) parallel faults just east of the Valley Mountains (not shown on plate 1) cut Quaternary pediment deposits, but may be the result of non-tectonic processes (Willis, 1991).

Thousand Lake fault
(14-1)

Parameter values:	late Quaternary(?)				

Age Criteria : deposit characteristics; drainage disruption
References : Anderson and Miller, 1979; Harty, 1987; Sergent, Hauskins, and Beckwith, 1991; Smith and others, 1963
Comments : Remnants of Fremont River strath terraces presumably truncated by faulting may date from early Wisconsin time and correlate with terraces on the downthrown side of the fault (Smith and others, 1963), but supporting evidence appears tenuous (Harty, 1987; Sergent, Hauskins, and Beckwith, 1991). Projection of the terrace profiles would suggest that about 85 meters of vertical displacement has occurred during late Pleistocene to Holocene time. The extent of possible late Quaternary faulting is unknown, although based on the displacement estimate by Smith and others (1963) and the distribution of total post-Oligocene throw along the fault, Anderson and Barnhard (1986) postulated that late Quaternary displacements may exceed 100 meters along the northern portion of the fault. Most of the fault is categorized as Quaternary(?) on plate 1.

Aquarius and Awapa Plateaus (faults)
(14-2)

Parameter values:	Quaternary(?)				

Age Criteria : basalt-flow characteristics
References : Luedke and Smith, 1978; Williams and Hackman, 1971
Comments : Faults displace or define margins of Tertiary to Quaternary (<5 million year old) basalts.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Paunsaugunt fault (14-3)					
Parameter values:	Quaternary(?)				

Age Criteria : range-front morphology; amount of displacement in Miocene to Pliocene basalts
References : Rowley and others, 1981
Comments : Basalts dated at 5.0-6.4 million years predate the main uplift of the Awapa and Aquarius Plateaus and are displaced vertically about 500 meters across the Paunsaugunt fault. Preliminary examination of aerial photos for the present study revealed no scarps in range-front deposits, although Carpenter and others (1967) show the fault crossing Quaternary deposits at several locations. In the vicinity of Bryce Canyon National Park, south of where the fault is shown on plate 1, differential erosion has resulted in weakly expressed, obsequent fault-line topography. However at two locations in this area, low (~1-meter-high) fault(?) scarps cross remnants of Pleistocene pediments, indicating Quaternary(?) movement along this southern section of the fault (Bowers, 1991).

Tenmile graben (14-4)					
Parameter values:	Quaternary(?)				

Age Criteria : continuity with zone of Quaternary deformation
References : Woodward-Clyde Consultants, 1984
Comments : The graben is at the northern end of a long zone of faulting that includes the Moab and Lisbon Valley faults (location nos. 18-2 and 18-8). Like the rest of the zone, the graben is probably related to salt dissolution, but may have a tectonic component.

Koosharem (fault) (14-5)					
Parameter values:	Quaternary(?)				

Age Criteria : presence of faulted alluvium
References : Rowley and others, 1986
Comments : Several closely spaced bedrock faults have short sections which cut Quaternary piedmont-slope deposits. On aerial photos (inspected for this study) the faults appear as lineaments crossing dissected alluvial deposits.

Bright Angel fault system (15-1)					
Parameter values:	Quaternary(?)				

Age Criteria : geometry and orientation; antecedent drainage
References : Menges and Pearthree, 1983; Shoemaker and others, 1978; Woodward-Clyde Consultants, 1982a
Comments : Geometry and orientation are similar to known or Quaternary(?) structures in the San Francisco volcanic field in Arizona. A drainage system in the Cataract Creek basin in Arizona(?) appears to be older than movement on the fault system. Fold activity in the region is possible, although uncertain.

Diamond Gulch (faults) (16-1)					
Parameter values:	Quaternary(?)				

Age Criteria : landform characteristics
References : Hansen, 1984; Hansen and others, 1981
Comments : Faults cut pediments and colluvial slopes. Scarps are subdued but well-defined. Combined throw is perhaps 30 meters. A fault 20 km west of Diamond Gulch mapped as Quaternary(?) in age by Anderson and Miller (1979) was not recognized by Hansen and others (1981) as having had Quaternary activity (and thus, is not shown on plate 1). In addition, two short faults(?) shown by Anderson and Miller (1979) 40 km south of Diamond Gulch along the Green River are not included on geologic maps of the region (Carrara, 1980; Rowley and others, 1985).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT X10^3 years	SLIP RATE mm/yr (Time Period X10^3 years ago)	RECURRENCE INTERVAL X10^3 years (Time Period X10^3 years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Pot Creek (faults)
(16-2)

Parameter values:	Quaternary(?)				

Age Criteria : landform characteristics
References : Hansen, 1984; Hansen and others, 1981
Comments : Scarps representing 5-6 meters (?) of displacement are eroded and less well defined than those along Diamond Gulch (location no. 16-1).

Salt and Cache Valleys (warp, faults, and folds)
(18-1)

Parameter values:	late Quaternary				

Age Criteria : drainage disruption and pattern; tephrochronology, stratigraphic relations; soil development
References : Oviatt, 1988
Comments : Collapse of the Salt Valley anticline appears to largely post-date late Pliocene(?) deposition of exotic fluvial gravels (likely derived from a since-eroded source in the Book Cliffs) on the rim and floor of Salt Valley and formation of an erosion surface on the flank of the anticline. Small depositional basins within Salt Valley containing Bishop ash (~740,000 years old) and Lava Creek B ash (670,000 years old) were localized by salt dissolution and collapse and/or salt flow during early and middle Quaternary time and record syn- and post-depositional folding and faulting. The faults parallel and appear related to the major older structures of the Salt Valley anticline. At the lower end of the valley, middle to late Quaternary basin-fill deposits unconformably overlie the older deformed units and are only slightly tilted and relatively undeformed. Structural relations exposed at other localities in the valley suggest that Quaternary sediments have been deformed and localized by movement within salt diapirs of the Paradox Formation. In places, bedding dips away from the outcrop of the Paradox Formation and is fractured, thrust-faulted, and infolded into the caprock of the formation. Locally thick accumulations of sediments suggest that subsidence occurred adjacent to the diapirs. Playas and mudflats in upper Salt Valley indicate active deformation (due to salt flow or dissolution) and damming of surface runoff. A stream that crosses the south end of the Salt Valley anticline at a high angle is entrenched and bordered by probable late Holocene terraces north of the anticline and is braided and unentrenched in the short reach within Salt Valley, suggesting that the core of the anticline is presently subsiding and causing stream aggradation. In Cache Valley, a Quaternary(?) erosion surface that apparently post-dates collapse-related deformation is displaced by a major bedrock fault and may have been tilted. East of Cache Valley, Colorado River terraces are tilted upstream on the upstream side of the Cache Valley anticline, indicating that salt flowed into the collapsed structure during Quaternary time.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Moab fault/Spanish Valley (warp and faults) (18-2)					
Parameter values:	late Quaternary				

Age Criteria : drainage disruption; ^{14}C; U-trend; paleontology; geomorphic position; soil development

References : Harden and others, 1985; Woodward-Clyde Consultants, 1982a, 1982b, 1984

Comments : Like the Lisbon Valley fault zone to the south (location no. 18-8), the Moab fault is probably related to salt dissolution, but may have a tectonic component. Studies (Jones, 1959; Shoemaker and others, 1958) indicate that the Moab fault may extend below the salt, offsetting pre-Paradox Formation strata. Collapse of the Spanish Valley anticline appears to largely post-date deposition of early and middle Pleistocene alluvium on and near the rim of the valley (Harden and others, 1985). A well preserved relic canyon on the rim of Moab Canyon, whose headwaters were apparently removed by collapse of the anticline, probably formed during late Tertiary to early Quaternary time (Oviatt, 1988). Distribution of middle Pleistocene through Holocene alluvial deposits suggests differential subsidence in Spanish Valley due to tectonism or dissolution/migration of salt. Marshes at the lower end of Spanish Valley may be evidence of Holocene subsidence. In the middle of the valley, a set of alluvial terraces converges downstream and a Bull Lake age (130,000-~200,000 year old) paleosurface may be locally warped and buried. In addition, older alluvial fans are entrenched and successively younger fans have been deposited farther down-valley, suggesting down-dropping of the valley relative to the mountain front. However, hydrologic controls on deposition could also explain these observed relations. An unusual saddle and gradient anomalies in Bull Lake age terrace remnants may reflect faulting. Furthermore, several small (10-centimeter) displacements were observed in the middle to late Pleistocene deposits. Fine-grained late Pleistocene to early Holocene sediments deposited along Bartlett Wash near the northern end of the Moab fault may indicate displacement-related ponding. If so, the sense of movement is opposite to that during the Mesozoic.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Uncompahgre fault zone (18-3)					
Parameter values:	Quaternary(?)				

Age Criteria : drainage pattern; deposit characteristics

References : Ely and others, 1986

Comments : Faults are within a faulted monoclinal flexure that forms the southwest margin of the Uncompahgre uplift (on the northeast side of the Paradox Basin). The Uinta Basin borders the uplift on the northwest side. About 15 kilometers east of the Utah-Colorado border, the fault zone crosses Unaweep Canyon, a large wind gap that was likely abandoned due to uplift of the Uncompahgre arch. Different movement histories and cumulative Quaternary displacements have been inferred for the fault zone based on studies of the canyon and related drainage changes, but most studies suggest that differential uplift has continued into the early or late Pleistocene. A computer simulation of stream-profile evolution along the abandoned stream course indicates that differential uplift began ~1.8 million years ago and proceeded at a rate of ~0.4 mm/yr. Diversion of drainage, which followed impoundment and formation of a lake, occurred ~775,000 years ago (Perry and Annis, 1990). The Ute Creek graben (part of the fault zone in Colorado) appears youthful. It is little eroded and topographic displacements are similar to stratigraphic displacements (Cater, 1970).

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Castle Valley (warp and faults)
(18-4)

Parameter values:	Quaternary(?)				

Age Criteria : Geomorphic position; surface characteristics
References : Doelling and Ross, 1993; M.L. Ross, written communication, 1993
Comments : Collapse of Castle Valley due to salt dissolution has apparently occurred episodically from Pliocene to late Pleistocene-early Holocene(?) time, progressing northwestward away from the northern La Sal Mountains. This conclusion derives from the unconformable, inset relations of alluvial deposits in the upper part of Castle Valley and apparent conformable deposition of similar alluvium in the lower, northwestern end of the valley.

Pine Ridge area (faults)
(18-5)

Parameter values:	Quaternary(?)				

Age Criteria : fault control of bedrock-alluvium contact; association with Quaternary(?) deformation
References : Williams, 1964; Woodward-Clyde Associates, 1982a
Comments : The faults border an area of collapse along the crest of the Spanish Valley salt anticline.

Sinbad and Paradox Valleys (faults)
(18-6)

Parameter values:	Quaternary(?)				

Age Criteria : association with Quaternary deformation
References : Anderson and Miller, 1979; Cater, 1970
Comments : Faults along the Utah-Colorado border southeast of Fisher Valley are spatially associated with Sinbad and Paradox Valleys in Colorado, which have evidence for Quaternary deformation.

Fisher Valley (warp, faults, and folds)
(18-7)

Parameter values:	late Quaternary				

Age Criteria : tephrochronology; soil development; stream-dissection rates
References : Colman and others, 1986
Comments : Fisher Valley is on the crest of a long anticlinal structure that includes Salt and Cache Valleys in Utah (location no. 18-1) and Sinbad and Rock Creek Valleys in Colorado. Formation of Fisher Valley by collapse of the anticline beheaded streams whose broad shallow channels are preserved on the rim of the valley. Upper Cenozoic deposits, by far the thickest sequence in the Paradox basin (>125 meters thick), have ages between >2.5 million (based on paleomagnetic analysis) and about 250,000 years (based on secondary carbonate accumulation rates) and record episodic deformation from movements of the Onion Creek salt diapir and subsidence of the basin (resulting from salt flowage into the diapir and/or salt solution and collapse). Lower basin-fill deposits, which contain the Bishop ash bed (~730,000 years old), are locally infolded into the Paradox Formation caprock, although not as severely as older, Pliocene(?) gravels. Lower and upper basin-fill deposits (which contain the 610,000-year-old Lava Creek ash bed) are found tilted up to 25° and 10°, respectively, in a radial pattern away from the diapir, indicating multiple upward movements. Angular unconformities within the deposits along the edges of the basin, notably at the base of the Lava Creek ash bed, contrast with conformable relationships toward the center of the basin and suggest intermittent subsidence, in addition to the uplift. Projection of dips in the upper Cenozoic deposits indicates at least 70 meters of upward movement on the diapir and a similar amount of basin subsidence between 2-3 million and 0.25 million years ago. The anomalous thickness of the basin-fill sediments and evidence that Fisher Creek used to flow through the present area of the diapir suggest that drainage was first impeded and then diverted as movement on the diapir progressed. Younger basin-fill deposits with which to demonstrate more recent movement are absent, but evidence for rapid incision (30 meters in 10,000 years based on ^{14}C dates) and the steep, unstable slopes of Onion Creek where it cuts through the caprock suggest that the diapir may be presently active.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT X10^3 years	SLIP RATE mm/yr (Time Period X10^3 years ago)	RECURRENCE INTERVAL X10^3 years (Time Period X10^3 years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Lisbon Valley fault zone (18-8)					
Parameter values:	Quaternary(?)				

Age Criteria : presence of lineaments; drainage disruption (?)

References : Woodward-Clyde Consultants, 1982a

Comments : The fault zone can be divided into three distinct segments based on the complexity of surface expression. Lineaments are subparallel, but not coincident with mapped traces. Geomorphic expression (such as apparent offset drainages) suggests recent faulting, but more work is needed to identify the origin and age of features. The faults display a normal sense of displacement that is most probably related to evaporite dissolution and collapse along salt anticline crests. Analysis of subsurface data suggests that surface faults do no extend below the Paradox Formation, but the evidence is not conclusive, and a tectonic origin for at least part of the displacement cannot be discounted. Evidence for post-Laramide growth of the Lisbon Valley anticline is inconclusive, but there is evidence for Quaternary growth on the collinear Dolores anticline in Colorado. The Lisbon Valley fault zone and Moab fault (location no. 18-2) are the longest and most prominent faults in the Paradox Basin.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT X10^3 years	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Meander anticline (18-9)					
Parameter values:	Holocene(?)				

Age Criteria : geomorphic position; river gradient

References : Huntoon, 1982, 1988

Comments : Formation of the Needles fault zone (location no. 18-13) is likely linked to growth of the adjacent Meander anticline, whose axis follows the Colorado River. Evidence for recent, continuing activity on the Meander anticline includes topographically controlled thrust faults that crosscut narrow goosenecks north of the Needles fault zone; the steep gradient of the river through Cataract Canyon; and growth of small (up to 60-meters-high) salt diapirs on the floor of Cataract Canyon.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT X10^3 years	SLIP RATE	RECURRENCE INTERVAL	DISPLACEMENT PER EVENT	RUPTURE LENGTH
Gibson Dome anticline (18-10)					
Parameter values:	Quaternary(?)				

Age Criteria : distribution of Quaternary deposits; stream gradient

References : Huntoon, 1988

Comments : Deposition of alluvium and the gentle gradient of Indian Creek upstream of the axis of the gently dipping anticline suggest continued growth of the dome due to salt flowage. However, Woodward-Clyde Consultants (1982b) concluded that all flowage and resulting folding occurred during the Late Pennsylvanian, based on seismic-reflection evidence that the overlying Permian rocks have been unaffected.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers

Needles fault zone
(18-11)

Parameter values:	Holocene(?)				

Age Criteria : drainage disruption; ^{14}C; TL; soil development
References : Biggar, 1987; Oviatt, 1988
Comments : The fault zone likely formed due to combination of gravity tectonics and salt flowage. Most theories (Baker, 1933, McGill and Stromquist, 1974; Stromquist, 1976) envision extension in sedimentary strata above evaporites that mobilized and flowed down dip into the Meander anticline (location no. 18-9) as canyon cutting along the Colorado River reduced overburden load. Alternative theories include salt dissolution and collapse (Hite, 1982) and simple down-dip gravity sliding on the salt toward the Colorado River gorge and resultant compression across the floor of the canyon to form the Meander anticline (Huntoon, 1982). Similar anticlines occur along deep canyons tributary to Cataract Canyon (Huntoon, 1988). Multiple mechanisms may be operating. Youthfulness of faulting is suggested by good preservation of an abandoned, pre-graben drainage network and persistence of grabens as closed depressions. Sinkholes, some which may be historical, in many closed graben valleys may have formed by opening of bedrock fissures or, alternatively, by periodic flushing of material from old fissures. Stream braiding and aggradation within the grabens also suggest recent (Holocene?) subsidence. Changes in drainage patterns from north to south and the relatively simple, linear pattern of grabens at the eastern margin of the area suggest graben formation has progressed northward and eastward, away from the river. The oldest grabens (closest to the river) are inferred to have begun forming between about 1.4 million years ago (based on a conservatively high estimate of canyon incision) and 85,000 years ago (extrapolated from a 65,000 year age for shallow graben sediments located a quarter of the distance from the river to the eastern margin of the graben system). Thus, some grabens may have formed during early Pleistocene time. Development of grabens from west to east has apparently occurred at rates of 5-140 mm/yr, and the process may be ongoing.

Lockhart fault
(18-12)

Parameter values:	Quaternary(?)				

Age Criteria : recency of sedimentation
References : Huntoon, 1988; Woodward-Clyde Consultants, 1982c
Comments : Quaternary deposits (estimated to be ~10,000-30,000 years old) overlie the fault and are apparently not displaced. Seismic-reflection data indicate that the fault is confined to strata above the Paradox Formation, suggesting that it may be a tensional feature related to collapse of the Lockhart Basin. Although direct evidence is lacking, Woodward-Clyde Consultants (1982b) inferred the collapse structures of the basin to be Tertiary in age. In contrast, Huntoon (1988) inferred Quaternary subsidence in Lockhart Basin and Beef Basin (south of the Needles fault zone; not shown on plate 1), based on the presence of recent deposits.

Shay graben
(19-1)

Parameter values:	Quaternary(?)				

Age Criteria : escarpment morphology; pediment-surface characteristics
References : Woodward-Clyde Consultants, 1982c
Comments : The north Shay fault has generally poorer surface expression than the south Shay fault and is less likely to have had Quaternary displacement. The south Shay fault exhibits dip-slip displacement totaling less than 100 meters and is regarded as a possible seismotectonic feature.

NAME OR LOCATION OF FEATURE (Location No.)	AGE OF MOST RECENT MOVEMENT $X10^3$ years	SLIP RATE mm/yr (Time Period $X10^3$ years ago)	RECURRENCE INTERVAL $X10^3$ years (Time Period $X10^3$ years ago)	DISPLACEMENT PER EVENT meters	RUPTURE LENGTH kilometers
Wasatch fault zone - composite					
Parameter values:	0.5 ?		0.22 (<1.5) 0.4 (<6)	2 - 3	40 -70

Age Criteria : ^{14}C; TL

References : Machette and others, 1991, 1992

Comments : Ten discrete, independent segments, totaling 343 kilometers in length, have been identified on the Wasatch fault zone; the northernmost (Malad City) segment is in Idaho. Events on the five most active, medial segments of the Wasatch fault zone (location nos. 6-6, 11-22, 12-3, 12-6, and 13-21) appear to be randomly distributed in time between about 1,500 and 6,000 years ago, but events are clustered in time between 400 and 1,500 years ago. During the temporal clustering of earthquakes, movement occurred on all but one (Brigham City, location no. 6-6) of the medial segments of the fault zone. Slip rates of 1-2 mm/yr are typical for the medial segments during Holocene time. In contrast, late Quaternary (<150,000-250,000 years ago) slip rates on these segments are about 0.1-0.3 mm/yr, an order of magnitude lower than the Holocene rates. This suggests a causal relation between increased slip rates and isostatic rebound/crustal relaxation following deep lake cycles such as Bonneville (Machette and others, 1986, 1992). Based on comparisons with historical surface fault ruptures in the region, the medial segments of the Wasatch fault zone may produce up to magnitude (M_s) 7.5-7.7 earthquakes.

REFERENCES - APPENDIX A

Allmendinger, R.W., Sharp, J.W., Von Tish, Douglas, Serpa, Laura, Brown, Larry, Kaufman, Sidney, Oliver, Jack, and Smith, R.B., 1983, Cenozoic and Mesozoic structure of the eastern Basin and Range Province, Utah, from COCORP seismic-reflection data: Geology, v. 11, no. 9, p. 532-536.

Anderson, J.J., 1986, Geologic map of the Circleville Mountain quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 80, 6 p. pamphlet, scale 1:24,000.

Anderson, J.J., and Grant, T.C., 1986, Geologic map of the Fremont Pass quadrangle, Iron and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 81, 6 p. pamphlet, scale 1:24,000.

Anderson, J.J., and Rowley, P.D., 1987, Geologic map of the Panguitch NW quadrangle, Iron and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 103, 8 p. pamphlet, scale 1:24,000.

Anderson J.J., Rowley, P.D., and Blackman, J.T., 1986, Geologic map of the Circleville quadrangle, Beaver, Piute, and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 82, 5 p. pamphlet, scale 1:24,000.

Anderson, J.J., Rowley, P.D., Blackman, J.T., Mehnert, H.H., and Grant, T.C., 1990a, Geologic map of the Circleville Canyon area, southern Tushar Mountains and northern Markagunt Plateau, Beaver, Garfield, Iron, and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2000, scale 1:50,000.

Anderson, J.J., Rowley, R.D., Machette, M.N., Decatur, S.H., and Mehnert, H.H., 1990b, Geologic map of the Nevershine Hollow area, eastern Black Mountains, southern Tushar Mountains, and northern Markagunt Plateau, Beaver and Iron Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1999, scale 1:50,000.

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Long Beach, California, Fugro, Inc., 35 p., scale 1:500,000.

Anderson, L.W., and Miller, D.G., 1980, Quaternary faulting in Utah, in Andriese, P.D., compiler, Earthquake hazards along the Wasatch and Sierra-Nevada frontal fault zones: U.S. Geological Survey Open-File Report 80-801, p. 194-226.

Anderson, R.E., 1980, The status of seismotectonic studies of southwestern Utah, in Andriese, P.D., compiler, Earthquake hazards along the Wasatch and Sierra-Nevada frontal fault zones: U.S. Geological Survey Open-File Report 80-801, p. 519-547.

Anderson, R.E., and Barnhard, T.P., 1986, Genetic relationship between faults and folds and determination of Laramide and neotectonic paleostress, western Colorado Plateau--transition zone, central Utah: Tectonics, v. 5, no. 2, p. 335-357.

----1992, Neotectonic framework of the central Sevier Valley area, Utah, and its relationship to seismicity, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-F, 47 p.

Anderson, R.E., and Bucknam, R.C., 1979a, Map of fault scarps in unconsolidated sediments, Richfield 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-1236, 15 p., scale 1:250,000.

----1979b, Two areas of probable Holocene deformation in southwestern Utah, in Whitten, C.A., Green, Ronald, and Meade, B.K., editors, Recent crustal movements, 1977: Tectonophysics, v. 52, no. 1-4, p.

417-430.

Anderson, R.E., Bucknam, R.C., and Hamblin, W.K., 1978, Road log to the Quaternary tectonics of the Intermountain seismic belt between Provo and Cedar City, Utah: Geological Society of America, Rocky Mountain Section Annual Meeting, Provo, Utah, Field Trip no. 8, 50 p.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p., scale 1:250,000.

Anderson, R.E., and Mehnert, H.H., 1979, Reinterpretation of the history of the Hurricane fault in Utah, in Newman, G.D., and Goode, H.D., editors, 1979 Basin and Range Symposium and Great Basin field conference: Rocky Mountain Association of Geologists and Utah Geological and Mineral Survey, p. 145-165.

Anderson R.E., Zoback, M.L., and Thompson, G.A., 1983, Implications of selected subsurface data on the structural form and evolution of some basins in the northern Basin and Range Province, Nevada and Utah: Geological Society of America Bulletin, v. 94, no. 9, p. 1055-1072.

Arabasz, W.J., and Julander, D.R., 1986, Geometry of seismically active faults and crustal deformation within the Basin and Range-Colorado Plateau transition in Utah, in Mayer, Larry, editor, Extensional tectonics of the southwestern United States--a perspective on processes and kinematics: Geological Society of America Special Paper 208, p. 43-74.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1989, Evaluation of seismicity relevant to the proposed siting of a Superconducting Supercollider (SSC) in Tooele County, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-1, 107 p.

----1992, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-D, 36 p.

Arabasz, W.J., and Smith, R.B., 1979, The November 1971 earthquake swarm near Cedar City, Utah, in Arabasz, W.J., Smith, R.B., and Richins, W.D., editors, Earthquake studies in Utah, 1850 to 1978: University of Utah Seismograph Stations Special Publication, p. 423-432.

Averitt, Paul, and Threet R.L., 1973, Geologic map of the Cedar City quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1120, scale 1:24,000.

Baker, A.A., 1933, Geology and oil possibilities of the Moab District, Grand and San Juan Counties, Utah: U.S. Geological Survey Bulletin 841, 95 p.

----1976, Geologic map of the west half of the Strawberry quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-931, scale 1:62,500.

Banks, R.L., 1991, Provisional geologic map of the Fountain Green North quadrangle, Sanpete and Juab Counties, Utah: Utah Geological Survey Map 134, 21 p. pamphlet, scale 1:24,000.

Bard, Edouard, Hameltin, Bruno, Fairbanks, R.G., and Zindler, Alan, 1990, Calibration of the ^{14}C timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals: Nature, v. 345, no. 6274, p. 405-410.

Barnhard, T.P., and Dodge, R.L., 1988, Map of fault scarps formed on unconsolidated sediments, Tooele 1° x 2° quadrangle, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1990, scale 1:250,000.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, no. 10, p. 1035-1050.

Biek, R.F., 1991, Provisional geologic map of the Nephi quadrangle, Juab County, Utah: Utah Geological Survey Map 137, 21 p. pamphlet, scale 1:24,000.

Biggar, N.E., 1987, Quaternary studies in the Paradox Basin, southeastern Utah: Walnut Creek, California, Woodward-Clyde Consultants' report prepared for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-622, 252 p.

Bjorklund, L.J., and Robinson, G.B., Jr., 1968, Ground-water resources of the Sevier River Basin between Yuba Dam and Leamington Canyon, Utah: U.S. Geological Survey Water-Supply Paper 1848, 79 p.

Bowers, W.E., 1991, Geologic map of Bryce Canyon National Park and vicinity, southwestern Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2108, scale 1:24,000.

Brimhall, W.H., and Merritt, L.B., 1981, The geology of Utah Lake--implications for resource management: Great Basin Naturalist Memoirs Number 5, p. 24-42.

Bruhn, R.L., Gibler, P.R., and Parry, W.T., 1987, Rupture characteristics of normal faults--an example from the Wasatch fault zone, Utah, in Coward, M.P., Dewey, J.F., and Hancock, P.L., editors, Continental extensional tectonics: Geological Society of America Special Publication No. 28, p. 337-353.

Bryant, Bruce, 1990, Geologic map of the Salt Lake City 30' x 60' quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, scale 1:100,000.

Bucknam, R.C., and Anderson, R.E., 1979a, Map of fault scarps on unconsolidated sediments, Delta 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-366, 21 p., scale 1:250,000.

----1979b, Estimation of fault-scarp ages from a scarp-height-slope-angle relationship: Geology, v. 7, no. 1, p. 11-14.

Bucknam R.C., Crone, A.J., and Machette, M.N., 1989, Characteristics of active faults, in Jacobson, J.L., compiler, National Earthquake Hazards Reduction Program, summaries of technical reports volume XXVIII: U.S. Geological Survey Open-File Report 89-453, p. 117.

Callaghan, Eugene, and Parker, R.L., 1961, Geologic map of the Monroe quadrangle, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-155, scale 1:62,500.

Carpenter, C.H., Robinson, G.B., and Bjorklund, L.J., 1967, Ground-water conditions and geologic reconnaissance of the upper Sevier River Basin, Utah: U.S. Geological Survey Water-Supply Paper 1836, 91 p.

Carrara, P.E., 1980, Surficial geologic map of the Vernal 1° x 2° quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1204, scale 1:250,000.

Cashion, W.B., 1961, Geology and fuel resources of the Orderville-Glendale area, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C-49, scale 1:62,500.

Cater, F.W., 1970, Geology of the salt anticline region in southwestern Colorado: U.S. Geological Survey

Professional Paper 637, 80 p.

Clark, D.L, 1990, Provisional geologic map of the Juab quadrangle, Juab County, Utah: Utah Geological and Mineral Survey Map 132, 14 p. pamphlet, scale 1:24,000.

Clark, E.E., 1977, Late Cenozoic volcanic and tectonic activity along the eastern margin of the Great Basin, in the proximity of Cove Fort, Utah: Brigham Young University Geology Studies, v. 24, pt. 1, p. 87-114.

Cluff, L.S., Glass, C.E., and Brogan, G.E., 1974, Investigation and evaluation of the Wasatch fault north of Brigham City and Cache Valley faults, Utah and Idaho; a guide to land-use planning with recommendations for seismic safety: Oakland, California, Woodward-Lundgren and Associates, unpublished report for U.S. Geological Survey, contract no. 14-08-001-13665, 147 p.

Colman, S.M., Choquette, A.F., Rosholt, J.N., Miller, G.H., and Huntley, D.J., 1986, Dating the upper Cenozoic sediments in Fisher Valley, southeastern Utah: Geological Society of America Bulletin, v. 97, no. 12, p. 1422-1431.

Colman, S.M., and Watson, Ken, 1983, Ages estimated from a diffusion equation model for scarp degradation: Science, v. 221, no. 4607, p. 263-265.

Compton, R.R., 1972, Geologic map of the Yost quadrangle, Box Elder County, Utah and Cassia County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-672, scale 1:31,680.

----1975, Geologic map of the Park Valley quadrangle, Box Elder County, Utah and Cassia County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-873, scale 1:31,680.

Condie, K.C., and Barsky, C.K., 1972, Origin of Quaternary basalt from the Black Rock Desert region, Utah: Geological Society of America Bulletin, v. 83, no. 2, p. 333-352.

Cook, K.L., Gray, E.F., Iverson, R.M., and Strohmeier, M.T., 1980, Bottom gravity meter regional survey of the Great Salt Lake, Utah, in Gwynn, J.W., editor, Great Salt Lake--a scientific, historical and economic overview: Utah Geological and Mineral Survey Bulletin 116, p. 125-143.

Crecraft, H.R., Nash, W.P., and Evans, S.H., Jr., 1981, Late Cenozoic volcanism at Twin Peaks, Utah--geology and petrology: Journal of Geophysical Research, v. 86, no. B11, p. 10303-10320.

Crittenden, M.D., Jr., and Sorensen, M.L., 1985, Geologic map of the Mantua quadrangle and part of the Willard quadrangle, Box Elder, Weber, and Cache Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1605, scale 1:24,000.

Crone, A.J., 1983, Amount of displacement and estimated age of a Holocene surface-faulting event, eastern Great Basin, Millard County, Utah, in Gurgel, K.D., editor, Geologic excursions in neotectonics and engineering geology in Utah: Utah Geological and Mineral Survey Special Studies 62, p. 49-55.

Crone, A.J., and Harding, S.T., 1984a, Relationship of late Quaternary fault scarps to subjacent faults, eastern Great Basin, Utah: Geology, v. 12, no. 5., p. 292-295.

----1984b, Near-surface faulting associated with Holocene fault scarps, Wasatch fault zone, Utah--a preliminary report, in Hays, W.W., and Gori, P.L., editors, A workshop on "Evaluation of regional and urban earthquake hazards and risk in Utah": U.S. Geological Survey Open-File Report 84-763, p. 241-268.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Glassgold, L.B., and Anderson, J.J., 1983, Geologic map of the Tushar Mountains and adjoining areas, Marysvale volcanic field, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1430-A, scale 1:50,000.

Currey, D.R., 1980, Coastal geomorphology of Great Salt Lake and vicinity, in Gwynn, J.W., editor, Great Salt Lake--a scientific, historical and economic overview: Utah Geological and Mineral Survey Bulletin 116, p. 69-82.

----1982, Lake Bonneville--selected features of relevance to neotectonic analysis: U.S. Geological Survey Open-File Report 82-1070, 30 p.

Dames and Moore, 1978, Phase II - preliminary geotechnical studies, proposed powerplant, lower Sevier River area, Utah: Los Angeles, unpublished consultant's report for Intermountain Power Project, Job nos. 10629-00206 and 10629-003-06, 45 p.

----1985, Preliminary investigations and engineering evaluation - Cutler Dam and Reservoir enlargement project, Box Elder and Cache Counties, Utah: Salt Lake City, unpublished consultant's report for Utah Division of Water Resources, Job no. 13423-005-06, 61 p.

dePolo, C.M., Clark, D.G., Slemmons, D.B., and Aymard, W.H., 1989, Historical Basin and Range Province surface faulting and fault segmentation, in Schwartz, D.P., and Sibson, R.H., editors, Fault segmentation and controls of rupture initiation and termination--proceedings of conference XLV: U.S. Geological Survey Open-File Report 89-315, p. 131-162.

Doelling, H.H., 1980, Geology and mineral resources of Box Elder County, Utah: Utah Geological and Mineral Survey Bulletin 115, 251 p.

Doelling, H.H., and Ross, M.L., 1993, Interim geologic map of the Big Bend quadrangle, Grand County, Utah: Utah Geological Survey Open-File Report 285, 108 p., scale 1:24,000.

Dohrenwend, J.C., Schell, B.A., and Moring, B.C., 1991a, Reconnaissance photogeologic map of young faults in the Elko 1° by 2° quadrangle, Nevada and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2179, scale 1:250,000.

----1991b, Reconnaissance photogeologic map of young faults in the Lund 1° by 2° quadrangle, Nevada and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2180, scale 1:250,000.

Doser, D.I., 1989, Extensional tectonics in northern Utah-southern Idaho, U.S.A., and the 1934 Hansel Valley sequence: Physics of the Earth and Planetary Interiors, v. 54, no. 1-2, p. 120-134.

Eardley, A.J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geological Society of America Bulletin, v. 55, p. 819-894.

----1962, Glauber's salt bed west of Promontory Point, Great Salt Lake: Utah Geological and Mineral Survey Special Studies 1, 12 p.

Earth Science Associates, 1982, Phase I report, seismic safety investigation of eight SCS dams in southwestern Utah: Palo Alto, unpublished consultant's report for U.S. Soil Conservation Service, 2 volumes, variously paginated.

Ely, R.W., Wong, I.G., and Chang, P.S., 1986, Neotectonics of the Uncompahgre uplift, eastern Utah and western Colorado, in Rogers, W.P., and Kirkham, R.M., editors, Contributions to Colorado seismicity and tectonics - a 1986 update: Colorado Geological Survey Special Publication 28, p. 75-92.

Ertec Western, Inc., 1981a, MX siting investigation, faults and lineaments in the MX siting region, Nevada and Utah: Long Beach, California, unpublished consultant's report no. E-TR-54 for U.S. Air Force, volume I, 77 p.; volume II, variously paginated.

----1981b, MX siting investigation, geotechnical evaluation, verification study - Wah Wah Valley, Utah, volume I - synthesis: Long Beach, California, unpublished consultant's report no. FN-TR-27-WA-I for U.S. Air Force, 46 p.

Evans, J.P., 1991, Structural setting of seismicity in northern Utah: Utah Geological Survey Contract Report 91-5, 37 p.

Everitt, B.L., 1982, Potential for ground-water development in the Thatcher-Penrose area: Utah Division of Water Resources, unpublished memorandum, 10 p.

Everitt, B.L., and Kaliser, B.N., 1980, Geology for assessment of seismic risk in the Tooele and Rush Valleys, Tooele County, Utah: Utah Geological and Mineral Survey Special Studies 51, 33 p.

Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report No. 86-7, 132 p.

Fong, A.W., 1991, Fountain Green South quadrangle, Juab and Sanpete Counties, Utah: Utah Geological and Mineral Survey Open-File Report 204, 96 p., scale 1:24,000.

Forman, S.L., Nelson, A.R., and McCalpin, J.P., 1991, Thermoluminescence dating of fault-scarp-derived colluvium--deciphering the timing of paleoearthquakes on the Weber segment of the Wasatch fault zone, north-central Utah: Journal of Geophysical Research, v. 96, no. B1, p. 595-605.

Fugro National, Inc., 1981a, MX siting investigation, preliminary geotechnical investigation, proposed operational base site, Milford, Utah, volume I - synthesis: Long Beach, California, unpublished consultant's report no. FN-TR-44 for U.S. Air Force, 77 p.

----1981b, MX siting investigation, geotechnical evaluation, verification study - Pine Valley, Utah, volume I - synthesis: Long Beach, California, unpublished consultant's report no. FN-TR-27-PI-I for U.S. Air Force, 48 p.

Galyardt, G.L., and Rush, F.E., 1981, Geologic map of the Crater Springs Known Geothermal Area and vicinity, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1297, scale 1:24,000.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey Monograph 1, 438 p.

Gilliland, W.N., 1963, Sanpete-Sevier Valley anticline of central Utah: Geological Society of America Bulletin, v. 74, no. 2, p. 115-123.

Goode, H.D., 1959, Surficial deposits, geomorphology, and Cenozoic history of the Eureka quadrangle, Utah: Boulder, University of Colorado, Ph.D. dissertation, 120 p.

Goter, S.K., 1990, Earthquakes in Utah, 1884-1989: U.S. Geological Survey Open-File Report 91-128, scale 1:500,000.

Hamblin, W.K., 1970, Late Cenozoic basalt flows of the western Grand Canyon region, in Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Utah Geological Society, Guidebook to the Geology of Utah Number 23, p. 21-37.

Hamblin, W.K., Damon, P.E., and Bull, W.B., 1981, Estimates of vertical crustal strain rates along the western margins of the Colorado Plateau: Geology, v. 9, no. 7, p. 293-298.

Hanks, T.C., Bucknam, R.C., Lajoie, K.R., and Wallace, R.E., 1984, Modification of wave-cut and faulting-controlled landforms: Journal of Geophysical Research, v. 89, no. B7, p. 5771-5790.

Hansen, W.R., 1969a, Quaternary faulting at Towanta Flat on the south flank of the Uinta Mountains, Duchesne County, Utah, in Lindsay, J.B., editor, Geologic guidebook of the Uinta Mountains, Utah's maverick range: Intermountain Association of Geologists and the Utah Geological Society, Sixteenth Annual Field Conference, p. 91-92.

----1969b, The geologic story of the Uinta Mountains: U.S. Geological Survey Bulletin 1291, 144 p.

----1984, Post-Laramide tectonic history of the eastern Uinta Mountains, Utah, Colorado, and Wyoming: The Mountain Geologist, v. 21, no. 1, p. 5-29.

Hansen, W.R., Carrara, P.E., and Rowley, P.D., 1981, Geologic map of the Crouse Reservoir quadrangle, Uintah and Daggett Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1554, scale 1:24,000.

Harden, D.R., Biggar, N.E., and Gillam, M.L., 1985, Quaternary deposits and soils in and around Spanish Valley, Utah, in Weide, D.L., editor, Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 43-64.

Harty, K.M., 1987, Field reconnaissance of Thousand Lake fault zone: Utah Geological and Mineral Survey, unpublished memorandum, 2 p.

Hawks, R.L., Jr., 1980, The stratigraphy and structure of the Cedar Hills, Sanpete County, Utah: Brigham Young University Geology Studies, v. 27, pt. 1, p. 67-80.

Hecker, Suzanne, 1987a, June 29-30 reconnaissance of Crawford Mountains and "Saleratus Creek" faults by Suzanne Hecker and Gary E. Christenson: Utah Geological and Mineral Survey, unpublished memorandum, 5 p.

----1987b, May 26, 1987 reconnaissance of late Quaternary fault along west side of Sanpete Valley, by S. Hecker, K.M. Harty, and G.E. Christenson: Utah Geological and Mineral Survey, unpublished memorandum, 2 p.

----1989, November 16, 1989 reconnaissance of range-front fault on west side of Sanpete Valley by Suzanne Hecker and Susan S. Olig: Utah Geological and Mineral Survey, unpublished memorandum, 3 p.

Hite, R.J., 1982, Task 1--geology, technical progress report for the quarter 1 July--30 September, 1982: Unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-9.

Hood, J.W., and Rush, F.E., 1965, Water-resources of the Snake Valley area, Utah and Nevada: Utah State Engineer Technical Publication No. 14, 43 p.

Hoover, J.D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 3-72.

Howard, K.A., Aaron, J.M., Brabb, E.E., Brock, M.R., Gower, H.D., Hunt, S.J., Milton, D.J., Muehlberger, W.R., Nakata, J.K., Plafker, George, Prowell, D.C., Wallace, R.E., and Witkind, I.J., compilers, 1978, Preliminary map of young faults in the United States as a guide to possible fault activity: U.S. Geological Survey Miscellaneous Field Studies Map MF-916, scales 1:5,000,000 and 1:7,500,000.

Hunt, C.B., editor, 1982, Pleistocene Lake Bonneville, ancestral Great Salt Lake, as defined in the notebooks of G.K. Gilbert, 1875-1880: Brigham Young University Geology Studies, v. 29, pt. 1, p. 1-225.

Huntoon, P.W., 1982, The Meander anticline, Canyonlands, Utah, an unloading structure resulting from horizontal gliding on salt: Geological Society of America Bulletin, v. 93, no. 10, p. 941-950.

----1988, Late Cenozoic gravity tectonic deformation related to the Paradox salts in the Canyonlands area of Utah, in Doelling, H.H., Oviatt, C.G., and Huntoon, P.W., editors, Salt deformation in the Paradox Basin: Utah Geological and Mineral Survey Bulletin 122, p. 81-93.

Jackson, M.E., 1991, Paleoseismology of Utah, volume 3--the number and timing of Holocene paleoseismic events on the Nephi and Levan segments, Wasatch fault zone, Utah: Utah Geological Survey Special Studies 78, 23 p.

Jones, R.W., 1959, Origin of salt anticlines of Paradox Basin: American Association of Petroleum Geologists Bulletin v. 43, no. 8, p. 1869-1895.

Jordan, T.E., Allmendinger, R.W., and Crittenden, M.D., Jr., 1988, Geologic map of the Howell quadrangle, Box Elder County, Utah: Utah Geological and Mineral Survey Map 107, 10 p. pamphlet, scale 1:24,000.

Kaliser, B.N., 1972, Environmental geology of Bear Lake area, Rich County, Utah: Utah Geological and Mineral Survey Bulletin 96, 32 p.

Keaton, J.R., Currey, D.R., and Olig, S.J., 1987, Paleoseismicity and earthquake hazards evaluation of the West Valley fault zone, Salt Lake City urban area, Utah: Salt Lake City, Dames and Moore, Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-22048, 55 p.

Krinitzsky, E.L., 1989, Empirical earthquake ground motions for an engineering site with fault sources--Tooele Army Depot, Utah: Bulletin of the Association of Engineering Geologists, v. 26, no. 3, p. 283-308.

Lamerson, P.R., 1982, The Fossil Basin and its relationship to the Absaroka thrust system, Wyoming and Utah, in Powers, R.B., editor, Geologic studies of the Cordilleran thrust belt, volume I: Rocky Mountain Association of Geologists, p. 279-340.

Lofgren, B.E., 1955, Resume of the Tertiary and Quaternary stratigraphy of Ogden Valley, Utah, in Eardley, A.J., editor, Tertiary and Quaternary geology of the eastern Bonneville basin: Utah Geological Society, Guidebook to the Geology of Utah Number 10, p. 70-84.

Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Colorado, Utah, and southwestern Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1091-B, scale 1:1,000,000.

Lund, W.R., Schwartz, D.P., Mulvey, W.E., Budding, K.E., and Black, B.D., 1991, Paleoseismology of Utah, volume 1--fault behavior and earthquake recurrence on the Provo segment of the Wasatch fault zone at Mapleton, Utah County, Utah: Utah Geological and Mineral Survey Special Studies 75, 41 p.

Machette, M.N., 1985, Late Cenozoic geology of the Beaver Basin, southwestern Utah: Brigham Young University Geology Studies, v. 32, pt. 1, p. 19-37.

----1989, Preliminary 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 Field Studies Map MF-2109, scale 1:50,000.

----1990, Temporal and spatial behavior of late Quaternary faulting, western United States, in Jacobson, J.L., compiler, National Earthquake Hazards Reduction Program, summaries of technical reports, volume XXXI: U.S. Geological Survey Open-File Report 90-680, p. 438-440.

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

Machette, M.N., Personius, S.F., and Nelson, A.R., 1986, Late Quaternary segmentation and slip-rate history of the Wasatch fault zone, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 76, no. 44, p. 1107.

----1992, Paleoseismology of the Wasatch fault zone--a summary of recent investigations, interpretations, and conclusions, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

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.

Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

Maldonado, Florian, and Williams, V.S., 1991a, Preliminary geologic map of the Paragonah quadrangle, Iron County, Utah: U.S. Geological Survey Open-File Report 90-494, 13 p., scale 1:24,000.

----1991b, Preliminary geologic map of the Parowan Gap quadrangle, Iron County, Utah: U.S. Geological Survey Open-File Report 90-495, 15 p., scale 1:24,000.

Martin, R.A., Jr., Nelson, A.R., Weisser, R.R., and Sullivan, J.T., 1985, Seismotectonic study for Taskeech Dam and Reservoir site, Upalco Unit and Upper Stillwater Dam and Reservoir site, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 85-2, 95 p.

McCalpin, J.P., 1985, Quaternary fault history and earthquake potential of the Hansel Valley area, north-central Utah: Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-21899, 37 p.

----1987, Late Quaternary tectonics and earthquake hazard in Cache Valley, Utah: Final Technical Report for U.S. Geological Survey, Contract No. 14-08-0001-G1091, 187 p.

----1989, Surficial geologic map of the East Cache fault zone, Cache County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2107, scale 1:50,000.

----1990, Latest Quaternary faulting in the northern Wasatch to Teton corridor (NWTC): Final Technical Report for U.S. Geological Survey, Contract No. 14-08-001-G1395, 42 p.

McCalpin, J.P., and Forman, S.L., 1991, Late Quaternary faulting and thermoluminescence dating of the East Cache fault zone, north-central Utah: Bulletin of the Seismological Society of America, v. 81, no. 1, p. 139-161.

McCalpin, J.P., Robison, R.M., and Garr, J.D., 1992, Neotectonics of the Hansel Valley-Pocatello Valley corridor, northern Utah and southern Idaho, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-G, 18 p.

McCalpin, J.P., Zhang, Liren, and Khromovskikh, V.S., 1990, Quaternary faulting in the Bear Lake graben, Idaho and Utah [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 38.

McGill, G.E., and Stromquist, A.W., 1974, A model for graben formation by subsurface flow; Canyonlands National Park, Utah: Amherst, University of Massachusetts, Department of Geology and Geography Contribution No. 15, 79 p.

Meibos, L.C., 1983, Structure and stratigraphy of the Nephi NW 7½-minute quadrangle, Juab County, Utah: Brigham Young University Geology Studies, v. 30, pt. 1, p. 37-58.

Menges, C.M., and Pearthree, P.A., 1983, Map of neotectonic (late Pliocene-Quaternary) deformation in Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 83-22, 15 p.

Mikulich, M.J., and Smith, R.B., 1974, Seismic-reflection and aeromagnetic surveys of the Great Salt Lake, Utah: Geological Society of America Bulletin, v. 85, no. 6, p. 991-1002.

Miller D.M., Crittenden, M.D., Jr., and Jordan, T.E., 1991, Geologic map of the Lampo Junction quadrangle, Box Elder County, Utah: Utah Geological Survey Map 136, 16 p. pamphlet, scale 1:24,000.

Miller, D.M., and Lush, A.P., 1991, Geologic map of the Pilot Peak quadrangle, Box Elder County, Utah, and Elko County, Nevada: Utah Geological and Mineral Survey Open-File Report 208, 49 p., scale 1:24,000.

Miller, D.M., Lush, A.P., and Schneyer, J.D., 1990, Geologic map of the Patterson Pass quadrangle, Box Elder County, Utah, and Elko County, Nevada: Utah Geological and Mineral Survey Open-File Report 172, 56 p., scale 1:24,000.

Miller, D.M., and Schneyer, J.E., 1990, Geologic map of the Sunset Pass quadrangle, Box Elder County, Utah: Utah Geological and Mineral Survey Open-File Report 201, 32 p., scale 1:24,000.

Moore, W.J., and Sorensen, M.L., 1979, Geologic map of the Tooele 1° x 2° quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1132, scale 1:250,000.

Morris, H.T., 1987, Preliminary geologic map of the Delta 2° quadrangle, Tooele, Juab, Millard, and Utah Counties, Utah: U.S. Geological Survey Open-File Report 87-185, 18 p., scale 1:250,000.

Nelson, A.R., 1988, The northern part of the Weber segment of the Wasatch fault zone near Ogden, Utah, in Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 33-37.

Nelson, A.R., and Martin, R.A., Jr., 1982, Seismotectonic study for Soldier Creek Dam, Central Utah Project: Denver, U.S. Bureau of Reclamation Seismotectonic Report 82-1, 115 p.

Nelson, A.R., and Personius, S.F., 1990, Preliminary surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2132, 22 p. pamphlet, scale 1:50,000.

----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. pamphlet, scale 1:50,000.

Nelson, A.R., and Sullivan, J.T., 1992, Late Quaternary history of the James Peak fault, southernmost Cache Valley, north-central Utah, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-J, 13 p.

Nelson, A.R., and Van Arsdale, R.B., 1986, Recurrent late Quaternary movement on the Strawberry normal fault, Basin and Range - Colorado Plateau transition zone, Utah: Neotectonics, v. 1, p. 7-37.

Nelson, A.R., and Weisser, R.R., 1985, Quaternary faulting on Towanta Flat, northwestern Uinta Basin, Utah, in Picard, M.D., editor, Geology and energy resources, Uinta Basin of Utah: Utah Geological Association Publication 12, p. 147-158.

Nishenko, S.P., and Schwartz, D.P., 1990, Preliminary estimates of large earthquake probabilities along the Wasatch fault zone, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 71, no. 43, p. 1448.

Osborn, G.D., 1973, Quaternary geology and geomorphology of the Uinta Basin and the south flank of the Uinta Mountains: Berkeley, University of California, Ph.D. dissertation.

Ostenaa, Dean, 1990, Late Holocene displacement history, Water Canyon site, Wasatch fault zone [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 42.

Osterwald, F.W., Maberry, J.O., and Dunrud, C.R., 1981, Bedrock, surficial, and economic geology of the Sunnyside coal-mining district, Carbon and Emery Counties, Utah: U.S. Geological Survey Professional Paper 1166, 68 p.

Oviatt, C.G., 1986a, Geologic map of the Cutler Dam quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 91, 7 p. pamphlet, scale 1:24,000.

----1986b, Geologic map of the Honeyville quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 88, 13 p. pamphlet, scale 1:24,000.

----1988, Evidence for Quaternary deformation in the Salt Valley anticline, southeastern Utah, in Doelling H.H., Oviatt, C.G., and Huntoon, P.W., editors, Salt deformation in the Paradox region: Utah Geological and Mineral Survey Bulletin 122, p. 63-76.

----1989, Quaternary geology of part of the Sevier Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 70, 41 p.

----1991a, Quaternary geology of the Fish Springs Flat, Juab County, Utah: Utah Geological Survey Special Studies 77, 16 p.

----1991b, Quaternary geology of the Black Rock Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 73, 23 p.

----1992, Quaternary geology of the Scipio Valley area, Millard and Juab Counties, Utah: Utah Geological Survey Special Studies 79, 16 p.

Pechmann, J.C., 1987, Earthquake design considerations for the interisland diking project, Great Salt Lake, Utah: Salt Lake City, unpublished technical report for Rollins, Brown and Gunnell, Provo, Utah, 31 p.

Pechmann, J.C., Nash, W.P., Viveiros, J.J., and Smith, R.B., 1987, Slip rate and earthquake potential of the East Great Salt Lake fault, Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 68, no. 44, p. 1369.

Perry, T.W., and Annis, D.R., 1990, Pleistocene history of the Gunnison River in Unaweep Canyon, Colorado, and implications for Colorado Plateau uplift [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 75.

Personius, S.F., 1988, A brief summary of the surficial geology along the Brigham City segment of the Wasatch fault zone, Utah, in Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 27-32.

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

----1991, Paleoseismology of Utah, volume 2--paleoseismic analysis of the Wasatch fault zone at the Brigham City trench site, Brigham City, Utah, and Pole Patch trench site, Pleasant View, Utah: Utah Geological and Mineral Survey Special Studies 76, 39 p.

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.

Petersen, C.A., 1973, Geology of the Roosevelt Hot Springs area, Beaver County, Utah: Utah Geology, v. 2, no. 2, p. 109-116.

Petersen, S.M., 1983, The tectonics of the Washington fault zone, northern Mojave County, Arizona: Brigham Young University Geology Studies, v. 30, pt. 1, p. 83-94.

Picha, Frank, 1986, The influence of pre-existing tectonic trends on geometries of the Sevier orogenic belt and its foreland in Utah: American Association of Petroleum Geologists Memoir 41, p. 309-320.

Piekarski, L.L., 1980, Relative age determination of Quaternary fault scarps along the southern Wasatch, Fish Springs, and House Ranges: Brigham Young University Geology Studies, v. 27, pt. 2, p. 123-139.

Pierce, K.L., and Colman, S.M., 1986, Effect of height and orientation (microclimate) on geomorphic degradation rates and processes, late glacial terrace scarps in central Idaho: Geological Society of America Bulletin, v. 97, no. 7, p. 869-885.

Richins, W.D., Zandt, George, and Arabasz, W.J., 1981, Swarm seismicity along the Hurricane fault zone during 1980-81--a typical example for SW Utah [abs.]: EOS, Transactions of the American Geophysical Union, v. 62, no. 45, p. 966.

Robison, R.M., and Burr, T.N., 1991, Fault-rupture hazard analysis using trenching and borings--Warm Springs fault, Salt Lake City, Utah, in McCalpin, J.P., editor, Proceedings of the 27th Symposium on Engineering Geology and Geotechnical Engineering: Boise, Idaho Department of Transportation, p. 26-1 - 26-13.

Rowley, P.D., 1968, Geology of the southern Sevier Plateau, Utah: Austin, University of Texas, Ph.D. dissertation, 385 p.

----1978, Geologic map of the Thermo 15-minute quadrangle, Beaver and Iron Counties, Utah: U.S.

Geological Survey Geologic Quadrangle Map GQ-1493, scale 1:62,500.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., Naeser, C.W., 1988, Geologic map of the Marysvale quadrangle, Piute County, Utah: Utah Geological and Mineral Survey Map 105, 15 p. pamphlet, scale 1:24,000.

Rowley, P.D., Hansen, W.R., Tweto, Ogden, and Carrara, P.E., 1985, Geologic map of the Vernal 1° x 2° quadrangle, Colorado, Utah, and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1526, scale 1:250,000.

Rowley, P.D., Hereford, Richard, and Williams, V.S., 1987, Geologic map of the Adams Head-Johns Valley area, southern Sevier Plateau, Garfield County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1798, scale 1:50,000.

Rowley, P.D., Steven, T.A., and Mehnert, H.H., 1981, Origin and structural implications of upper Miocene rhyolites in Kingston Canyon, Piute County, Utah: Geological Society of America Bulletin v. 92, no. 8, p. 590-602.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986, Geologic map of the Koosharem quadrangle, Sevier and Piute Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1590, scale 1:24,000.

Runyon, D.M., 1977, Structure, stratigraphy, and tectonic history of the Indianola quadrangle, central Utah: Brigham Young University Geology Studies, v. 24, pt. 2, p. 63-82.

Sack, Dorothy, 1990, Geologic map of the Tule Valley, west-central Utah: Utah Geological and Mineral Survey Map 124, 26 p. pamphlet, scale 1:100,000.

Scarborough, R.B., Menges, C.M., and Pearthree, P.A., 1986, Late Pliocene-Quaternary (post 4 m.y.) faults, folds, and volcanic rocks in Arizona: Arizona Bureau of Geology and Technology Map 22, scale 1:1,000,000.

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.

Schwartz, D.P., and Lund, W.R., 1988, Paleoseismicity and earthquake recurrence at Little Cottonwood Canyon, Wasatch fault zone, Utah, in Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 82-85.

Scott, W.E., 1988, G.K. Gilbert's observations of post-Bonneville movement along the Warm Springs fault, Salt Lake County, Utah, in Machette, M.N., editor, In the footsteps of G.K. Gilbert--Lake Bonneville and neotectonics of the eastern Basin and Range Province, Guidebook for Field Trip Twelve: Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 44-46.

Sergent, Hauskins, and Beckwith, 1991, Report for final preliminary engineering geology, geoseismic, and geotechnical study, proposed Torrey dam and reservoir, approximately one mile west of Torrey, Utah, for Wayne County Conservancy District: Salt Lake City, unpublished consultant's report prepared for Utah Department of Natural Resources, Division of Water Resources, SHB Job No. E90-2027, 18 p.

Shoemaker, E.M., Case, J.E., and Elston, D.P., 1958, Salt anticlines of the Paradox Basin, in Sanborn, A.R., editor, Guidebook to the geology of the Paradox Basin, Ninth Annual Field Conference: Intermountain Association of Petroleum Geologists, p. 39-59.

Shoemaker, E.M., Squires, R.L., and Abrams, M.J., 1978, Bright Angel and Mesa Butte fault systems of northern Arizona, in Smith R.B., and Eaton, G.P., editors, Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 341-367.

Skeen, R.C., 1975, A reflection seismic study of the subsurface structure and sediments of Bear Lake, Utah-Idaho: Salt Lake City, University of Utah, senior thesis, 25 p.

Smith, J.F., Jr., Huff, L.C., Hinrichs, E.N., and Luedke, R.G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geological Survey Professional Paper 363, 102 p.

Smith, R.B., and Bruhn, R.L., 1984, Intraplate extensional tectonics of the western U.S. Cordillera--inferences on structural style from seismic-reflection data, regional tectonics and thermal-mechanical models of brittle-ductile deformation: Journal of Geophysical Research, v. 89, no. B7, p. 5733-5762.

Smithson, S.B., and Johnson, R.A., 1989, Crustal structure of the western U.S. based on reflection seismology, in Pakiser, L.C., and Mooney, W.D., editors, Geophysical framework of the continental United States: Geological Society of America Memoir 172, p. 577-612.

Sorensen, M.L., and Crittenden, M.D., Jr., 1979, Geologic map of the Huntsville quadrangle, Weber and Cache Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1503, scale 1:24,000.

Spieker, E.M., and Billings, M.P., 1940, Glaciation in the Wasatch Plateau, Utah: Geological Society of America Bulletin, v. 51, no. 8, p. 1173-1197.

Standlee, L.A., 1982, Structure and stratigraphy of Jurassic rocks in central Utah--their influence on tectonic development of the Cordilleran foreland thrust belt, in Powers, R.B., editor, Geologic studies of the Cordilleran thrust belt, volume I: Rocky Mountain Association of Geologists, p. 357-382.

Sterr, H.M., 1980, The seismotectonic history and morphological evolution of late Quaternary fault scarps in southwestern Utah: Boulder, University of Colorado, Ph.D. dissertation, 286 p.

----1985, Rates of change and degradation of hill slopes formed in unconsolidated materials--a morphometric approach to dating Quaternary fault scarps in western Utah, USA: Zeitschrift fur Geomorphologie, v. 29, no. 3, p. 315-333.

Steven, T.A., and Morris, H.T., 1983, Geologic map of the Cove Fort quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1481, scale 1:50,000.

Steven, T.A., Morris, H.T., and Rowley, P.D., 1990, Geologic map of the Richfield 1° x 2° quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1901, scale 1:250,000.

Stifel, P.B., 1964, Geology of the Terrace and Hogup Mountains, Box Elder County, Utah: Salt Lake City, University of Utah, Ph.D. dissertation, 173 p.

Stromquist, A.W., 1976, Geometry and growth of grabens, lower Red Lake Canyon area, Canyonlands National Park, Utah: Amherst, University of Massachusetts, Department of Geology and Geography Contribution No. 28, 118 p.

Sullivan, J.T., 1982, Late Cenozoic faulting in the back valleys of the Wasatch Mountains, northeastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 14, no. 6, p. 351.

----1988, Seismotectonic study for Starvation Dam, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-7, 14 p.

Sullivan, J.T., and Baltzer, E.M., 1986, Seismotectonic study for Mona Dam and Reservoir: Denver, U.S. Bureau of Reclamation Seismotectonic Report 86-4, 17 p.

Sullivan, J.T., Foley, L.L., Baltzer, E.M., and Krinsky, C.K., 1987, Seismic sources, maximum credible earthquakes, and related seismic hazards for Monks Hollow damsite: Denver, U.S. Bureau of Reclamation Seismotectonic Report 87-2, 35 p.

Sullivan, J.T., Martin, R.A., and Foley, L.L., 1988, Seismotectonic study for Jordanelle Dam, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-6, 76 p.

Sullivan, J.T., and Nelson, A.R., 1983, Late Cenozoic faulting in Heber and Keetley Valleys, northeastern Utah, in Gurgel, K.D., editor, Geologic excursions in neotectonics and engineering geology in Utah: Utah Geological and Mineral Survey Special Studies 62, p. 55-62.

----1992, Late Quaternary displacement on the Morgan fault, a back valley fault in the Wasatch Range of northeastern Utah, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front: U.S. Geological Survey Professional Paper 1500-I, 19 p.

Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p.

Taylor, J.M., 1980, Geology of the Sterling quadrangle, Sanpete County, Utah: Brigham Young University Geology Studies, v. 27, pt. 1, p. 117-135.

Threet, R.L., 1963, Geology of the Parowan Gap area, Iron County, Utah, in Heylmun, E.B., editor, Guidebook to the geology of southwestern Utah: Intermountain Association of Petroleum Geologists, Twelfth Annual Field Conference, p. 136-145.

Todd, V.R., 1973, Structure and petrology of metamorphosed rocks in the central Grouse Creek Mountains, Box Elder County, Utah: Palo Alto, Stanford University, Ph.D. dissertation, 316 p.

Tooker, E.W., and Roberts, R.J., 1988, Interim geologic maps and explanation pamphlet for parts of the Stockton and Lowe Peak 7½-minute quadrangles, Utah: U.S. Geological Survey Open-File Report 88-280, 20 p., scale 1:24,000.

U.S. Department of the Army, 1989, Disposal of chemical agents and munitions at Tooele Army Depot, Tooele, Utah, Draft Environmental Impact Statement: U.S. Department of the Army, Program Manager for Chemical Demilitarization, Aberdeen Proving Ground, Maryland, variously paginated.

Utah Geological and Mineral Survey, 1977, Earthquakes shake northwest Uinta Basin: Utah Geological and Mineral Survey, Survey Notes, v. 11, no. 4, p. 1, 3.

Van Arsdale, R.B., 1979, Geology of Strawberry Valley and regional implications: Salt Lake City, University of Utah, Ph.D. dissertation, 65 p.

Viveiros, J.J., 1986, Cenozoic tectonics of the Great Salt Lake from seismic-reflection data: Salt Lake City, University of Utah, M.S. thesis, 81 p.

Walter, H.G., 1934, Hansel Valley, Utah, earthquake: The Compass of Sigma Gamma Epsilon, v. 14, no. 4, p 178-181.

West, M.W., 1988, Geologic and tectonic studies in the vicinity of Meeks Cabin and Stateline Dams, in

Seismotectonic study for Meeks Cabin and Stateline Dams, Lyman Project, Wyoming: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-11, 121 p.

----1989, Neotectonics of the Darby-Hogsback and Absaroka thrust plates, Uintah County, Wyoming, and Summit County, Utah, with applications to earthquake hazard assessment: Golden, Colorado School of Mines, Ph.D. dissertation, 2 volumes, 450 p.

----in press, Paleoseismology of Utah, volume 4--seismotectonics of north-central Utah and southwestern Wyoming: Utah Geological Survey Special Studies.

Westway, Rob, and Smith R.B., 1989, Source parameters of the Cache Valley (Logan), Utah, earthquake of 30 August 1962: Bulletin of the Seismological Society of America, v. 79, no. 5, p. 1410-1425.

Williams, P.L., compiler, 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-360, scale 1:250,000.

Williams, P.L., and Hackman, R.J., compilers, 1971, Geology, structure, and uranium deposits of the Salina quadrangle, Utah: U.S. Geological Survey Miscellaneous Geological Map I-591, scale 1:250,000.

Williams, V.S., and Maldonado, Florian, 1990, Quaternary movement on the Little Salt Lake fault, Parowan Valley, southwestern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 94.

Willis, G.C., 1986, Geologic map of the Salina quadrangle, Sevier County, Utah: Utah Geological and Mineral Survey Map 83, 20 p. pamphlet, scale 1:24,000.

----1988, Geologic map of the Aurora quadrangle, Sevier County, Utah: Utah Geological and Mineral Survey Map 112, 21 p. pamphlet, 1:24,000 scale.

----1991, Geologic map of the Redmond Canyon quadrangle, Sanpete and Sevier Counties, Utah: Utah Geological Survey Map 138, 17 p. pamphlet, scale 1:24,000.

Wilson, E.A., Saugy, Luc, and Zimmermann, M.A., 1986, Cenozoic tectonics and sedimentation of the eastern Great Salt Lake area, Utah: Bulletin de Société Géologicque Francaise, v. 2, no. 5, p. 777-782.

Witkind, I.J., 1981, Reconnaissance geologic map of the Redmond quadrangle, Sanpete and Sevier Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1304-A, scale 1:24,000.

----1982, Salt diapirism in central Utah, in Nielson, D.L., editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 13-30.

Witkind, I.J., and Page, W.R., 1984, Origin and significance of the Wasatch and Valley Mountains monoclines, Sanpete-Sevier Valley area, central Utah: The Mountain Geologist, v. 212, no. 4, p. 143-156.

Witkind, I.J., and Sprinkel, D.A., 1982, Field conference road log - second day--salt diapirism in central Utah, in D.L. Nielson, editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 315-330.

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, 16 p. pamphlet, scale 1:100,000.

Witkind, I.J., Weiss, M.P., and Brown, T.L., 1987, Geologic map of the Manti 30' x 60' quadrangle, Carbon, Emery, Juab, Sanpete, and Sevier Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1631, scale 1:100,000.

Woodward-Clyde Consultants, 1982a, Geologic characterization report for the Paradox Basin study region, Utah study areas, volume IV, Lisbon Valley: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, variously paginated.

----1982b, Geologic characterization report for the Paradox Basin study region, Utah study areas, volume I, regional overview: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, variously paginated.

----1982c, Geologic characterization report for the Paradox Basin study region, Utah study areas, volume II, Gibson Dome: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, variously paginated.

----1984, Geologic characterization report for the Paradox Basin study region, Utah study areas, volume VI, Salt Valley: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, 190 p.

Young, G.H., 1978, Geology of the Billies Mountain quadrangle, Utah County, Utah: Brigham Young University Geology Studies, v. 24, pt. 1, p. 205-280.

Young, J.C., 1955, Geology of the southern Lakeside Mountains, Utah: Utah Geological and Mineral Survey Bulletin 56, 116 p.

Youngs, R.R., Swan, F.H., III, Power, M.P., Schwartz, D.P., and Green, R.K., 1987, Analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, volume II: U.S. Geological Survey Open-File Report 87-585, p. M-1-110.

----in press, Probabilistic analysis of earthquake ground shaking hazard along the Wasatch Front, Utah, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-K-Z.

Zoback, M.L., 1992, Superimposed late Cenozoic, Mesozoic, and possible Proterozoic deformation along the Wasatch fault zone in central Utah, in Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-E, 20 p.

APPENDIX B

Age Data for Quaternary Volcanic Rocks in Utah

This table presents information on the ages of Quaternary volcanic rocks in Utah. Areas of volcanic rocks (in some cases composed of individual flows or cinder cones) have been defined as entries for this table using age information and spatial associations among smaller, discrete areas of mapped rocks. These specified areas (delimited on an index map, appendix C) are identified in the table by: (1) a name used in the literature or some geographic context (second column), and (2) a "location number" (first column), which consists of a number representing the 1° x 2° quadrangle where the area is located followed by a number that reflects the sequence in which the area was digitally compiled within each 1° x 2° quadrangle (in sequence following the faults and folds of appendix A). An alphabetical listing of volcanic areas with locations numbers appears in appendix C. Several individually dated, closely spaced features in the Mineral Mountains have been listed as separate table entries, but have been assigned common location numbers (no. 9-40 and 9-41).

Numeric ages (third column; listed numerically by alphabetized reference, fourth column) and descriptive age information (summarized under "Comments") for each entry in the table are the basis for assigning age categories to volcanic features on plate 2. For the purpose of creating plate 2, existing age information was used to infer general ages for undated volcanic rocks and vents within a given area (see text discussion on volcanic chronologies under "Tectonic activity parameters and compilation techniques").

Unless otherwise noted by the following symbols or by written comments, volcanic rocks are mafic or intermediate in composition, and rock ages were determined by the potassium-argon dating method.

+	Radiocarbon age
++	Obsidian hydration age. More than one value for the same feature is the result of differences in assumed temperature histories.
+++	Fission-track age.
++++	Ages determined by other dating method(s).
*	Rhyolite

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
6-20	southern Curlew Valley	~400	D.M. Miller, 1991; verbal communication, 1991	A basaltic ash (the "Thiokol" ash of Oviatt and Nash, 1989) interpreted from its stratigraphic context to be about 25,000 years old has been found interbedded with Lake Bonneville deposits in and north of the Great Salt Lake. The ash has a compositional affinity with, and thus may have erupted from, the volcanic field in southern Curlew Valley (Oviatt and Nash, 1989).
6-21	southern Curlew Valley (Cedar Hills)	~1150	D.M. Miller, 1991; verbal communication, 1991	
6-22	southern Curlew Valley	~720	D.M. Miller, 1991; verbal communication, 1991	
8-23	Smelter Knolls	310 ± 80	Turley and Nash, 1980	The surface morphology of the lava flow is similar to the Pavant flows (location no. 8-28). A phreatic explosion crater is younger than the basalt, but older than Bonneville deep water deposits (Oviatt, 1989).
8-24	Pot Mountain			The feature may be a volcanic neck. Its age is unknown, but is probably early Pleistocene (Oviatt, 1989).
8-25	Sunstone Knoll			The feature may be a volcanic neck. Its age is unknown, but is probably early Pleistocene (Oviatt, 1989).
8-26	Deseret	400 ± 400	Best and others, 1980	The geomorphic expression of the lava flow is similar to the Black Rock and Fumarole Butte (Crater Bench) flows (location nos. 8-27 and 9-51; Oviatt, 1989), suggesting an early Pleistocene age.
8-27	Fumarole Butte (Crater Bench)	950 ± 100 880 ± 10	H.H. Mehnert, written communication, in Galyardt and Rush, 1981 Peterson and Nash, 1980	

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
8-28	Pavant	160 ± 160 180 ± 180 220 ± 260 31 ± 38 32 ± 51 70 ± 56 93 ± 78 133 ± 97	Best and others, 1980 Condie and Barsky, 1972 Hoover, 1974	Field relations indicate a pre-Bonneville age (greater than about 30,000 years) for the lava flows. The reported ages have large uncertainties, although the well preserved morphology of the flows substantiates a middle or late Pleistocene age. The remains of a pre-Bonneville cinder cone south of Pavant Butte (location no. 8-29) are younger than the Pavant flows (Oviatt, 1989).
8-29	Pavant Butte	15.3^{+} - 16.0^{++++}	Oviatt and Nash, 1989	Radiocarbon ages on material stratigraphically associated with the Pavant Butte ash bed, plus stratigraphic and geomorphic relations at Pavant Butte and elsewhere, indicate that the tuff cone and ash were erupted into Lake Bonneville during its transgressive phase, when the lake was about 15 meters below the Bonneville shoreline.
9-37	northeast side, Mineral Mountains	920 ± 260	Nash, 1986	The vents are likely sources of flows in the Black Rock field (location no. 9-51). An undated vent has the same composition as a Black Rock flow.
9-38	North dome*	540 ± 60	Lipman and others, 1978	
9-39	Bailey Ridge*	1100^{++} 550 ± 300^{+++} 790 ± 80 800^{++} 950 ± 120	Friedman and Obradovich, 1981 Lipman and others, 1978 Nash, 1986	
9-40	Big Cedar Cove dome*	800 ± 40	Nash, 1986	

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
9-40	Wildhorse Canyon*	1100++	Friedman and Obradovich, 1981	
		850++	Lipman and others, 1978	
9-40	Little Bearskin Mountain*	610 ± 50	Lipman and others, 1978	
		740 ± 470	Nash, 1986	
9-40	Bearskin Mountain*	640++	Friedman and Obradovich, 1981	The anomalously young fission-track age probably is due to annealing of fossil fission tracks from a recent thermal event.
		<20+++	Lipman and others, 1978	
		480++		
		600 ± 120		
		750 ± 100		
		620 ± 110	Nash, 1986	
9-41	North Twin Flat Mountain*	680 ± 30	Nash, 1986	
		730 ± 60		
9-41	South Twin Flat Mountain*	320++	Friedman and Obradovich, 1981	
		250++	Lipman and others, 1978	
		500 ± 70		
		620 ± 40	Nash, 1986	
		630 ± 30		
		690 ± 40		
9-41	Tuff of Ranch Canyon*	550 ± 6	Izett, 1981	
		700 ± 40	Lipman and others, 1978	
9-42	Cove Fort	500 ± 100	Best and others, 1980	Although vegetation covers much of the field, surface flow features are well preserved. Flows in the northwest portion of the field overlie the Black Rock flows (location no. 9-51).
9-43	Manderfield (Cunningham Hill)	1100 ± 300	Best and others, 1980	The flows are stratigraphically above the Crater Knoll field (location no. 9-44; Nash, 1986).
		690 ± 480	Nash, 1986	

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
9-44	Crater Knoll	1000 ± 300	Best and others, 1980	Machette and others (1984) mapped the flows as middle Pleistocene in age.
9-45	Beaver Ridge	1500 ± 200	Nash, 1986	
9-46	Beaver Ridge 1	900 ± 100	Hoover, 1974	
9-47	Beaver Ridge 2	500 ± 100	Hoover, 1974	
9-48	Tabernacle Hill	14.3^{+} - 14.5^{++++}	Oviatt, 1991 Oviatt and Nash, 1989	The flow was extruded into Lake Bonneville at or near the level of the Provo shoreline, as evidenced by flow-margin pillow lavas and radiocarbon-dated tufa, the planar form and altitude of the flow, and stratigraphic position of the associated ash.
9-49	White Mountain*	390 ± 20 430 ± 70 400 ± 100	Lipman and others, 1978 Nash, 1986	Youngest dated rhyolite in Utah.
9-50	Kanosh (Black Rock Volcano)	618 ± 64 717 ± 83	Hoover, 1974	
9-51	Black Rock	970 ± 250 1320 ± 90	Condie and Barsky, 1972 Crecraft and others, 1981 Nash, 1986	The flows overlie lake sediments which contain the Pearlette type B ash erupted 1.8 million years ago. The flows originated from vents on the northeast margin of the Mineral Mountains (location no. 9-37; Nash, 1986).

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
9-52	Cedar Grove	300 ± 100	Best and others, 1980	The high viscosity of the latite lavas contributes to prominent, well developed flow features (Clark, 1977).
9-53	Red Knoll			The latite flows are stratigraphically above the Crater Knoll field (location no. 9-44), but their stratigraphic relation to other flows is unknown. The flows are oxidized and have not yielded accurate ages (Nash, 1986). The youngest of the Red Knoll flows appears geomorphically to be the youngest within the Cove Fort area (Clark, 1977). Machette and others (1984) mapped the flows as middle Pleistocene in age.
9-54	Burnt Mountain		Nash, 1986	The basalt flows, one of which has an age of 2.1 million years, post-date a 2.3-2.7 million-year-old suite of silicic volcanics and subsequent growth of the Cove Creek dome (location no. 9-5, appendix A). Geomorphic youthfulness (Clark, 1977) suggests a possible Quaternary age for some of the undated flows.
9-55	Ice Springs	<0.66 ± 0.17^{+}	Valastro and others, 1972	The radiocarbon age is from root fragments beneath the basalt flow. The tephra of Ice Springs is interbedded with late Holocene lagoon fill at one locality (Oviatt, 1991). The freshness of the lava suggested to Hoover (1974) and to Nash (1986) ages less than 4,000-1,000 years and 1,000 years, respectively.

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
10-25	western Pine Valley Mountains	1200 ± 100 1500 ± 200	Best and others, 1980	Flows have been categorized into relative age Stage II (together with the Airport, Middleton, and Washington flows near St. George, location no. 10-28) and younger Stage III (Hamblin, 1970). The reported ages pertain to Stage II flows. Hamblin (1963) had previously divided the flows into five stages and substages. Hausel and Nash (1977) assigned a Holocene age to volcanic rocks from several cones and flows in and around Pine Valley (not indicated on plate 2).
10-26	Gunlock	1600 ± 100 1100 ± 100	M.G. Best, written communication, in Anderson and Christenson, 1989 Best and others, 1980	The geomorphic position and gradient of the flow are similar to a flow above the St. George airport (Hamblin, 1970) whose age is 2.2 million years (Hamblin and others, 1981). The Gunlock flow is displaced 8 meters across the Gunlock fault (location no. 10-6, appendix A; Anderson and Christenson, 1989).
10-27	Santa Clara			Based on their fresh appearance and comparison with Sunset Crater features in Arizona, the flow and associated cones are judged to be ~1,000 years old, or slightly older (Hamblin, 1987).

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
10-28	Airport, Middleton, and Washington Black Ridges	1500 ± 100 1700 ± 100 1070 ± 40	Best and others, 1980 Hamblin and others, 1981	The three north-trending ridges of basalt near St. George and Washington are geomorphologically alike and are all thought to be similar in age (Hamblin, 1970, 1987). Flows at the north end of the Airport and Washington flows may be younger than ~0.5 million years old (Hamblin, 1987).
10-29	Hurricane area	289 ± 86 293 ± 87	Best and others, 1980 Hamblin and others, 1981	Multiple periods of extrusion are evidenced by differences in the relative ages of flows. The youngest flows west of Hurricane (at Volcano Mountain), which cap an older volcanic platform, retain their original margins and surface features (Hamblin, 1963, 1970). The reported ages pertain to one or more flows near Hurricane that have been displaced vertically 87 meters across the Hurricane fault (location no. 10-7, appendix A).
10-30	Pintura area	~1400 1000 ± 100	M.G. Best, written communication, in Anderson and Christenson, 1989 Best and others, 1980	Million-year age is from the center flow of a thick sequence of flows on top of the Hurricane Cliffs (Best and others, 1980).
10-31	North Creek area	260 ± 90 1000 ± 100 1130 ± 50 1400 ± 80 1600 ± 400 1100 ± 80	Best and others, 1980 Hamblin and others, 1981	Luedke and Smith (1978) indicated that the volcanic rocks at the south end of North Creek are <10,000 years old. However, Best and others (1980) obtained an age of 1 million years on a volcanic sample from that area.

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
10-32	Crater Hill			The field is composed of four flows that represent two periods of extrusion. The flows have been classified according to relative ages into Stages II and III after Hamblin, 1970 (Nielson, 1976). Faint evidence of flow morphology is preserved on the youngest flow, although features appear much less fresh than the ~1,000-year-old flows near Sunset Crater in Arizona. Thus, the youngest flow is estimated to be between a few thousand and a few tens of thousands of years old (Threet, 1958). Luedke and Smith (1978) included the field in their < 10,000-year age group.
10-33	southern Escalante Valley area			The volcanic rocks are shown as Quaternary basalts by Hintze (1980). Several ages from the area are Tertiary, but one sample yielded an age of 500,000 years (Best and others, 1980, table 1).
10-34	Enoch	1280 ± 400	Anderson and Mehnert, 1979	
10-35	Cinder Hill/Braffits Creek	930 ± 140 1000 ± 160 1110 ± 110	Anderson and Bucknam, 1979; Anderson and Mehnert, 1979	The basalt is monoclinally folded, indicating at least 250 meters of uplift across the Cedar City-Parowan monocline (location no. 10-21, appendix A). Gregory (1950) described fresh-looking sheets of basalt in the area.

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
10-36	Cross Hollow Hills	1200 ± 100	Anderson and others, 1978	The dated basalt appears to be interstratified with fanglomerate deposits, which are overlain by another Quaternary basalt (Averitt and Threet, 1973). A basalt exposed to the south in the North Hills (not shown on plate 2) has an age of 1.09 ± 0.34 million years (Anderson and Mehnert, 1979).
10-37	Water Canyon	440 ± 40	Fleck and others, 1975	The lava was extruded high on the plateau, flowed down ancestral Water Canyon, and has been displaced vertically about 200 meters across the Paragonah fault and an adjacent fault (location no. 10-22, appendix A; Anderson and Christenson, 1989).
10-38	Deep Creek area	360 ± 80 810 ± 50 1200 ± 600	Best and others, 1980	In places, stream erosion has isolated patches of basalt from the main flows. The volcanic rocks were tentatively estimated to be Pleistocene in age by Cashion (1961).
10-39	Black Mountain (Kolob Terrace)	800 ± 240 870 ± 40	Anderson and Mehnert, 1979 Best and others, 1980	The basalts are relatively old. Flow features have faded, and erosion has left remnants of basalt that were likely part of a continuous sheet extending northward from Black Mountain (Gregory, 1950).

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
10-40	Cedar Mountain area	1060 ± 280	Anderson and Mehnert, 1979	The dated basalt is equivalent to a dated flow in the North Hills area (not shown on plate 2), recording about 400 meters of vertical displacement across the Hurricane fault (location no. 10-7, appendix A; Anderson and Mehnert, 1979). Flow features have faded and the lateral extent of the flows has been reduced by erosion (Gregory, 1950).
10-41	eastern Markagunt Plateau	520 ± 50	Best and others, 1980	On many flows, original surface features and flow margins are preserved, and soil development is minimal. Lava that was extruded into valleys disrupted drainages; one flow dammed Duck Creek Valley, forming Navajo Lake (Gregory, 1950). The youngest basalt may be as young as ~1,000 years old based on a tree ring study which showed that junipers on the lava beds are as old as 900 years (Gregory, 1949). Luedke and Smith (1978) delimited the general extent of volcanic rocks in the area considered to be <10,000 years old (see plate 2).
10-42	Red Canyon	560 ± 70	Best and others, 1980	The lava is displaced about 200 meters across the Sevier fault (location no. 10-1, appendix A; Anderson and others, 1978).

Location No.	Name or Location of Feature	Reported Ages ($X10^3$ years)	References	Comments
10-43	Black Mountain/Buck Knoll/Bald Knoll	560 ± 60	Best and others, 1980	In places, stream erosion has isolated patches of basalt from the main flows. The volcanic rocks were tentatively estimated to be Pleistocene in age by Cashion (1961). The dated flow is from Black Mountain on the East Fork of the Virgin River. A younger flow in the area is undated (Anderson and Christenson, 1989).

REFERENCES - APPENDIX B

Anderson, R.E., and Bucknam, R.C., 1979, Two areas of probable Holocene deformation in southwestern Utah, in Whitten, C.A., Green, Ronald, and Meade, B.K., editors., Recent crustal movements, 1977: Tectonophysics, v. 52, no. 1-4, p. 417-430.

Anderson, R.E., Bucknam, R.C., and Hamblin, W.K., 1978, Road log to the Quaternary tectonics of the Intermountain seismic belt between Provo and Cedar City, Utah: Geological Society of America, Rocky Mountain Section Annual Meeting, Provo, Utah, Field Trip no. 8, 50 p.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p., scale 1:250,000.

Anderson, R.E., and Mehnert, H.H., 1979, Reinterpretation of the history of the Hurricane fault in Utah, in Newman, G.D., and Goode, H.D., editors, 1979 Basin and Range symposium and Great Basin field conference: Denver, Rocky Mountain Association of Geologists and Utah Geological and Mineral Survey, p. 145-165.

Averitt, Paul, and Threet, R.L., 1973, Geologic map of the Cedar City quadrangle, Iron County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1120, scale 1:24,000.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, no. 10, p. 1035-1050.

Cashion, W.B., 1961, Geology and fuel resources of the Orderville-Glendale area, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C-49, scale 1:62,500.

Clark, E.E., 1977, Late Cenozoic volcanic and tectonic activity along the eastern margin of the Great Basin, in the proximity of Cove Fort, Utah: Brigham Young University Geology Studies, v. 24, pt. 1, p. 87-114.

Condie, K.C., and Barsky, C.K., 1972, Origin of Quaternary basalt from the Black Rock Desert region, Utah: Geological Society of America Bulletin, v. 83, no. 2, p. 333-352.

Crecraft, H.R., Nash, W.P., and Evans, S.H., Jr., 1981, Late Cenozoic volcanism at Twin Peaks, Utah -- geology and petrology: Journal of Geophysical Research, v. 86, no. B11, p. 10303-10320.

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in the High Plateau region of Utah, in Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., Cenozoic geology of southwestern high plateaus of Utah: Geological Society of America Special Paper 160, p. 53-61.

Friedman, Irving, and Obradovich, John, 1981, Obsidian hydration dating of volcanic events: Quaternary Research, v. 16, no. 1, p. 37-47.

Galyardt, G.L., and Rush, R.E., 1981, Geologic map of the Crater Springs Known Geothermal Area and vicinity, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1297, scale 1:24,000.

Gregory, H.E., 1949, Geologic and geographic reconnaissance of eastern Markagunt Plateau, Utah: Geological Society of America Bulletin, v. 60, no. 6, p. 969-998.

----1950, Geology of eastern Iron County, Utah: Utah Geological and Mineral Survey Bulletin 37, 153 p.

Hamblin, W.K., 1963, Late Cenozoic basalts of the St. George Basin, Utah, in Heylmun, E.B., editor, Guidebook to the geology of southwestern Utah: Intermountain Association of Petroleum Geologists Twelfth Annual Field Conference, p. 84-89.

----1970, Late Cenozoic basalt flows of the western Grand Canyon region, in Hamblin, W.K., and Best, M.G., editors, The western Grand Canyon district: Utah Geological Society, Guidebook to the Geology of Utah Number 23, p. 21-37.

----1987, Late Cenozoic volcanism in the St. George Basin, Utah, in Beus, S.S., editor, Centennial field guide, volume 2, Rocky Mountain Section of the Geological Society of America: Geological Society of America, p. 291-294.

Hamblin, W.K., Damon, P.E., and Bull, W.B., 1981, Estimates of vertical crustal strain rates along the western margins of the Colorado Plateau: Geology, v. 9, no. 7, p. 293-298.

Hausel, W.D., and Nash, W.P., 1977, Petrology of Tertiary and Quaternary volcanic rocks, Washington County, southwestern Utah: Geological Society of America Bulletin, v. 88, no. 12, p. 1831-1842.

Hintze, L.F., compiler, 1980, Geologic map of Utah: Utah Geological and Mineral Survey Map A-1, scale 1:500,000.

Hoover, J.D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 3-72.

Izett, G.A., 1981, Chart showing stratigraphic succession, isotopic ages, and partial chemical analyses of certain silicic volcanic ash beds (4.0 to 0.1 m.y.) of the western United States: U.S. Geological Survey Open-File Report 81-763.

Lipman, P.W., Rowley, P.D., Mehnert, H.H., Evans, S.H., Jr., Nash, W.P., and Brown, F.H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah - geothermal and archeological significance: U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 133-147.

Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Colorado, Utah, and southwestern Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1091-B, scale 1:1,000,000.

Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

Miller, D.M., 1991, Mesozoic and Cenozoic tectonic evolution of the northeastern Great Basin, in Buffa, R.H., and Coyner, A.R., editors, Geology and ore deposits of the Great Basin -- fieldtrip guidebook compendium: Geological Society of Nevada, volume 1, p. 202-228.

Nash, W.P., 1986, Distribution, lithology, and ages of late Cenozoic volcanism on the eastern margin of the Great Basin, west-central Utah: Salt Lake City, University of Utah Research Institute, Earth Science Laboratory Final Report for U.S. Department of Energy, contract DEAC0780 ID12079, DOE/ID/12079-131, 82 p.

Nielson, R.L., 1976, The geomorphic evolution of the Crater Hill volcanic field of Zion National Park: Brigham Young University Geology Studies, v. 24, pt. 1, p. 55-70.

Oviatt, C.G., 1989, Quaternary geology of part of the Sevier Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 70, 41 p.

Oviatt, C.G., 1991, Quaternary geology of the Black Rock Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 73, 23 p.

Oviatt, C.G., and Nash, W.P., 1989, Late Pleistocene basaltic ash and volcanic eruptions in the Bonneville Basin, Utah: Geological Society of America Bulletin, v. 101, no. 2, p. 292-303.

Peterson, J.B., and Nash, W.P., 1980, II. Geology and petrology of the Fumarole Butte volcanic complex, Utah, Studies in late Cenozoic volcanism in west-central Utah: Utah Geological and Mineral Survey Special Studies 52, p. 34-58.

Threet, R.L., 1958, Crater Hill lava flow, Zion National Park, Utah: Geological Society of America Bulletin, v. 69, no. 8, p. 1065-1070.

Turley, C.H., and Nash, W.P., 1980, I. Petrology of late Tertiary and Quaternary volcanism in western Juab and Millard Counties, Utah, in Studies in late Cenozoic volcanism in west-central Utah: Utah Geological and Mineral Survey Special Studies 52, p. 1-33.

Valastro, S., Jr., Davis, E.M., and Varela, A.G., 1972, University of Texas at Austin radiocarbon dates IX: Radiocarbon, v. 14, no. 2, p. 461-485.

APPENDIX C
Alphabetical Listing of Quaternary Faults and Folds in Utah
(with location numbers)

Annabella graben
(9-32)

Antelope Range fault
(10-11)

Aquarius and Awapa Plateaus (faults)
(14-2)

Bald Mountain fault
(12-15)

Bear Lake
- west side (fault)
(11-5)

Bear River fault zone
(12-18)

Bear River Range (faults)
(11-7)

Beaver Basin (faults and a fold)
(9-3, 9-4)

Beaver Basin
- eastern margin faults
(9-3)

Beaver Basin
- Last Chance Bench antiform, Maple Flat horst, and central basin faults
(9-4)

Beaver Ridge faults
(9-19)

Big and Water Hollows (faults and warps?)
(13-24)

Big Pass fault
(6-7)

Black Mountains (faults)
(9-12)

Black Rock area (faults)
(9-16)

Blue Spring Hills (faults)
(6-12)

Bright Angel fault system
(15-1)

Broadmouth Canyon (faults)
(11-13)

Buckskin Valley (faults)
(9-30)

Castle Valley (warp and faults)
(18-4)

Cedar City-Parowan monocline
(10-21)

Cedar Mountains
- east side (faults)
(7-9)

Cedar Valley
- north end (faults)
(10-16)

Cedar Valley
- south end (fault)
(7-3)

Cedar Valley
- west side (faults)
(10-15)

Clear Lake fault zone
(8-5)

Clover fault zone
(7-11)

Cove Creek dome
(9-5)

APPENDIX C
Alphabetical Listing of Quaternary Volcanic Rocks in Utah
(with location numbers)

Airport, Middleton, and
Washington Black Ridges
(10-28)

Bailey Ridge
(9-39)

Bearskin Mountain
(9-40)

Beaver Ridge
(9-45)

Beaver Ridge 1
(9-46)

Beaver Ridge 2
(9-47)

Big Cedar Cove dome
(9-40)

Black Mountain (Kolob Terrace)
(10-39)

Black Mountain/Buck Knoll/Bald Knoll
(10-43)

Black Rock
(9-51)

Burnt Mountain
(9-54)

Cedar Grove
(9-52)

Cedar Mountain area
(10-40)

Cinder Hill/Braffits Creek
(10-35)

Cove Fort
(9-42)

Crater Hill
(10-32)

Crater Knoll
(9-44)

Cross Hollow Hills
(10-36)

Deep Creek area
(10-38)

Deseret
(8-26)

eastern Markagunt Plateau
(10-41)

Enoch
(10-34)

Fumarole Butte (Crater Bench)
(8-27)

Gunlock
(10-26)

Hurricane area
(10-29)

Ice Springs
(9-55)

Kanosh (Black Rock Volcano)
(9-50)

Little Bearskin Mountain
(9-40)

Manderfield (Cunningham Hill)
(9-43)

North Creek area
(10-31)

North dome
(9-38)

APPENDIX C
References Used to Compile Plates 1 and 2
(Index maps showing location numbers, in pocket)

(note: References for age designations appear in appendices A and B)

Location No.	Reference(s)
6-01	Robison, 1986
6-02	Robison, 1986
6-03	Robison, 1986
6-04	Robison, 1986
6-05	Doelling, 1980; Machette and others, 1992; Oviatt, 1986a; Oviatt, 1986b; Personius, 1990
6-06	Personius, 1990
6-07	Doelling, 1980
6-08	Mikulich and Smith, 1974; Viveiros, 1986
6-09	Currey, 1980
6-10	Jordan, 1985; Jordan and others, 1988
6-11	Miller and Lush, 1991; Miller and others, 1990
6-12	Everitt, 1982; Hecker, 1989
6-13	Oviatt, 1986a
6-14	Mikulich and Smith, 1974
6-15	Cluff and others, 1974; Machette and others, 1992
6-16	Cluff and others, 1974
6-17	Doelling, 1980
6-18	Doelling, 1980
6-19	Compton, 1975; Doelling, 1980; Todd, 1973
6-20	Miller, 1991
6-21	Miller, 1991
6-22	Miller, 1991
7-01	Barnhard and Dodge, 1988
7-02	Madsen, 1987
7-03	Hecker, 1989
7-04	Moore and Sorensen, 1979
7-05	Moore and Sorensen, 1979
7-06	Moore and Sorensen, 1979
7-07	Barnhard and Dodge, 1988; Hecker, 1989; Moore and Sorensen, 1979
7-08	Barnhard and Dodge, 1988
7-09	Barnhard and Dodge, 1988
7-10	Barnhard and Dodge, 1988
7-11	Barnhard and Dodge, 1988
7-12	Barnhard and Dodge, 1988
7-13	Barnhard and Dodge, 1988
7-14	Barnhard and Dodge, 1988
7-15	Barnhard and Dodge, 1988
7-16	Barnhard and Dodge, 1988
7-17	Dohrenwend and others, 1991a
8-01	Bucknam and Anderson, 1979; Oviatt, 1989b
8-02	Oviatt, 1989b
8-03	Oviatt, 1989b

8-04	Galyardt and Rush, 1981
8-05	Oviatt, 1989b; Oviatt, 1991
8-06	Morris, 1987; Oviatt, 1989b; Oviatt, 1991
8-07	Ertec Western, 1981
8-08	Ertec Western, 1981
8-09	Ertec Western, 1981
8-10	Ertec Western, 1981
8-11	Ertec Western, 1981
8-12	Dohrenwend and others, 1991b; Ertec Western, 1981
8-13	Ertec Western, 1981
8-14	Ertec Western, 1981
8-15	Bucknam, 1989; Ertec Western, 1981
8-16	Anderson and Miller, 1979; Bucknam and Anderson, 1979; Goode, 1959; Hecker, 1989; Morris, 1975; Morris, 1987
8-17	Oviatt, 1992
8-18	Oviatt, 1992
8-19	Oviatt, 1992
8-20	Oviatt, 1992
8-21	Oviatt, 1992
8-22	Dames and Moore, 1978
8-23	Oviatt, 1989b
8-24	Oviatt, 1989b
8-25	Oviatt, 1989b
8-26	Oviatt, 1989b
8-27	Morris, 1987
8-28	Morris, 1987; Steven and others, 1990
8-29	Oviatt, 1989b
9-01	Oviatt, 1991; Steven and Morris, 1983
9-02	Anderson and Bucknam, 1979; Steven and Morris, 1983
9-03	Anderson and others, 1990; Machette, 1985
9-04	Anderson and others, 1990; Machette, 1985; Steven and Morris, 1983
9-05	Nash, 1981; Oviatt, 1989a; Oviatt, 1991
9-06	Anderson and others, 1986; Cunningham and others, 1983; Hecker, 1987c; Rowley, 1979; Rowley and others, 1979; Rowley and others, 1988
9-07	Cunningham and others, 1983; Steven and others, 1990; Willis, 1988
9-08	Callaghan and Parker, 1961; Cunningham and others, 1983
9-09	Callaghan and Parker, 1962; Cunningham and others, 1983
9-10	Cunningham and others, 1983
9-11	Cunningham and others, 1983
9-12	Ertec Western, 1981; Rowley, 1978
9-13	Rowley, 1978
9-14	Anderson and Bucknam, 1979; Ertec Western, 1981; Rowley, 1978
9-15	Anderson and Grant, 1986
9-16	Oviatt, 1991
9-17	Oviatt, 1991; Steven and Morris, 1983
9-18	Oviatt, 1991
9-19	Oviatt, 1991
9-20	Oviatt, 1991
9-21	Ertec Western, 1981
9-22	Ertec Western, 1981
9-23	Ertec Western, 1981
9-24	Ertec Western, 1981

9-25	Ertec Western, 1981
9-26	Ertec Western, 1981
9-27	Ertec Western, 1981
9-28	Ertec Western, 1981; Oviatt, 1989b
9-29	Steven and others, 1990
9-30	Anderson and Bucknam, 1979
9-31	Anderson and Bucknam, 1979
9-32	Anderson and Bucknam, 1979
9-33	Anderson and Bucknam, 1979
9-34	Anderson and Christenson, 1989; Ertec Western, 1981
9-35	Cunningham and others, 1983
9-36	Dohrenwend and others, 1991b
9-37	Steven and others, 1990
9-38	Sibbett and Nielson, 1980; Steven and others, 1990
9-39	Sibbett and Nielson, 1980; Steven and others, 1990
9-40	Sibbett and Nielson, 1980; Steven and others, 1990
9-41	Sibbett and Nielson, 1980; Steven and others, 1990
9-42	Steven and Morris, 1983
9-43	Machette and others, 1984
9-44	Machette and others, 1984; Steven and Morris, 1983
9-45	Hoover, 1974; Oviatt, 1991
9-46	Hoover, 1974; Oviatt, 1991
9-47	Hoover, 1974; Oviatt, 1991
9-48	Oviatt, 1991
9-49	Oviatt, 1991
9-50	Oviatt, 1991
9-51	Oviatt, 1991
9-52	Steven and Morris, 1983
9-53	Machette and others, 1984; Steven and Morris, 1983
9-54	Steven and Morris, 1983
9-55	Morris, 1987; Steven and others, 1990
10-01	Anderson and Christenson, 1989
10-02	Anderson and Christenson, 1989
10-03	Anderson and Christenson, 1989
10-04	Anderson and Christenson, 1989
10-05	Anderson and Christenson, 1989
10-06	Anderson and Christenson, 1989
10-07	Anderson and Christenson, 1989
10-08	Anderson and Christenson, 1989
10-09	Anderson and Christenson, 1989
10-10	Anderson and Christenson, 1989
10-11	Anderson and Christenson, 1989
10-12	Anderson and Christenson, 1989
10-13	Anderson and Christenson, 1989
10-14	Anderson and Christenson, 1989
10-15	Anderson and Christenson, 1989
10-16	Anderson and Christenson, 1989
10-17	Anderson and Christenson, 1989
10-18	Anderson and Christenson, 1989
10-19	Anderson and Christenson, 1989
10-20	Anderson and Bucknam, 1979; Anderson and Christenson, 1989
10-21	Anderson and Christenson, 1989

10-22	Anderson and Christenson, 1989
10-23	Anderson and Christenson, 1989; Carpenter and others, 1967
10-24	Anderson and Christenson, 1989
10-25	Anderson and Christenson, 1989; Hintze, 1963
10-26	Hintze, 1963
10-27	Hintze, 1963; Luedke and Smith, 1978
10-28	Hintze, 1963
10-29	Anderson and Christenson, 1989; Hamblin, 1984; Hintze, 1963
10-30	Anderson and Christenson, 1989; Hintze, 1963
10-31	Anderson and Christenson, 1989; Hintze, 1963
10-32	Hintze, 1963
10-33	Anderson and Christenson, 1989; Hintze, 1963
10-34	Hintze, 1963
10-35	Anderson and Christenson, 1989; Hintze, 1963
10-36	Hintze, 1963
10-37	Hintze, 1963
10-38	Anderson and Christenson, 1989; Hintze, 1963
10-39	Hintze, 1963
10-40	Hintze, 1963
10-41	Anderson and Christenson, 1989; Hintze, 1963; Luedke and Smith, 1978
10-42	Anderson and Christenson, 1989; Hintze, 1963
10-43	Anderson and Christenson, 1989; Hintze, 1963
11-01	McCalpin, 1989
11-02	McCalpin, 1989
11-03	Cluff and others, 1974; McCalpin, 1989; Sullivan, Nelson, and others, 1988
11-04	Hecker, 1987b
11-05	Kaliser, 1972
11-06	Hecker, 1987b
11-07	Sullivan, Nelson, and others, 1988
11-08	Hecker, 1987a
11-09	Sullivan, Nelson, and others, 1988
11-10	Personius, 1990; Sullivan, Nelson, and others, 1988
11-11	Sullivan, Nelson, and others, 1988
11-12	Sullivan, Nelson, and others, 1988
11-13	Sullivan, Nelson, and others, 1988
11-14	Personius, 1990; Sullivan, Nelson, and others, 1988
11-15	Sullivan, Nelson, and others, 1988
11-16	Sullivan, Nelson, and others, 1988
11-17	Sullivan, Nelson, and others, 1988
11-18	Sullivan, Nelson, and others, 1988
11-19	Sullivan, Nelson, and others, 1988
11-20	Bryant, 1990; Stokes and Madsen, 1961
11-21	Cluff and others, 1974; Oviatt, 1986a; Oviatt, 1986b
11-22	Nelson and Personius, 1990; Personius, 1990
12-01	Stokes and Madsen, 1961
12-02	Martin and others, 1985
12-03	Machette, 1989
12-04	Nelson and Martin, 1982
12-05	Nelson and Martin, 1982
12-06	Bryant, 1990; Nelson and Personius, 1990; Personius and Scott, 1992; Van Horn and Crittenden, 1987
12-07	Personius and Scott, 1992

12-08	Personius and Scott, 1992
12-09	Sullivan, Nelson, and others, 1988
12-10	Sullivan, Nelson, and others, 1988
12-11	Sullivan, Nelson, and others, 1988
12-12	Sullivan, Nelson, and others, 1988
12-13	Sullivan, Nelson, and others, 1988
12-14	Sullivan, Ostenaa, and other, 1988
12-15	Sullivan, Martin, and other, 1988
12-16	Sullivan, Nelson, and others, 1988
12-17	Sullivan, Nelson, and others, 1988
12-18	Sullivan, Ostenaa, and other, 1988
12-19	Brimhall and Merritt, 1981
13-01	Witkind and Sprinkel, 1982
13-02	Robison, 1989
13-03	Jensen, 1984; Meibos, 1983
13-04	Davis, 1983; Jensen, 1984
13-05	Foley and others, 1986
13-06	Foley and others, 1986
13-07	Foley and others, 1986
13-08	Foley and others, 1986
13-09	Foley and others, 1986
13-10	Foley and others, 1986
13-11	Foley and others, 1986
13-12	Foley and others, 1986
13-13	Foley and others, 1986
13-14	Clark, 1990
13-15	Witkind and others, 1987
13-16	Willis, 1989
13-17	Willis, 1989
13-18	Hecker, 1989
13-19	Witkind and others, 1978
13-20	Oviatt, 1992; Witkind and others, 1987
13-21	Machette and others, 1992
13-22	Machette and others, 1992
13-23	Machette and others, 1992
13-24	Hawks, 1980
13-25	Sprinkel, 1990
13-26	Witkind and Page, 1984
14-01	Williams and Hackman, 1971
14-02	Williams and Hackman, 1971
14-03	Williams and Hackman, 1971
14-04	Williams, 1964; Williams and Hackman, 1971
14-05	Rowley and others, 1986
15-01	Hintze, 1963
16-01	Rowley and others, 1985
16-02	Rowley and others, 1985
18-01	Williams, 1964
18-02	Williams, 1964
18-03	Gualtieri, 1988; Williams, 1964
18-04	Williams, 1964
18-05	Williams, 1964
18-06	Williams, 1964

18-07	Williams, 1964
18-08	Woodward-Clyde Consultants, 1982a
18-09	Woodward-Clyde Consultants, 1982b
18-10	Woodward-Clyde Consultants, 1982b
18-11	Woodward-Clyde Consultants, 1982b
18-12	Woodward-Clyde Consultants, 1982b
19-01	Woodward-Clyde Consultants, 1982a

REFERENCES

Anderson, J.J., and Grant, T.C., 1986, Geologic map of the Fremont Pass quadrangle, Iron and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 81, 6 p. pamphlet, scale 1:24,000.

Anderson, J.J., Rowley, P.D., and Blackman, J.T., 1986, Geologic map of the Circleville quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 82, 5 p. pamphlet, scale 1:24,000.

Anderson, J.J., Rowley, P.D., Machette, M.N., Decatur, S.H., and Mehnert, H.H., 1990, Geologic map of the Nevershine Hollow area, eastern Black Mountains, southern Tushar Mountains, and northern Markagunt Plateau, Beaver and Iron Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1999, scale 1:50,000.

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Long Beach, California, Fugro, Inc., 35 p., scale 1:500,000.

Anderson, R.E., and Bucknam, R.C., 1979, Map of fault scarps in unconsolidated sediments, Richfield 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-1236, 15 p., scale 1:250,000.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City 1° x 2° quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p., scale 1:250,000.

Barnhard, T.P., and Dodge, R.L., 1988, Map of fault scarps formed on unconsolidated sediments, Tooele 1° x 2° quadrangle, northwestern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1990, scale 1:250,000.

Brimhall, W.H., and Merritt, L.B., 1981, The geology of Utah Lake--implications for resource management: Great Basin Naturalist Memoirs Number 5, p. 24-42, scale 1:250,000.

Bryant, Bruce, 1990, Geologic map of the Salt Lake City 30' x 60' quadrangle, north-central Utah, and Uinta County, Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1944, scale 1:100,000.

Bucknam, R.C., 1989, written communication and unpublished mapping, scale 1:24,000.

Bucknam, R.C., and Anderson, R.E., 1979, Map of fault scarps on unconsolidated sediments, Delta 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 79-366, 21 p., scale 1:250,000.

Callaghan, Eugene, and Parker, R.L., 1961, Geologic map of the Monroe quadrangle, Utah: U.S. Geological Survey Map GQ-155, scale 1:62,500.

----1962, Geologic map of the Sevier quadrangle, Utah: U.S. Geological Survey Map GQ-156, scale

1:62,500.

Carpenter, C.H., Robinson, G.B., and Bjorkland, L.J., 1967, Ground-water conditions and geologic reconnaissance of the upper Sevier River Basin: U.S. Geological Survey Water-Supply Paper 1836, 91 p., scale 1:250,000.

Clark, D.L., 1990, Provisional geologic map of the Juab quadrangle, Juab County, Utah: Utah Geological and Mineral Survey Map 132, 14 p. pamphlet, scale 1:24,000.

Cluff, L.S., Glass, C.E., and Brogan, G.E., 1974, Investigation and evaluation of the northern Wasatch and Cache Valley faults: a guide to land-use planning with recommendations for seismic safety: Oakland, California, Woodward-Lundgren and Associates, unpublished report for the U.S. Geological Survey, contract no. 14-08-001-13665, 147 p., scale 1:24,000.

Compton, R.R., 1975, Geologic map of the Park Valley quadrangle, Box Elder County, Utah and Cassia County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-873, scale 1:31,680.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Glassgold, L.B., and Anderson, J.J., 1983, Geologic map of the Tushar Mountains and adjoining areas, Marysvale volcanic field, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1430-A, scale 1:50,000.

Currey, D.R., 1980, Coastal geomorphology of Great Salt Lake and vicinity, in Gwynn, J.W., editor, Great Salt Lake--a scientific, historical and economic overview: Utah Geological and Mineral Survey Bulletin 116, p. 69-82, scale 1:250,000.

Dames and Moore, 1978, Phase II - preliminary geotechnical studies, proposed powerplant, lower Sevier River area, Utah: Los Angeles, unpublished consultant's report for the Intermountain Power Project, Job nos. 10629-002-06 and 10629-003-06, 45 p., scale 1:24,000.

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

Doelling, H.H., 1980, Geology and mineral resources of Box Elder County, Utah: Utah Geological and Mineral Survey Bulletin 115, 251 p., scale 1:125,000.

Dohrenwend, J.C., Schell, B.A., and Moring, B.C., 1991a, Reconnaissance photogeologic map of young faults in the Elko 1° by 2° quadrangle, Nevada and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2179, scale 1:250,000.

----1991b, Reconnaissance photogeologic map of young faults in the Lund 1° by 2° quadrangle, Nevada and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2180, scale 1:250,000.

Ertec Western, Inc., 1981, MX siting investigation, faults and lineaments in the MX siting region, Nevada and Utah: Long Beach, California, unpublished consultant's report no. E-TR-54 for U.S. Air Force, volume I, 77 p.; volume II, variously paginated, scale 1:250,000.

Everitt, B.L., 1982, Potential for ground-water development in the Thatcher-Penrose area: Utah Division of Water Resources unpublished memorandum, 10 p., scale 1:62,500.

Foley, L.L., Martin, R.A., Jr., and Sullivan, J.T., 1986, Seismotectonic study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah: Denver, U.S. Bureau of

Reclamation Seismotectonic Report 86-7, 132 p., scales 1:60,000 and 1:155,000.

Galyardt, G.L., and Rush, F.E., 1981, Geologic map of the Crater Springs Known Geothermal Resources Area and vicinity, Juab and Millard Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1297, scale 1:24,000.

Goode, H.D., 1959, Surficial deposits, geomorphology, and Cenozoic history of the Eureka quadrangle, Utah: Boulder, University of Colorado, Ph.D. dissertation, 120 p., scale 1:20,000.

Gualtieri, J.L., 1988, Geologic map of the Westwater 30' x 60' quadrangle, Grand and Uintah Counties, Utah and Garfield and Mesa Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-1765, scale 1:100,000.

Hamblin, W.K., 1984, Unpublished geologic map of the Hurricane 15-minute quadrangle, Washington County, Utah, scale 1:62,500.

Hawks, R.L., Jr., 1980, The stratigraphy and structure of the Cedar Hills, Sanpete County, Utah: Brigham Young University Geology Studies, v. 27, pt. 1, p. 67-80, scale 1:24,000.

Hecker, Suzanne, 1987a, July 1 and 2 reconnaissance of Bear Lake fault by Suzanne Hecker and Gary Christenson: Utah Geological and Mineral Survey unpublished memorandum, 3 p., scale 1:24,000.

----1987b, June 29-30 reconnaissance of Crawford Mountains and "Salertus Creek" faults by Suzanne Hecker and Gary E. Christenson: Utah Geological and Mineral Survey unpublished memorandum, 5 p., scale 1:100,000.

----1987c, Unpublished mapping, scale 1:24,000.

----1989, Unpublished mapping, scales 1:24,000, 1:62,500, and 1:100,000.

Hintze, L.H., compiler, 1963, Geologic map of Utah, southwest quarter: Utah State Land Board, scale 1:250,000.

Hoover, J.D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 3-72.

Jensen, M.E., 1984, Geologic map and section of the Slate Jack Canyon quadrangle, Juab and Utah Counties, Utah: Brigham Young University Geology Studies, v. 33, pt. 1, p. 1-19, scale 1:24,000.

Jordan, T.E., 1985, Geologic map of the Bulls Pass quadrangle, Box Elder County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1491, scale 1:24,000.

Jordan, T.E., Allmendinger, R.W., and Crittenden, M.D., Jr., 1988, Geologic map of the Howell quadrangle, Box Elder County, Utah: Utah Geological and Mineral Survey Map 107, 10 p. pamphlet, scale 1:24,000.

Kaliser, B.N., 1972, Environmental geology of the Bear Lake area, Rich County, Utah: Utah Geological and Mineral Survey Bulletin 96, 32 p., scale 1:42,240.

Luedke, R.G., and Smith, R.L., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Colorado, Utah, and southwestern Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1091-B, scale 1:1,000,000.

Machette, M.N., 1985, Late Cenozoic geology of the Beaver Basin, southwestern Utah: Brigham Young University Geology Studies, v. 32, pt. 1, p. 9-37, scale 1:100,000.

----1989, Preliminary surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counies, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2109, 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, in Gori, P.L., and Hays, W.W., editors., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p., figure 6, scale 1:352,000, figure 18, scale 1:264,000, and figure 19, scale 1:270,000.

Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

Madsen, D.B., 1987, written communication and unpublished mapping, scale 1:24,000.

Martin, R.A., Jr., Nelson, A.R., Weisser, R.R., and Sullivan, J.T., 1985, Seismotectonic study for Taskeech Dam and Reservoir site, Upalco Unit and Upper Stillwater Dam and Reservoir site, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 85-2, 95 p., scale 1:24,000.

McCalpin, J.P., 1989, Surficial geologic map of the East Cache fault zone, Cache County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2107, scale 1:50,000.

Meibos, L.C., 1983, Structure and stratigraphy of the Nephi NW 7½-minute quadrangle, Juab County, Utah: Brigham Young University Geology Studies, v. 30, pt. 1, p. 37-58, figure 20, scale 1:24,000.

Mikulich, M.J., and Smith, R.B., 1974, Seismic reflection and aeromagnetic surveys of the Great Salt Lake, Utah: Geological Society of America Bulletin, v. 85, no. 6, p. 991-1002, scale 1:695,000.

Miller, D.M., 1991, Mesozoic and Cenozoic tectonic evolution of the northeastern Great Basin, in Buffa, R.H., and Coyner, A.R., editors, Geology and ore deposits of the Great Basin -- fieldtrip guidebook compendium: Geological Society of Nevada, volume 1, p. 202-228, scale 1:18,000,000.

Miller, D.M., and Lush, A.P., 1991, Geologic map of the Pilot Peak quadrangle, Box Elder County, Utah, and Elko County, Nevada: Utah Geological and Mineral Survey Open-File Report 208, 49 p., scale 1:24,000.

Miller, D.M., Lush, A.P., and Schneyer, J.D., 1990, Geologic map of the Patterson Pass quadrangle, Box Elder County, Utah, and Elko County, Nevada: Utah Geological and Mineral Survey Open-File Report 172, 56 p., scale 1:24,000.

Moore, W.J., and Sorensen, M.L., 1979, Geologic map of the Tooele 1° x 2° quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1132, scale 1:250,000.

Morris, H.T., 1975, Geologic map and sections of the Tintic Mountain quadrangle and adjacent part of the McIntyre quadrangle, Juab and Utah Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-883, scale 1:24,000.

----1987, Preliminary geologic map of the Delta 2° quadrangle, Tooele, Juab, Millard, and Utah Counties, Utah: U.S. Geological Survey Open-File Report 87-185, 18 p., scale 1:250,000.

Nash, W.P., 1981, Topical report, geologic map of the South Twin Peak-Cove Creek area, west-central Utah: Unpublished report for U.S. Department of Energy, contract no. DE-AC07-801ID12079, DOE/ID/12079-38, 9 p., scale 1:24,000.

Nelson, A.R., and Martin, R.A., Jr., 1982, Seismotectonic study for Soldier Creek Dam, Central Utah Project: Denver, U.S. Bureau of Reclamation Seismotectonic Report 82-1, 115 p., scale 1:250,000.

Nelson, A.R., and Personius, S.F., 1990, Preliminary surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2132, 22 p. pamphlet, scale 1:50,000.

Oviatt, C.G., 1986a, Geologic map of the Cutler Dam quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 91, 7 p. pamphlet, scale 1:24,000.

----1986b, Geologic map of the Honeyville quadrangle, Box Elder and Cache Counties, Utah: Utah Geological and Mineral Survey Map 88, 13 p. pamphlet, scale 1:24,000.

----1989a, written communication and unpublished mapping, scale 1:24,000.

----1989b, Quaternary geology of part of the Sevier Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 70, 41 p., scale 1:100,000.

----1991, Quaternary geology of the Black Rock Desert, Millard County, Utah: Utah Geological and Mineral Survey Special Studies 73, 23 p., scale 1:100,000.

----1992, Quaternary geology of the Scipio Valley area, Millard and Juab Counties, Utah: Utah Geological Survey Special Studies 79, 16 p., scale 1:62,500.

Personius, S.F., 1990, Surficial geologic map of the Brigham City segment and adjacent parts of the Weber and Collinston segments, Wasatch fault zone, Box Elder and Weber Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map 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.

Robison, R.M., 1986, The surficial geology and neotectonics of Hansel Valley, Box Elder County, Utah: Logan, Utah State University, M.S. thesis, 120 p, scale 1:24,000.

----1989, written communication and unpublished mapping, scale 1:24,000.

Rowley, P.D., 1978, Geologic map of the Thermo 15-minute quadrangle, Beaver and Iron Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1493, scale 1:62,500.

----1979, Geologic map of the Marysvale SE quadrangle, Piute County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1115, scale 1:24,000.

Rowley, P.D., Cunningham, C.G., Anderson, J.J., and Steven, T.A., 1979, Geologic map of the Marysvale SW quadrangle, Piute County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map

MF-1116, scale 1:24,000.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1988, Geologic map of the Marysvale quadrangle, Piute County, Utah: Utah Geological and Mineral Survey Map 105, 15 p. pamphlet, scale 1:24,000.

Rowley, P.D., Hansen, W.R., Tweto, Ogden, and Carrara, P.E., 1985, Geologic map of the Vernal 1° x 2° quadrangle, Colorado, Utah, and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1526, scale 1:250,000.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986, Geologic map of the Koosharem quadrangle, Sevier and Piute Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1590, scale 1:24,000.

Sibbett, B.S., and Nielson, D.L., 1980, Geology of the central Mineral Mountains, Beaver County, Utah: Salt Lake City, University of Utah Research Institute, Earth Science Laboratory report ESL-33, scale 1:24,000.

Sprinkel, D.A., 1990, verbal communication and unpublished mapping, scale 1:250,000.

Steven, T.A., and Morris, H.T., 1983, Geologic map of the Cove Fort quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1481, scale 1:50,000.

Steven, T.A., Morris, H.T., and Rowley, P.D., 1990, Geologic map of the Richfield 1° x 2° quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1901, scale 1:250,000.

Stokes, W.L., and Madsen, J.H., Jr., compilers, 1961, Geologic map of Utah, northeast quarter: Utah State Land Board, scale 1:250,000.

Sullivan, J.T., Martin, R.A., and Foley, L.L., 1988, Seismotectonic study for Jordanelle Dam, Bonneville Unit, Central Utah Project, Utah: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-6, 76 p., scale 1:24,000.

Sullivan, J.T., Nelson, A.R., LaForge, R.C., Wood, C.K., and Hansen, R.A., 1988, Central Utah regional seismotectonic study for USBR dams in the Wasatch Mountains: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-5, 269 p., scale 1:250,000.

Sullivan, J.T., Ostenaa, D.A., and West, M.W., 1988, Seismotectonic study for Meeks Cabin and Stateline Dams, Lyman Project, Wyoming: Denver, U.S. Bureau of Reclamation Seismotectonic Report 88-11, 121 p., scale 1:100,000.

Todd, V.R., 1973, Structure and petrology of metamorphosed rocks in the central Grouse Creek Mountains, Box Elder County, Utah: Palo Alto, Stanford University, Ph.D. dissertation, 316 p., scale 1:42,250.

Van Horn, Richard, and Crittenden, M.D., Jr., 1987, Map showing surficial units and bedrock geology of the Fort Douglas quadrangle and parts of the Mountain Dell and Salt Lake City North quadrangles, Davis, Salt Lake, and Morgan Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1762, scale 1:24,000.

Viveiros, J.J., 1986, Cenozoic tectonics of the Great Salt Lake from seismic reflection data: Salt Lake City, University of Utah, M.S. thesis, 81 p., scale 1:389,900.

Williams, P.L., compiler, 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-360, scale 1:250,000.

Williams, P.L., and Hackman, R.J., compilers, 1971, Geology, structure, and uranium deposits of the Salina quadrangle, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-591, scale 1:250,000.

Willis, G.C., 1988, Geologic map of the Aurora quadrangle, Sevier County, Utah: Utah Geological and Mineral Survey Map 112, 21 p. pamphlet, scale 1:24,000.

----1989, verbal communication and unpublished mapping, scale 1:100,000.

Witkind, I.J., Lidke, D.J., and McBroome, L.A., compilers, 1978, Preliminary geologic map of the Price 1° x 2° quadrangle, Utah: U.S. Geological Survey Open-File Report 78-465, scale 1:250,000.

Witkind, I.J., and Page, W.R., 1984, Origin and significance of the Wasatch and Valley Mountains monoclines, Sanpete-Sevier Valley area, central Utah: The Mountain Geologist, v. 21, no. 4, p. 143-156, scale 1:715,000.

Witkind, I.J., and Sprinkel, D.A., 1982, Field conference road log - second day: salt diapirism in central Utah, in Nielson, D.L., editor, Overthrust belt of Utah: Utah Geological Association Publication 10, p. 315-330, scale 1:24,000.

Witkind, I.J., Weiss, M.P., and Brown, T.L., 1987, Geologic map of the Manti 30' x 60' quadrangle, Carbon, Emery, Juab, Sanpete, and Sevier Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1631, scale 1:100,000.

Woodward-Clyde Consultants, 1982a, Geologic characterization report for the Paradox Basin study region, Utah study areas, volume IV, Lisbon Valley: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, variously paginated, scale 1:170,000.

----1982b, Geologic characterization report for the Paradox Basin study region, Utah study areas, volume II, Gibson Dome: Walnut Creek, California, unpublished consultant's report for Battelle Memorial Institute, Office of Nuclear Waste Isolation, ONWI-290, variously paginated, scale 1:340,000.

PLATES TO ACCOMPANY

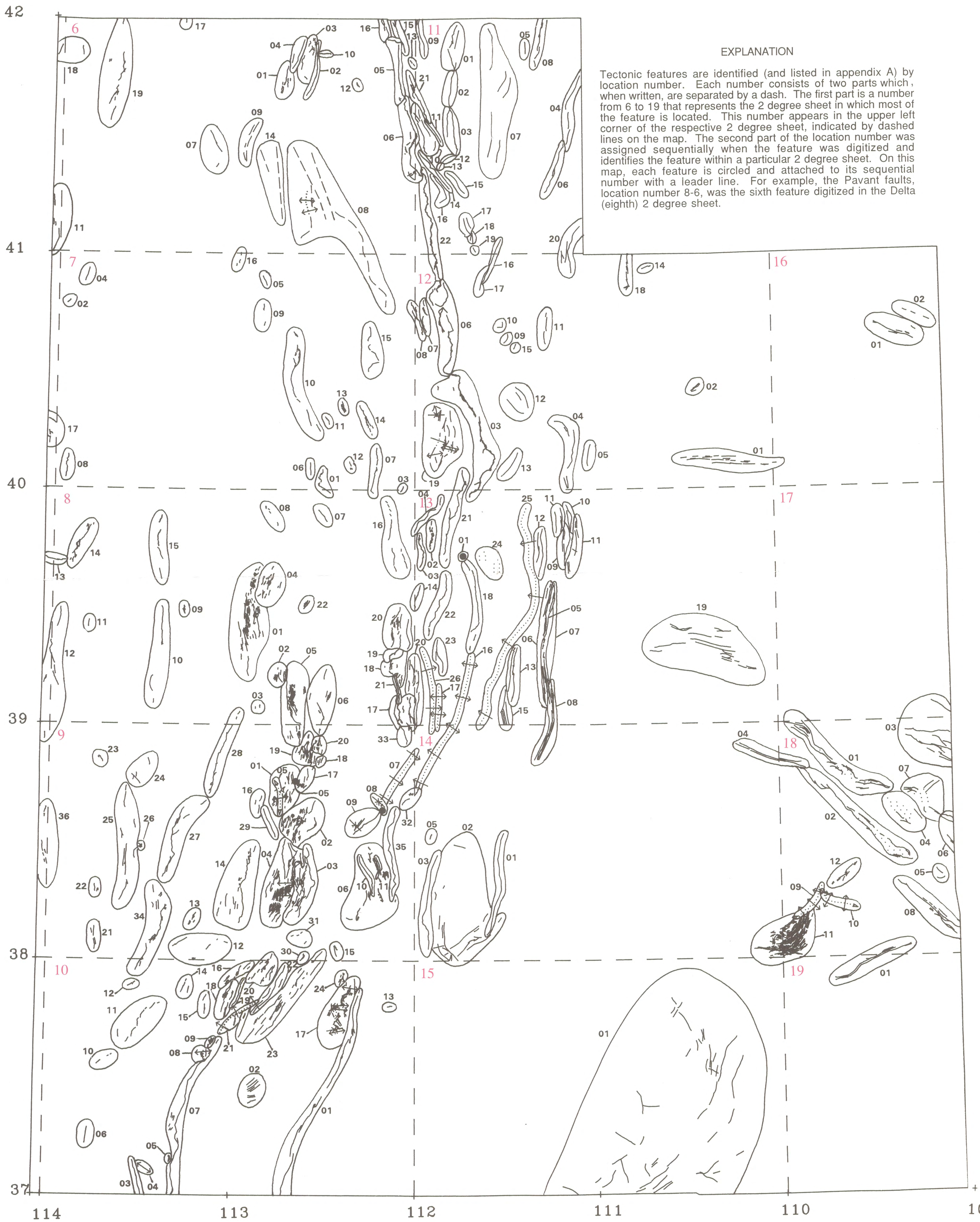
QUATERNARY TECTONICS OF UTAH WITH EMPHASIS ON EARTHQUAKE-HAZARD CHARACTERIZATION

by
Suzanne Hecker
Utah Geological Survey

BULLETIN 127 **1993**
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

Hecker QUATERNARY TECTONICS OF UTAH UGS Bulletin 127

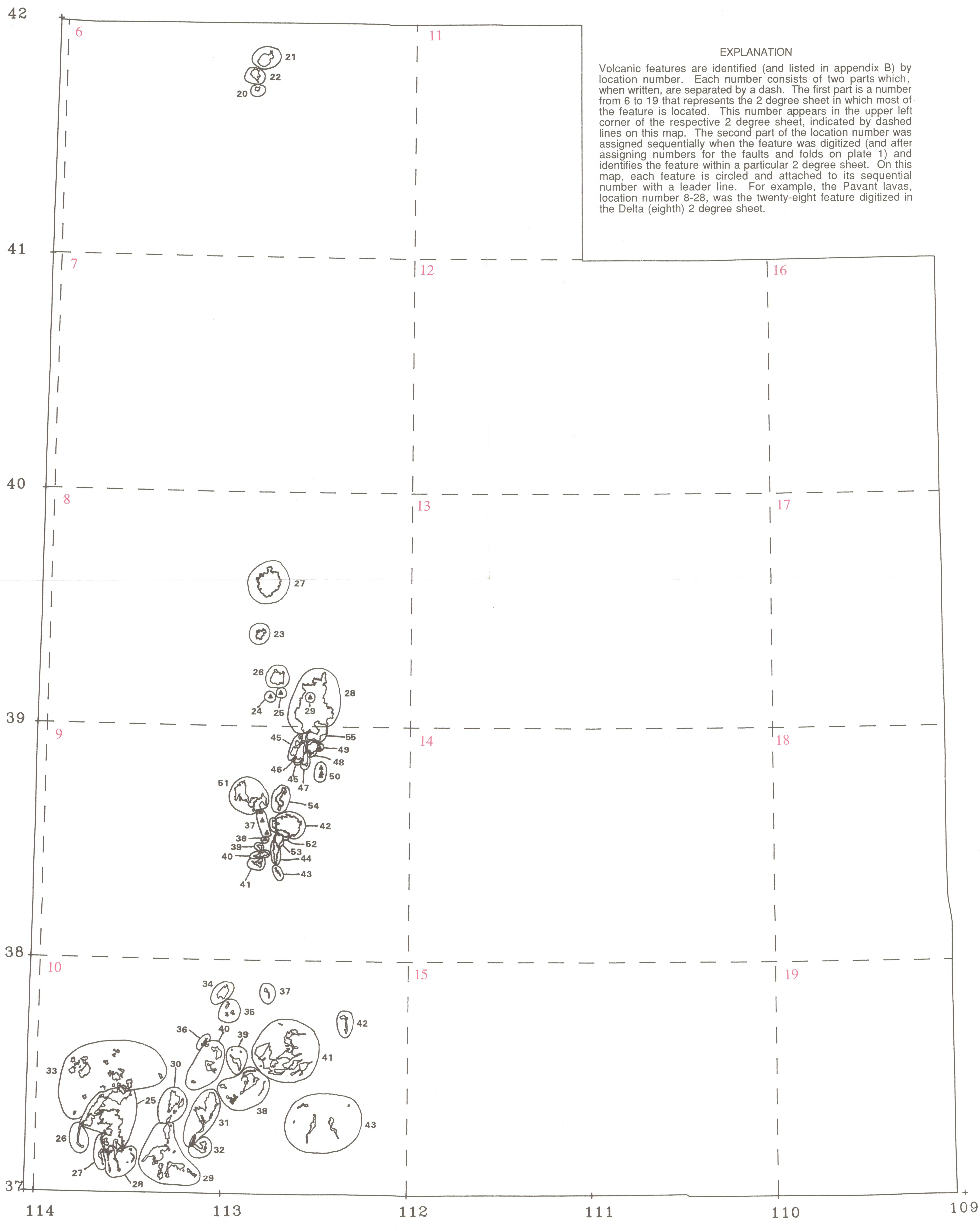
APPENDIX C
INDEX MAP FOR PLATE 1



EXPLANATION

Tectonic features are identified (and listed in appendix A) by location number. Each number consists of two parts which, when written, are separated by a dash. The first part is a number from 6 to 19 that represents the 2 degree sheet in which most of the feature is located. This number appears in the upper left corner of the respective 2 degree sheet, indicated by dashed lines on the map. The second part of the location number was assigned sequentially when the feature was digitized and identifies the feature within a particular 2 degree sheet. On this map, each feature is circled and attached to its sequential number with a leader line. For example, the Pavant faults, location number 8-6, was the sixth feature digitized in the Delta (eighth) 2 degree sheet.

APPENDIX C
INDEX MAP FOR PLATE 2



EXPLANATION

Volcanic features are identified (and listed in appendix B) by location number. Each number consists of two parts which, when written, are separated by a dash. The first part is a number from 6 to 19 that represents the 2 degree sheet in which most of the feature is located. This number appears in the upper left corner of the respective 2 degree sheet, indicated by dashed lines on this map. The second part of the location number was assigned sequentially when the feature was digitized (and after assigning numbers for the faults and folds on plate 1) and identifies the feature within a particular 2 degree sheet. On this map, each feature is circled and attached to its sequential number with a leader line. For example, the Pavant lavas, location number 8-28, was the twenty-eight feature digitized in the Delta (eighth) 2 degree sheet.

UTAH GEOLOGICAL SURVEY
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UTAH DEPARTMENT OF NATURAL RESOURCES

Plate 1a
Bulletin 127
Quaternary Faults and Folds, Utah

Plate 1

QUATERNARY FAULTS AND FOLDS, UTAH

Compiled by Suzanne Hecker

Digital Compilation by Janine L. Jarva

1993

Scale 1:500,000

1 inch equals approximately 8 miles

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometers

Contour interval 500 feet
National Geodetic Vertical Datum of 1929

Explanation

Faults, Folds, and Areas of Deformation
(colors indicate probable age of most recent deformation)

Faults (dashed where concealed by water)	Anticline	Syncline	Monocline	Broad Area	Local Area	Age
						Holocene to latest Pleistocene (0 - 30,000 yrs)
						Late Pleistocene (10,000 - 130,000 yrs)
						Middle to late Pleistocene (10,000 - 750,000 yrs)
						Early to middle Pleistocene (130,000 - 1,650,000 yrs)
						Quaternary (?) (< 1,650,000 yrs?)

Base map from U. S. Geological Survey, State of Utah, 1988

Lori J. Douglas, Cartographer


MILLARD
EMERY
GRAND
SEVIER
BEAVER
PIUTE
WAYNE
IRON
GARFIELD
SAN JUAN
WASHINGTON
KANE
ARIZONA
COLORADO
Richfield
Cedar City
St George
Kanab
Fillmore
Milford
Minersville
Salina
Castle Dale
Ferron
Orangeville
Green River
Blanding
Monticello
Hurricane
Washington
NATIONAL FOREST
MONUMENT INDIAN RESERVATION
39°
38°
37°
114°
113°
112°
111°
110°
109°


UTAH GEOLOGICAL SURVEY
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Plate 2
QUATERNARY VOLCANIC ROCKS AND VENTS, UTAH
Compiled by Suzanne Hecker
Digital Compilation by Janine L. Jarva
1993
Plate 2a
Bulletin 127
Quaternary Volcanic Rocks and Vents, Utah
Scale 1:500,000
10 0 10 20 30 40 Miles
10 0 10 20 30 40 50 Kilometers
1 inch equals approximately 8 miles
Contour interval 500 feet
National Geodetic Vertical Datum of 1929
Explanation
Volcanic Rocks
Volcanic Vents
Age Estimate
Holocene to latest Pleistocene (0 - 30,000 yrs)
Middle to late Pleistocene (10,000 - 750,000 yrs)
Early to middle Pleistocene (130,000 - 1,650,000 yrs)
Quaternary (?) (< 1,650,000 yrs?)
Quaternary faults, folds, and areas of deformation, shown in black are from plate 1.
Base map from U. S. Geological Survey, State of Utah, 1988
Lori J. Douglas, Cartographer
IDAHO
WYOMING
NEVADA
BOX ELDER
CACHE
RICH
WEBER
MORGAN
DAVIS
SALT LAKE
SUMMIT
DAGGETT
TOOELE
WASATCH
DUCHESNE
UINTAH
UTAH
JUAB
CARBON
SANPETE
GREAT SALT LAKE
GREAT SALT LAKE DESERT
UTAH TEST AND TRAINING RANGE
DUGWAY PROVING GROUND
UINTAH AND OURAY INDIAN RESERVATION
Ogden
Provo
Orem
American Fork
West Jordan
Sandy

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Plate 2b
Bulletin 127
Quaternary Volcanic Rocks and Vents, Utah