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Characterization of Quaternary and Suspected Quaternary Faults, Regional Studies, Nevada and California

by

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INTRODUCTION

This report presents the results of geologic studies that help define the Quaternary history of selected faults in the region around Yucca Mountain, Nevada. These results are relevant to the seismic-design basis of a potential nuclear waste repository at Yucca Mountain. The relevancy is based, in part, on a need for additional geologic data that became apparent in ongoing studies by S. Pezzopane (written commun., 1995) that resulted in the identification of 51 relevant and potentially relevant (see appendix A for definitions) individual and compound faults and fault zones in the 100-km-radius region around the Yucca Mountain site. These structures were divided into local and regional categories by Pezzopane (1995); this report deals with selected structures from the regional category. In this introduction, we outline the scope and strategy of the studies and the tectonic environment of the studied structures.

Geologic data used to characterize the regional faults and fault zones as relevant or potentially relevant seismic sources (Pezzopane, 1995, written commun., 1995) includes age and displacement information, maximum fault lengths, and minimum distances between the fault and the Yucca Mountain site. Most of these data are in Piety (1994) who compiled the data from maps, literature reviews, and reconnaissance investigations of faults. For many of the regional faults, no paleoseismic field studies had been conducted at the time of Piety's study, and age and displacement data were sparse to nonexistent. In November 1994, the Branch of Earthquake and Landslide Hazards entered into two Memoranda of Agreement with the Yucca Mountain Project Branch to conduct field reconnaissance, analysis, and interpretation of six relevant and six potentially relevant regional faults whose approximate traces are shown in figure 1. Data on these faults from Pezzopane (1995) are given in table 1. This report describes the results of study of those faults exclusive of those in the Pahrump-Stewart Valley-Ash Meadows-Amargosa Valley areas, which are covered in a companion report (Anderson and others, 1995). Although not on the list of candidate faults of Pezzopane (1995), we also include results of a cursory study of faults on the west flank of the Specter Range (WSR in fig. 1) and in the northern part of the Last Chance Range (LC in fig. 1).

A four-phase strategy was implemented for the field study. The first phase was a 4-day field orientation that utilized the expertise of geologists and paleoseismologists with past and current research experience in the region including J. Whitney, S. Pezzopane, J. Yount, C. Menges, L. Anderson, and D. Donovan. The purpose was to familiarize project personnel with the geography, access, and geology of the region. The orientation included a visit to Yucca Mountain and several faults and trench sites. A subsequent field

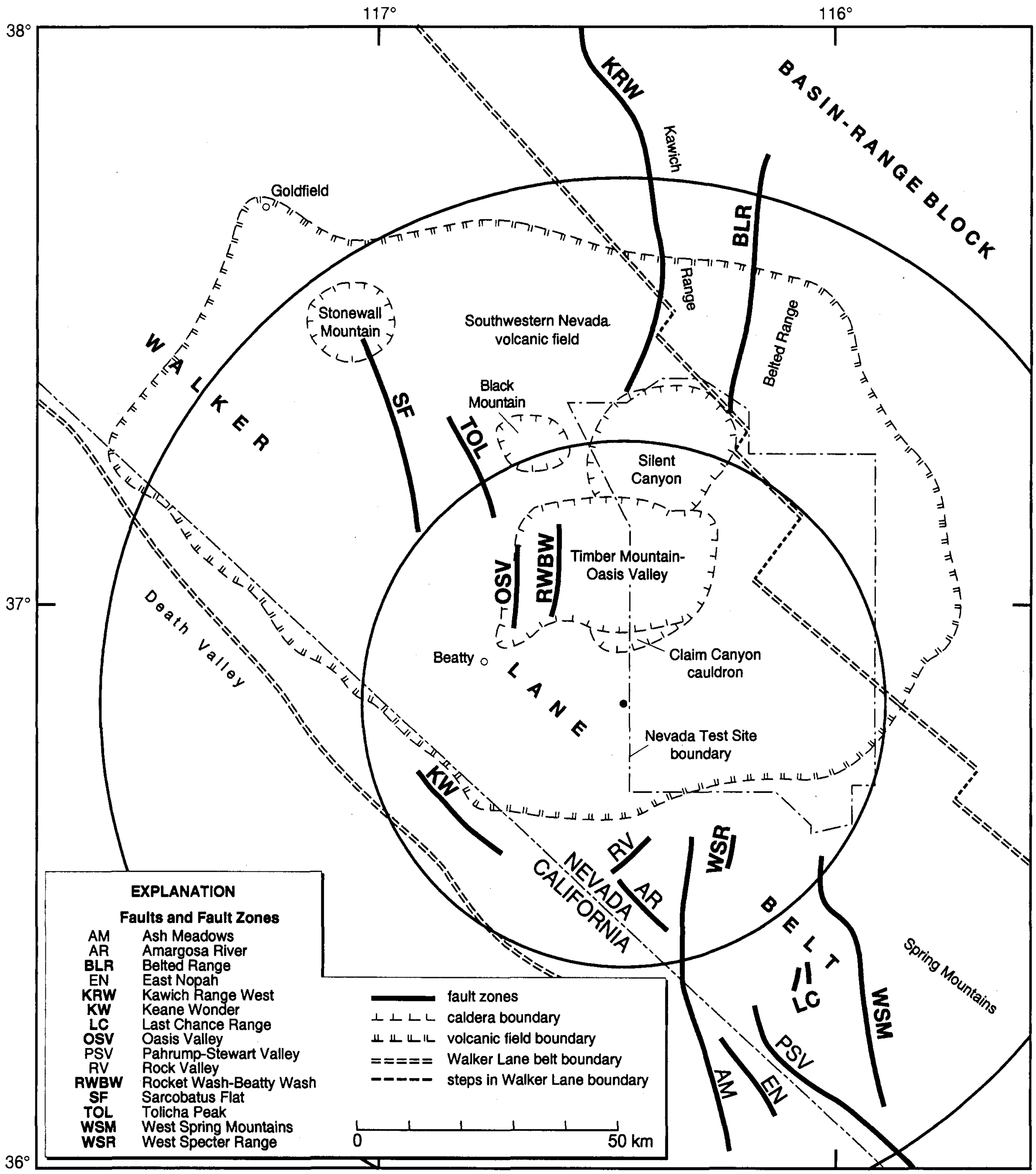

Figure 1. Map showing generalized traces of the regional faults studied under the two Memoranda of Agreement between the Yucca Mountain Project Branch and Branch of Earthquake and Landslide Hazards, U.S.G.S. Abbreviations in bold type identify faults described in this report, abbreviations in regular type identify faults described in a companion report (Anderson and others, 1995). Selected regional geologic features include Walker Lane belt, boundaries of the southern Nevada volcanic field, and some calderas within that field (modified from Carr, 1988). Dot at center of 50- and 100-km-radius circles marks location of proposed repository site. Most fault traces and abbreviations are from Pezzopane (1995).

TABLE 1. Fault data from Pezzopane (1995, written commun., 1995) for selected regional faults.

[These data pre-date our results. They are organized according to distance from Yucca Mountain (YM). Fault names in bold type indicate structures described in this report; others are described in a companion report (Anderson and others, 1995).]

Minimum distance to YM (km)	Fault name and abbreviation	Relevant fault*	Documented Quaternary displacement**	Maximum fault length (km)
19	**Rocket Wash-Beatty Wash RWBW**	yes?	yes?	17
24	**Oasis Valley OSV**	yes?	yes?	20
27	Rock Valley RV	yes	yes	65
34	Ash Meadows AM	yes	yes	60
40	Amargosa River AR	yes	yes	15
42	**Tolicha Peak TOL**	yes?	yes?	22
43	**Keane Wonder KW**	yes?	yes?	25
52	**Sarcobatus Flat SF**	yes	yes?	51
53	**West Spring Mountain WSM**	yes	yes	60
55	**Belted Range BLR**	yes	yes	54
57	**Kawich Range West KRW**	yes?	yes?	84
70	Pahrump-Stewart Valley PSV	yes	yes	70

* yes indicates relevant; yes? indicates potentially relevant

** yes indicates documented Quaternary displacement or compelling evidence for displacement potential such as seismicity; yes? indicates suspected Quaternary displacement

orientation for S. Personius and E. Anderson (Principal Investigator) to faults in the Oasis Valley-Beatty Wash area was conducted by S. Minor and S. Schilling, U.S.G.S. geologists with recent geologic mapping experience in those areas. The second phase consisted of office and lab study of aerial photographs and maps that, for some areas, included unpublished Quaternary fault maps provided by M. Reheis and L. Anderson. The third phase consisted mainly of field study of the faults shown by bold type in figure 1. Each of the faults was studied by a field team led by the following geologists: R.C. Bucknam, Belted Range and Sarcobatus Flat fault zones; K.M. Haller, Kawich Range West fault zone; S.F. Personius, Rocket Wash-Beatty Wash, Oasis Valley, Tolicha Peak, and Keane Wonder fault zones; M.N. Machette, West Spring Mountains and West Specter Range faults; A.J. Crone, Last Chance Range faults (fig. 1). The scope of our studies as outlined in the memorandum of agreement included: (1) determining the geomorphic characteristics that define the subject fault's capability, (2) determining the length of the capable faults, and (3) estimating the time of the most recent surface offset along the fault and, where indicated, evidence of

TABLE 2. Terminology of time intervals for the Quaternary Period used in this report and approximate dates of time boundaries (modified from Morrison, 1991, and Izett and Obradovich, 1994).

Subdivision	Time Span
Holocene	present-10 ka
latest Pleistocene	10 ka-~28 ka
late Pleistocene	10 ka-~128 ka
middle Pleistocene	~128 ka-770 ka
early Pleistocene	770 ka-1650 ka
Pleistocene	10 ka-1650 ka
late Quaternary	present-~128 ka
Quaternary	present-1650 ka

recurrent offsets during the Quaternary. The final phase consisted of a 5-day field review (with the team leaders, Principal Investigator, and others) by M. Reheis and A. Nelson. This field review served as a formal review of the field-data package pertaining to these studies.

In this report we use terminology for several subdivisions of the Quaternary period. Although the terminology for most subdivisions is widely agreed upon by earth scientists, the accepted age of these subdivisions has varied through the years. In this report, we generally follow the subdivisions as defined by Morrison (1991), but we use a revised age of 770 ka for the early Pleistocene-middle Pleistocene boundary (Izett and Obradovich, 1994) and use an informal latest Pleistocene subdivision. The subdivisions we use are shown in table 2.

The types of data gathered in this study are listed in figure 2. The first two types, pre-Quaternary displacements in Tertiary strata and scarps in bedrock, are not normally included in studies of Quaternary faulting. However, previous studies resulting in the characterization of some faults as potential Quaternary structures, especially those in the Goldfield section of the Walker Lane belt (fig. 3B), relied on stratigraphic displacements of and scarps developed on Tertiary strata for the characterizations. For this reason, we provide qualitative evaluations of the displacements of and scarps on Tertiary strata.

We gathered limited data on displacements in Quaternary deposits because time and resources did not allow for trenching. Also, natural exposures of displaced Quaternary marker horizons are very rare.

Along most faults, we use the morphology of fault scarps on alluvium to characterize the history of surface faulting. The morphology is defined by topographic profiles measured across the scarp. Parameters derived from the profiles and used in this report to characterize the scarps are defined in figure 4. The

- Pre-Quaternary displacements in Tertiary strata
- Scarps on bedrock
- Offsets of Quaternary surfaces
- Length of fault characterized by offset Quaternary surfaces
- Estimated age of last displacement
- Some boundaries on permissible slip rates

FIGURE 2. Types of data gathered in U.S.G.S. study of candidate faults within 100 km of Yucca Mountain.

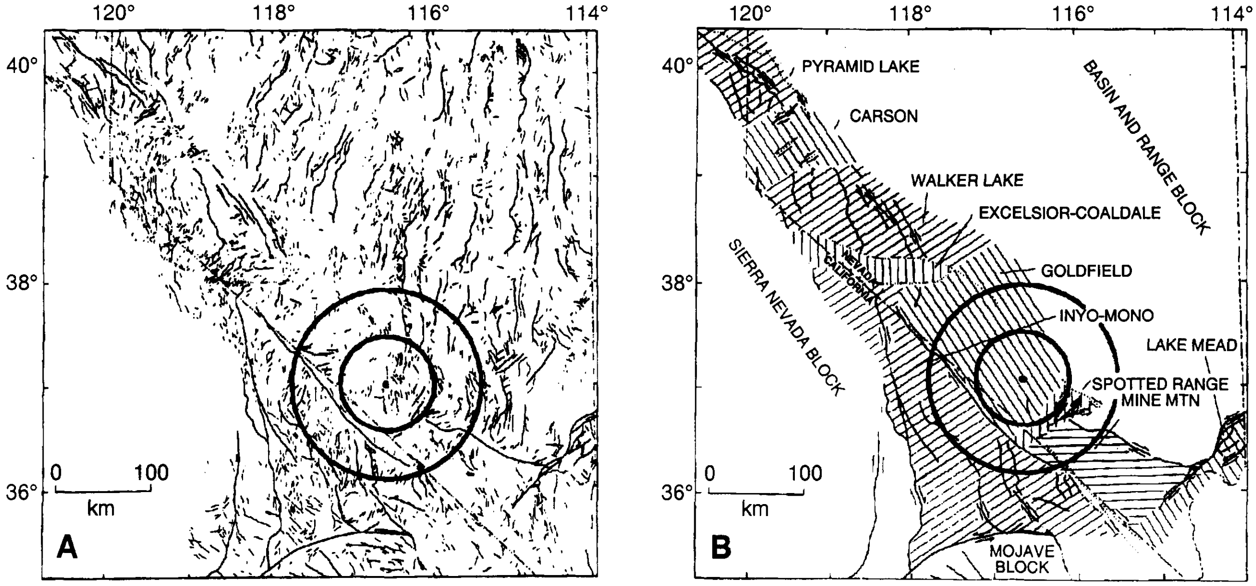

Figure 3. A, Map showing the Yucca Mountain site (dot at center of 50- and 100-km circles) relative to late Cenozoic faults in the western Great Basin (modified from Stewar, 1988). B, Same area as in A showing selected major faults and regional structural blocks (cross ruled) of the Walker Lane belt (from Stewart, 1988).

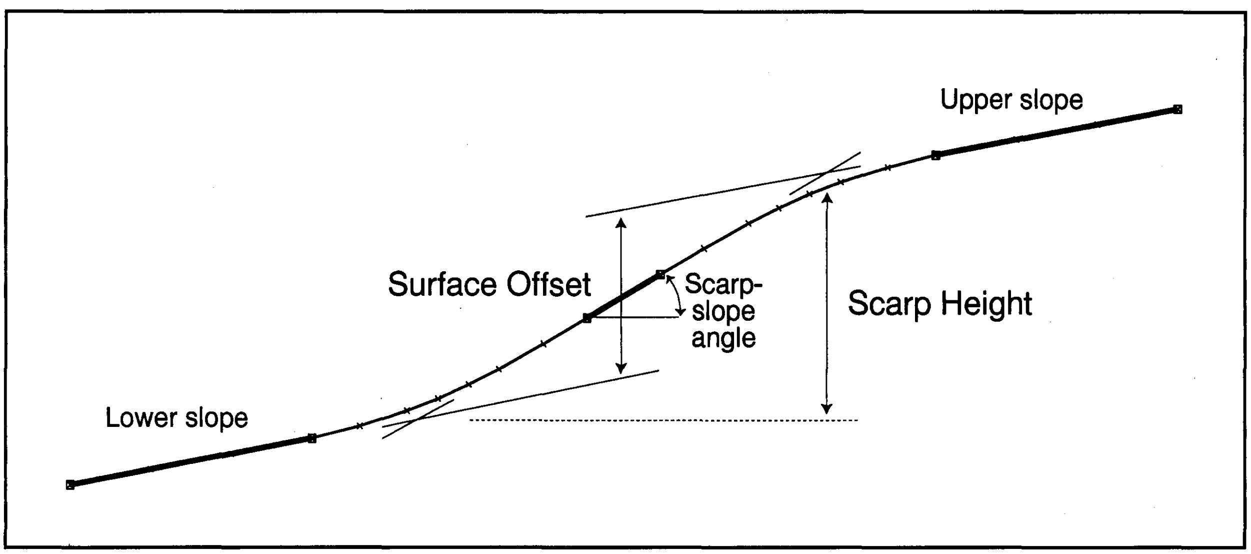

Figure 4. Definitions of scarp parameters. Upper and lower slope are intervals of the scarp profile that represent the prefaulting surfaces above and below the scarp. Scarp-slope angle is the steepest interval on the scarp face. Surface offset is the vertical distance between the projections of the upper and lower surfaces measured mid-way between the intersections of the steepest interval of the scarp face and the projections of the upper and lower surfaces; scarp height is the vertical relief between those intersections.

parameters are either taken directly from measurements recorded in the field (scarp-slope angle) or derived from the profile (scarp height, surface offset).

Profiles were made by measuring a sequence of short intervals (typically ≤4.5 m) of slope distance and slope angle along the ground surface, perpendicular to the local strike of the scarp. The profiles are long enough to include intervals of the surfaces above and below the scarp that are judged to be unaffected by scarp modification processes, such as erosion and deposition. To minimize the influence of local topographic irregularities, several measurements of the scarp-slope angle may be made adjacent to the line of profile.

Scarp profiles provide information for estimating the time of surface-faulting events based on the intuitively obvious observation that with increasing age a scarp profile becomes more rounded and the slope of the scarp face becomes less steep. A variety of methods of analyzing the form of scarp profiles have been developed, and most of these methods model the profile as a solution to the diffusion equation (Nash, 1980; Hanks and others, 1984). In most cases, the profile data in this study are very limited, and we have not attempted to model the scarps using the diffusion model. Instead we graph several parameters of our profiles as a convenient visual means of characterizing the relative age based on the morphology of the scarps. For this we use the relation of Bucknam and Anderson (1979), who showed that at a given scarp height, the scarp-slope angle decreases with increasing age. They also found that, for a scarp of a given age, there is a linear relation between scarp-slope angle and the logarithm of the scarp height. Figure 5 shows this relation for 3 scarps on uncemented alluvial-fan gravel in western Utah. The ages of the scarps are about 15 ka for the Lake Bonneville shoreline (Machette, 1989), about 10 ka for the Drum Mountains fault (Crone, 1983), and about 2 ka for the Fish Springs Range fault (Bucknam and others, 1989). The data shown in figure 5 illustrate the resolution and variability expected from profile data taken from late Pleistocene and

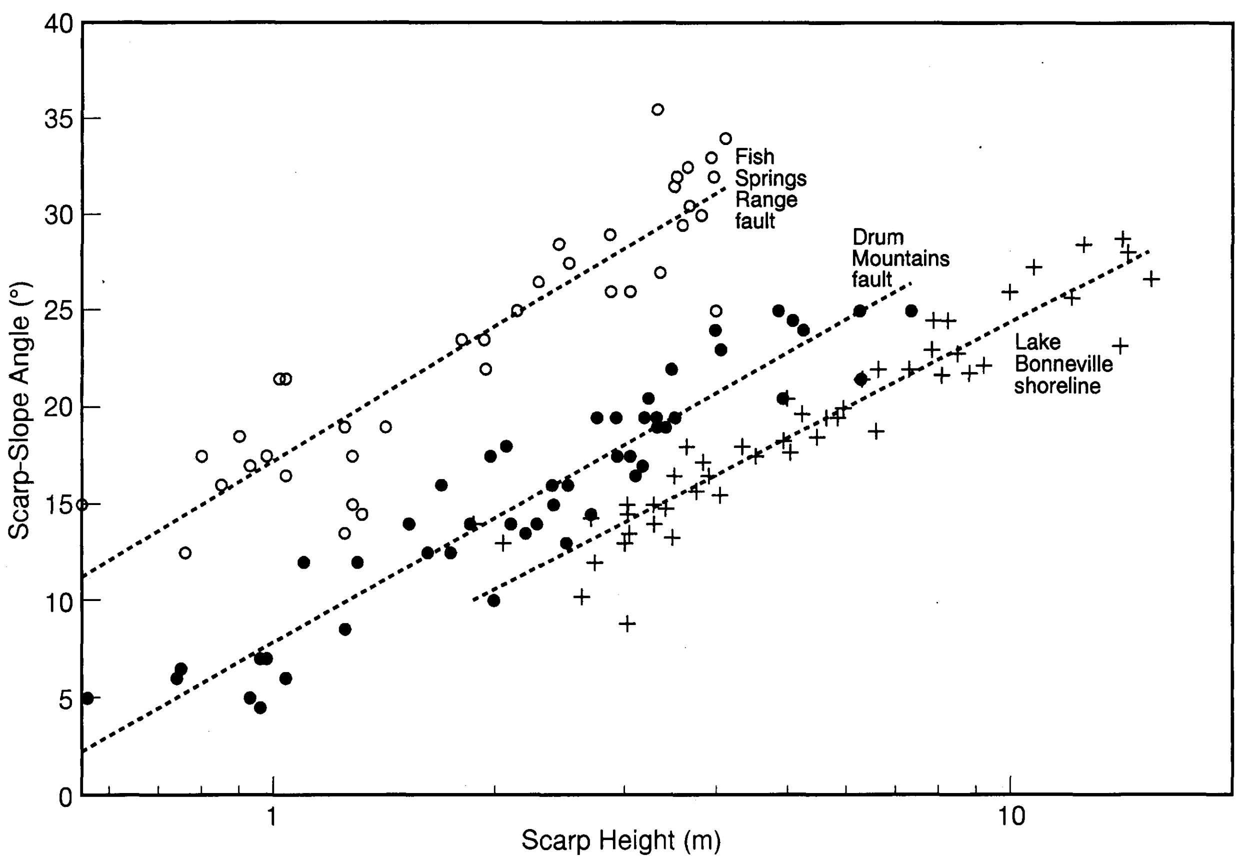

FIGURE 5. Scarp-slope angle versus log scarp-height data for single-event scarps in western Utah. The figure illustrates the resolution and variability of scarp-morphology data. Dotted lines are linear regressions to each of the sets of data. Open circles, fault scarp of Fish Springs Range (about 2 ka; Bucknam and others, 1989); solid circles, fault scarp of Drum Mountains (about 10 ka; Crone, 1983); crosses, shoreline scarp of Lake Bonneville (about 15 ka; Machette, 1989).

Holocene scarps that represent a single scarp-forming event. In this report we use plots of scarp-slope angle versus log scarp height to qualitatively compare the data from this study to the about 10 ka fault scarp of the Drum Mountains, the about 15 ka shoreline scarp of Lake Bonneville in western Utah, and the about 100 ka Santa Rita scarp in southern Arizona (Pearthree and Calvo, 1987).

To assess the Quaternary history of most of the faults, we estimated the age of most the recent displacement and placed some boundaries (constraints) on fault slip rates. We did this by estimating the age of the offset surface based on its surface morphology and, in some cases, the degree of soil development.

The faults we studied occupy contrasting tectonic environments. Two of them, the Belted Range and Kawich Range West fault zones, are located in the main part of the Basin and Range structural province, whereas the others are located in the Walker Lane belt of the Basin and Range (fig. 1). The Belted Range and Kawich Range West fault zones are range-bounding structures with northerly trends typical of the main part of the Basin and Range (figs. 1, 3).

The Rocket Wash-Beatty Wash, Oasis Valley, Tolicha Peak, Sarcobatus Flat, Keane Wonder, West Spring Mountains, West Specter Range, and Last Chance Range faults are located in the Walker Lane belt (fig. 1). The Walker Lane belt is characterized by mountain ranges with unusual shapes and trends (fig. 3A) resulting from a mixture of (1) strike-slip faults, (2) regional sections of quasi-coherent internal structure, (3) basin-range faults, (4) oroflexural folds, and (5) areas of large-scale extension, detachment faults, and metamorphic core complexes (Stewart, 1988). The Walker Lane belt is divided into regional structural sections, each of which has undergone internal deformation independent of adjacent sections. Adjustments for intersectional strain contrasts are most likely made at section boundaries (Stewart, 1988; Carr, 1988). Individual strike-slip faults do not extend along the length of the Walker Lane belt despite many published illustrations that suggest they do. According to Stewart (1988), strike-slip faults do not even extend from one section to another. Several of the faults we studied, including the Sarcobatus Flat, Tolicha Peak, Oasis Valley, and Rocket Wash-Beatty Wash fault zones, are located in an area that Stewart (1988) referred to as the Goldfield section of the Walker Lane belt. That section is characterized by a lack of major through-going strike-slip faults and by a scarcity of major basin and range faults. The faults we studied seem to fit this characterization because they have primarily normal displacement in Tertiary bedrock and are marked by subtle scarps and lineaments. The Keane Wonder and West Spring Mountains faults, by contrast, are examples of range-bounding faults with physiographic expressions somewhat similar to the Belted Range and Kawich Range West fault zones.

Structural development of the Yucca Mountain region during the Tertiary was strongly influenced by volcano-tectonic processes related to formation of the southwest Nevada volcanic field (Byers and others, 1976) from which hundreds of cubic kilometers of silicic tuff and lava were erupted (Carr, 1984). The locations of the faults we studied and the southwest Nevada volcanic field and associated calderas are shown in figure 1. Despite the proximity of some of the faults to calderas, only the Oasis Valley fault has been suggested as having a volcano-tectonic origin or to have been reactivated in volcano-tectonic deformation (Connors and others, 1995).

We describe each fault or fault zone separately using the abbreviations of Pezzopane (1995). The descriptions are grouped mainly according to tectonic environment: first are the faults bounding the Belted Range and west Kawich Range of the main Basin and Range, next faults that typify the Goldfield section—the Rocket Wash-Beatty Wash, Oasis Valley, Tolicha Peak, and Sarcobatus Flat fault zones followed by faults that bound ranges in the Walker Lane section—the Keane Wonder and West Spring Mountains faults, and finally the results of cursory study of two faults that were not part of our formal assignment—West Specter Range and Last Chance Range faults. The descriptions are organized to facilitate the integration of our results into future updates of regional compilations such as that of Piety (1994).

BELTED RANGE FAULT ZONE (BLR)

SUMMARY: The Belted Range fault zone (BLR) lies along the west foot of the Belted Range on the east side of Kawich Valley; the southern limit of scarps on alluvium in the zone is 66 km north northeast of Yucca Mountain. Quaternary scarps on alluvium along BLR form a N. 11° E. striking zone 20.8 km long between the northern and southern limits of the scarps and 21.9 km long as measured along the trace. The sense of slip is normal and down to the west. The most recent movement along the zone is probably early Holocene to latest Pleistocene and produced a maximum surface offset of about 1 m. Total surface offset across scarps on alluvium ranges from 0.6 m on the youngest faulted alluvium to 11.3 m on older alluvium. Evidence of recurrent movement along the zone of scarps in alluvium is conspicuous and widespread but quantitative estimates of recurrence intervals are poorly constrained.

LOCATION: The BLR lies along the west foot of the Belted Range on the east side of Kawich Valley (figs. 1, 6). The central part of the fault zone is at lat 37°27′N., long 116°09′W., about 120 km southeast of Tonopah. The southernmost point on the fault zone as mapped by Piety is 55 km north-northeast of Yucca Mountain. As shown on the compilation of Piety (1994), the BLR extends from the northern end of the Belted Range at Railroad Valley (lat 37°45′N.) south to the southern end of Kawich Valley at Kawich Canyon (lat 37°18′N.). The fault zone lies entirely within the northern Nellis Air Force Bombing and Gunnery Range.

ORIENTATION: The overall trend of fault scarps on alluvium along the BLR is N. 11° E. and generally conforms to the trend of the adjacent range. The zone of scarps consists of 3 sections with contrasting orientations and separated by short intervals that lack scarps—a northern section 10 km long trending N. 3° W., a central section 7 km long trending N. 28° E., and a southern section 1 km long trending N. 6° E.

LENGTH

Length reported in Piety (1994): 38-54 km

Length of known Quaternary scarps (this study): 21 km

Quaternary displacement along the BLR is expressed by a relatively continuous zone of well-defined scarps on alluvium between lat 37°33′04″N., long 116°08′44″W. and lat 37°22′04″N., long 116°11′27″W. The straight-line distance between the northern and southern limits of the scarps is 20.8 km, the corresponding distance measured along the trace of the scarps is 21.9 km. There are 4 conspicuous gaps in the continuity of the scarps that range from 1-2 km long. Scarps as small as 90 cm high (60 cm surface offset) are clearly visible on the 1:30,000-scale color aerial photographs used in this study. Some subtle lineaments visible on smaller scale black and white aerial photographs (1:60,000) are not visible on the larger scale color photographs. Some of these subtle features evident on the smaller scale aerial photographs appear to be the basis for several lineaments mapped by Reheis (1992) and for a 400-m-long fault mapped by Sargent and Orkild (1973) as displacing alluvium near Ocher Ridge at the southern end of the Belted Range. Only features mapped and confirmed by this study are shown in figure 6.

STYLE OF FAULTING: Normal, down to the west

Scarps on alluvium along the western foot of the Belted Range show relative down-to-the-west movement. We did not find any exposures of the faults associated with the scarps, but geologic mapping of the region by Ekren and others (1971) indicates that the BLR is a west-dipping normal fault. We saw no evidence of

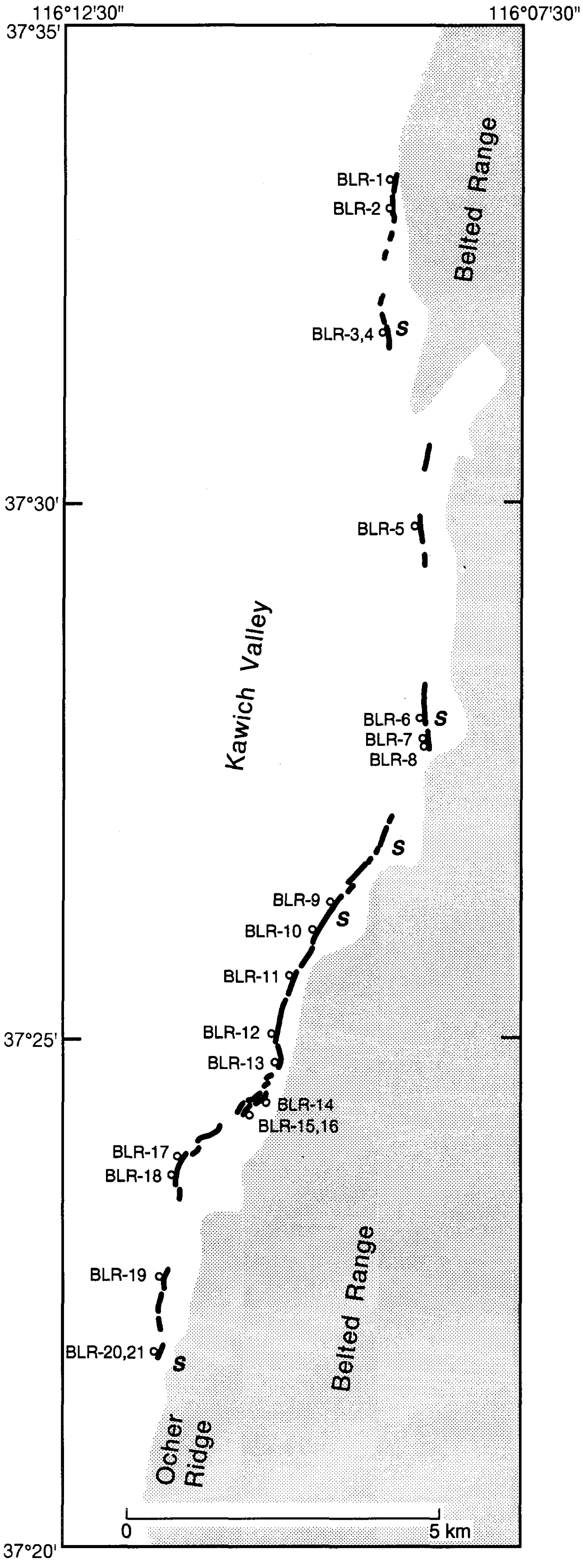

Figure 6. Map showing scarps on alluvium (solid lines) along Belted Range fault zone (BLR). Open circles show scarp-profile sites, numbered from north to south; ***S***, site of probable single-event scarp. Range boundary drawn at approximate limit of exposed bedrock.

lateral displacement of features, such as wash channels, that cross the scarps, although in this geomorphic environment such features tend to provide an unreliable record of the presence or absence of as much as several meters of early Holocene lateral displacement.

DISPLACEMENT AND AGE

Range of observed surface offset and scarp height representing the youngest movement:
0.6–0.9 m (surface offset) and 0.9-1.5 m (scarp height)

In order to characterize the amount of offset of alluvial surfaces and to estimate the age of the scarps we measured topographic profiles across fault scarps on alluvium at 21 places along the 21-km-long zone of late Quaternary faulting (fig. 6, appendix B). Surface offsets range from 0.6 m to 11.3 m (table 3), but only the smallest are thought to be the result of the most recent surface faulting event. Fan slopes at profile sites are typically 3°-5°.

TABLE 3. Scarp-profile data for the Belted Range fault zone, southern Nevada.

[Positive slope angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources. All scarps face to the west and are presumed to be normal. Evidence of recurrent movement: S, single-event scarp—no evidence of more than one episode of movement; M, multiple-event scarp—geomorphic or other evidence for more than one episode of movement; U, undetermined. Fault parameters as defined in figure 4: LS, lower slope angle, US, upper slope angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle—values are average of at least 3 measurements except those noted by *, which represent one measurement.]

Profile No.	Recurrence	LS	US	SO (m)	SH (m)	θ
BLR-1	M	4.5°	4.5°	1.8	3.0	10.7°
BLR-2	M	3.2°	3.3°	4.6	6.1	13.2°
BLR-3	M	4.5°	4.6°	4.5	6.5	14.9°
BLR-4	S	3.2°	3.4°	0.6	1.1	8.5°*
BLR-5	M	2.3°	3.3°	2.6	4.0	7.4°
BLR-6	S	3.3°	3.5°	0.6	1.4	6.0°
BLR-7	M	3.2°	2.7°	2.4	3.8	7.8°
BLR-8	U	3.2°	3.1°	1.6	2.9	4.5°
BLR-9	S	3.9°	3.9°	0.9	1.5	8.9°
BLR-10	M	4.3°	4.5°	3.4	4.8	15.0°
BLR-11	M	4.1°	4.4°	1.3	1.8	13.7°
BLR-12	U	2.7°	2.6°	1.9	2.5	10.9°
BLR-13	U	4.0°	4.6°	4.7	6.2	17.0°*
BLR-14	U	5.0°	4.5°	1.8	2.7	14.0°*
BLR-15	M	4.7°	4.6°	11.3	14.7	19.3°*
BLR-16	M	6.1°	5.1°	2.2	3.4	16.4°*
BLR-17	M	3.3°	3.9°	4.9	6.2	16.9°*
BLR-18	U	3.9°	4.4°	2.3	3.2	14.3°*
BLR-19	M	3.9°	5.0°	1.6	2.7	11.9°
BLR-20	M	2.7°	1.2°	1.9	2.4	8.6°*
BLR-21	S	3.0°	3.9°	0.6	0.9	10.7°

Scarps with less than 1 m of surface offset lack evidence of multiple movement and are probably the result of a single surface-faulting event (table 3; figs. 7, 8). This interpretation is consistent with data from historical normal surface-faulting earthquakes. Regression equations derived from the historical data (Wells and Coppersmith, 1994) give a mean maximum displacement of 1 m (with 1-σ limits of 0.4 m and 2.5 m) for a 20-km-long surface rupture length. Most scarps along the BLR with more than 1 m of surface offset, including one with as little as 1.3 m of surface offset, show field evidence of multiple displacement. The most recent, probably single-event scarps, are distributed along nearly the entire length of the mapped scarps in alluvium (fig. 6), which suggests that the entire zone of scarps ruptured during the most recent surface faulting event.

Profiles with surface offsets between 1 and 2.5 m commonly show evidence for multiple movement. However, there are several profiles in this range of surface offsets for which we did not see evidence of multiple movement. Because lack of such evidence is not evidence, by itself, for a single event, we show these profiles as undetermined with respect to multiple movement. With only one exception, scarps with more than 2.3 m of surface offset show distinctive geomorphic evidence of multiple movement, and we show these as multiple-event scarps. In general, multiple-event scarps represent several periods of movement

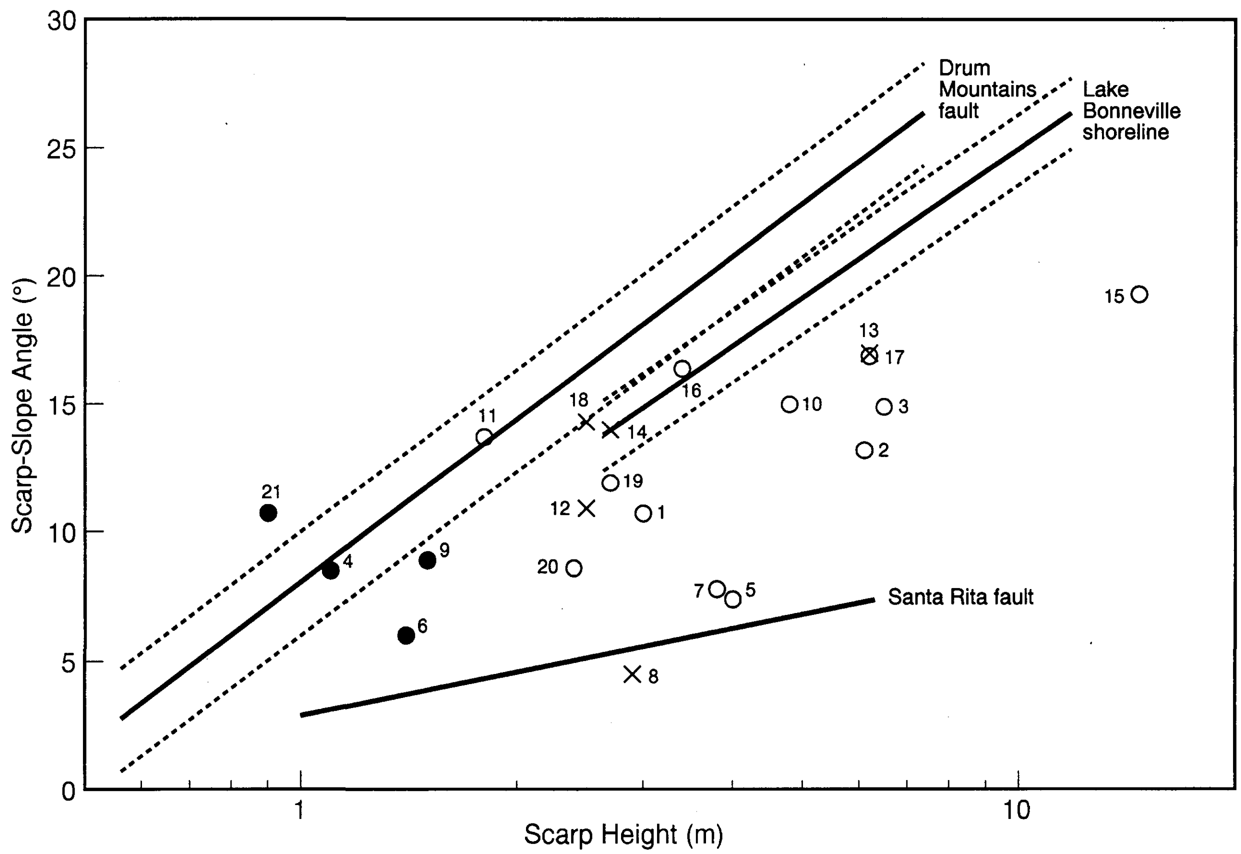

FIGURE 7. Plot of scarp-height—slope-angle values for scarps on alluvium along the Belted Range fault zone (BLR). Closed circles, probable single-event scarps; open circles, multiple-event scarps; x, large scarps that lack evidence of multiple periods of movement; numbers are BLR site numbers in figure 6 and table 3. Solid lines, regression lines for reference scarps; dotted lines, 1-σ limits for regressions. Lake Bonneville shoreline scarp (about 15 ka; Machette, 1989) and Drum Mountains fault scarp (about 10 ka; Crone, 1983) both from Bucknam and Anderson (1979); Santa Rita fault scarp (estimated age about 100 ka; Pearthree and Calvo, 1987). Points that plot above or below the 1-σ limits of a regression line suggest relative ages that are younger or older than those of the reference scarps, respectively.

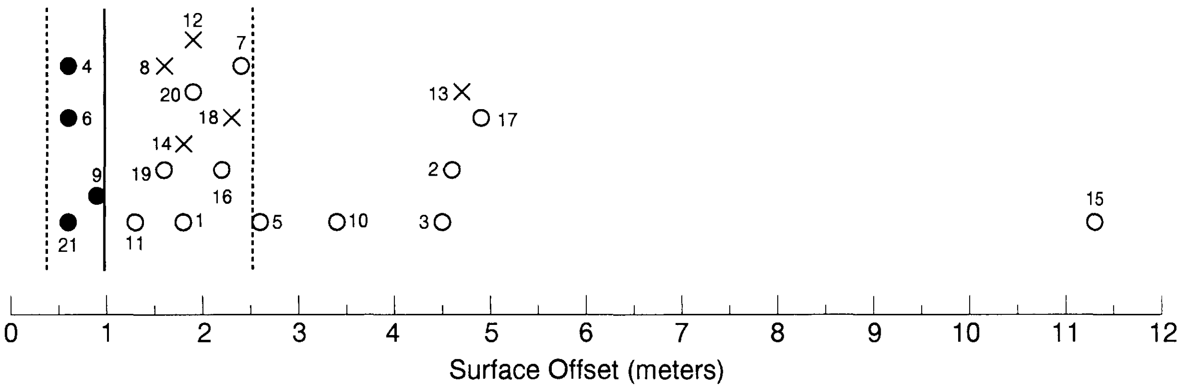

FIGURE 8. Range of measured surface offsets of alluvium along the Belted Range fault zone (BLR). Closed circles, probable single-event scarps; open circles, multiple-event scarps; X, large scarps that lack evidence of multiple periods of movement; numbers are BLR site numbers plotted in figure 6. Solid vertical line at mean maximum displacement for 20-km-long surface rupture length calculated from regression equations for historical normal surface-faulting earthquakes (Wells and Coppersmith, 1994); dotted vertical lines are 1-σ limits. No vertical scale, vertical distribution of points for clarity only.

each of which may represent several displacement events closely spaced in time relative to the time between the preceding and subsequent periods of displacement.

Estimated age of most recent surface-faulting event: early Holocene

There are almost no data on the ages of surficial deposits or alluvial fan surfaces along the BLR to help constrain the time of faulting represented by the scarps on alluvium. Dohrenwend and others (1992) developed photogeologic and geomorphic criteria to estimate the ages of surficial deposits and erosion surfaces in the region, but they pointed out that such estimates provide only very general constraints on the time of surface faulting (e.g. the older of their three age categories ranges from 0.13-1.5 Ma).

The probable single-event scarps from the most recent event along the BLR are formed on alluvial fan surfaces of low relief. Smoothly rounded drainages, typically 0.5-1.5 m deep, are cut into a generally planar surface on which subdued remnants of debris flow levees are preserved. These characteristics are similar to those of surficial deposits and erosion surfaces of Holocene to late Pleistocene age (0-130 ka) under the criteria of Dohrenwend and others (1992).

Topographic profiles across the scarps provide a basis for placing additional constraints on the probable ages of the scarps. We use geomorphic data derived from the profiles to characterize the geomorphic age of the scarps relative to that of other scarps of known age. If factors affecting modification of scarps along the BLR are similar to those that controlled modification of the reference scarps, we expect the age based on the scarp profile data to resemble their calendar age. There is considerable scatter in the limited data from scarps of the most recent surface faulting event, but the data points plot near the regression line for scarps of early Holocene to latest Pleistocene age.

Many of the measured scarps whose scarp-height—slope-angle coordinates plot near the regression line of the Lake Bonneville shoreline scarp data reflect more than one period of movement. In those cases the scarp-slope angle plotted reflects the most recent movement, whereas the scarp height reflects the total offset of the surface. Because the scarp height associated with the scarp-slope angle of the younger surface faulting event should be smaller than the plotted height, the data for multiple-event scarps shown in figure 7 represent a maximum geomorphic age for the most recent surface faulting event. Hence, the most recent event of multiple-event scarps shown by profiles BLR-11, 16, and 19 (fig. 7) are also consistent with a latest Pleistocene or early Holocene age.

Range of observed total surface offset along scarps on alluvium: 0.6 to 11.3 m

Surface offsets reported in table 3 are based on projection of alluvial surfaces above and below the scarp, (fig. 4), and are the total offset of the surfaces. In profile, distinct periods of displacement on multiple-event scarps are marked by a subtle discontinuity in the scarp profile that separates a relatively steep interval on the central or lower part from a more smoothly rounded upper part. We did not attempt to reconstruct the geometry of the youngest event on multiple-event scarps because the bouldery and irregular character of the scarps and adjacent alluvial surfaces obscures details needed to make a well-constrained offset.

Use of the surface offsets reported in table 3 as a direct measure of fault slip at depth should be made with caution. Locally, there is evidence that a graben formed along the base of the scarps and that alluvial surfaces below the scarps on the hanging wall block of the fault were back tilted toward the main fault, thus, reducing the valleyward slope. Net displacement across a fault zone with a graben or zone of back rotation is less than that derived from scarp profiles that do not span the graben or zone of back rotation. Our profiles did not span the large graben in the vicinity of profiles BLR-15 through BLR-17.

Estimates of recurrence intervals and slip rates: Evidence of recurrent movement in Quaternary time is conspicuous; quantitative estimates of the time between events are poorly constrained.

With the exception of the relatively well-defined estimates for the age and amount of offset for the most recent surface-faulting event along the BLR, there are few data to constrain recurrence intervals and slip rates for the zone. Several arguments can be made, however, to provide some broad estimates of rates along the zone. The most recent surface faulting event provides only open-ended information on the current rate, but using an estimated age for the most recent event of 10 ka and assuming that the most-recent-event slip of 1 m were to be repeated today yields a maximum Holocene slip rate of 0.1 mm/yr. The scarps older than the most recent surface faulting event contain information most relevant to estimating late Quaternary slip rates and recurrence intervals along BLR. Our study provides some estimates on the amounts of Quaternary displacement along the zone, but information of comparable precision on the ages of the offset surfaces is lacking. Dohrenwend and others (1992) assigned general age categories to the deposits and surfaces along the BLR based on general photogeologic and geomorphic criteria. Using those criteria they assigned an early to middle Pleistocene age (0.13-0.78 Ma) to the oldest surfaces along the BLR (in the vicinity of profile BLR-15). Using that age range and the largest surface offset (11.3 m, profile BLR-15) gives slip rates ranging from 0.09 to 0.01 mm/yr. Profile BLR-15 and most of the other multiple-event scarps plot well above (younger than) similar data from the approximately 100 ka scarp of the Santa Rita fault of southern Arizona (Pearthree and Calvo, 1987). Although the morphology of multiple-event scarps integrates displacements older and younger than are expressed by the profile, the strong divergence of the BLR data from that of a 100 ka scarp suggests that the scarps are no older than 100 ka and may be much younger. If the scarp at BLR-15 reflects movements during the past 100 k. y., we get a poorly constrained slip rate on the order of 0.1 mm/yr since late Pleistocene time.

The location and amount of offset on scarps in alluvium along the BLR correlate in a general way with the topographic and structural relief along the Belted Range. The scarps coincide with the part of the range with the highest topographic relief and with a prominent gravity low (Ekren and others, 1971) beneath Kawich Valley, which suggests that the Quaternary record is reflecting, in a general way, the long term pattern of deformation of the range. They cite analysis of the gravity data that indicates at least 600 m of displacement along the central part of the BLR since deposition of the 12.5-11.5 Ma (Sawyer and others, 1994) Timber Mountain Tuff, which indicates a long term slip rate of about 0.05 mm/yr. This rate may include a short period with a conspicuously high relative rate of extension between 11.5 and about 9 Ma that Sawyer and others (1994) report for several areas adjacent to the extensive volcanic field south of the Belted Range. If so, the post 9 Ma slip rate would be lower than 0.05 mm/yr.

KAWICH RANGE WEST FAULT ZONE (KRW)

SUMMARY: The Kawich Range West fault zone (KRW) is mapped as numerous subparallel normal faults and lineaments on the west side of the Kawich Range (figs. 1, 9), 75 km east of Goldfield, Nevada. The average orientation of the fault zone is N. 10° W., with sections characterized by average orientations of N. 34° W., N. 7° W., and N. 16° E. Over its 84-km length, most faults shown by Piety (1994) are in bedrock or at the bedrock-alluvium contact. Scarps on alluvium are low (<2.6 m surface offset), discontinuous, span only 3.6-7.4 km of the fault zone, and are probably latest Pleistocene in age. Estimates of recurrence intervals and slip rate were not attempted because evidence of recurrent movement is equivocal. However, the character of the range front, bounding basins, and the general absence of scarps along 99 percent of the length of the KRW suggest long recurrence intervals and low slip rates. Possible seismogenic segmentation of the fault zone is indicated by a pattern of closed gravity lows in the hanging wall of the fault zone.

LOCATION: The KRW bounds the west side of the Kawich Range from lat 38°N. south to near Silent Butte (Piety, 1994). The north central part of the fault zone is 75 km east of Goldfield, Nevada. Most of the fault, with the exception of the northern 13 km, is within the boundaries of the northern Nellis Air Force Bombing and Gunnery Range.

We define 3 informal sections of the KRW (fig. 9) based on range-front morphology, orientation, and width of the mapped fault zone. The sections reflect segmentation of the mountain block based on footwall geology (as described by Ekren and others, 1971) and are used here to simplify discussion. The sections, which roughly coincide with closed gravity lows in the hanging wall, may reflect long-term seismogenic segmentation of the KRW. The northern section trends northwest and includes the broad (up to 12-km-wide, in east-west direction) zone of faults shown by Piety (1994) extending from lat 38°N. southwest to Cedar Pass. The central section trends south from Cedar Pass to Gold Reed Pass, is characterized by fewer mapped strands than to the north or south, and includes a gap approximately 9 km long adjacent to the northern part of Cathedral Ridge (Piety, 1994). Ekren and others (1971) indicate a buried fault in this gap. The southern section extends from Gold Reed Pass south to Silent Butte and is characterized by a broad zone of mapped faults that widens to a maximum of 9.5 km at the southern end.

ORIENTATION: The KRW has an overall trend of N. 10° W. The northern section has an average trend of N. 34° W., but individual faults trend between N. 48° E. and N. 65° W. Generally, the northeast-trending faults are confined to the area between lat 38°N. and the latitude of Stinking Spring and may be part of a separate fault zone. The central section has an average trend of N. 7° W., but individual faults trend between N. 10° E. and N. 20° W. The southern section has an average trend of N. 16° E.; individual faults trend between N. 44° E. and N. 15° W. The only scarps on alluvium are found in the southern part of the central section and the northern part of the southern section.

LENGTH

Length reported in Piety (1994): 84 km

The straight-line distance of mapped faults as shown by Piety (1994) is 72 km. The northern section of KRW consists of overlapping faults that define a nearly continuous boundary of the topographically high part of the mountain block that is 35 km long from end to end; no faults are mapped along a 1.5-km-long gap north of Corral Spring (fig. 9). The central section is 22 km long (straight-line distance) and includes a

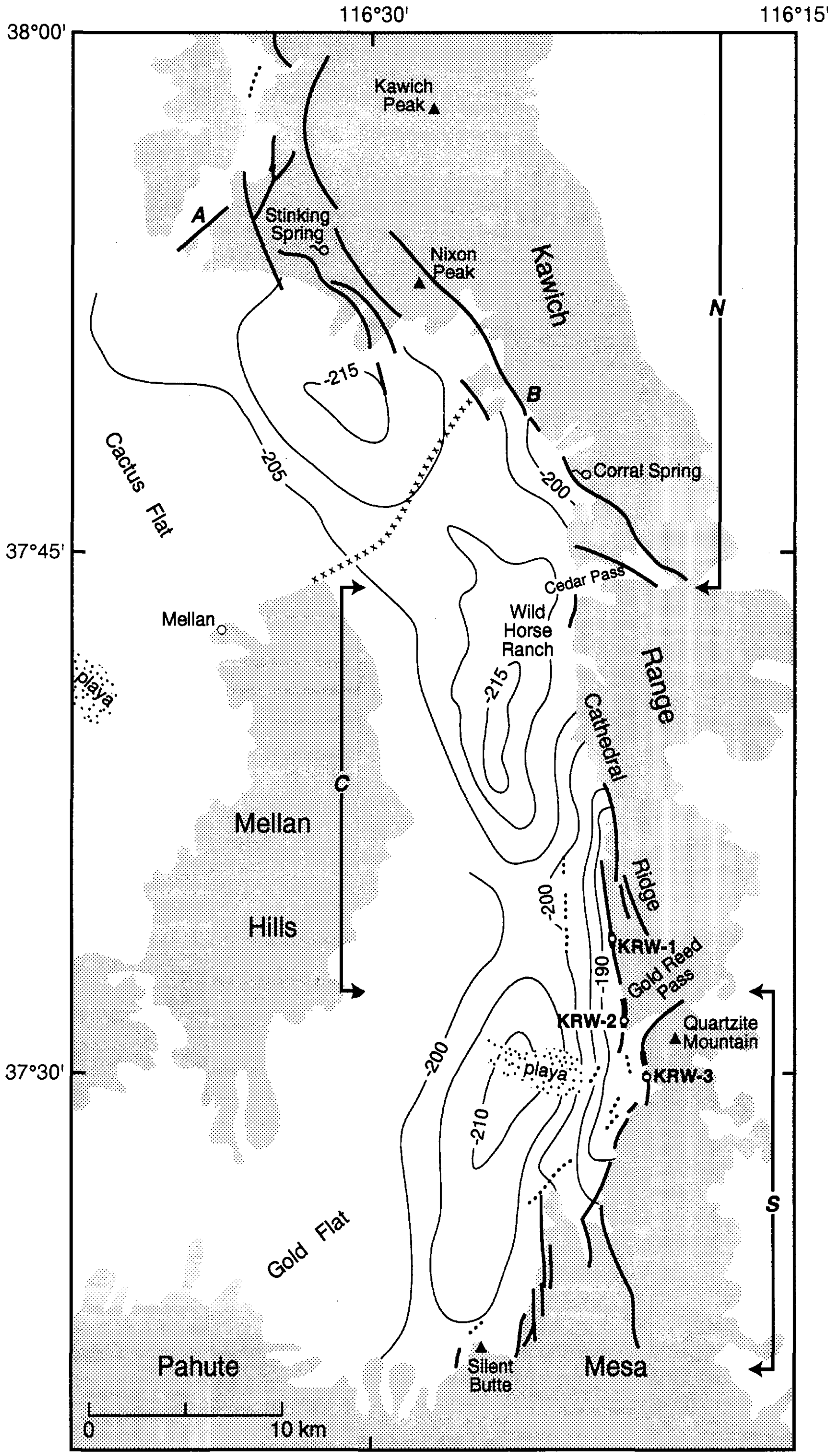

Figure 9. Map showing faults of the Kawich Range West fault zone (KRW) from Piety (1994). Zone is informally divided into three sections: ***N,*** northern; ***C,*** central; and ***S,*** southern. Medium solid lines are faults in bedrock or at the bedrock-alluvium contact and heavy lines are scarps on alluvium. Fine dotted lines are faults shown by Piety (1994) that do not have topographic expression, are possible shoreline scarps, or could not be recognized on low-altitude color photography (this study). Extent of mostly continuous bedrock (half-tone fill) is from Ekren and others (1971) and Gardner and others (1980). Fine solid lines are gravity contours (contour interval 5 mgal) in eastern part of Cactus Flat and Gold Flat (Ekren and others, 1971). Drainage divide between Cactus and Gold Flat shown by X's.

9-km-long gap in mapped faults along the northern end of Cathedral Ridge. The southern section is 21 km long (straight-line distance) and is shown as subparallel, overlapping faults. The sum of the section lengths is 78 km.

Length of known Quaternary scarps (this study): 3.6-7.4 km

The 7.4-km length includes a scarp of questionable tectonic origin (KRW-1) north of Gold Reed Pass (fig. 9, table 4, appendix B) and discontinuous scarps along the flank of Quartzite Mountain (KRW-2 and KRW-3). The questionable feature, at lat 37.57°N., long 116.36°W., is less than 10 m long and may have formed from erosion caused by surface runoff rather than by surface faulting. There are no other scarps on alluvium to the south of this feature for a distance of 3.8 km, but there is a 0.5-km-long prominent bedrock scarp (possibly a fault-line scarp) in this interval. The 3.6-km total length represents the straight-line distance between the northern end of a tectonic scarp on the steep flank of a small bedrock hill (lat 37.53°N., long 116.35°W.) and the southern limit of scarps on alluvium along the flank of Quartzite Mountain (lat 37.50°N., long 116.34°W.). Even over this short distance, there are four gaps ranging from approximately 100 m to 1 km (totaling 2.4 km).

STYLE OF FAULTING: Normal, down to the west

The sense of movement on the KRW is shown as normal by Ekren and others (1971). The short discontinuous scarps on alluvium as well as the bedrock scarps all indicate relative down-to-the west movement. A lateral component of movement, especially a localized one, can not be precluded, but no evidence of lateral movement was found on the discontinuous, locally modified scarps we studied.

DISPLACEMENT AND AGE

Range of observed surface offset and scarp height representing the youngest movement:
0.2-0.4 m (surface offset) and 1.2-2.6 m (scarp height)

KRW scarp-profile data is of limited use in estimating fault displacements and ages. Only three sites on alluvium were located that were even marginally suitable for scarp profiling along the entire length of the KRW. At each site, unknown amounts and rates of erosion and deposition complicate the evaluation of scarp degradation.

The scarp profiled at site KRW-1, near the mouth of a small channel 2.4 km northwest of Gold Reed Pass, is subtle (appendix B) and may not have a tectonic origin. The scarp is a gentle inflection (8.4°) on a 5.2° alluvial slope. The surface of the scarp is irregular in profile and the scarp has limited aerial extent because it is on the only remaining remnant of a high terrace adjacent to this drainage. The scarp is between

TABLE 4. Scarp-profile data for the Kawich Range West fault zone, southern Nevada.

[Positive slope angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources. Fault section refers to informal subdivisions of fault described in text. All scarps face to the west and are presumed to be normal. Fault parameters as defined in figure 4: LS, lower slope angle, US, upper slope angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle—values are average of at least 3 measurements except that noted by *, which represent two measurements.]

Profile No.	Fault section	LS	US	SO (m)	SH (m)	θ
KRW-1	Central	5.2°	5.3°	0.4	1.2	8.4°
KRW-2	Southern	3.7°	2.6°	2.2	3.3	9.6°
KRW-3	Southern	5.5°	9.1°	1.5	2.6	15.6°*

and on trend with a prominent, fault-controlled topographic break of the range front to the north and a near-vertical bedrock-alluvium contact in a natural exposure below a low terrace level to the south (which is not associated with a scarp on the surface). This spatial relation points to a tectonic origin. However, the occurrence of the scarp on the high terrace between obvious structurally controlled features may be fortuitous, and the scarp at KRW-1 instead might have an erosional origin. We are unable to confidently interpret its origin due to the limited aerial extent of the terrace at the scarp and the absence of nearby similar-age deposits. We include the equivocal data from profile site KRW–1 in our constraints of surface offset and scarp height because our data are limited.

The southernmost profile site (KRW-3) is about 7.4 km south of KRW-1; the scarp is moderately degraded and its profile suggests the presence of an adjacent antithetic scarp or localized backtilting of the gently sloping downthrown surface.

Estimated age of most recent surface-faulting event: latest Pleistocene?

The data from the three scarp profiles on the 7.4-km-long part of the KRW suggest differences in the relative ages of surface faulting that make estimating the time of the most recent event difficult. Profiles KRW-1 and KRW-3 plot in a position on the graph of scarp height versus scarp-slope angle (fig. 10) that suggests an age similar to that of the early Holocene (Crone, 1983) Drum Mountain fault scarps in west-central Utah. Both points plot below the regression line but within one standard deviation of the Drum Mountain data (Bucknam and Anderson, 1979). In contrast, the morphology of the higher scarp (KRW-2) suggests an age older than that of the latest Pleistocene Lake Bonneville shoreline scarps. All points plot above the regression line for the approximately 100-ka Santa Rita fault scarps (Pearthree and Calvo, 1987). The apparent differences in the ages of the scarps, localized erosional or depositional conditions at each site, and the small number of scarp-profile data yield a poorly constrained estimate of the age of faulting.

The discontinuous nature of the scarps is somewhat problematic if the most-recent surface-faulting event occurred as recently as that indicated by the youngest relative-age relations. Either the scarps are mostly buried by younger alluvial deposits or they were discontinuous when they formed. No detailed mapping of Quaternary deposits exists in the area to help constrain the timing of faulting on this part of the KRW. Photogeologic mapping by Dohrenwend and others (1992) using high-altitude aerial photography provides no additional constraint on the ages of faulted deposits; these authors recognized scarps along the southern KRW on Pleistocene (10 ka-1.5 Ma) alluvium.

The present discontinuous nature of KRW scarps may reflect originally discontinuous surface faulting. The morphology of the KRW scarps are broadly similar to those of the BLR, and all of the KRW data plot within the scatter of BLR data (fig. 7). The KRW scarps may have formed discontinuously in sympathetic response to earthquake(s) on the nearby BLR. A historic analog is provided by the rupture of the Madison fault during the 1959 Hebgen Lake earthquake southwestern Montana. During the Hebgen Lake earthquake, discontinuous, north-trending, <1-m-high ruptures formed over a distance of approximately 3 km (Myers and Hamilton, 1964) along a range-front fault approximately 30 km west of the epicenter. The distance between the BLR and the KRW is less, about 20 km.

Range of observed total surface offset along scarps on alluvium: 0.2-2.2 m

The range of surface offsets are defined by previously described profile data and the scarp with the largest surface offset (KRW-2), which is south of Gold Reed Pass (approximately 4.4 km south of profile site KRW-1 and 3 km north of profile site KRW-3). The highest scarp has a distinct asymmetric appearance that may be caused by burial of the toe of the scarp by alluvium deposited by a small wash south of the profile site. The morphology of the scarp at KRW-2 suggests a relative age older than the other two scarps (fig. 10) even though it is on a more gently sloping fan. These characteristics may indicate that this scarp is the result of multiple movements, but the data are inadequate to make a definitive interpretation.

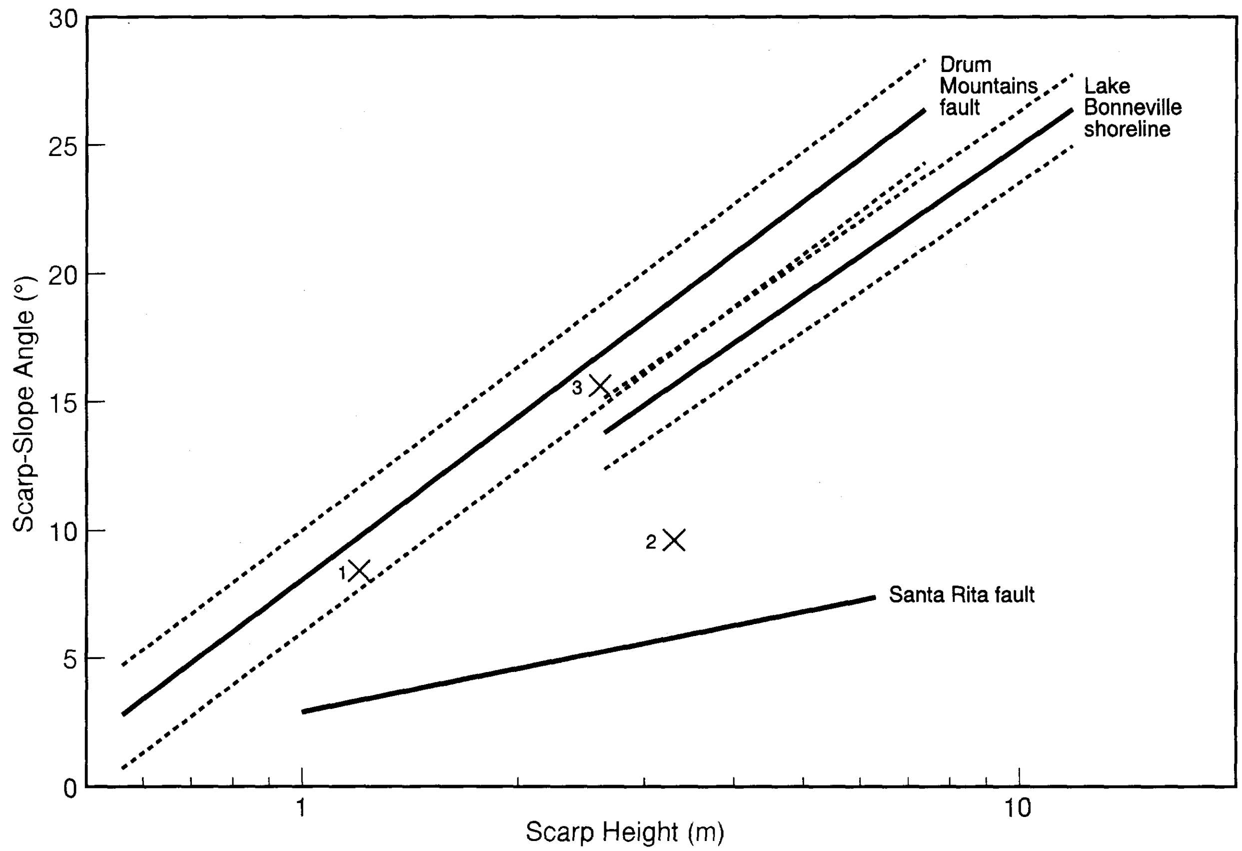

FIGURE 10. Plot of scarp-height—slope-angle values for scarps on alluvium along the Kawich Range West fault zone (KRW). KRW site numbers shown in figure 9 and table 4. Solid lines, regression lines for reference scarps; dotted lines, 1-σ limits for regressions. Lake Bonneville shoreline scarp (about 15 ka; Machette, 1989) and Drum Mountains fault scarp (about 10 ka; Crone, 1983) both from Bucknam and Anderson (1979); Santa Rita fault scarp (estimated age about 100 ka; Pearthree and Calvo, 1987). Points that plot above or below the 1-σ limits of a regression line suggest relative ages that are younger or older than those of the reference scarps, respectively.

Estimates of recurrence intervals and slip rates: Not determined

Qualitatively, the scarp data and the character of the range front indicates long recurrence intervals and low slip rates for all of the KRW, including the part with scarps on alluvium. There is no clear evidence of recurrent late Quaternary movement along the scarps on alluvium, as noted above. The absence of scarps on alluvium along the rest of the fault zone indicates the slip rate is low. Single-event scarps may become unrecognizable in a few hundred thousand years (Wallace, 1977; Machette, 1989). Hanks and others (1984) suggest that a 1-m-high scarp degrades to a feature that is unrecognizable within 100 k. y. If this is the case, then the maximum slip rate would be 0.01 mm/yr.

The rest of the KRW as mapped by Piety (1994) consists of numerous faults in bedrock and at the bedrock-alluvium contact (fig. 9). Scarps on bedrock are present in the northern section along a northeast-striking fault (locality A in fig. 9) and a northwest-striking fault (locality B in fig. 9). The scarps at locality A were profiled, but because they are not formed on alluvium, morphologic characteristics are not useful in determining Quaternary ages of displacements. The poorly defined range-front faults in the central section shown by Reheis (1992) more appropriately characterizes this section than the major range-front fault classification of Dohrenwend and others (1992). The precipitous range front north of Gold Reed Pass is probably lithologically controlled by Precambrian Stirling Quartzite (Ekren and others, 1971).

The morphology of the Kawich Range does not reflect characteristics typically associated with active range fronts in the Basin and Range province (Bull, 1987). Much of the mountain front is sinuous and deeply embayed. The piedmont along most of the west flank of the Kawich Range is characterized by bedrock beneath a thin veneer of pediment gravel and high-standing outcrops of bedrock hundreds of meters to more than 1 km west of the range front. Even along the reach of the fault where scarps on alluvium are present, well-developed pediment surfaces on bedrock extend hundreds of meters valleyward of the main mountain block and, locally, beyond the projections of the fault scarps. Summit elevations of most ranges in the Basin and Range and maximum topographic relief across range-bounding faults typically are low at the ends and reach a maximum somewhere near the center of the mountain block. In contrast, the greatest topographic relief across the KRW is 1.2 km in the northern section, 0.9 km in the central section (but for most of its length the maximum is <0.65 km), and 0.8 km in the southern section. All of these relations qualitatively suggest low long-term slip rates.

Gravity data (Ekren and others, 1971) and basin physiography in Gold and Cactus Flats reveal a pattern suggesting fault-zone segmentation that coincides roughly with the major segmentation of the bedrock block. Cactus Flat is separated from Gold Flat to the south by a drainage divide that trends to the northeast as shown in figure 9. The drainage divide is nearly coincident with and subparallel to a gravity saddle between a roughly circular, closed gravity low (-215 mgal) southwest of Nixon Peak and a similar low (-215 mgal) south of Wild Horse Ranch. This spatial coincidence may reflect the long-term existence of a segment boundary of the KRW. The southern gravity low (-210 mgal) is located near the principle playa in Gold Flat. The two southernmost gravity lows are elongate and subparallel to the range front, and are separated from one another by a saddle in the gravity data that projects into the range front north of profile site KRW-1. All of the scarps on alluvium occur south of the southern gravity saddle. The approximate coincidence of the southern range block, the southern gravity low, the playa, and the discontinuous Quaternary scarps suggest the southern section of the KRW may have a long history as a seismogenic fault segment. Such segmented behavior, if applicable to the KRW, significantly decreases potential earthquake rupture lengths and, thus, other seismogenic characteristics of the fault zone.

ROCKET WASH-BEATTY WASH FAULT ZONE (RWBW)

SUMMARY: The Rocket Wash-Beatty Wash fault zone (RWBW) lies west and southwest of Timber Mountain, 13-25 km northeast of Beatty, Nevada. The zone consists of a series of north-trending fault strands, with both down-to-the-east and down-to-the-west displacements of 10-30 m in Miocene volcanic rocks. No evidence of faulting in Quaternary deposits was found in this study. Several lines of evidence indicate that most or all displacement on this fault zone occurred in the late Miocene. Lack of geophysical signature (McCafferty and Grauch, in press) and along-strike contrasts in fault trend and displacement direction indicate that this is not a major crustal fault zone.

LOCATION: The RWBW of Piety (1994) lies west and southwest of Timber Mountain, 13-25 km northeast of Beatty, Nevada, and 20-35 km from Yucca Mountain (fig. 1).

ORIENTATION: North of lat 37°N., the RWBW trends due north; south of lat 37°N., two strands of the RWBW trend northeasterly (N. 20°-25° E.).

LENGTH

Length reported in Piety (1994): 5-17 km

Length of known Quaternary scarps (this study): 0 km

Most of the RWBW is located in Tertiary bedrock (Cornwall and Kleinhampl, 1961; Lipman and others, 1966; Swadley and Parrish, 1988; Minor and others, 1993), except where the fault traces project across drainages containing fluvial gravel of Quaternary age. No unequivocal evidence of faulting was found in any Quaternary deposits examined in this study.

The trace of the RWBW may extend about 10 km southward of the southern limit reported by Piety (1994), if a 5-km-long gap and a 5-km-long lineament in the vicinity of Tates Wash are included. This lineament has the same northeast trend as the southernmost of the RWBW strands. The southern 3 km of this lineament, herein informally termed the Tates Wash fault, have been mapped as a down-to-the-northwest normal fault by Monsen and others (1992). Reheis and Noller (1991) extend the Tates Wash fault 2 km to the northeast across Quaternary deposits. We found several anastomosing drainages that parallel the modern course of Tates Wash in the area mapped by Reheis and Noller (1991), but no evidence of fault scarps or other unequivocal evidence of Quaternary displacement.

Excavation of a deep open-pit mine in 1988, the Mother Load Mine, has exposed a large area of the subsurface across the northern end of the Tates Wash fault as mapped by Monsen and others (1992). An 8- to 10-m-thick sequence of gravelly alluvium with at least three stage-IV petrocalcic horizons is exposed at the surface in the western part of the mine. These deposits are mapped as Q2c alluvium (middle Pleistocene) by Swadley and Parrish (1988) and as Qif alluvium (late Pleistocene) by Monsen and others (1992). Recent soils analysis and uranium-series dating in nearby Crater Flat (Peterson and others, 1995) also yielded middle Pleistocene ages (>160 ka) for deposits that correlate with Q2c deposits of Swadley and Parrish (1988). The thick, well developed soils exposed in the pit preclude a late Pleistocene age for these deposits, so we conclude that they are middle Pleistocene or older.

We found no clear evidence of faulting in the alluvial deposits exposed in the Mother Lode Mine. The eastern margin of the alluvium on both the north and south sides of the pit is in depositional contact against the underlying Tertiary bedrock. On the south side of the pit, this contact is listric in shape, and flattens from a steep (~60°) upper part to horizontal over a distance of 8-10 m. The contact appears to be the margin of a channel cut in the underlying bedrock during deposition of the alluvium. The listric shape of the alluvium/bedrock contact supports our conclusion that this feature is not a Quaternary fault. However, the margin is now marked by numerous fractures of various orientations that have subsequently been filled with carbonate-rich, fine-grained sediment. The processes responsible for forming these fractures are unknown, but fracture truncations near the channel margin suggest two or more episodes of fracturing since deposition of the alluvium. The bedrock/alluvium contact on the north side of the pit was not examined, but it has the same listric geometry without the fracturing that is present in the southern wall of the pit. The channel margin trends northeastward for several hundred meters across the pit, and may be the source of the lineament mapped by Reheis and Noller (1991) in this location.

A steeply west dipping fault is exposed in Tertiary bedrock in the western part of the Mother Lode Mine. Stratigraphic relations in the pit indicate a post-11 Ma age of faulting on this structure (C. Friedrich, written commun., 1995), which we assume corresponds to the Tates Wash fault as mapped by Monsen and others (1992). The upward projection of the bedrock fault is not well exposed in the pit, but the upper trace of the fault appears to intersect the base of the alluvium a few tens of meters west of the southern channel margin. A small (< 1-m-high) step may be present in the bedrock floor of the alluvial channel at this location, but we found no obvious evidence of faulting in the alluvium above the bedrock fault. In a trench exposure that has been destroyed by the mining operation, Monsen and others (1992) described evidence of offset in Pliocene or early Quaternary alluvium. The excellent exposures in the mine pit lead us to conclude that if alluvium is faulted along the Tates Wash fault, then a Pliocene age for latest movement is most likely.

STYLE OF FAULTING: Normal; both down-to-the-east and down-to-the-west displacements (Cornwall and Kleinhampl, 1961; Lipman and others, 1966; Minor and others, 1993).

Reheis (1992) shows right-lateral slip on a north-trending fault in bedrock a few kilometers east of the RWBW as mapped by Piety (1994). The surface trace of this fault lies entirely in Tertiary bedrock (Lipman and others, 1966). We found no expression of surface faulting (fault scarps, aligned drainages) where the trace crosses extensive late and middle(?) Pleistocene alluvium in Rocket Wash.

DISPLACEMENT AND AGE

Estimated age of most recent surface-faulting event: late Miocene

No evidence of offset of Quaternary deposits was found along any of the RWBW traces examined in this study, but the ages of the unfaulted Quaternary deposits are poorly known. Unfaulted stream terraces along Beatty Wash are 15-23 m above modern stream level; unfaulted terraces along Rocket Wash are about 10 m above modern stream level. Soils in these deposits are similar (weak Bt and stage II carbonate horizons), so they may represent similar-aged deposits. Swadley and Parrish (1988) map the terraces in Beatty Wash as Q2c deposits; Hoover and others (1981) suggest that Q2c deposits have ages of 270-750 ka, and recent studies in nearby Crater Flat suggest that deposits with similar soils are >160 ka (Peterson and others, 1995). Such ages imply that latest movement on the RWBW predates the middle Pleistocene.

However, relations along several strands of the RWBW near a major drainage 2.5-3 km south of Rocket Wash indicate that most displacement occurred much earlier, in late Miocene time. At this location, fault displacements in the Trail Ridge Tuff, an ash-flow tuff erupted from the nearby Black Mountain caldera about 9.3 Ma, typically are only about 20 percent of displacements of the underlying Pahute Mesa Tuff, another welded tuff of the Black Mountain caldera erupted about 9.4 Ma (Minor and others, 1993; Sawyer and others, 1994). Total displacement of the Pahute Mesa Tuff on most strands is about 30 m, and displacement of the Trail Ridge Tuff is about 5 m. The Trail Ridge Tuff also thins across fault-line scarps on several strands in the underlying Pahute Mesa Tuff (Lipman and others, 1966). These relations indicate that most displacement on the RWBW probably occurred in the short time period (~100 k. y.) between emplacement of these welded tuffs in the late Miocene.

Pre-Pliocene displacement also is consistent with fault relationships in the overlying Miocene and Pliocene gravels of Oasis Valley. Reheis (1992) used photo-lineaments to extend several strands of the RWBW into these gravels between Rocket Wash and Beatty Wash, but Lipman and others (1966) and Minor and others (1993) show these gravels lying unfaulted across all traces of the RWBW in this area. The gravels of Oasis Valley are late Miocene to early Pliocene age, as indicated by inclusion of the Spearhead Member of the Stonewall Flat Tuff (7.5 Ma) near their base and Thirsty Mountain Basalt (4.6 Ma) near their top (Minor and others, 1993; Schilling, 1994). Although these gravels are usually poorly exposed, we found no evidence of faulting at several locations along the lineaments identified by Reheis (1992); thus the gravels of Oasis Valley post-date the age of latest movement on the RWBW.

The southernmost strand of the RWBW as mapped by Piety (1994) has a similar history. This fault has substantial down-to-the-east displacement (Cornwall and Kleinhampl, 1961) but appears to die out at its northern end at Beatty Wash. Here the fault does not cut a 20- to 23-m-high, middle Pleistocene stream terrace along Beatty Wash, and also does not appear to offset the 7.5 Ma Spearhead Member of the Stonewall Flat Tuff, which is exposed in several hillsides directly north of Beatty Wash. Thus the field relations indicate that movement on most strands of the RWBW was restricted to the late Miocene, with little or no movement since that time. The geomorphology of this area (lack of a range front, similarity of erosional and fault controlled escarpments, inversion of topography along some fault-line scarps) supports a late Miocene age for latest movement on the RWBW.

OASIS VALLEY FAULT ZONE (OSV)

SUMMARY: The Oasis Valley fault zone (OSV) is a cluster of north-trending normal faults mapped in the vicinity of Springdale, Nevada. In contrast to the Tolicha Peak and Rocket Wash-Beatty Wash fault zones nearby, the OSV appears to be a distinct structural and geophysical feature (Conners and others, 1995; McCafferty and Grauch, in press). However, we found no evidence of faulting in late Quaternary deposits, and only equivocal evidence of faulting in early Pleistocene or older deposits on a single 2.5 km strand of the OSV.

LOCATION: As mapped by Reheis and Noller (1991), Reheis (1992), and Piety (1994), the OSV is a cluster of north-trending normal faults in the vicinity of Springdale, Nevada; most strands lie 10-15 km north of Beatty, Nevada. The southern end of the OSV is approximately 25 km northwest of Yucca Mountain (fig. 1).

ORIENTATION: Generally ±10° of due north

LENGTH

Length reported in Piety (1994): 20 km, includes all strands and 4 km of gaps

Length of known Quaternary scarps (this study): 0-2.5 km

The OSV of Piety (1994) may be extended northward about 10 km to a total length of 30 km, if two north-trending fault strands on Thirsty Mountain (Reheis, 1992) are included. These two strands are about 2.5 and 4 km long, and offset the 4.6 Ma basalts of the Thirsty Mountain shield volcano about 2-6 m (Minor and others, 1993; Fleck and others, in press). They are separated from the northern end of the OSV as mapped by Piety (1994) by a 5-km-long gap. We found no evidence of Quaternary movement on the Thirsty Mountain strands, but they lie on the same steep north-south gravity gradient as the rest of the OSV (McCafferty and Grauch, in press), are on trend with the most prominent OSV strand, and may have similar displacement histories. We found no unequivocal evidence of late Quaternary movement along any of the strands of the OSV. However, a 2.5-km-long section of the prominent strand east of Springdale is marked by a distinct airphoto lineament that may reflect minor early Pleistocene displacement.

STYLE OF FAULTING: Primarily normal, down-to-the-west and down-to-the-east

DISPLACEMENT AND AGE

Estimated age of most recent surface-faulting event: Pre-middle Quaternary

We found only equivocal evidence of displacement in Quaternary deposits on a few strands of the OSV. Our observations on the separate strands mapped by Reheis and Noller (1991), Reheis (1992), and Piety (1994) are discussed below in three sections: (1) photolineaments, (2) faults in Tertiary rocks, and (3) possible Quaternary faults.

(1) Photolineaments. This category includes several photolineaments mapped by Reheis and Noller (1991), Reheis (1992), and Piety (1994). These include a graben-like feature mapped at the northern end of the OSV (Reheis, 1992), and the southernmost of several strands mapped as having possible late Pleistocene movement by Reheis (1992) and Piety (1994). Both features are mapped in areas of dissected Tertiary-aged gravels of Oasis Valley (4.6-7.5 Ma), and are not shown on recent geologic maps in the region (Minor and

others, 1993; Schilling, 1994). We found no evidence of these features on the ground or on 1:24,000-scale aerial photographs, in either Tertiary or Quaternary deposits. We conclude that whatever their origin, these photolineaments are not Quaternary structural features.

(2) Faults in Tertiary rocks. This category includes most strands of the OSV as mapped by Reheis and Noller (1991), Reheis (1992), and Piety (1994). These strands include the hook-shaped strand at the southern end of the OSV, and two strands located 3-4 km east of Springdale. These strands are mapped in Miocene and lower Pliocene volcanic and sedimentary rocks on recent geologic maps (Minor and others, 1993; Schilling, 1994). None of these structures is associated with topographic range fronts, and we found no evidence of faulting where the faults project across or into Quaternary deposits. We found no difference between these and numerous other faults that displace Pliocene and older rocks throughout the region, and thus conclude that they are not Quaternary structural features.

(3) Possible Quaternary faults. We found two fault strands in the OSV that have equivocal evidence of displacement in Quaternary deposits. The westernmost strand of the OSV shown by Reheis (1992) and Piety (1994) is exposed in a roadcut on the west side of U.S. Highway 95 about 2.5 km southeast of Springdale. Here a steeply eastward-dipping fault juxtaposes carbonate-cemented gravels against Tertiary volcaniclastic rocks. Several other similar faults are exposed in another roadcut 300-500 m to the north. The faulted gravel could be interpreted as Quaternary alluvium displaced against Tertiary rocks. However, Minor and others (1993) map these gravels as Tertiary gravels of Oasis Valley (Miocene and Pliocene), and we found no evidence of scarps in well-preserved alluvial surfaces along several washes that cross the projection of this fault to the south. These surfaces have well-developed desert pavements and soils similar to nearby deposits mapped as middle Pleistocene Q2c deposits by Swadley and Parrish (1988). We did find abundant evidence of displacement in Tertiary volcanic and volcaniclastic rocks along the trace of this fault. If the faulted gravels exposed in the roadcut are Quaternary, then they must pre-date the extensive unfaulted middle Pleistocene alluvial deposits present along the southern part of the fault. Our interpretation is that this and other faults exposed in roadcuts in the area displace Tertiary-aged gravels of Oasis Valley (4.6-7.5 Ma) and older Rainier Mesa Tuffs (11.6 Ma), and do not displace Quaternary deposits.

A second strand showing possible evidence of displacement in Quaternary deposits has been described by Reheis and Noller (1989). This strand lies 5 km east of Springdale and is the central of several strands mapped as having possible late Pleistocene displacement by Piety (1994). Reheis (1992) maps this strand as a 2.5-km-long, predominantly west-facing scarp, with a small graben at its northern end. Reheis and Noller (1989) measured 4 m of down-to-the-east displacement on the antithetic scarp in this graben across a QTa alluvial surface (Hoover and others, 1981), thought to be 0.73-3 Ma in age. We agree that the lineament mapped by Reheis (1992) and Piety (1994) probably marks the trace of a fault, but the amount and timing of displacement across this feature are open to interpretation. This region is mapped as dissected Miocene and Pliocene gravels of Oasis Valley (4.6-7.5 Ma) by Minor and others (1993). The Tertiary gravels are cut by numerous intermittent stream channels and by a large wash that is paralleled by the lower part of the Cat Canyon Road. The fault is marked in the field by a discontinuous alignment of short drainages and gaps in whaleback-like linear remnants of Tertiary or Quaternary(?) gravel that lie between late Quaternary alluvial deposits in the intermittent wash bottoms. Several of the gaps in the whalebacks are now occupied by stream channels, and have obviously been widened by stream erosion. We found no evidence of faulting of the alluvial deposits in the intermittent channels or of an extensive Q2c(?) terrace that lies 10-15 m above the Cat Creek Road wash at the northern end of the strand. Discontinuous vegetation lineaments may be the source of a north-trending extension of this fault strand mapped by Reheis (1992) on the north side of the Cat Creek Road wash, but we found no scarps in the late Quaternary wash deposits in this area. These lineaments probably are caused by shallow groundwater damming along the fault, and are not related to Quaternary faulting.

Our interpretation of the recency of faulting on this strand primarily depends on the age(s) of the faulted gravels. Either these deposits are eroded Miocene and Pliocene gravels with no apparent Quaternary displacement (e.g. Minor and others, 1993), or these are Tertiary gravels beveled by Quaternary alluvial surfaces, which subsequently have been faulted (e.g. Reheis and Noller, 1989, 1991). Some of the whalebacks have relatively planar surfaces, but most are so dissected that little remains of any pre-existing surfaces. We found no place along this strand where surfaces could be correlated across the fault with any certainty. At one of the best locations near the southern end of the fault, a possible Quaternary surface with poorly exposed multiple stage-IV petrocalcic horizons is present on both sides of the fault. A profile across a 40-m-wide gap or graben(?) at this site yields an apparent down-to-the-west displacement of 0.2 m (profile OSV-1 in table 5, appendix B). Such small displacement is within the error limits of the surface profiling technique, so we cannot determine with confidence either the direction of displacement or the amount of surface offset at this site. At the location described by Reheis and Noller (1989) near the northern end of the strand, we could not find correlative surfaces across the approximately 100-m-wide gap or graben(?) present at this site, so their measurement of 4 m of offset on an antithetic scarp cannot be used to determine either the amount or direction of displacement. This site has been breached by a broad channel, so the large apparent displacement here can easily be explained by post-faulting erosion. The poor preservation of potentially correlative surfaces along this fault leads us to conclude that the latest movement on this strand was either very small (<< 1 m), or more likely, is very old (Pliocene or early? Pleistocene).

TABLE 5. Scarp-profile data for the Oasis Valley fault zone, southern Nevada.

[Positive slope angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources. Fault section refers to informal subdivisions of fault described in text. Fault parameters as defined in figure 4: LS, lower slope angle, US, upper slope angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle; ?, questionable.]

Profile No.	Fault section	Scarp type, aspect	LS	US	SO (m)	SH (m)	θ
OSV-1	central strand	Normal with graben?, W?	1.3°	1.3°	0.2	2.1	2.7°

TOLICHA PEAK FAULT ZONE (TOL)

SUMMARY: The Tolicha Peak fault zone (TOL) lies west and southwest of Tolicha Peak; its southernmost end is about 25 km north of Beatty, Nevada. As mapped by Reheis (1992) and Piety (1994), the TOL is a cluster of northwest-trending fault strands on the west flank of Tolicha Peak, and several short, isolated lineaments to the south. Most are mapped with down-to-the-west normal displacements. We found no unequivocal evidence of faulting in Quaternary deposits along any of the mapped traces, and found little evidence to support the presence of a throughgoing fault zone in this area. We recommend that usage of the name Tolicha Peak fault zone be abandoned.

LOCATION: The TOL as mapped by Reheis (1992) and Piety (1994) consists of a cluster of north-northwest trending faults on the west flank of Tolicha Peak. The fault zone extends southward along the western edge of Pahute Mesa as three short, isolated lineaments, to the vicinity of Little Black Peak. The southern end as mapped by Reheis (1992) and Piety (1994) is about 25 km north of Beatty, Nevada, and 43 km northwest of Yucca Mountain (fig. 1).

ORIENTATION: Most strands of the TOL trend N. 20°-40° W.; a single mapped strand near its southern end trends a few degrees west of due north.

LENGTH

Length reported in Piety (1994): 22 km

Length of known Quaternary scarps (this study): 0 km

The faults mapped by Reheis (1992) and Piety (1994) on the western flank of Tolicha Peak are located in an area where pedimented Tertiary bedrock is discontinuously mantled by a thin veneer of Quaternary gravel. The three isolated lineaments to the south are mapped in Quaternary alluvium, but we found no unequivocal evidence of Quaternary faulting along these lineaments.

STYLE OF FAULTING: Normal; primarily down-to-the-southwest (Reheis, 1992; Minor and others, 1993; Piety, 1994).

DISPLACEMENT AND AGE

Estimated age of most recent surface-faulting event: Pre-middle Quaternary, probably Tertiary

No unequivocal evidence of offset of Quaternary deposits was found along any of the TOL traces examined in this study. Numerous north-northwest-trending faults are present on the west flank of Tolicha Peak, but these structures are only present in the underlying Tertiary bedrock. Bedrock here consists mostly of bedded tuff of Quartz Mountain and Tuff of Tolicha Peak (Minor and others, 1993). Quaternary deposits in this area are restricted to Holocene alluvium in the active drainages and thin pediment lag gravels on the intervening interfluves. The pediment gravels consist of angular, monolithologic tuff clasts, and contain soils (Bw or weak Bt , stage I-II carbonate development) typical of middle or late Pleistocene surfaces in the region (Hoover and others, 1981; Swadley and Parrish, 1988; Peterson and others, 1995). However, the age of faulting at Tolicha Peak is probably much older because: (1) there is little or no control of drainages by the north-northwest trending faults, and (2) we found no steps or deflections in the bedrock pediment surface or changes in thickness of lag alluvium where bedrock faults project into the interfluves.

Only one of the isolated lineaments mapped by Reheis (1992) and Piety (1994) south of Tolicha Peak shows any evidence of possible faulting. On the ground, the northernmost of these lineaments appears as a discontinuous change in degree of preservation of desert varnish and a slight change in fan slope. Several lines of field evidence indicate that this is probably not a fault: (1) the lineament is not marked by any topographic scarp; (2) the lineament is not linear, but rather is an irregular change in degree of pavement preservation; and (3) this short (<1 km) feature is the only one of its type mapped along this trend, despite the presence of extensive fan deposits of similar or older age. Exposures of fan alluvium with similar surface appearance to the south have 20- to 30-cm-thick stage-IV petrocalcic horizons, which are similar to middle Pleistocene or older soils in Crater Flat (Hoover and others, 1981; Swadley and Parrish, 1988; Peterson and others, 1995). In addition, these fan deposits are overlain by basalt flows from nearby Little Black Peak, which have been dated at 300-350 ka (Minor and others, 1993; Fleck and others, in press). We found no definitive stratigraphic, structural (Minor and others, 1993) or geophysical (McCafferty and Grauch, in press) evidence to support the presence of a throughgoing fault zone in this area. We agree with Reheis (1992, p. 7) that faults in this region have little or no offset in the Quaternary.

SARCOBATUS FLAT FAULT ZONE (SF)

SUMMARY: The Sarcobatus Flat fault zone (SF) lies along the western margin of Pahute Mesa and northeast of Sarcobatus Flat. The southernmost (closest) point on the SF is 52 km from Yucca Mountain. The zone has been previously mapped as a series of short faults and lineaments in Tertiary deposits and several short, inconspicuous lineaments in Quaternary deposits. We found no unequivocal evidence of fault scarps on alluvium along the SF. We found one possible fault scarp about 100 m long with about 0.6 m of relief on an isolated patch of alluvium. Because of the scarp's weak expression, very limited extent, and lack of association with a mappable fault, we are unsure it is a fault scarp. No surface offset was found across the remaining lineaments in the SF fault zone. Tonal lineaments on aerial photographs may reflect structural control, but faults have not displaced the surface.

LOCATION: The Sarcobatus Flat fault (SF) zone of Piety (1994) lies along the foot of the steep western margin of Pahute Mesa northeast of Sarcobatus Flat (figs. 1, 11). The central part of the zone is at 37° 22' N., 117° 01' W., 9 km north-northeast of Scottys Junction (junction of U.S. Highway 95 and Nevada Highway 267) and 50 km south-southeast of Goldfield. The southernmost (closest) point on the SF is 52 km from Yucca Mountain.

ORIENTATION: Overall trend shown on Piety (1994) is N. 20° W., but some faults and lineaments in the zone (Reheis, 1992) diverge from that trend by as much as 55°.

LENGTH

Length reported in Piety (1994): 27-51 km

Length of known Quaternary scarps (this study): 0? km

Only one highly degraded possible fault scarp about 100 m long on alluvium was detected in this study (profile SF-1 in fig. 11, appendix B), and we found no evidence that the scarp extends beyond this site.

STYLE OF FAULTING: Faults in Tertiary deposits shown as down-to-the-west by Reheis (1992)

DISPLACEMENT AND AGE

Range of observed surface offset and scarp height representing the youngest movement:

Reheis (1992) mapped short faults and lineaments in Tertiary deposits and several short inconspicuous lineaments in Quaternary deposits. The presence of scarps on alluvium is evidence of Quaternary faulting, but the absence of scarps on alluvium only implies a lack of surface faulting during the period of time represented by the age of the alluvial surfaces. Ages of alluvial surfaces along the fault zone are poorly constrained; in general the surfaces have characteristics similar to surfaces that Dohrenwend and others (1992) assigned to the Holocene and late Pleistocene.

In a search for fault scarps on alluvium in and adjacent to the SF, we mapped lineaments on 1:25,000- to 1:30,000-scale black and white aerial photographs that might represent fault scarps (fig. 11). Nearly all lineaments are very subtle and short (a few hundred meters to about 1 km). We examined the most prominent lineaments in field to determine if they are associated with offset surfaces; only one lineament has detectable relief across it. The remainder are tonal lineaments whose origin is unknown.

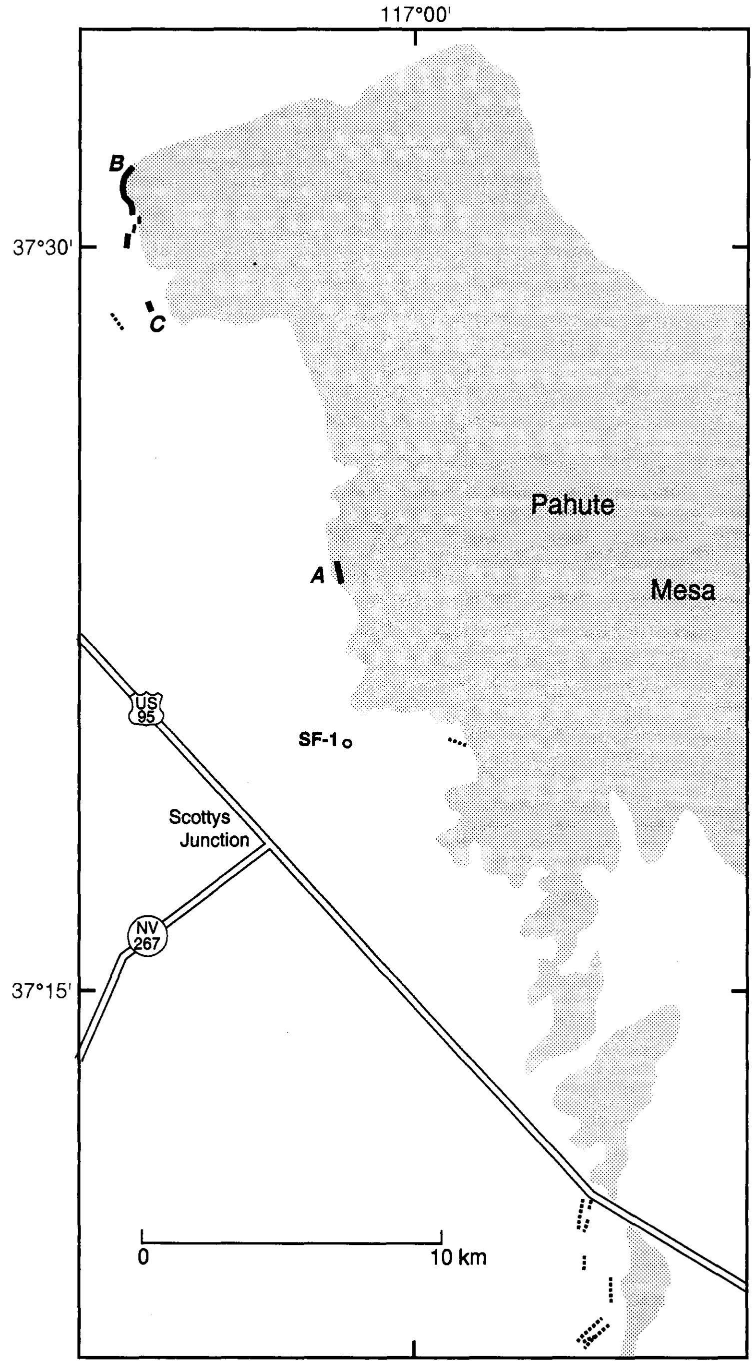

FIGURE 11. Map showing scarps and photo lineaments along the Sarcobatus Flat fault zone (SF). Range boundary (edge of shaded area) drawn at approximate limit of exposed bedrock. Heavy solid lines, fault-line or bedrock scarps; letters, location discussed in text; thin solid line, photo lineament not examined in field; dotted line, tonal or vegetation lineament examined in field; small open circle, site of scarp profile.

The one feature that we consider to be a possible fault scarp (SF-1 in fig. 11) is 5 km N. 39° E. of Scottys Junction. It forms a subtle N. 20° W.-trending scarp about 100 m long on an isolated patch of old alluvium that contrasts with the alluvium that surrounds it. The surrounding younger alluvium is characterized by low relief and an anastamosing network of poorly defined channels, both of which indicate a Holocene age. The old alluvium lies several meters above the surrounding younger alluvium and is dissected by small swales 1-2 m deep with smoothly rounded sides that merge at narrow rounded interfluves. Profile SF-1 was taken along a lightly scraped road that follows the crest of one of these interfluves. The scarp is recognized in the field more as a zone of more gentle fan slope at the toe of the scarp than steepening of the slope on the face of the scarp. The zone of lower fan slope gives the appearance in the field of a possible graben or zone of back rotation. Projection of the dissected alluvial surfaces above and below the scarp shows the topographic relief across the scarp to be about 0.6 m. About 50 m north of the scarp, across a currently active wash, the scarp projects into a hill of volcanic rock that does not show evidence of a fault on trend with the scarp, nor is there a scarp on alluvium of possibly equivalent age on trend with the scarp to the south. We consider the scarp to be a possible fault scarp, but, because of its low angle and height, its very limited extent, and its lack of association with a mappable fault, surface faulting is unconfirmed.

Estimates of recurrence intervals and slip rates: Not determined

There is no clear evidence of late Quaternary movement along any of the possible fault-related lineaments on alluvium, and the morphology of the range front indicates long recurrence intervals and low slip rates. The range front is sinuous and deeply embayed and numerous bedrock outliers are present valleyward of the mapped range-front fault. Although pediments are not as conspicuous as those along the Kawich Range, there are places along the SF where entrenchment of drainages is deep enough to observe continuous bedrock pediments that extend up to 0.5 km valleyward of the faults mapped by Piety (1994).

We mapped 3 prominent lineaments in the SF that are controlled by faults in bedrock. One of these (A in fig. 11) lies 10.4 km, N. 12° E. of Scottys Junction. On aerial photographs, the N. 16° W. trending feature resembles a dissected scarp in old alluvium. In the field, it is marked by the aligned truncated ends of subparallel bedrock ridges with narrow, smoothly rounded crests. Locally, a fault plane with striations raking 87° S. is exposed in volcanic rock along the aligned ends of the truncated spurs. Alluvium that fills the valleys between the ridges is unfaulted. The unfaulted alluvium is relatively old as shown by its dissection by numerous subparallel drainages with narrow, smoothly rounded interfluves. No data constrain the time of most recent movement on this fault except the observation that it does not displace alluvium at the surface.

A second bedrock-related lineament at the north end of the SF (B in fig. 11) is a scarp that follows the contact between bedrock and alluvium. In places, faulted bedrock extends across the lineament with no topographic relief at the projection of the nearby bedrock-alluvium contact. The lack of topographic relief across the lineament where it traverses bedrock suggests that locally the lineament is a fault-line scarp that was produced by differential erosion.

A third bedrock-related lineament (C in fig. 11) forms a conspicuous 200-m-long lineament 20.5 km N. 12° W. of Scottys Junction. Bedrock that stands a few meters higher than the surrounding alluvium along the lineament is exposed along the scarp at the north and south ends of the mapped lineament. No scarp crosses the alluvium, which extends through a notch in the bedrock near the middle of the lineament. The fan remnant on which the lineament occurs is more than 10 m above the modern wash channel and has surface characteristics that Dohrenwend and others (1992) associate with deposits of early to middle Pleistocene age.

We found no evidence of topographic relief across the remaining lineaments in the fault zone. They are expressed only as tonal contrasts on aerial photographs, and although they may reflect structural control, fault movement has not displaced the ground surface.

KEANE WONDER FAULT ZONE (KW)

SUMMARY: The Keane Wonder fault zone (KW) is an anastomosing group of northwest-trending fault strands and topographic lineaments mapped along the southwestern flank of the Funeral Mountains in Death Valley. The northern end of the KW as mapped by Reheis and Noller (1991) and Piety (1994) is about 29 km southwest of Beatty, Nevada. We found no evidence of faulting in late Quaternary deposits, and only equivocal evidence of isolated faulting in middle Pleistocene or older deposits along the main range-front fault zone. We did find clear evidence of recurrent faulting in late Quaternary deposits on a 2-km-long, north-south splay near the southern end of the KW, but movement on this splay is more likely related to faulting on the nearby Death Valley-Furnace Creek fault system than to movement on the main strand of the KW.

LOCATION: The KW bounds the southwestern flank of the Funeral Mountains, between Winters Peak on the south and Boundary Canyon on the north. The northern end as mapped by Reheis and Noller (1991) and Piety (1994) is about 29 km southwest of Beatty, Nevada; the southern end is 38 km southwest of Yucca Mountain (fig. 1).

ORIENTATION: N. 40°-50° W.; one active splay at southern end trends due north

LENGTH

Length reported in Piety (1994): 25 km

Length of known Quaternary scarps (this study): 0 km (main trace); 2 km (north-south splay—Death Valley-Furnace Creek fault system?)

The main range-front fault zone of the KW displaces Tertiary basin-fill sedimentary rocks against Precambrian metasedimentary rocks along the southwestern flank of the Funeral Mountains (Hunt and Mabey, 1966). We found no unequivocal evidence for late Quaternary movement along the main trace of the range-front fault zone. However, a 2-km-long, north-trending splay near the southern end of the fault zone is marked by scarps on late Quaternary deposits (fig. 12). This splay is probably part of the Death Valley-Furnace Creek fault system, and does not characterize the age of movement on the rest of the KW.

STYLE OF FAULTING:

(1) Main range-front fault zone: primarily normal, down to the southwest

(2) North-south splay near the southern end of the KW: normal, down to the west with associated graben

DISPLACEMENT AND AGE

(1) Main range-front fault zone:

Estimated age of most recent surface-faulting event: Pre-late Quaternary

We found only equivocal evidence of displacement in Quaternary deposits along the main trace of the KW. Most of the range front is not marked by a well-expressed fault zone, but rather is an eroded escarpment

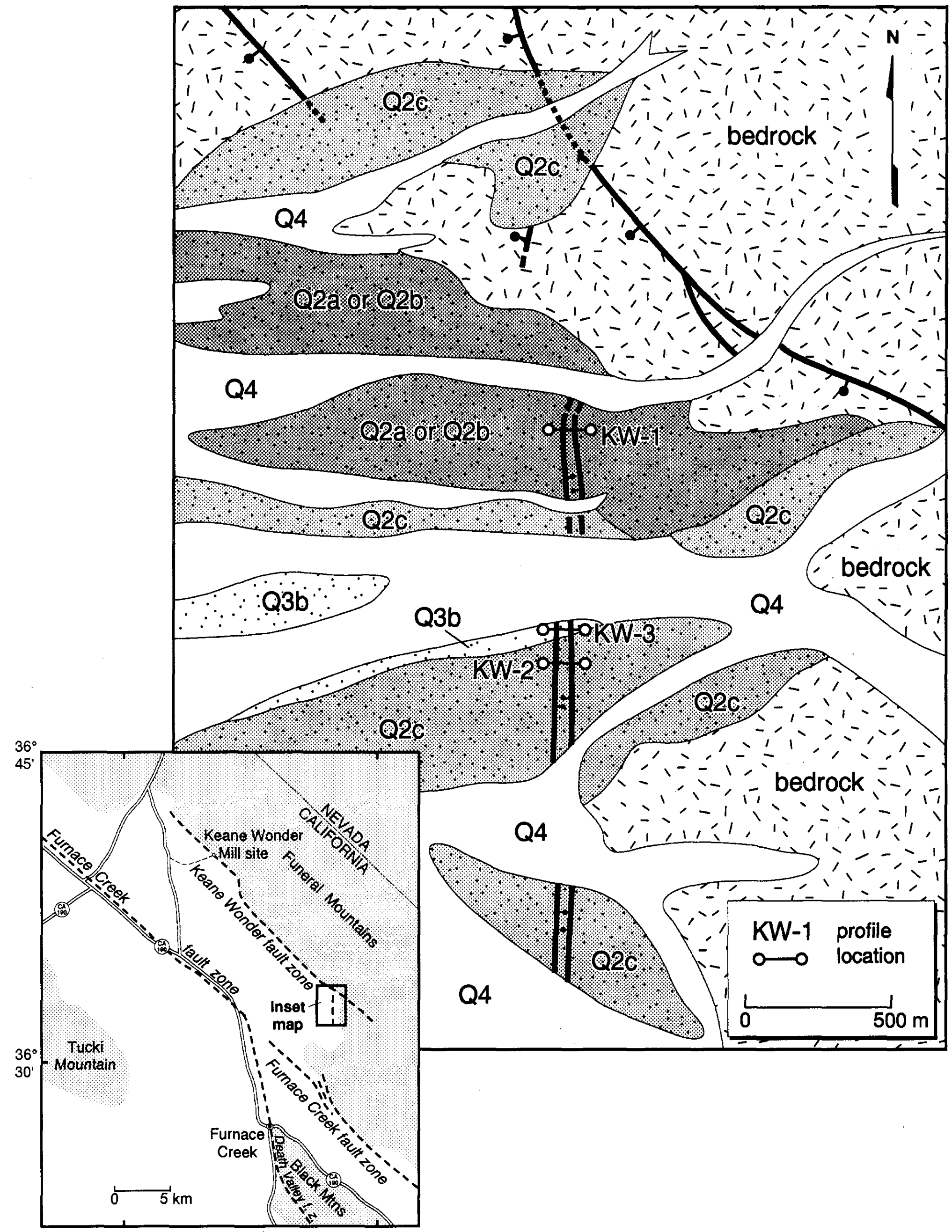

FIGURE 12. Surficial geologic map of north-south splay near the southern end of the Keane Wonder fault zone, Death Valley, California. Quaternary map units are tentatively correlated to surfaces described by Bull (1991) in Death Valley and elsewhere in the lower Colorado River region; ages are described in text. Bedrock is primarily Precambrian metasedimentary rocks and Tertiary basin-fill sedimentary rocks. Traces of Death Valley and Furnace Creek fault zones are generalized from Hunt and Mabey (1966) and Brogan and others (1991).

in metasedimentary Precambrian bedrock; numerous dissected outcrops of coarse Tertiary basin-fill sedimentary rocks are present in the hanging wall block adjacent to the range front (Hunt and Mabey, 1966). Numerous faults cut Precambrian and Tertiary rocks primarily in a down-to-the-southwest sense of displacement. The presence of Tertiary basin-fill sedimentary rocks adjacent to the range-front fault zone indicates that slip rates on this structure cannot be very high during the Quaternary. Such rocks are rarely extensively exposed at the surface along active range-front fault zones. We found no evidence of faulting in the extensive late Quaternary alluvial fans present along most of the KW. These fans have soil and desert pavement characteristics similar to the Q2c surfaces of Bull (1991), which have been dated at 12-70 ka elsewhere in the lower Colorado River region. However, in two isolated locations older, higher fan/pediment surfaces may be faulted. In one exposure about 3.5 km southwest of the Keane Wonder Mill site, an unconsolidated debris flow(?) deposit with a 0.5-m-thick, truncated stage-III carbonate horizon is faulted against Tertiary sedimentary rocks, but the fault does not offset alluvium overlying the debris-flow deposit. The unfaulted alluvium has soil and desert pavement characteristics similar to Q2b surfaces described by Bull (1991) as 70-200 ka. We found no surface expression of this fault, so the most recent faulting event probably substantially pre-dates the age of the Q2b surface.

At another site near the mouth of a prominent canyon about 5.7 km southwest of the Keane Wonder Mill site, a topographic lineament mapped by Reheis and Noller (1991) is marked in one place by a 40-m-long, approximately 5-m-high scarp in a dissected pediment/fan surface that lies 30-35 m above the adjacent channel. This scarp trends discontinuously across the high pediment, and we found no other evidence of faulting in similar-aged surfaces elsewhere along the Keane Wonder range front. Well developed soils and desert pavement characteristics of the thin alluvium overlying the pediment are similar to those of Q2a or Q1 surfaces described by Bull (1991) as >400 ka. Thus we found no evidence of late Quaternary displacement on the KW, and only scattered, equivocal evidence for surface faulting in middle or older Quaternary deposits.

(2) North-south splay near the southern end of the KW:

Near the southern end of the KW, Reheis and Noller (1991) and Piety (1994) map an approximately 2-km-long, north-south trending fault and associated graben. We found clear evidence for recurrent late Quaternary movement along this fault splay, in alluvial fan deposits that range from 2.5 to 25 m above adjacent drainage channels (fig. 12). Soil and desert pavement characteristics of these deposits are similar to alluvial surfaces Q3b, Q2c, Q2b and Q2a described by Bull (1991) as 4-730 ka. However, the anomalous trend and lack of similar evidence of late Quaternary faulting along the main range-front trace of the KW indicates that the recent movement on this splay is not characteristic of the KW. Rather, the northerly trend and more recent activity on this splay are similar to characteristics of the nearby Death Valley or Furnace Creek fault zones (e.g. Brogan and others, 1991). The north-south splay is located in the Salt Springs section (Brogan and others, 1991), a transition zone of late Quaternary fault scarps of various orientations and senses of displacement that lie between the northwest-trending, strike-slip Furnace Creek fault zone and the north-trending, normal-slip Death Valley fault zone. We interpret the north-south splay as either a splay of the Furnace Creek fault zone (Hunt and Mabey, 1966), or as part of the transition zone between these two active fault systems (Brogan and others, 1991). Thus we consider the scarp data presented below to only be characteristic of the north-south splay, and not of the rest of the KW.

Range of observed surface offset representing the youngest movement: ≤1.8 m

Scarp profiles in the middle of three scarps mapped by Reheis and Noller (1991) show evidence of recurrent faulting in late Quaternary alluvium (fig. 12, table 6, appendix B). The youngest faulted fan surface, which lies about 2.5 m above the modern channel floor, is offset a total of 1.8 m, down to the west, across an approximately 50-m-wide graben (profile KW-3). The main scarp has been modified at its base by

TABLE 6. Scarp-profile data for the Keane Wonder fault zone, southeastern California.

[Positive slope angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources. Fault section refers to informal subdivisions of fault described in text. Fault parameters as defined in figure 4: LS, lower slope angle, US, upper slope angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle; ?, questionable.]

Profile No.	Fault section	Scarp type, aspect	LS	US	SO (m)	SH (m)	θ
KW-1	north-south splay; in Q2a or Q2b deposit	Normal with graben, W	3.5°	3.5°	2.5?	5.0?	11.9°
KW-2	north-south splay; in Q2c deposit	Normal with graben, W	3.5°	5°	3.6	5.5	11.9°
KW-3	north-south splay; in Q3b deposit	Normal with graben, W	3°	3°	1.8	2.6	12°

an animal trail, so we cannot determine whether this is a single event scarp. The surface offset during the most recent event at this site is probably no more than about 1.8 m, but may have been less.

Estimated age of most recent surface-faulting event: <8 ka

The youngest fan surface has soil and desert pavement characteristics similar to surface Q3b of Bull (1991), which has been dated elsewhere in the lower Colorado River region at 4-8 ka. This age range is a reasonable maximum age of the most recent faulting event on the north-south splay.

Range of observed total surface offset along scarps on alluvium: 1.8 m to 8-10 m (estimated)

We measured surface offset of 1.8 m across the youngest faulted fan surface. A profile in the adjacent late Quaternary surface yielded a surface offset of 3.6 m (profile KW-2 in table 6, appendix B), twice the single event(?) offset. These results support a minimum of two post-late Quaternary surface-faulting events on the north-south splay. The age of the late Quaternary fan surface, which lies about 8.5 m above the modern drainage, is unknown, but soils and desert pavement characteristics of this widely distributed surface are similar to Q2c surfaces of Bull (1991), which have been dated at 12-70 ka elsewhere in the region. The maximum Quaternary surface offset could not be determined with accuracy, because of dissection of the scarps on the older fan deposits. One scarp profiled on these deposits (profile KW-1) probably has been buried by younger deposits, and thus yields a minimum offset. We estimate from field and airphoto analysis an 8-10 m surface offset on the older fan deposits. The age of this fan surface, which lies 15-25 m above the modern drainage, is unknown but soils and desert pavement characteristics of this surface are similar to Q2b or Q2a surfaces of Bull (1991), which have been dated elsewhere at 70-730 ka. The estimated displacement of this surface is similar to the offset of Tertiary sedimentary rocks exposed in a wash at the northern end of the north-south splay (fig. 12). The similar Tertiary and Quaternary displacements and lack of significant topography along the north-south splay indicate that this fault strand probably is not a long-lived structural feature.

WEST SPRING MOUNTAINS FAULT (WSM)

SUMMARY: The West Spring Mountains fault (WSM) forms scarps on surficial materials of Pleistocene age across the western piedmont of the Spring Mountains, east of Pahrump, Nevada. The WSM has an average strike of N. 22° W. for a distance of 31.4 km and may extend another 15 km to the south, which would yield a potential Quaternary rupture length of 46.7 km on an overall trend of N. 20° W. The main fault probably dips to the west at a high angle and has predominantly normal slip, but scarps along the southern extension show a left-stepping pattern that suggests possible right-lateral, oblique-normal slip. The youngest surface-faulting event probably occurred during the latest Pleistocene or early Holocene and caused about 1.8-2.0 m of surface offset along the central section of the fault. The 11-km-long central section contains the largest scarps along the WSM, indicating either larger displacement events than normal and (or) more frequent events than elsewhere along the fault. Even though similar-age surfaces are distributed all along the fault, the central section has composite scarps that are typically 3-4 times larger than elsewhere. This indirect evidence suggests that the entire WSM probably did not rupture in the latest faulting event and that the cumulative Quaternary displacement is greatest in the central section. Scarps as large as 13.4 m (9.4 m of surface offset) on middle Pleistocene fan alluvium (200-500? ka) along the central section may record average recurrence intervals of more than 28 k. y. and long-term slip rates of less than 0.07 mm/yr.

LOCATION: The WSM extends across the piedmont on the western flank of the Spring Mountains, east of Pahrump, Nevada.

We define 3 informal sections of the WSM and a possible extension to the south (fig. 13). The northern section includes a broad (1.5- to 2.5-km-wide) band of subparallel faults that extend from about 1.5 km south of Grapevine Springs (GVS in fig. 13; sec. 21, T. 17 S., R. 53 E., Mt. Schrader 7.5' quadrangle) to the SE$^1/_4$ sec. 26 (T. 18 S., R. 53 E., Horse Springs 7.5' quadrangle). The central section is comprised mainly of a single fault that extends from about 1.5 km west of Santa Cruz Spring (SCS in fig. 13; SW$^1/_4$ sec. 32, T. 18 S., R. 54 E., Horse Springs 7.5' quadrangle) southward to the Wheeler Pass Road where it associated with a 800- to 1100-m-wide graben (near center of sec. 8, T. 20 S., R. 54 E., Pahrump 7.5' quadrangle). The southern section extends from Wheeler Wash (near center of sec. 16, T. 20 S., R. 54 E., Pahrump 7.5' quadrangle) as a 80- to 150-m-wide fault zone (with graben) to the SW$^1/_4$ sec. 27 (T. 20 S., R. 54 E., Pahrump 7.5' quadrangle). The WSM probably continues southward beneath a 4.8-km-long gap near Nevada Highway 160 and connects to a series of left-stepping piedmont scarps (*SX* in fig. 13) that extend from the SE$^1/_4$ sec. 10 (T. 21 S., R. 54 E., Pahrump 7.5' quadrangle) to the north edge of sec. 13 (T. 22 S., R. 54 E., Pahrump 7.5' quadrangle) on the south.

ORIENTATION: The WSM has an average strike of N. 22° W. with sections striking N. 35° W., N. 14° W., and N. 16° W. as shown in figure 13.

The northern section is comprised of multiple scarps that trend from N. 30° W. to due north and form a broad zone that has an overall trend of N. 35° W. The trace of the fault through the central section is irregular, ranging from N. 60° W. to N. 30° E. and averaging N. 14° W. The southern section is the most linear of the three sections, averaging N. 16° W. The trend of the piedmont scarps of the southern extension range from N. 8°-18° E. but have an overall N. 16° W. trend through their left-stepping pattern. If the southern extension is included, the overall trend of the WSM is N. 20° W.

Hoffard (1991) included the Grapevine fault (fig. 13) of Burchfiel (1983) as a northern extension of the WSM. The Grapevine fault places undivided Quaternary/Tertiary sediment (QTs) against bedrock and

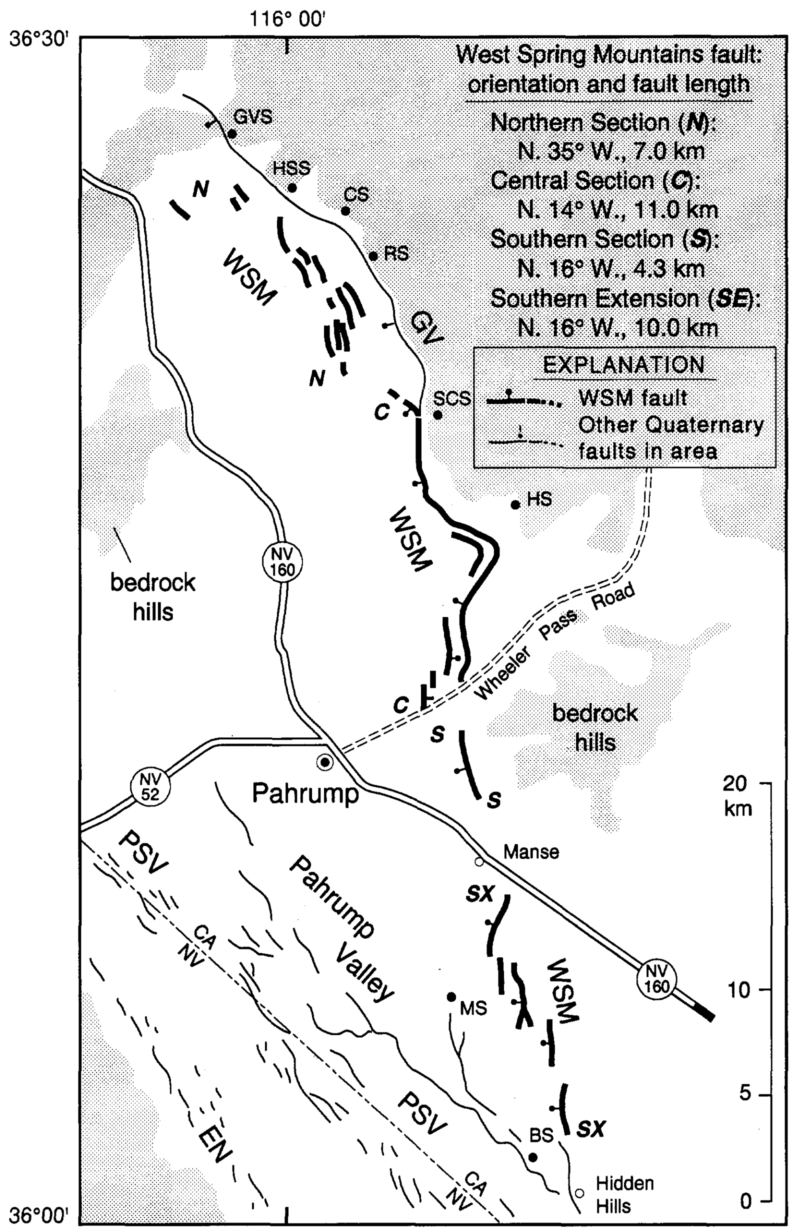

Figure 13. Map of West Spring Mountains fault and associated geographic and cultural features. Extent of fault sections and orientations shown by letter symbols keyed to tabulated data (***N***, northern section; ***C***, central section; ***S***, southern section; ***SX***, southern extension). Names of faults are abbreviated as follows: *WSM*, West Spring Mountains; *PSV*, Pahrump-Stewart Valley; *GV*, Grapevine. Other abbreviations (north to south): GVS, Grapevine Springs; HSS, Horseshutem Springs; CS, Crystal Springs; RS, Rainbow Springs; SCS, Santa Cruz Spring; HS, Horse Springs; MS, Mound Spring; and BS, Browns Spring.

much of its northwesterly orientation (N. 38°-57° W.) shows evidence of mineralization. The southeastern part of the Grapevine fault is parallel to a string of perennial springs that are along the western bedrock margin of the Spring Mountains (fig. 13). Nevertheless, the apparent lack of young scarps along the Grapevine fault (Dohrenwend and others, 1991), its different orientation (northwest), and its mineralization (Hoffard, 1991) argue against including it with the WSM. In addition, Quaternary movement at the northern end of the central section of the WSM trends to the northwest toward the northern section rather than to the north toward the Grapevine fault.

LENGTH

Length reported in Piety (1994): 30-60 km

Length of known Quaternary scarps (this study): 31.4-47.6 km

The northern section is about 7 km long, but only along the southern 3-4 km are there scarps on deposits of late to middle Pleistocene age. The northern section does not include the Grapevine fault of Burchfiel and others (1983) and Carr (1984). In contrast, the central section contains scarps on middle to late Pleistocene deposits along its entire length of 11 km. The northern and central sections are separated by a 4-km-wide step in which scarps are either lacking or highly dissected, and hence are quite old. The southern section is 4.3 km long and is separated from (1) the central section by a 1.5-km-long gap where evidence of faulting is buried and (2) the southern extension by a 4.8-km-long gap where scarps are either lacking or evidence of faulting is buried by young deposits. The southern extension is about 10 km long. The trace length of the three main sections of the WSM where Quaternary scarps are present is at least 37 km (or at least 31.4 km as measured in a straight line from end to end), but may be as much as 55 km (46.7 km end to end) if the southern extension and intervening gaps are included.

STYLE OF FAULTING: Normal for main sections of fault, possible lateral component for southern extension

The irregular surface trace of the WSM suggests a normal, dip-slip style of movement, especially along the central section. The northern section (fig. 13) has east-facing scarps on deposits of late to middle Pleistocene age, and it probably experienced coeval or older (Quaternary) movement on down-to-the-west normal faults inferred from linear saddles in highly dissected deposits on the western piedmont of the Spring Mountains. The central main section (fig. 13) , which has the largest scarps, is characterized by west-facing scarps related to down-to-the-west normal movement and associated minor antithetic (east-facing) scarps. The irregular trace of the fault in the central section, which has a pronounced bend of 100°, argues against a significant component of lateral slip (Hoffard, 1991; Reheis, 1992). The southern section (fig. 13) is comprised primarily of east-facing scarps related to down-to-the-east normal faults that are antithetic to the Spring Mountains; these scarps may reflect a possible scissors-geometry of the fault. The possible southern extension (fig. 13) of the WSM is characterized by west-facing scarps related to down-to-the-west normal movement and associated minor antithetic (east-facing) normal faults that form a discontinuous graben and left-stepping pattern. No evidence of a significant (>1:1) lateral component of slip was recognized along the main WSM in this study. However, the left-stepping pattern of scarps, which is restricted to the southern extension, implies a component of lateral movement (Hoffard, 1991) that may mark a transition in the style of deformation between normal-slip on the WSM and right-lateral slip on the Pahrump-Stewart Valley fault zone (PSV).

DISPLACEMENT AND AGE

Range of observed surface offset and scarp height representing the youngest movement:
1.8-2.0 m (surface offset) and 2.1-2.4 m (scarp height) in the central section

Information about the amount of vertical surface offset from the youngest movement comes from the smallest scarps preserved along the central section of the WSM (fig. 13). Even smaller scarps are present near the northern and southern ends of the fault, but their heights (and inferred offsets) probably reflect the small offsets that are typically found near the ends of active and prehistoric faults.

At several sites along the central section of the WSM, we found small scarps preserved on the north and south sides of arroyos that are deeply incised (typically 6-10 m) into large, multiple-event fault scarps (fig. 14). Profiles across two of these small scarps (WSM-16 and WSM-17 in table 7) indicate scarp heights of 2.2 m and apparent surface offsets of 1.8 and 1.7 m, respectively. In addition, another small scarp (WSM-11 in

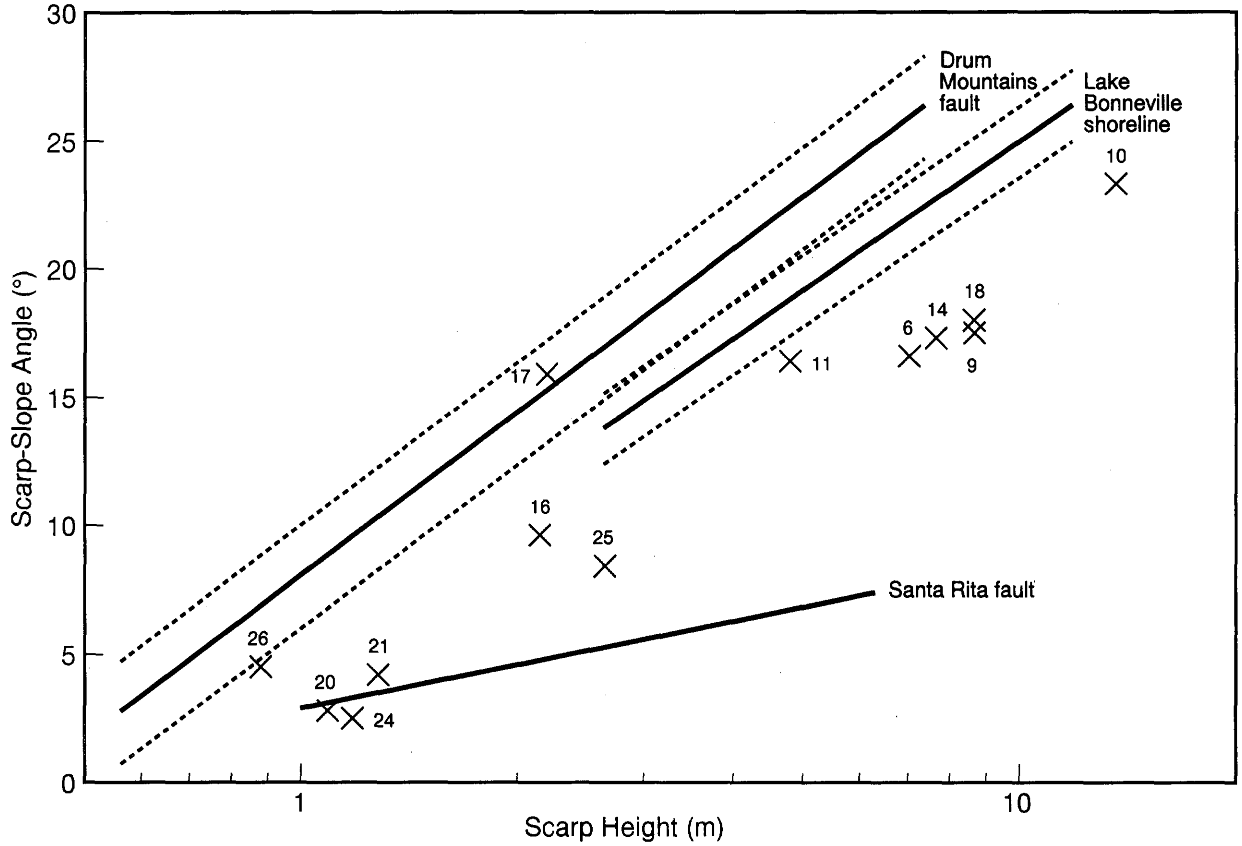

FIGURE 14. Plot of scarp-height—slope-angle values for scarps along the West Spring Mountains fault (WSM). WSM site numbers shown in table 7. Solid lines, regression lines for reference scarps; dotted lines, 1-σ limits for regressions. Lake Bonneville shoreline scarp (about 15 ka; Machette, 1989) and Drum Mountains fault scarp (about 10 ka; Crone, 1983) both from Bucknam and Anderson (1979); Santa Rita fault scarp (estimated age about 100 ka; Pearthree and Calvo, 1987). Points that plot above or below the 1-σ limits of a regression line suggest relative ages that are younger or older than those of the reference scarps, respectively.

fig. 15; table 7) has a height of 4.8 m and maximum scarp-slope angle of 16.4°-20°, which may reflect multiple movements. If the smallest scarps reflect single events, then the most recent rupture along the central section of the WSM may have caused about 1.8 m of surface offset. However, streams that dissect these scarps, may have deposited sediment on these lower (downdropped) surfaces; thus, 1.8-2.0 m is probably a better maximum value for offset during the most recent event. If the pattern of larger offsets along the central section of the WSM, which is observed along many active faults, is an analogy for future ruptures, then 1.8-2.0 m may be an average maximum value of fault displacement.

Estimated age of most recent surface-faulting event: latest Pleistocene or early Holocene

Scarp morphology was used for estimating the age of the most recent surface-faulting event on the WSM. Along the central section, scarp profiles WSM-16 and WSM-17 (table 7) indicate that scarps with heights of 2.2 m have scarp-slope angles of 15.9° and 9.6°. The scarp with the 15.9° slope angle (profile WSM-16) is noticeably steeper than similar-size scarps along this section; the steepness could be the result of recent fluvial erosion at the toe of the scarp. We profiled one other single-event scarp (2.2 m, 9.6°) and a possible multiple-event scarp (4.8 m, 16.4°; profile WSM-11 in table 7) that can be compared with scarps of known age. Although the small scarps are on unconsolidated material (very sandy pebble to cobble gravels), which is common on piedmont-slope landscapes, the material exposed by modern bioturbation (mixing by

TABLE 7. Scarp-profile data for the West Spring Mountains fault, southern Nevada.

[Positive surface and scarp angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources; negative angles indicate abnormal geomorphic gradients such as antithetic fault scarps. Fault parameters as defined in figure 4: LS, lower surface angle; US, upper surface angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle. NA, measurement not applicable; —, no measurement; e, estimated; ?, questionable.]

Profile No.	Fault section	Scarp type, aspect	LS	US	SO (m)	SH (m)	θ
WSM-1	Northern	Antithetic, NE	3.3°	4.9°	1.1	NA	NA
WSM-2	Northern	Antithetic, NE	4.1°	4.3°	2.7	2.3 NA	-9.0° NA
WSM-3	Northern	Antithetic, NE	4.6°e	4.6°e	1.4e	—	—
WSM-4	Northern	Antithetic, E	5.3°	4.8°	3.5	NA	-5.8° NA
WSM-5	Northern	Antithetic, E	4.5°	4.8°	1.4	NA	NA
WSM-6	Central	Normal with graben, W	5.5°	5.5°	2.0	7.0	16.6°
WSM-7	Central	Normal, W; antithetic, E	5.2°	5.7°	4.4	NA	NA
WSM-8	Central	Antithetic, E	5.2°	5.3°	0.2	2.7 NA	0.3° NA
WSM-9	Central	Normal, W	5.7°	5.7°	6.0	8.6	17.5°
WSM-10	Central	Normal, W	7.5°	7.8°	9.4	13.6	23.3°
WSM-11	Central	Normal, W	7.5°	6.7°	>2.3	4.8	16.4°
WSM-12	Central	Normal, W	—	6.6°	11.1e	—	18.6°
WSM-13	Central	Normal, W	3.0°e	3.0°e	6.6e	—	13.2°e
WSM-14	Central	Normal, W	3.0°e	3.0°e	6.8e	7.6e	17.3°
WSM-15	Central	Antithetic, E	3.0°	3.2°	0.9	0.2 NA	-1.0° NA
WSM-16	Central	Normal, W	2.3°	1.9°	1.7	2.2	9.6°
WSM-17	Central	Normal, W	3.2°	2.2°	1.8	2.2	15.9°?
WSM-18	Central	Normal, W	3.0°	1.3°	7.6	8.6	18.0°
WSM-19	Central	Antithetic, E	2.5°	2.4°	2.2	1.2 NA	-3.1° NA
WSM-20	Southern extension	Normal, W	1.2°	1.3°	0.6	1.1	2.8°
WSM-21	Southern extension	Normal, W	0.9°	0.7°	1.0	1.3	4.2°
WSM-22	Southern extension	Antithetic, E	1.6°	1.6°	1.2	0.7 NA	-2.2° NA
WSM-23	Southern extension	Antithetic, E	0.7°	0.7°	1.0	0.8 NA	-3.2° NA
WSM-24	Southern extension	Normal, NW	0.8°	0.7°	0.8	1.2	2.5°
WSM-25	Southern extension	Normal, W	1.4°	1.5°	2.2	2.6	8.4°
WSM-26	Southern extension	Normal, W	1.2°	1.0°	0.7	0.9	4.5°?

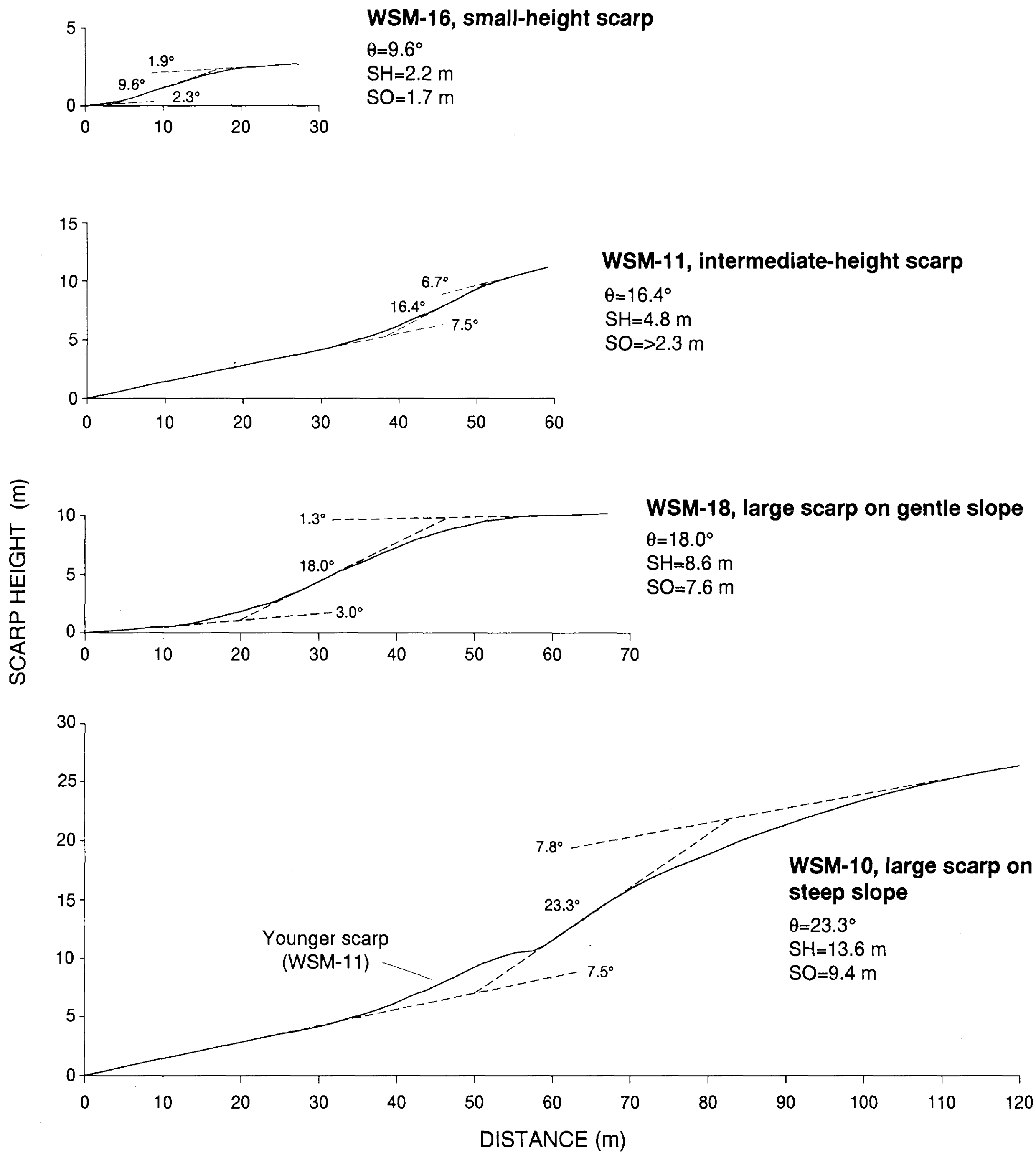

FIGURE 15. Plots of profiles across the West Spring Mountains fault (WSM) showing morphology of small- (2.2 m), intermediate- (4.8 m), and large- (8.6-13.8 m) height scarps.

rodents) is particularly fine-grained, perhaps owing to a significant component of loess. The materials, climate, and aspect (primarily east- and west-facing) are comparable to scarps associated with shorelines of the highest stand of Lake Bonneville in Utah, with the exception that the WSM scarps have been heavily bioturbated. These scarps appear slightly older than the Lake Bonneville shoreline scarps on the basis of plots of scarp height and maximum scarp-slope angle (fig. 14) and thus are probably of latest Pleistocene age.

Our age estimate of latest Pleistocene is partly supported by the pattern of fault rupture in surficial deposits along the central section of the WSM. Because deposition of major alluvial-fan units seem to be largely climatically controlled, the broad fan south of Wheeler Pass Road (new alignment) was probably formed by latest Pleistocene and early Holocene alluvium deposited after the most-recent glacial maxima (see Reheis and others, 1992), whereas the unfaulted alluvium is probably middle to late Holocene. On the south half of the Wheeler Wash fan, most of the fan surface is deformed by a narrow fault and graben system and the net offset is small (<2 m). From these relations we infer that the fan has experienced a single faulting event in the early Holocene or latest Pleistocene. In contrast, the northern half of the fan is deformed by a wide fault and graben system, and the net offset is large (>6 to almost 10 m). However, the most recently active portion of the fan (several hundred meters on both sides of Wheeler Wash) is unfaulted, and elsewhere young (middle? to late Holocene) alluvium covers the fault.

The youngest movement along the southern extension of the WSM fault seems to be older than latest Pleistocene. These scarps are on deposits that have, at a minimum, soils with thick Av horizons and moderately well-developed Btk horizons (see Birkeland, 1984), which we think are pre-latest Pleistocene in age. The morphology of the smallest scarps along this extension of the fault have maximum scarp-slope angles of only 2-3°, irrespective of their height (fig. 14). This subdued morphology coupled with the strong cementation of the carbonate-rich alluvium (shallow petrocalcic horizons) suggests that the scarps are considerably older than indicated by their morphology because the petrocalcic horizon has a bedrock-like resistance to erosion. In addition, scarps are discontinuous owing to extensive post-faulting erosion compared to those along the south and central sections. The morphology and soils data indicate that only the central and southern sections (length of 16.8 km) ruptured during the latest surface-faulting event.

Range of observed total surface offset along scarps on alluvium: 1.8-9.4 m

The smallest scarps in the central section are typically 2.2 m high and reflect about 1.8 m of surface offset. The largest scarps in the central section are 8.7-13.6 m high and reflect about 6.0-9.4 m of surface offset (fig. 14, 15; table 7). Although we have not mapped the surficial deposits along the WSM, the large scarps are on older fan alluvium. Dohrenwend and others (1991) suggested this old alluvium (Q_2) is probably late and (or) middle Pleistocene on the basis of the degree of fluvial dissection, drainage pattern, and weakly to moderately developed soils. Piety (1994) suggested that the old alluvium could correlate with deposits of Qf_2 (Sowers, 1986; Reheis and others, 1992), which is considered to be older than 130 ka, or the older surface Qf_1 at Kyle Canyon (Sowers, 1986; Reheis and others, 1992) that has rounded topography and which is known to be more than 770 ka (early Pleistocene) on the basis of reversely magnetized sediments. On the basis of a strong, thick petrocalcic horizon (stage IV; Machette, 1985) and mature degree of dissection, the old alluvium is probably at least 130 ka and is perhaps as old as 500 ka.

Estimates of recurrence intervals and slip rates: more than 28 k. y. to as much as 120 k. y. and less than 0.02 mm/yr to as much as 0.07 mm/yr

Using 1.8-2.0 m as a typical offset per surface-faulting event yields about 5 similar-sized events to create the offset recorded by the larger scarps. If the old fan alluvium is older than 130 to as much as 500 ka and the most recent event along the central section is between 5 ka and 20 ka, then the average recurrence interval for surface-faulting events is more than 28 k. y. (4 recurrence intervals in >110 k. y.) to perhaps as much as 124 k. y. (4 recurrence intervals in a maximum of 495 k. y.). Thus, slip rates on the most active part of the WSM (central section) could range from less than 0.02 mm/yr (1.8 m slip in >110 k. y.) to perhaps as much as 0.07 mm/yr (2.0 m slip in >28 k. y.).

LAST CHANCE RANGE FAULTS (LC)

SUMMARY: The Last Chance faults (LC) consist of two, north-trending (N. 6°-13° E.°) scarps on middle to early Pleistocene fan alluvium in an intermontane valley on the north and northwest sides of the Last Chance Range, which is about 18 km northwest of Pahrump, Nevada. These faults, which consist of a western and an eastern strand, were not discussed by Hoffard (1991) or Piety (1994). The 2- to 3-km-long scarps coincide with the traces of two Mesozoic thrust faults that were mapped by Burchfiel and others (1983), thus the LC appears to be reactivated thrust faults. The Quaternary sense of slip on the LC is down-to-the-west normal, which is opposite to the Mesozoic reverse slip. The amount of surface offset and age of the most recent surface faulting is unknown; we speculate that the youngest event on the western strand is late to middle Pleistocene, and the youngest event on the eastern strand could be early Pleistocene or late Tertiary in age. Surface offsets at two sites on the eastern strand are 1.8-2.6 m and scarp heights are 3.1-3.5 m. Based on the size of the scarps and the inferred age of the deposits, the long-term slip rate on the LC is probably a few thousandths of a millimeter per year. Because the LC has a small long-term slip rate and short surface-rupture lengths, it is not a relevant seismic source.

LOCATION: The LC is on the western slope of the Last Chance Range about 18 km northwest of the town of Pahrump in Nye County, Nevada (fig. 16). Quaternary scarps on the LC are located in a 950-m-high intermontane valley that is bounded on the south and east by the Last Chance Range, on the north by the southern end of the Montgomery Mountains, and on the west by the unnamed bedrock ridges that form the southeastern boundary of Ash Meadows. The LC consists of two subparallel fault scarps on Quaternary deposits that are about 2 km apart.

ORIENTATION: Quaternary scarps along the LC trend north-northeasterly. The eastern scarp trends N. 6° E. and the western N. 13° E. The trend of the eastern scarp is derived from field measurements at the two profile sites, whereas, the trend of the western scarp is based on measurements from plots of the scarp on 7.5' topographic maps.

LENGTH

Length reported in Piety (1994): Scarps were not labeled, named, or discussed by Piety. Hoffard (1991) showed them on her plate 1, but did not describe them.

Length of known Quaternary scarps (this study): 2.8 km for western scarp; 2.4 km for eastern scarp

The scarps are generally continuous along their length, although in places, they are eroded or buried by younger fan deposits. Because of their short length and distance from Yucca Mountain (60-65 km), the scarps are not relevant seismic sources with respect to design of the proposed repository.

STYLE OF FAULTING: Normal, down to west

The scarps on the LC probably record normal slip. We found no evidence of lateral slip from our field or aerial photograph studies. We infer normal slip even though we did not find any exposures where we could determine the attitude of the faults.

The scarps are significant because they show the potential of Mesozoic thrust faults being reactivated as normal faults in the Quaternary extensional stress field. The bedrock geology in the area of the LC has been studied by Burchfiel and others (1983), who mapped a series of Mesozoic-age thrust faults in the Last Chance

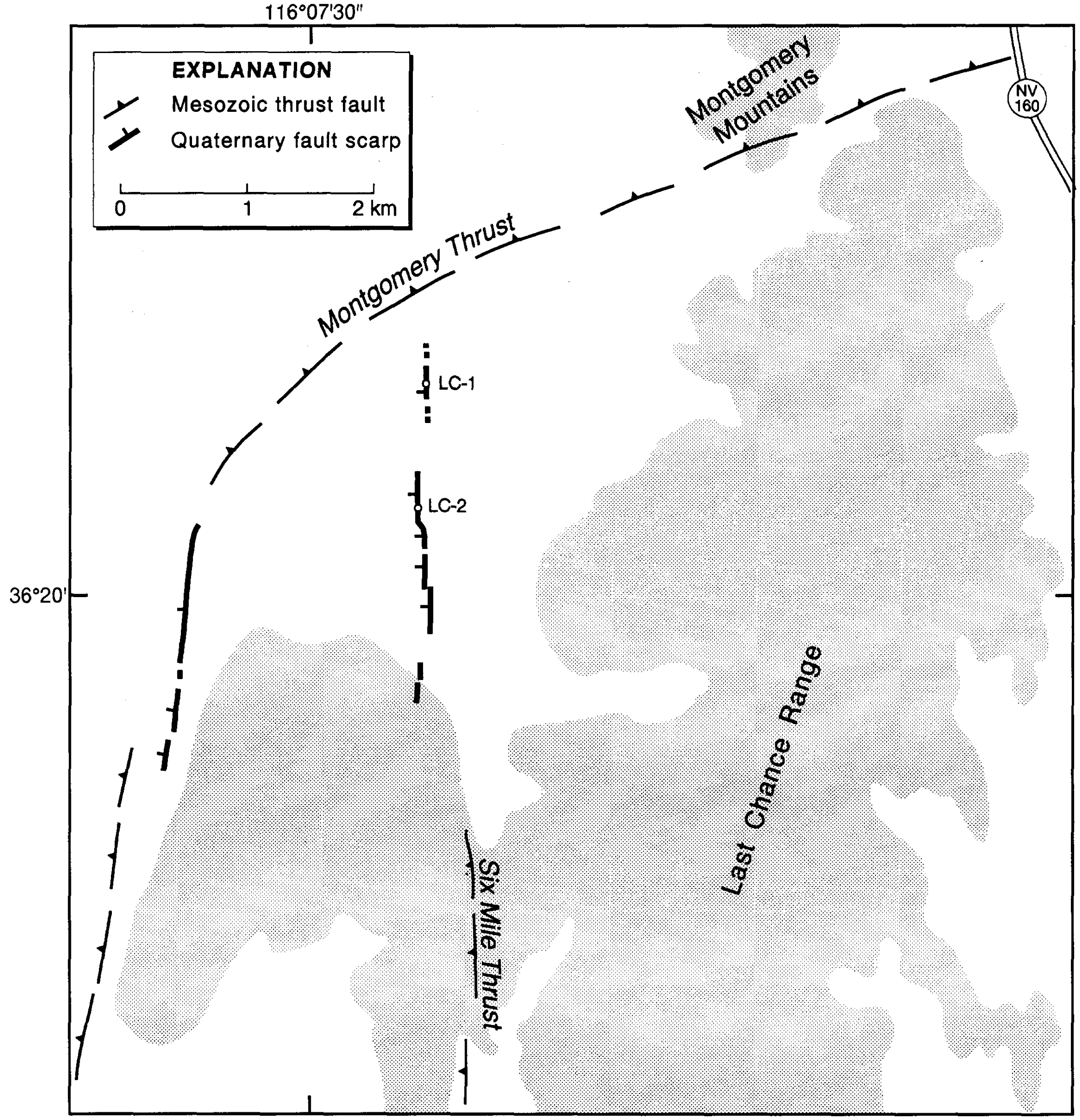

FIGURE 16. Generalized map of the Last Chance Range faults (LC), Nye County, Nevada, and selected Mesozoic-age thrust faults mapped by Burchfiel and others (1983). Scarps on Quaternary alluvium are coincident with the traces of thrust faults, although the sense of slip on Quaternary scarps is opposite that on the thrust faults. Open circles show locations of scarp-profile sites; data is listed in table 8.

Range and Montgomery Mountains. The traces of two of these thrust faults coincide with the LC scarps; the western and eastern scarps are coincident with the Montgomery and the Six Mile thrust faults, respectively (fig 16). In both cases, the overthrust block of the thrust fault is now the downdropped block of the normal fault, which indicates a reversal in fault slip direction. Reactivation of Mesozoic thrust faults as Quaternary normal faults has been recognized elsewhere in the Basin and Range, and paleoseismic studies suggest that this reactivation can be associated with significant earthquakes in some cases (West, 1993).

TABLE 8. Scarp-profile data for the Last Chance Range scarps, Nevada.

[Positive surface and scarp angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources. Fault parameters as defined in figure 4: LS, lower slope angle, US, upper slope angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle.]

Profile No.	Scarp type, aspect	LS	US	SO (m)	SH (m)	θ
LC-1	Normal, W	2.0°	2.0°	1.8	3.1	7.7°
LC-2	Normal, W	1.5°	2.7°	2.6	3.5	7.7°

DISPLACEMENT AND AGE

Range of observed surface offset and scarp height representing the youngest movement: Unknown. Measured values of surface offset are 1.8-2.6 m and scarp height are 3.1-3.5 m.

We collected scarp profile data at two locations on the eastern scarp (fig. 16; table 8), but because of time constraints, we did not visit the western scarp in the field. The geomorphic expression and characteristics of both scarps are similar, but from our studies of 1:12,000-scale aerial photographs, it appears that the western scarp is formed on younger alluvial deposits than the eastern scarp.

Estimated age of most recent surface-faulting event: late to middle Pleistocene

Quaternary deposits in the area surrounding the Last Chance Range have not been studied in detail, so our age estimates are based on correlations with similar but better studied alluvial deposits in the Resting Spring and Nopah Ranges, which are about 10-15 km to the west and southwest (McKittrick, 1988), and with alluvial deposits in the Kyle Canyon area, which is about 55 km to the east on the eastern flank of the Spring Mountains (Sowers, 1986; Reheis and others, 1992).

The eastern scarp is formed on old alluvial-fan deposits that have a massive petrocalcic horizon. The fan gravels are composed almost entirely of carbonate rock clasts, and clasts that are exposed on the surface are so extensively weathered that their originally rounded shape is now planar and level with the adjacent surface. The bottom of clasts have microstalagtite coats of carbonate (McKittrick, 1988) that are commonly more than 5 cm thick. On aerial photographs, these deposits have a light tone because fragments of the petrocalcic horizon cover more than half of the surface. On the basis of these characteristics, we correlate the deposits with McKittrick's (1988) unit QTf, which is thought to be early Pleistocene or late Tertiary age, and with geomorphic surface 1 of Sowers (1986), which has an age of about 800 ka (Reheis and others, 1992). Alternatively, the eastern scarp could be formed on deposits that correlate with McKittrick's unit Qf_1, which may be middle or early Pleistocene in age, and with surface 2 of Sowers (1986), which is an age of about 130 ka (Reheis and others, 1992).

The western strand of the LC offsets alluvial fans that we suspect correlate with McKittrick's unit Qf_1, and with Sowers' (1986) surface 2. These fans could correlate with McKittrick's late or middle Pleistocene unit Qf_2 and with Sowers surface 3, which is time transgressive and is increasingly older at higher elevations (Reheis and others, 1992). We did not study these deposits in the field, and therefore, our correlation with McKittrick's and Sowers' units is tenuous. Nevertheless, we suspect that the most recent surface-faulting event on the LC could be as young as late Pleistocene, more likely it is middle Pleistocene in age.

Range of observed total surface offset along scarps on alluvium: 1.8-2.6 m

As discussed in the preceding section, the LC scarps that we studied in the field are formed on alluvial fans that are several hundred thousand years old. The erosion-resistant, well-indurated petrocalcic horizon in the fan deposits forms small ledges in the face of the scarps. For this reason, bevels or facets that might be evidence of multiple rupturing events are difficult to detect. As a result, we do not know if the scarps that we profiled are the product of a single or multiple surface-faulting events.

The petrocalcic horizon greatly retards erosion and degradation of the scarps. As a result, the scarps have steeper slopes that suggest an age that is much younger age than their true age (fig. 17). Because the petrocalcic horizon is so erosion resistant, we speculate that the scarps could be as much as 10 times older than would be inferred from their morphology.

Based on the size of the scarps and the inferred age of the deposits, the long-term slip rate on the LC is probably a few thousandths of a millimeter per year. If the deposits offset by the eastern strand are Quaternary-Tertiary in age, then the slip rate is on the order of 0.001-0.003 mm/yr (1.8 m/1650 k. y. and 2.6 m/800 k. y.). If the offset deposits are middle to early Pleistocene (roughly 300 ka), then the slip rates are about 0.006-0.008 mm/yr (1.8 m/300 k. y. and 2.6 m/300 k. y.). Faults with such low slip rates and such short surface-rupture lengths are not likely to be a significant seismic source with respect to engineering design of the proposed repository at Yucca Mountain.

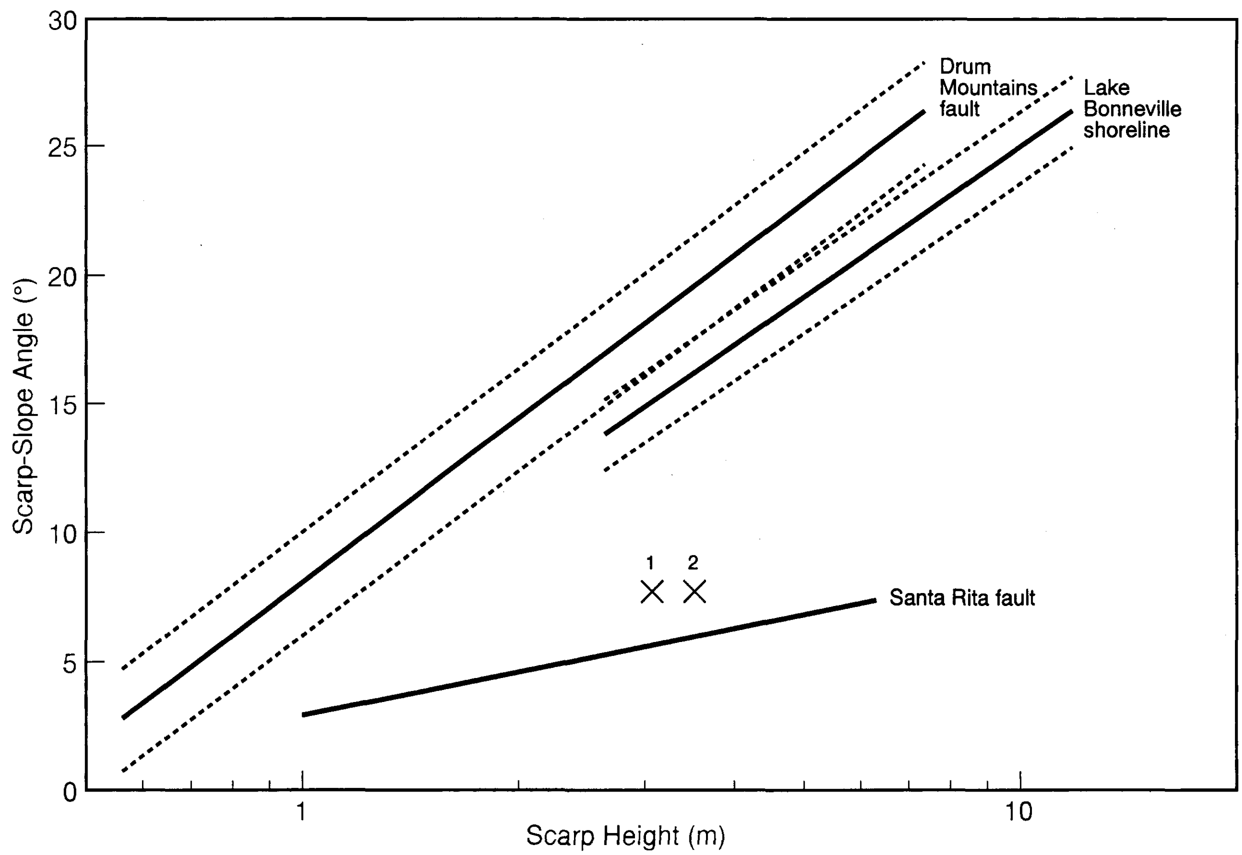

FIGURE 17. Plot of scarp-height—slope-angle values for scarps along the Last Chance Range faults (LC). LC site numbers shown in figure 16 and table 8. Solid lines, regression lines for reference scarps; dotted lines, 1-σ limits for regressions. Lake Bonneville shoreline scarp (about 15 ka; Machette, 1989) and Drum Mountains fault scarp (about 10 ka; Crone, 1983) both from Bucknam and Anderson (1979); Santa Rita fault scarp (estimated age about 100 ka; Pearthree and Calvo, 1987). Points that plot above or below the 1-σ limits of a regression line suggest relative ages that are younger or older than those of the reference scarps, respectively.

WEST SPECTER RANGE FAULT (WSR)

SUMMARY: The West Specter Range fault (WSR) bounds the western flank of a south-trending arm of the Specter Range; its northern end is about 33 km S. 39° E. of Yucca Mountain. Its trace length is about 8.9 km (8.3 km long as measured in a straight line from end to end) and has an average strike of N. 4° E., but individual scarps trend from N. 40° E. to N. 15° W. The sense of slip on the fault is most likely normal and predominantly down-to-the-west, with a possible minor lateral component. The youngest movement is probably latest Pleistocene or Holocene along the northern section of the fault. The total surface offset represented by scarps on alluvium range from 0.3-0.5 m on the youngest faulted alluvium (about 15 ka) to as much as 1.4 m on older faulted alluvium (>128 ka). Although poorly constrained, we estimate that the WSR has a recurrence interval of at least 113 k. y. and a slip rate of <0.004 mm/yr.

LOCATION: The WSR bounds the western flank of a south-trending arm of the Specter Range; its northern end is about 33 km S. 39° E. of Yucca Mountain. The WSR crosses U.S. Highway 95 about 19 km east of Nevada Highway 29 (fig. 18). From aerial photo reconnaissance, it appears that the fault extends discontinuously from about 2 km north-northwest of U.S. Highway 95 (1.5 km north-northwest of the NW corner of sec. 2, T. 16 S., R. 51 E., Specter Range SW 7.5' quadrangle) south to the water wells and levee (fig. 18) in the NW1/4 sec. 27 (T. 16 S., R. 51 E., Specter Range SW 7.5' quadrangle). The WSR was not shown on either the regional compilation of Quaternary faults within 100 km of Yucca Mountain by Piety (1994,) or on the more detailed (100,000-scale) compilation of Reheis and Noller (1991).

ORIENTATION: The WSR has an average strike of N. 4° E., but individual scarps trend between N. 20° W. to N. 40° E.

The WSR is divided into a northern section that is marked by small scarps and conspicuous lineations on alluvial deposits and a southern section that is marked by discontinuous but prominent scarps on alluvial deposits and by lineations in Tertiary(?) bedrock (fig. 18). The northern section is comprised of multiple subparallel strands marked by small scarps and fluvial scarps of south-flowing drainages that are suspected to be fault controlled; these strands have a fairly consistent orientation of N. 16° W. The southern section has prominent scarps on stable (older) fan surfaces along about 25 percent of its length; its overall trend is N. 18° E., although individual scarps trend between N. 5° E. to N. 40° E.

LENGTH

Length reported in Piety (1994): none (fault not included)

Length of known Quaternary scarps (this study): 8.3 km

The total trace length of the fault (fig. 18), which is divided into 2 sections, is about 8.9 km (8.3 km as measured in a straight-line distance). The northern section is about 3.5 km long and the southern section about 5.1 km long. Approximately 40 percent of the WSR is characterized by scarps on Quaternary materials; about 35 percent is marked by tonal or vegetational lineaments or drainage alignments that may be associated with surface rupturing, and about 25 percent is concealed beneath unfaulted deposits. Lineations in Tertiary (?) bedrock that look like fault traces suggest that the fault may continue further to the south (past the water wells and levee in the NW1/4 sec. 27, T. 16 S., R. 51 E., Specter Range SW 7.5' quadrangle). Other than photo reconnaissance, no effort was made to document scarps south of the levee.

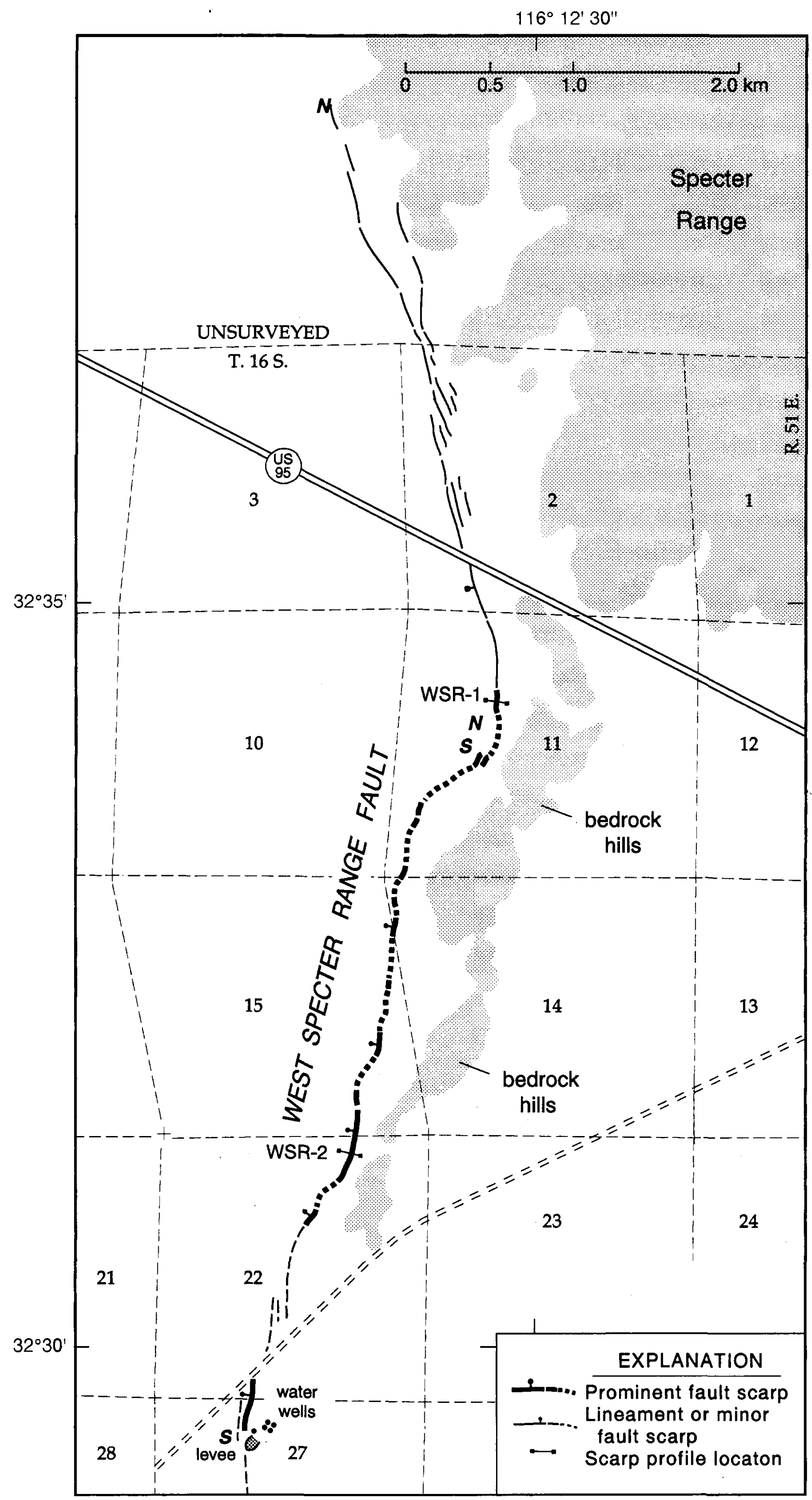

Figure 18. Map of the West Specter Range fault (WSR) and associated geographic and cultural features. Extent of fault sections and orientations shown by letter symbols: ***N***, northern section; ***S***, southern section. Location of scarp profiles listed in table 9 are shown by bar symbol.

TABLE 9. Scarp-profile data for the West Specter Range fault, Nevada.

[Positive slope angles denote normal geomorphic gradients; that is, toward basin center and away from sediment sources. Fault parameters as defined in figure 4: LS, lower surface angle; US, upper surface angle; SO, surface offset; SH, scarp height; θ, scarp-slope angle.]

Profile No.	Fault section	Scarp type, aspect	LS	US	SO (m)	SH (m)	θ
WSR-1	Northern	Normal, W	1.8°	2.2°	1.4	1.9	8.2°
WSR-2	Southern	Normal, W	2.9°	2.8°	1.0	1.5	8.7°

STYLE OF FAULTING: Normal, predominantly down to the west with possible minor lateral component

Although the fault was not observed in outcrop, the presence of consistent, albeit minor, right steps in the fault trace and a lack of large (>45°) changes in fault orientation would allow a minor(?) component of lateral-slip along the WSR. The fault is predominantly down to the west in the southern sections, but appears to have both down-to-the-west and down-to-the-east senses of motion along the northern section.

DISPLACEMENT AND AGE

Range of observed surface offset and scarp height representing the youngest movement:
Not measured, probably less than 0.5 m for both sections

Along the northern section of the fault, small scarps (estimated to have 0.3-0.5 m of surface offset) were found on deposits that are most likely latest Pleistocene in age (see discussion below). Along the southern section, evidence for young movement is less convincing. The southern section has scarps along about 20 percent of its length, and these scarps are on deposits of probable middle Pleistocene age.

Estimated age of most recent surface-faulting event: probably latest Pleistocene or Holocene (northern section)

The youngest faulting event appears to be of latest Pleistocene or Holocene in age along the northern section, but no profiles were measured across the resultant small scarps, and thus we have no morphometric evidence of the recency of movement relative to the age of the faulted deposits. The youngest faulted deposits have soils with a moderately well-developed desert pavement of limestone clasts, a thick Av horizon, and a weakly developed argillic B horizon (see Birkeland, 1984). In addition, these deposits still have some vestiges of original surface morphology. The soil on these deposits and their surface morphology are similar to those on surface 3, which was mapped by Sowers (1986) in the Kyle Canyon area, northwest of Las Vegas. Soils on surface 3 have been dated by ^{14}C at 10-15 ka and by the uranium-series method at 47±20 and 76±6 ka; the deposits appear to represent a time-transgressive late Pleistocene alluvial sequence (Reheis and others, 1992). For this discussion, we use 15 ka as a probable age for the stablization of surface 3. On aerial photographs, the scarps appear as lineations that control south-flowing drainages. Because the scarps may have been modified by fluvial processes, their morphology may reflect an age that is younger than the age of the most recent faulting event.

Scarps along the southern section are less abundant but larger and are typically preserved on old alluvial fans, ones that are of probable middle Pleistocene age as indicated by well-formed desert pavement of highly etched limestone clasts, thick Av horizons, and well-developed argillic and calcic B horizons that overlying thick stage III-IV calcic horizons (Machette, 1985). Similar soils were found on deposits mapped as surface 2 by Sowers (1986), which is considered to be >128 ka (pre-late Pleistocene) by Reheis and others (1992).

The morphometric data from the large scarps (WSR-1 and WSR-2 in table 9) are hard to interpret: resistant lithology and faulting-history effects may have skewed age estimates in opposite directions, increasing the uncertainty in age estimates based solely on morphology. These scarps have beveled crests and steep elements (8°-9°) in their mid-slope, which may reflect the youngest faulting event (estimated 0.3-0.5 m of surface offset) on the northern section. We suspect that these large fault scarps (1.0-1.4 m high) are the product of two or more faulting events. Profile data for the scarps plot near that of the Lake Bonneville shoreline scarps (fig. 19), which is of latest Pleistocene age. The scarp-slope angles (θ) from WSR-1 and WSR-2 (table 9) may reflect the youngest faulting event, whereas their scarp heights are clearly the product of the most recent and penultimate faulting events. In addition, the well-developed petrocalcic horizon in the older fan alluvium probably slows the erosion of the scarps.

Range of observed total surface offset along scarps on alluvium: 0.3-0.5 m (estimated) to 1.0-1.4 m (measured surface offset)

We estimate 0.3-0.5 m of surface offset for the youngest faulted alluvium (northern section of WSR). Scarps on old fan alluvium (WSR-1 and WSR-2 in table 9) are 1.5 and 1.9 m high and reflect 1.0 and 1.4 m of surface offset. The measured surface offsets probably reflect single- and multiple-faulting events on respective sections of the fault.

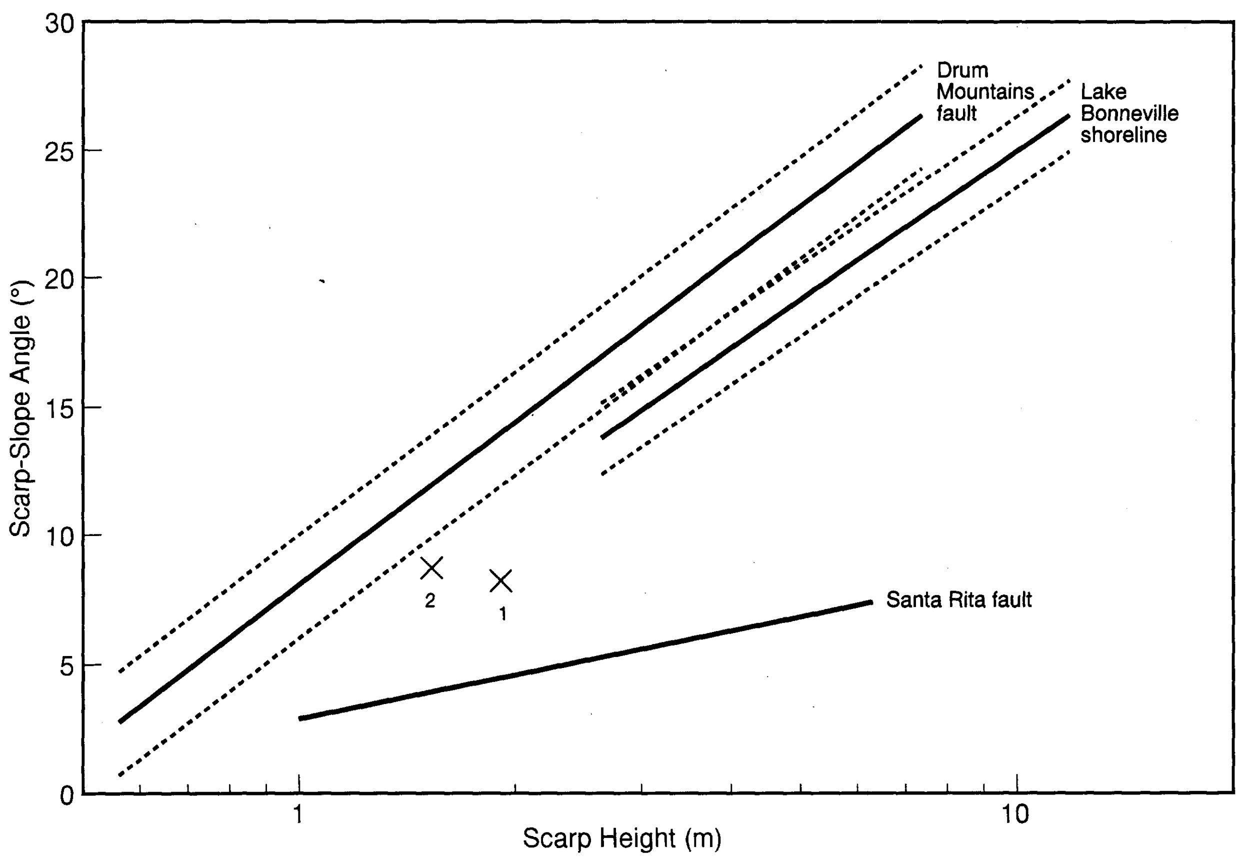

FIGURE 19. Plot of scarp-height—slope-angle values for scarps along the West Specter Range fault (WSR). WSR site numbers shown in figure 18 and table 9. Solid lines, regression lines for reference scarps; dotted lines, 1-σ limits for regressions. Lake Bonneville shoreline scarp (about 15 ka; Machette, 1989) and Drum Mountains fault scarp (about 10 ka; Crone, 1983) both from Bucknam and Anderson (1979); Santa Rita fault scarp (estimated age about 100 ka; Pearthree and Calvo, 1987). Points that plot above or below the 1-σ limits of a regression line suggest relative ages that are younger or older than those of the reference scarps, respectively.

Estimates of recurrence intervals and slip rates: more than 113 k. y. and less than 0.004 mm/yr

Both recurrence intervals and slip rates are difficult to estimate for the WSR because we cannot accurately define the timing of the most recent and penultimate faulting events. Without such information, the recurrence interval cannot be constrained and slip rates can only be estimated within broad bounds. Nevertheless, the above estimates are based on the following assumptions: (1) the majority of slip on the fault is normal dip slip, (2) 0.3-0.5 m of slip occurred during the most recent event (<15 ka), and (3) the recurrence interval is probably at least 113 k. y. (time between the most recent event and 128 ka, which is the minimum age we assign to the old fan deposits). From these assumptions, we calculate a maximum slip rate of 0.004 mm/yr (0.5 m in 113 k. y.).

SUMMARY

In the region surrounding Yucca Mountain, faults with a history of known or suspected Quaternary displacement have diverse orientations, senses of slip, and structural and tectonic settings. We studied the effects of Quaternary surface offset along a group of 10 faults that generally represent the complexities of extensional neotectonics of this region. We studied the generally north-trending normal fault zones bounding the west sides of the Belted and Kawich Ranges within the main Basin and Range part of the Yucca Mountain region and 8 faults within the Walker Lane structural belt of the Basin and Range. Most faults in the Walker Lane belt either lack evidence of Quaternary displacement, or the evidence is equivocal.

Unequivocal Quaternary fault scarps were only found along about 22 km of the central part of the 38- to 54-km-long Belted Range fault zone (BLR) and less than 10 km of the southern part of the 84-km-long Kawich Range West fault zone (KRW). The Quaternary scarps along the KRW are discontinuous and are restricted to the part of the fault zone that extends southward into the southern Nevada volcanic field of Carr (1988). Those in the BLR are mostly continuous and extend across the volcanic-field boundary. Evidence of a young (late Pleistocene or early Holocene) surface-faulting event of generally less than 1 m and evidence for recurrent fault movement is found along almost the entire 22 km of Quaternary scarps of the BLR, but there is no unequivocal evidence of recurrent movement during the Quaternary along the KRW. The discontinuous scarps of the KRW are generally low (< 3 m), whereas multiple-event scarps of the BLR are more than 15 m high. The parts of both range margins lacking Quaternary scarps also lack the straightness and steepness typical of active range fronts in the Basin and Range (Wallace, 1977). In contrast, range margins with scarps tend to be relatively straight and steep, and are flanked by playas and relatively steep gravity lows suggestive of adjacent, deep fault-controlled basins. These relations suggest that the Quaternary scarps mark the parts of the range-front fault zones that have had the most fault displacement during the long term development of basins and ranges in this area. If so, future surface-faulting events are likely to favor the distribution pattern of Quaternary events.

No unequivocal evidence was found of Quaternary surface offset on any of the four faults we studied within the Goldfield section of the Walker Lane belt northwest of Yucca Mountain. The four faults strike north to northwest and include the Rocket Wash-Beatty Wash (RWBW), Oasis Valley (OSV), Tolicha Peak (TOL), and Sarcobatus Flat (SF) fault zones. Of these, only along the SF and OSV did we find evidence of Quaternary surface offset, and that evidence is equivocal. Along the SF, the evidence is a 100-m-long scarp about 1 m high on an isolated patch of alluvium 5 km northeast of Scottys Junction. Along the OSV, isolated, erosionally modified gaps or grabens(?) are present in early(?) Pleistocene or older deposits along a 2.5-km-long strand of the fault. The four faults are located within the southern Nevada volcanic field in an area where a major episode of volcanism and extensional deformation ended at about 10 Ma. Deformation was followed by deposition of late Tertiary sedimentary and volcanic rocks that are little deformed (Ekren and others, 1971; Carr, 1988; Minor and others, 1993). The results of our study are consistent with this history of long-term structural stability, as are the results of recent geologic mapping in the area by U.S.G.S. geologists S. Schilling, S. Minor, and C. Fridrich (personal communs., 1995).

We also studied two range-front faults within the Walker Lane belt—the Keane Wonder fault zone (KW) in the Death Valley area near the boundary between the Inyo-Mono and Goldfield sections and the West Spring Mountains fault (WSM) in the Spring Mountains section. No evidence was found of late Quaternary surface offset along the main KW. We found equivocal evidence of surface offset at two isolated localities in middle Pleistocene or older deposits. Recurrent late Quaternary movement on a 2-km-long splay near the southern end of the KW is probably related to displacement along the Death Valley-Furnace Creek fault

system, rather than to faulting on the main KW range-front fault zone. In contrast, Quaternary scarps are found along 45-50 km of the WSM, and there is evidence of latest Pleistocene surface offset along about 20 km of that distance. The youngest surface faulting event along that 20-km interval produced a surface offset of about 2 m.

Included in this report are data on two Quaternary faults that were not among the candidate faults evaluated by Pezzopane (1995)—a fault on the west side of the Specter Range (WSR) southwest of Mercury, Nevada, and faults in the northern part of the Last Chance Range (LC) northwest of Pahrump, Nevada. Our study shows that because of their short lengths and distance from Yucca Mountain, they are not candidate faults. They are included because the data on them may be of value to future compilations of regional Quaternary faulting. Also, normal displacement on the LC may have resulted from Quaternary reactivation of ancient thrust faults. To our knowledge, this is the only known example of Quaternary thrust reactivation in the Yucca Mountain region.

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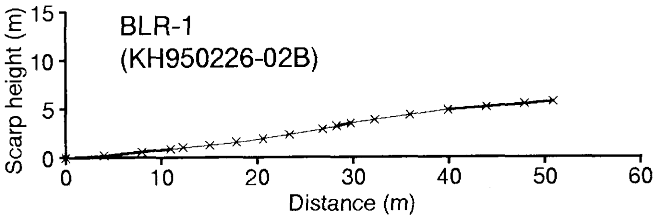
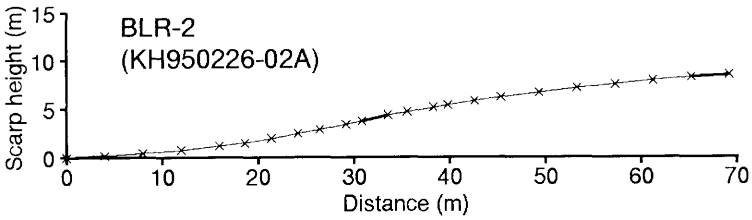
APPENDIX A: DEFINITIONS

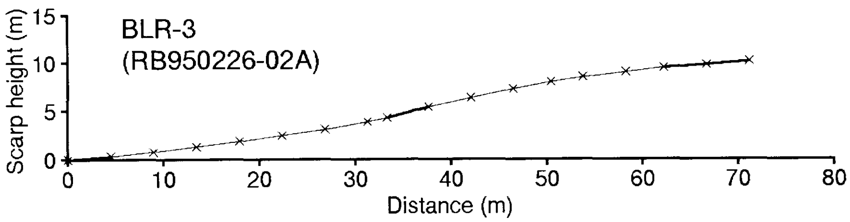
APPENDIX B: SCARP PROFILES

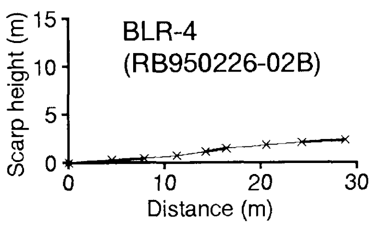
[Upper number on profiles is site number as discussed in text;
lower number is field-record number]

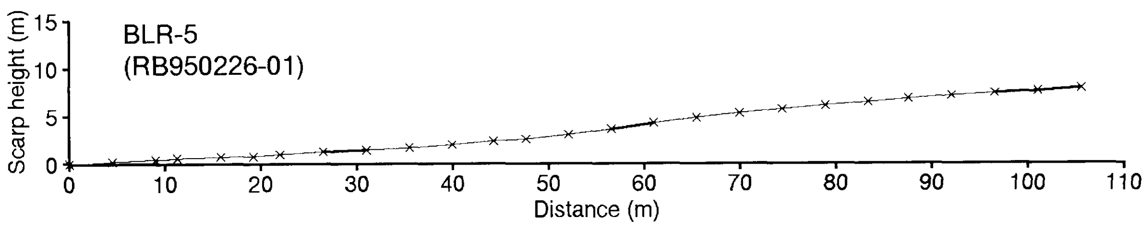
Profiles of the Belted Range fault zone (BLR)

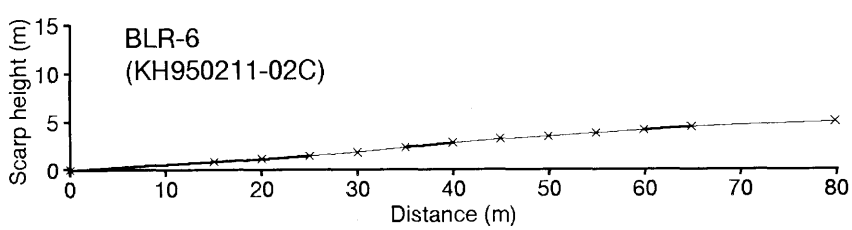


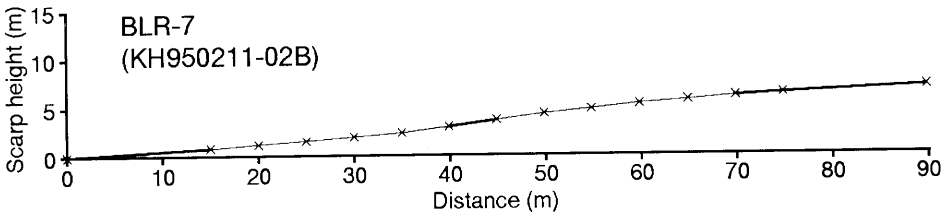








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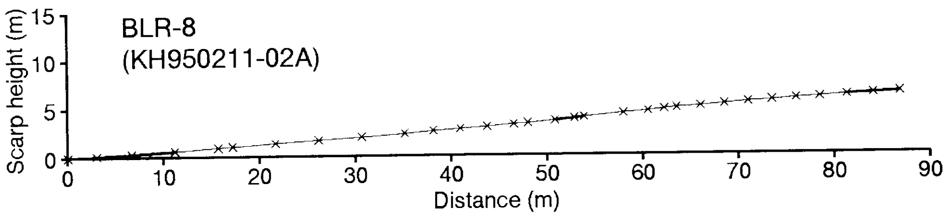
Distance (m)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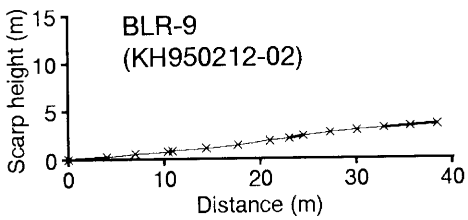
Scarp height (m)
Distance (m)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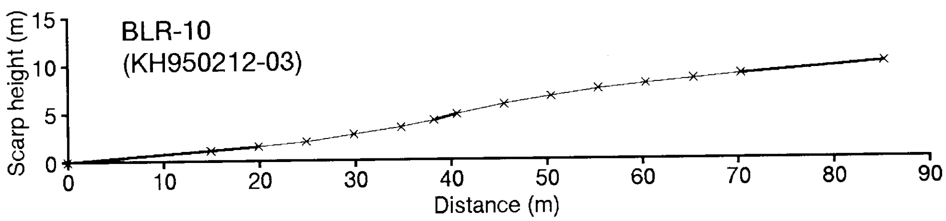
(KH950212-02)
Scarp height (m)
Distance (m)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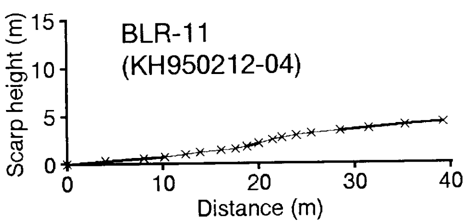
(KH950212-03)
Scarp height (m)
Distance (m)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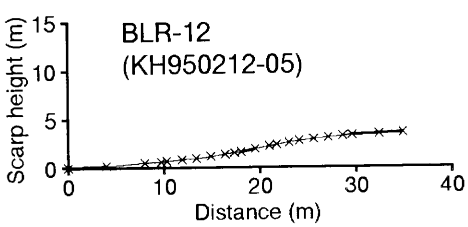
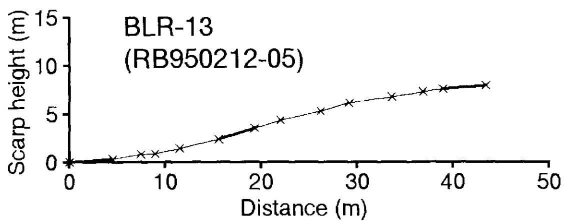
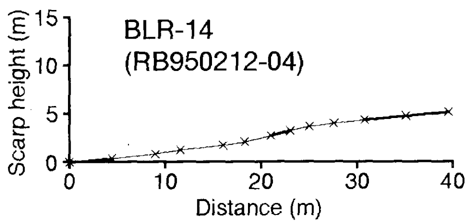
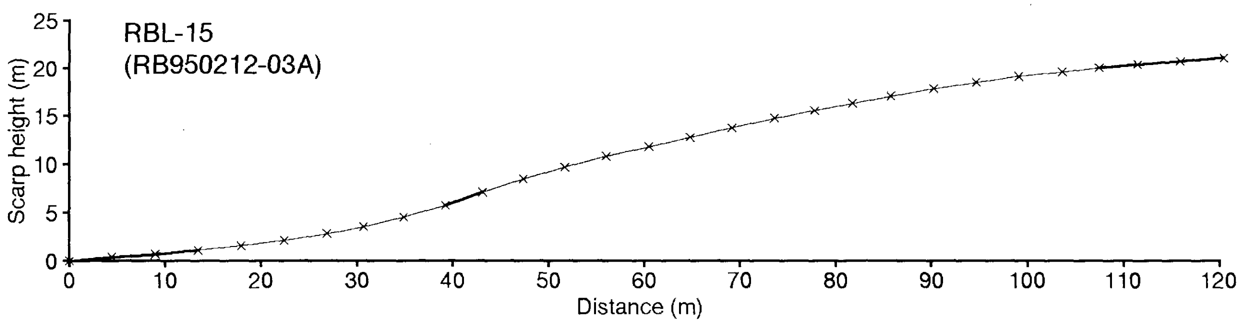
(KH950212-04)
Scarp height (m)
Distance (m)

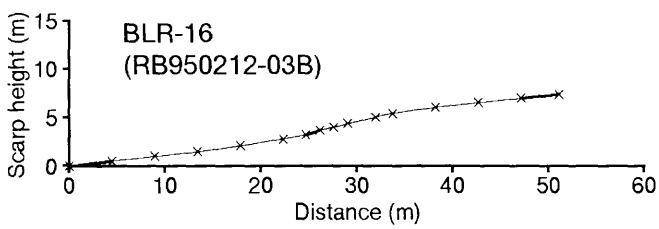

BLR-12
(KH950212-05)
Scarp height (m)
Distance (m)

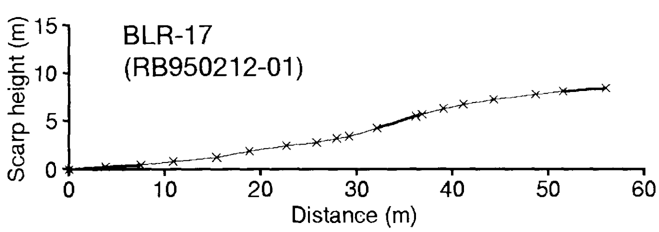
Profiles of the Belted Range fault zone (BLR) continued











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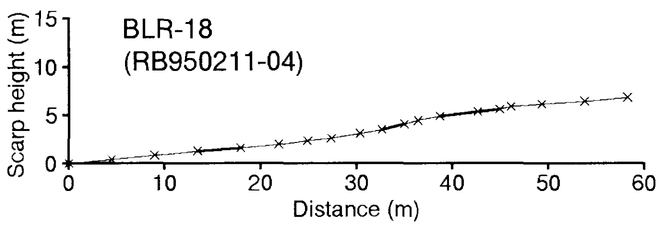

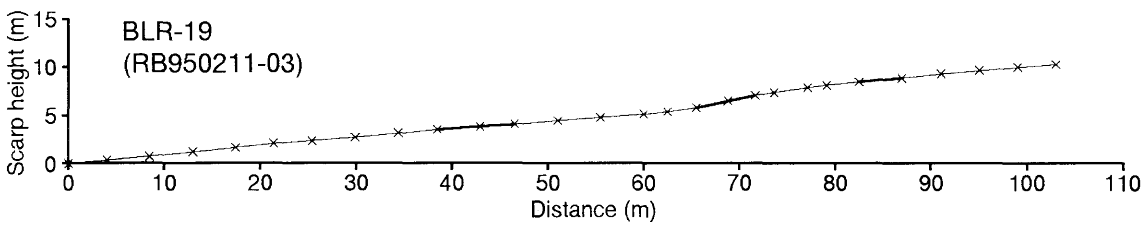

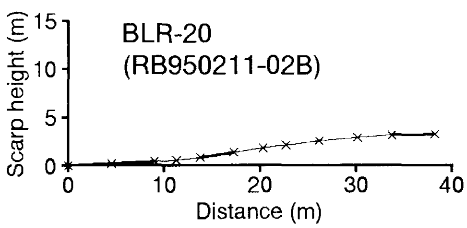

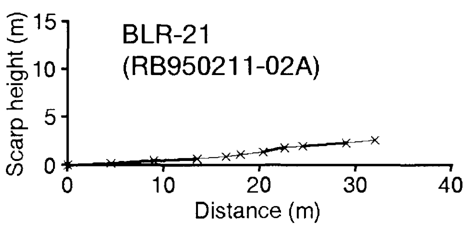

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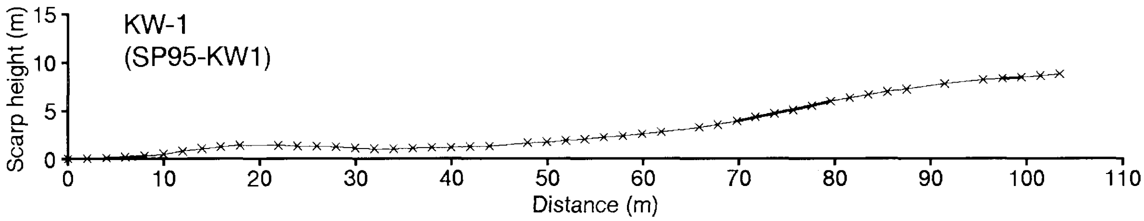
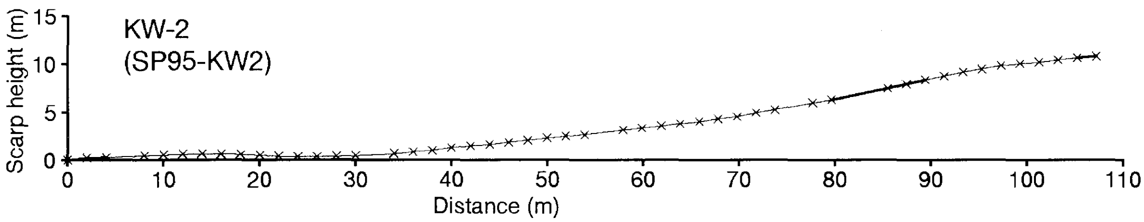
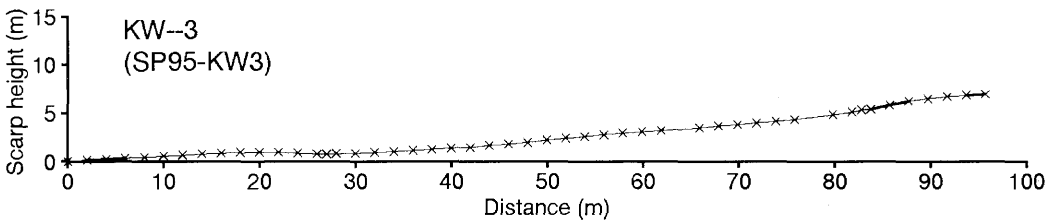
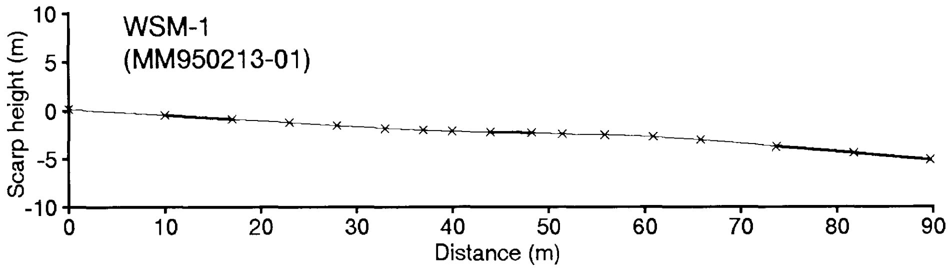
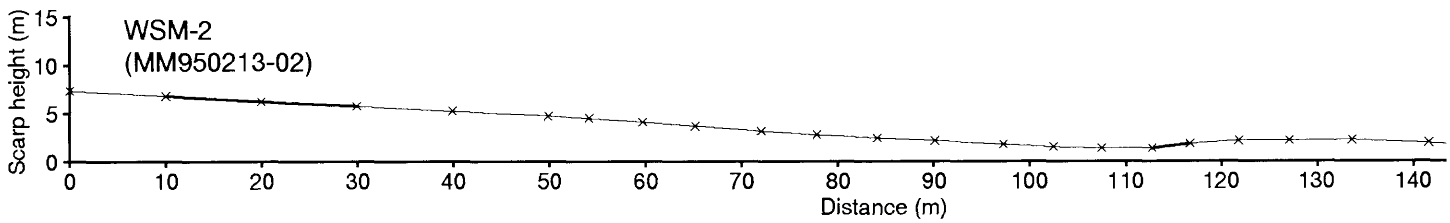


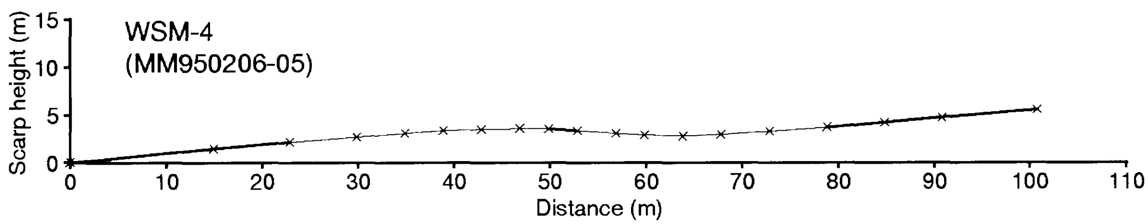


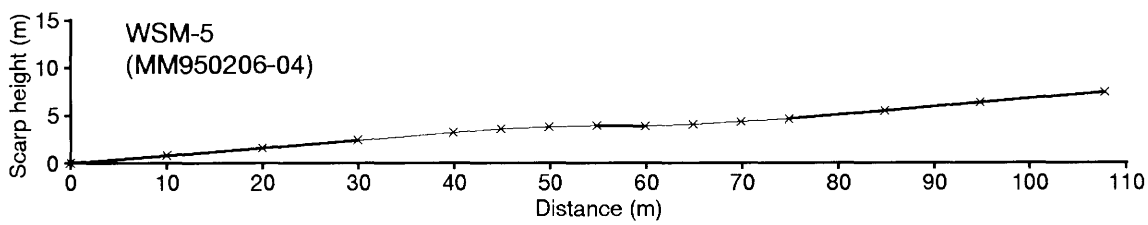


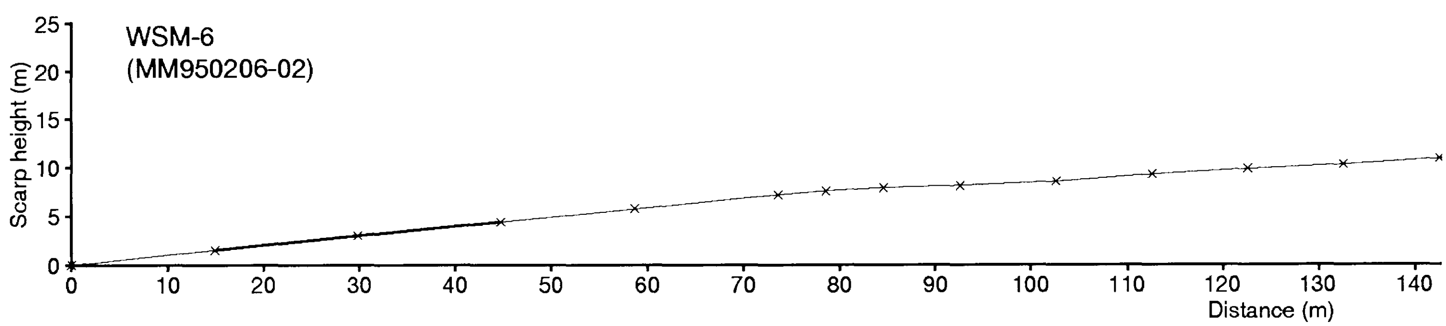
Profiles of the West Spring Mountains fault (WSM)

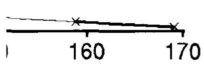








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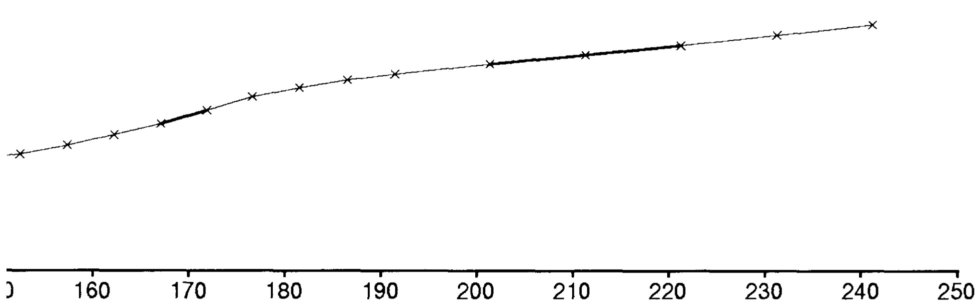
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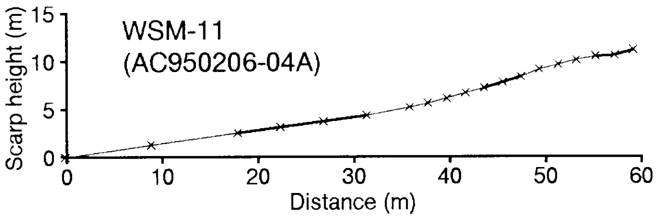
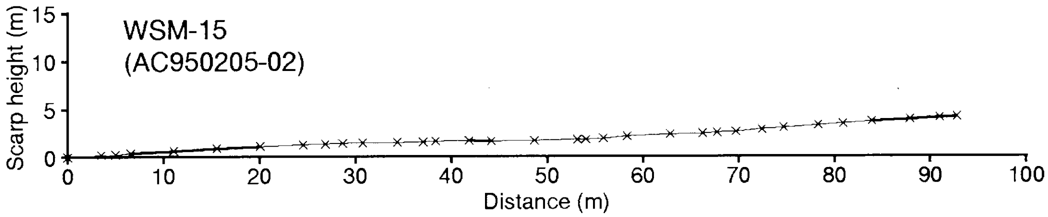
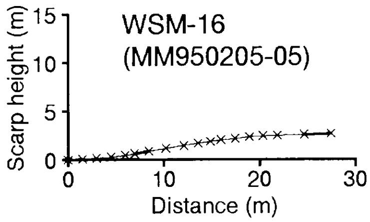
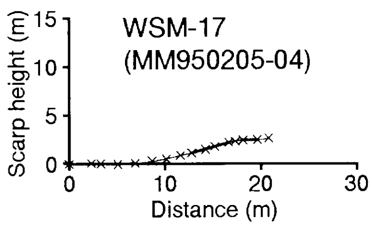
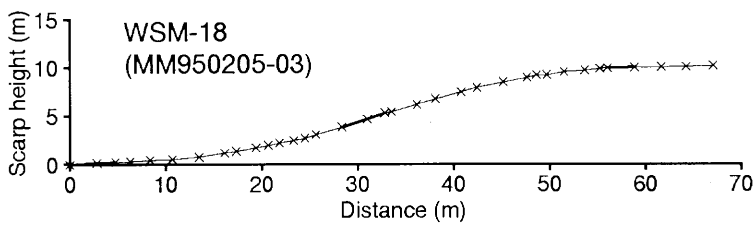
Profiles of the West Spring Mountains fault (WSM) continued

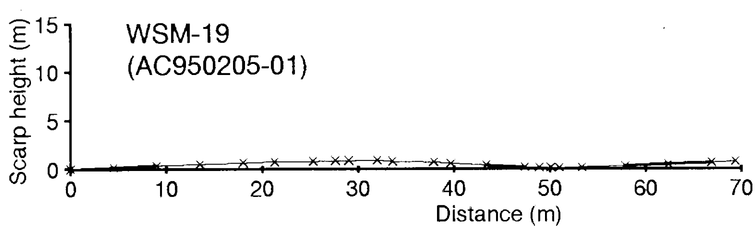


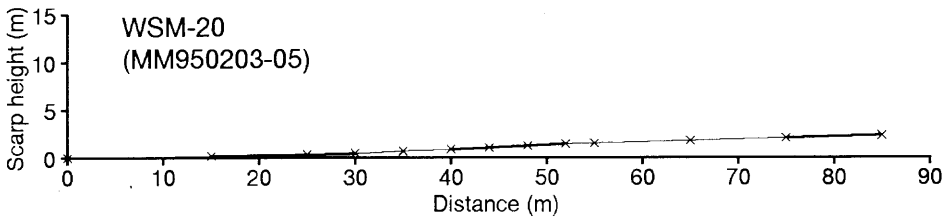








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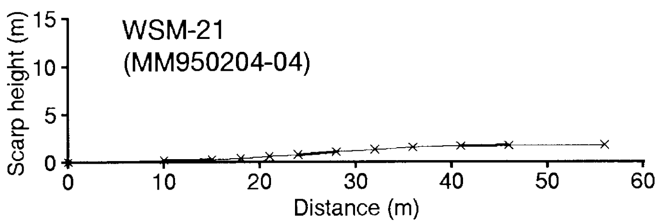
0
10
20
30
40
50
60
70
80
90
Distance (m)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40
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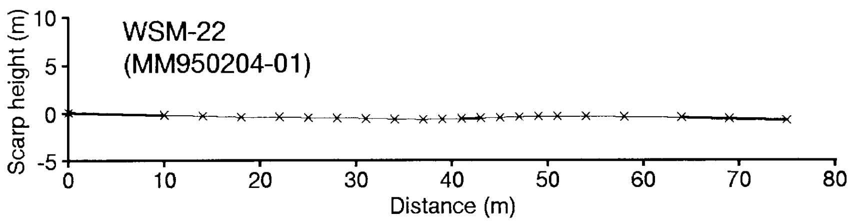
60
Distance (m)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(MM950204-01)
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0
10
20
30
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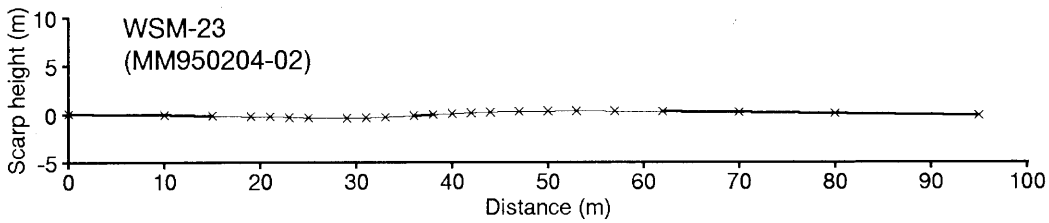
50
60
70
80
Distance (m)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(MM950204-02)
Scarp height (m)
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-5
0
10
20
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40
50
60
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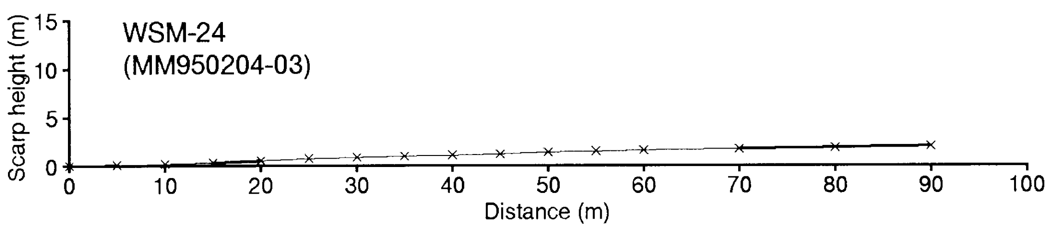
80
90
100
Distance (m)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40
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60
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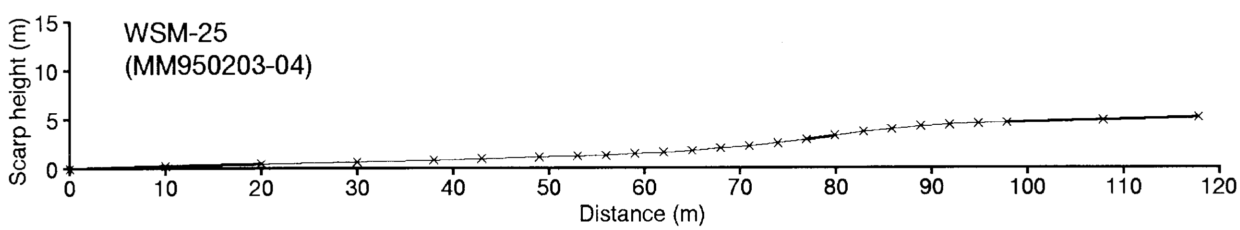
80
90
100
Distance (m)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(MM950203-04)
Scarp height (m)
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10
5
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40
50
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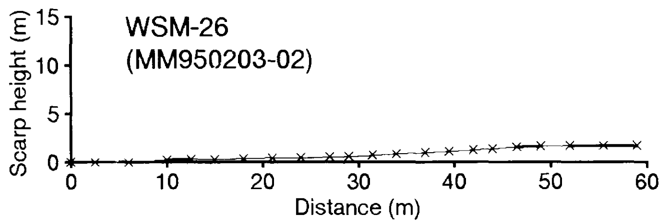
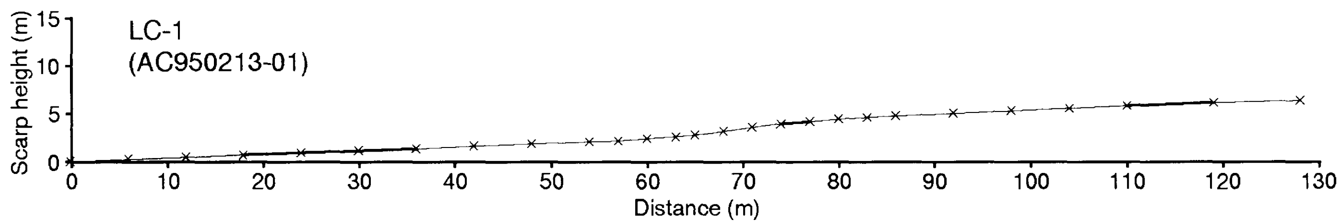
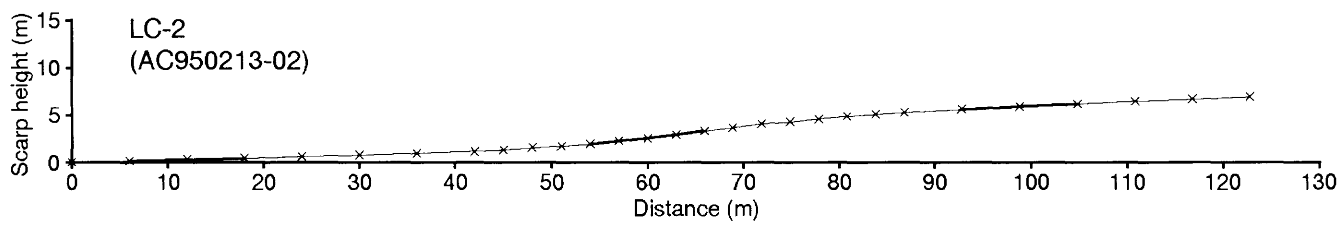
70
80
90
100
110
120
Distance (m)

Profiles of the West Spring Mountains fault (WSM) continued



Profiles of the Last Chance Range faults (LC)





Profiles of the West Specter Range fault (WSR)