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Geologic and Seismic Hazards Investigations of the Cow Creek Area, Death Valley National Park, California

By Michael N. Machette, Carlos Ninci Martinez, Anthony J. Crone, Kathleen M. Haller, *and* Giuliana D'Addezio

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INTRODUCTION

In May 1998, U.S. Geological Survey (USGS) and National Park Service (NPS) scientists and staff members held several meetings to discuss potential seismic-hazards issues at the NPS Cow Creek Administrative Area, located about 5 km north of Furnace Creek Ranch in Death Valley, California. Discussions centered on how to assess the potential for strong ground motion and fault rupturing that might impact the siting of new buildings or facilities at the Cow Creek Administrative Area. The meetings and a brief field review were attended by Linda Greene, Jed Davis, Mel Essington, Dick Anderson, Gerry Wolfe, Blair Davenport (all NPS), Ren Thompson (USGS), and the senior author (Michael Machette, USGS).

The NPS's primary concern is for the seismic integrity/vulnerability of several new building sites at the Cow Creek facility. Their near-term plan is to site a Museum Curator's building, a new building for the Death Valley Natural History Association (a private organization that operates within the park), and relocate the existing maintenance yard. In addition, a number of existing buildings at the site are constructed of adobe, and these present special challenges in terms of seismic risk. Of these new facilities, the Museum Curator's building was deemed the most critical in that NPS wanted to secure a bid for its construction by the end of fiscal year 1998 (*i.e.*, September 1998).

Working under a Memorandum of Agreement between the USGS and the NPS, we undertook a brief reconnaissance of geology and physiography of the Cow Creek Administrative area, planned two trench excavations at proposed building sites, and studied the surrounding area to determine if any faults posed a surface-rupture hazard to the facility. The reconnaissance was conducted in May and September of 1998, and geologic mapping and exploratory trenching was conducted in mid-October 1998. At the time of this report, samples have been submitted for experimental dating (thermoluminescence, uranium series, and chlorine-36). The uranium series analysis was unsuccessful, we have preliminary determinations for two thermoluminescence samples, and the chlorine-36 analyses will not be available until mid-1999.

History of Cow Creek Administrative Area

Death Valley National Monument was established on February 11, 1933, and elevated to National Park status in 1994 with the addition of large blocks of adjacent Federal land. Prior to 1933, the Civilian Conservation Corps (CCC) had constructed several buildings in the Cow Creek area, about 5 km north of Furnace Creek Ranch (fig. 1). The CCC Cow Creek camp burned in 1936, and soon thereafter the National Park determined that this would be a logical center for the monument's permanent administrative and utility (maintenance) operations. Water at the site is supplied by Nevares Spring, one of the few high volume springs in the area. Over the past 60 years, the facility has grown to include numerous buildings that serve the administrative and operational needs of the Park (fig. 2) as well as provide a base for the California Department of Transportation maintenance operations. The original CCC camp site, its buildings, and other historic (park-constructed) structures are currently listed for inclusion on the National Register as the Cow Creek Historic District. The buildings are of a variety of ages and construction types, although the adobe ones are especially pertinent to this study owing to their inherently poor resistance to ground shaking, as might occur in a moderate to large earthquake. The Park Service's housing area (the Park Village), which is located about 1 km to the east of the Cow Creek facility, was not evaluated in terms of seismic hazards, but recommendations of this report may well apply to this facility.

Objectives of the Study

The main objective of this study was to assess the presence or absence of Quaternary faults within the Cow Creek facility and to determine if any are sufficiently young or active to be considered a hazard in terms of surface rupturing. We approached this objective using standard seismic-hazard assessment techniques that are based on the fundamental assumption that young (*i.e.*, Holocene, <10,000 year old) faults are the ones most susceptible to renewed activity. Locating these faults and determining their activity rate can aid in assessing their future behavior.

Methods and Strategy

We needed a detailed base map on which to compile the geology and other information. The most detailed standard-issue map available for the area is the USGS Chloride Cliffs 7.5' quadrangle, which is published at 1:24,000 scale (1 inch equals 2000 feet). However, we were fortunate to obtain a set of pre-existing topographic and culture base maps of the area that were prepared in 1971 by Teledyne Geotronics (Long Beach, Calif.) as part of a surveying contract for the Park. Mylar reproducible copies of the base maps (18 sheets) were obtained from the National Park Service's Denver Service Center (drawing no. 143-41019). The maps were prepared at 1:1,200 scale

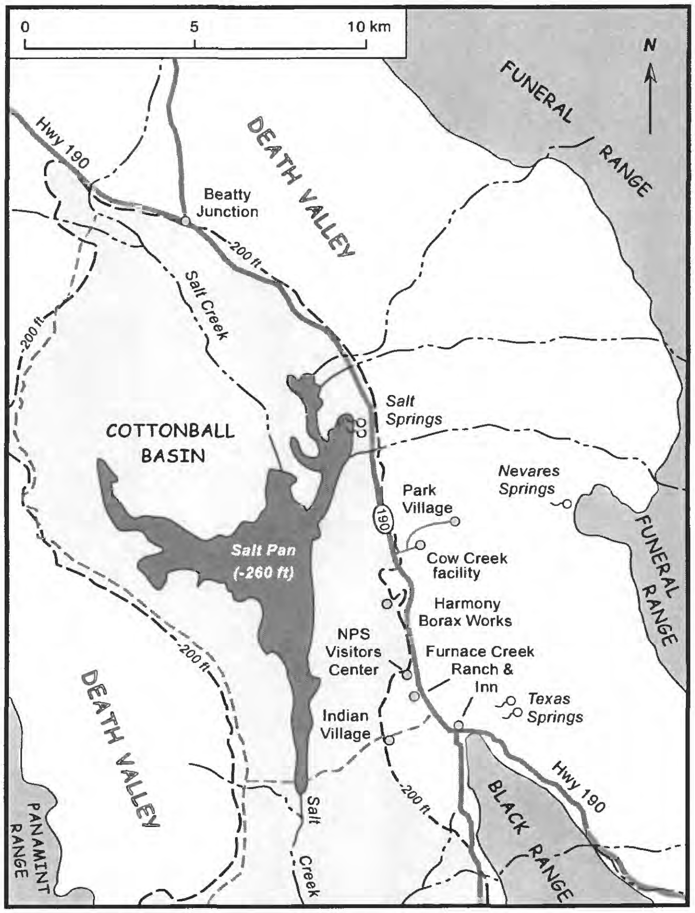

Figure 1. Index map of central Death Valley showing selected cultural and geographic features. Light stipple pattern is area below -200 ft contour; medium stipple pattern is areas of uplifted bedrock; and dark stipple pattern is the Salt Pan.

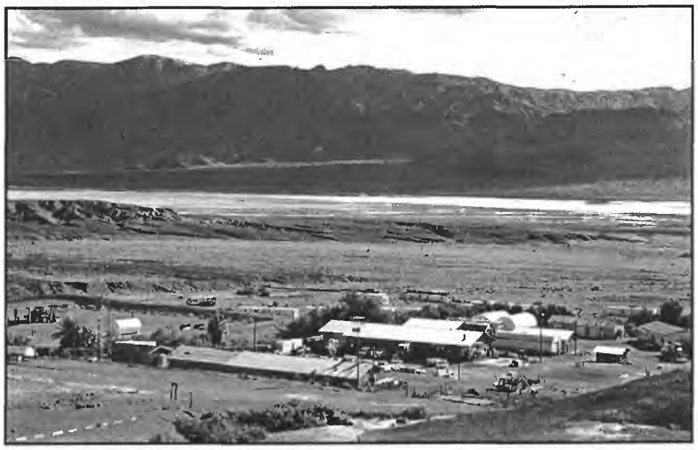

Figure 2. View to southwest of Cow Creek facility. Large buildings in foreground are part of NPS maintenance yard; Cottonball Basin is in the distance.

(twenty times more detailed that the USGS map) and contain both vertical and horizontal control with 2-foot elevation contours. The road outlines and building configurations are as of 1971, and are now partially outdated.

We digitized the topographic map sheets for the western portion of the surveyed area and constructed a new base map with 5-foot elevation contours using [1]ArcInfo GIS (Geographic Information System) software. Vertical and horizontal control points were retained from Teledyne Geotronics' original maps. The GIS map is used as a base for the surficial geologic map that is included in this report (plate 1). The map is projected in the California State Coordinate System (as was Teledyne Geotronics' originals) and printed at a scale of 1:2,000 (1 inch equals 167 feet).

We acquired several vintages of low-altitude aerial photos of the Cow Creek facility and the adjacent area. The first set was flown for the Teledyne Geotronics' surveying contract, and the negatives are archived at the University of Santa Barbara's Davidson Library, Map and Imagery Laboratory. These photos are black and white and have a nominal scale of 1:6,000. The photos used are frames 6-2 through 6-6 from flight TG-2954 (flown 6/18/71). Additional more-detailed (lower altitude) color aerial photos were obtained late in the study, after most of the aerial photo reconnaissance was completed. These color photos have a nominal scale of 1:2,400 and were flown by I.K. Curtis on contract to the NPS in 1995. We used frames 13-6 through 13-10, 14-6 through 14-10, and 15-6 through 15-10, all of which are from an April 10, 1995 flight. These photos provided detailed documentation of young surface faulting northwest of the administrative area and allowed us to update the cultural features shown on Teledyne Geotronics' 1971 maps. The boundaries of both photo coverages are roughly similar and include both the facility and the Park Village, to the east.

After studying the aerial photos, a series of analytical stereoplotter models were set by Jim Messerich of the USGS's Photogrammetry Laboratory in Denver. We used analytical stereoplotters to transfer geologic and cultural features to an appropriately scaled base map, which in our case was the 1:2,000-scale digital topographic map of the Cow Creek facility. We constructed a preliminary surficial geologic map and checked selected portions of it in September and October of 1998. We used a stratigraphic model (see table 1) based on previous regional mapping by Hunt and Mabey (1966), Klinger and Piety (1996) (and others), in our mapping of the surficial and basin-fill deposits.

To make our assessments it was necessary to map and differentiate surficial geologic units (which provide broad age constraints for faulting) and to determine the probable locations of bedrock (pre-Quaternary) faults that might be reactivated during a large earthquake. We made a photogeologic map of the facility that shows Quaternary deposits and faults (plate 1) and verified this mapping by field study. This map provided a basis for siting exploratory trenches across the footprint of the building sites: the trenches would allow us to determine if the shallow underlying (surficial) strata are deformed.

The locations of the building sites changed through the summer and fall of 1998 as we advised the NPS about their proximity to potentially hazardous structures at a number of locations. Finally, two areas were chosen for detailed investigations: (1) Salt Pan Vista (area A, fig. 3) and (2) the eastern margin of the facility (area B, fig. 3). Salt Pan Vista (SPV) is directly south of the Resource Management Headquarters building and west of the California DOT maintenance yard (plate 1). The second location (area B, fig. 3) is east of the pool and present NPS maintenance yard; this area contains a number of potential building sites, although our trenching investigations centered on the southern portion of the area, south and east of the pool. We refer to this area as the Ridgecrest (RC), owing to its location on the drainage divide between the pool area and a moderately incised stream channel that trends west on the southern side of the California DOT maintenance yard.

In mid October 1998, we excavated two exploratory trenches with a NPS backhoe; one each on Salt Pan Vista (SVP) and the Ridgecrest (RC). These trenches were 40 to 60 m long, about 1.5 m wide, and 1.5 to 3 m deep. The deeper portions of SPV were braced with hydraulic shoring according to OSHA regulations. Neither trench suffered significant collapses during the week that they were open. In

[1]Use of trade or brand names does not constitute endorsement by the U.S. Geological Survey.

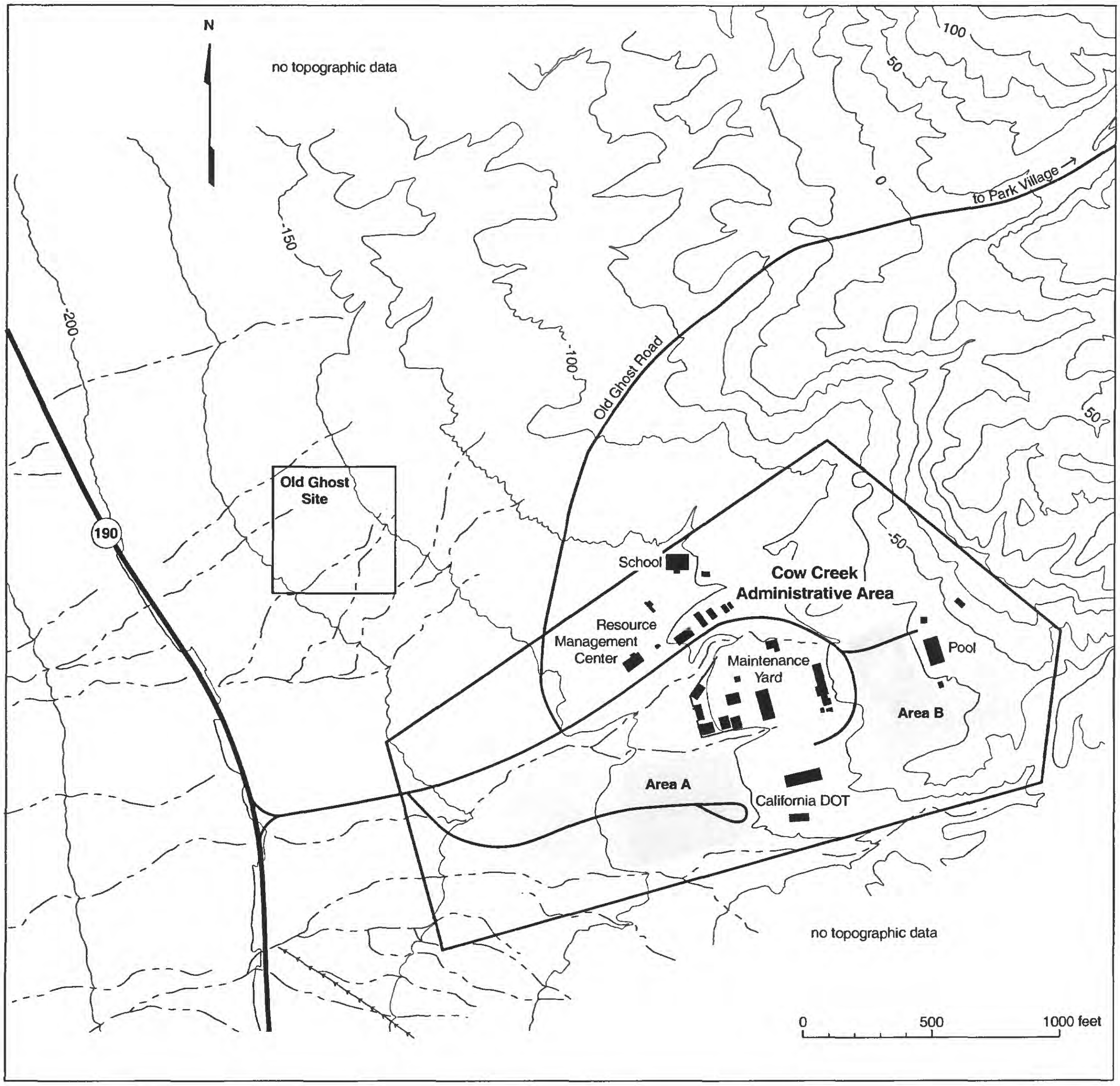

Figure 3. Index map showing Cow Creek Administrative area and surrounding study area.

addition, Tony Crone excavated a shallow, short trench on the alluvial fan that emanates from a stream canyon just north of the Cow Creek facility. This canyon and its alluvial-fan complex is unnamed, but it is crossed by the NPS's Old Ghost Road, which leads to the Park Village. Thus, we informally refer to this area as the Old Ghost alluvial-fan complex and the hand-dug trench as the Old Ghost trench.

Mapping of the two large trenches on the facility focused mainly on tracing units laterally in order to determine if they are offset by any faults that might prove to be a potential surface-rupture hazard to the building sites. Most of the units are either fluvial deposits (fan or stream gravel) or debris-flow units (gravelly mudflows) of local origin. In addition, a mantle of eolian material (sand and silt) was found in the RC trench, and the SVP trench bottomed in a fine-grained unit that is probably related to Lake Manly (late Pleistocene and older?), an ancient lake that has occasionally occupied the floor of Death

Valley. Materials for possible dating of stratigraphic units were sampled from both trenches and have been submitted for analysis, but the data were not available at the time of this report (early 1999).

The objective of siting the Old Ghost trench (which was hand dug and much smaller that the two previously mentioned) was to demonstrate the number of faulting events (suspected as being one) recorded on the younger part of the Old Ghost alluvial-fan complex. Descriptions of the stratigraphy and evidence for or against faulting are discussed in the following section on "Site Investigations."

Several topographic profiles were surveyed across the scarps near the Old Ghost trench in order to estimate the amounts of stratigraphic throw associated with faulting. Morphometric analysis of these profiles provides an estimate of the time of the faulting event(s) that are independent from but supportive of the stratigraphic control established from mapping. The results of the profiling and analysis are discussed later in the report, and the resulting morphometric data and scarp profiles are included in the Appendices.

GENERAL GEOLOGY

The Cow Creek facility is located at the western base of Park Village Ridge (see fig. 4), which is an uplifted (?) block of basin-fill deposits comprised by the Pliocene-Pleistocene Funeral Formation (QTf) and the Pliocene-Miocene Furnace Creek Formation. These deposits are exposed mainly in stream canyons, along stream channels, and in some of the steeper slopes along the margins of the ridge. Uplift of these basin-fill deposits along poorly exposed faults that have primarily normal (?) displacement has produced a horst-like structure. Conversely, the ridge's uplift may be due to transpression in a left-stepping system of right-lateral faults. Previous mapping by Hunt and Mabey (1966) and Wright and Troxel (1993) shows varying patterns of faulting without slip indicators, but either way the presence of these basin-fill deposits at the surface requires significant vertical uplift on a local scale.

Early Basin-Fill Deposits (Pliocene and Pleistocene)

The Cow Creek facility is just west of a steep escarpment (Park Village Ridge on fig. 4), at the mouth of a local stream, and in the interfluve between the Cow Creek and Old Ghost alluvial-fan complexes (to the south and north, respectively). Most of the buildings in the administrative area are built on alluvial-fan deposits (sandy gravel); although the pool and NPS maintenance yard appear to be constructed on earlier fine-grained basin-fill deposits of the Pliocene-Pleistocene Funeral Formation (unit QTf, fig. 4 and plate 1). The lithology and bedding attitudes of these early basin-fill deposits are difficult to detect in most exposures because of weathering, but these sediments are well exposed along the stream channels and cliffs south and east of the facility. The lower exposures consist mainly of siltstone, minor sandstone, and marl (fine-grained calcium carbonate-rich sediment) of probable lacustrine or playa origin. The uppermost exposures of sediment consist of conformable cliff-forming conglomerates derived from Paleozoic and Precambrian rocks in the nearby Funeral Mountains to the east. These conglomerates typically contain pebble- to small cobble-size clasts, are well indurated with calcium carbonate making them resistant to erosion. The cliff just east of the pool is held up by such materials, which dip about 15-20° to the east in the western limb of a north-trending syncline, as noted by Wright and Troxel (1993). The north-south elongate ridge east of the administrative area (and on which the Park Village is built) was called Park Village Ridge by Hunt and Mabey (1966). This ridge is comprised of conglomerates, coarse grained gravels (both in place and reworked), and an underlying package of finer-grained sediment. We mapped all of the materials in the Park Village Ridge as undifferentiated Funeral Formation (unit QTf) because the limited scope of our investigations did not allow for a more detailed determination. Interested readers should refer to the mapping of Hunt and Mabey (1996) and the latter revisions by Wright and Troxel (1993), which is the most detailed and recent geologic mapping conducted in the vicinity of the site.

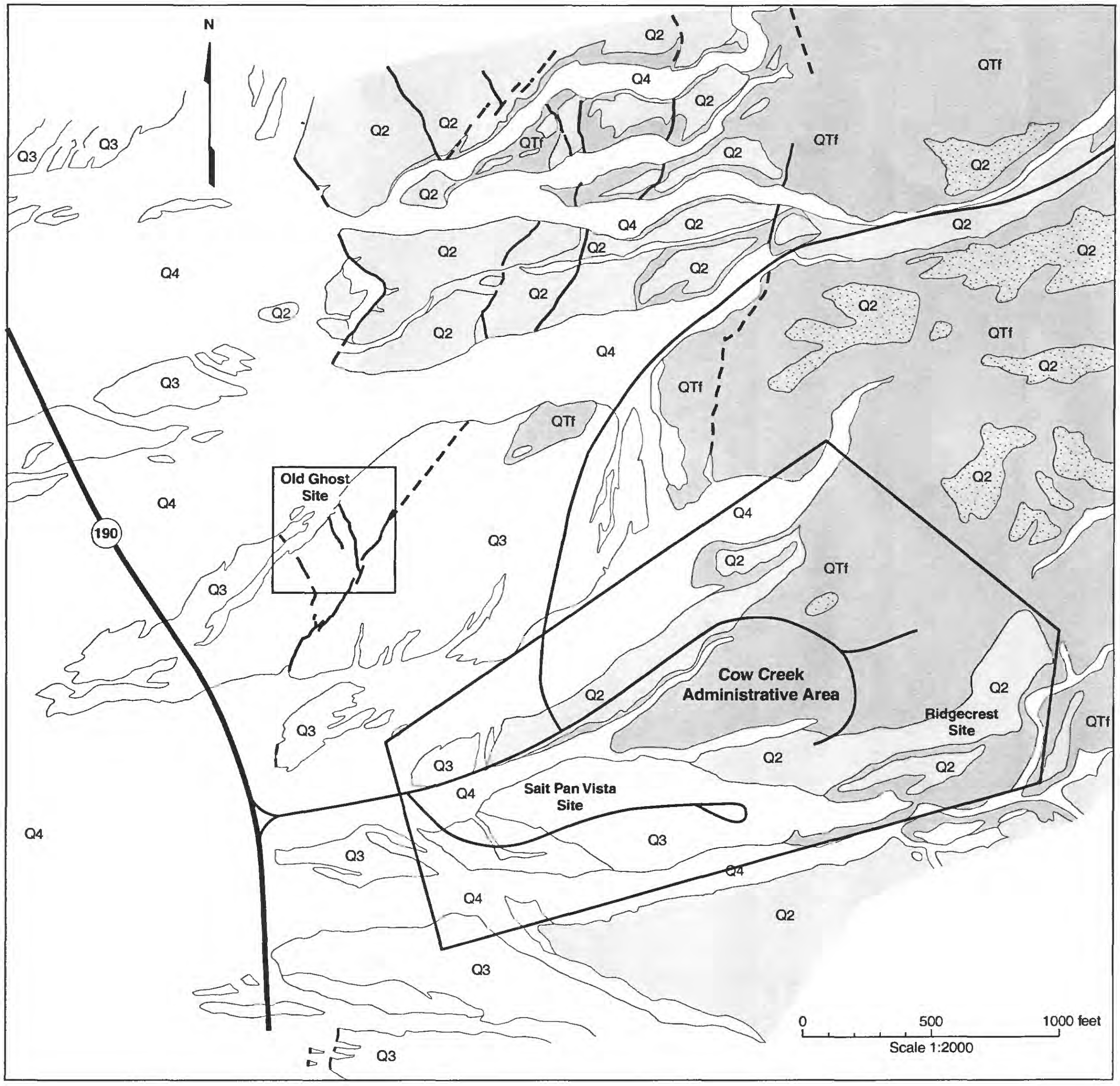

Figure 4. Geologic map of the Cow Creek Administrative area and surrounding study area. Geology generalized from plate 1 (this report). Refer to text and plate 1 for description and correlation of units and symbols. The upland area is the west margin of Park Village Ridge.

The Cow Creek facility is located in a transition zone between the southern end of the Furnace Creek fault and the north end of the Death Valley fault (fig. 5), which is well displayed near Furnace Creek Inn and extends south along the Black Mountains. This transition zone was defined by Klinger and Piety (1996) on the basis of a reconnaissance study of the Furnace Creek and Death Valley fault zones and Brogan and others' (1993) detailed mapping of the entire fault system. The area that has been problematic in most previous studies is a structurally complex area that accommodates a transfer of predominately right-lateral slip on the Furnace Creek fault to the Death Valley fault, which is considered to be a predominately normal fault. The surficial and bedrock geology of this area had been mapped at small scale (1:96,000) by Hunt and Mabey (1966), at intermediate scale (1:48,000) by Wright and Troxel (1993), but little is known about the subsurface linkages of these two fundamental seismic sources. In terms of the transition zone's history of recent faulting, Brogan and others (1991) geomorphic study of the entire fault system at 1:62,500 scale was the most detailed available at the time we initiated this study.

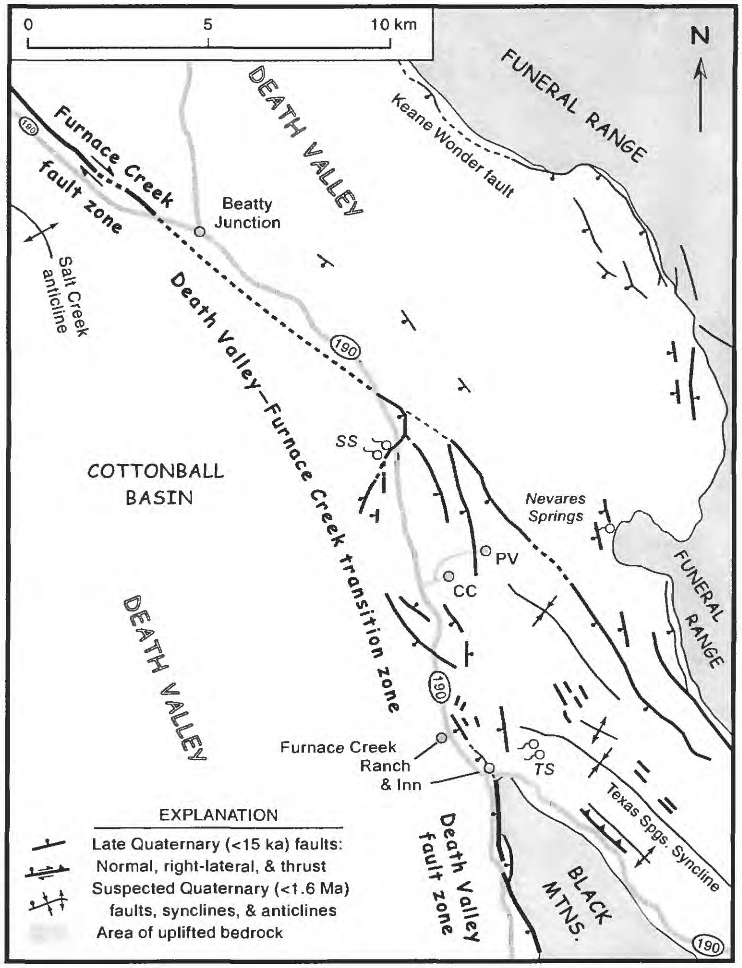

Figure 5. Generalized map of Furnace Creek and Death Valley fault zones, and intervening transition zone. Quaternary faults slightly modified from figure 15 in Klinger and Piety (1996). Abbreviations: CC, Cow Creek facility; PV, Park Village; SS, Salt Springs; and TS, Texas Springs.

The Cow Creek facility is located in the central part of the transition zone, at the western margin of Park Village Ridge (see fig. 6A). In this area, Hunt and Mabey (1966) mapped the southern end of the Furnace Creek fault zone as a series of south-trending faults that displace surficial deposits (fig. 6B). From Salt Springs south, the zone bifurcates, with one strand bounding the east margin of the Park Village Ridge, and a series of short faults bordering the west margin. Hunt and Mabey (1966) did not show any Quaternary (or older) faults extending through the Cow Creek facility, but did map a series of three closely spaced north-south trending faults just to the northwest of the facility. According to their mapping, these faults displace Qg3 and Qg4, their two youngest surficial units. In retrospect their small-scale mapping is a fairly accurate depiction of Quaternary faulting as assessed in this study.

The more recent detailed mapping by Wright and Troxel (1993) is similar to that of Hunt and Mabey (1966), but included a number of faults within the western part of the Park Village Ridge (fig. 6D). In addition, they mapped a syncline in the Furnace Creek Formation just east of the Cow Creek facility, which we confirmed in the field. Their mapping of surficial and young (Pleistocene) bedrock units seems accurate, but we believe that some of their mapped faults on Park Village Ridge may in fact be shoreline features related to Lake Manly. The young faults north and northwest of the Cow Creek

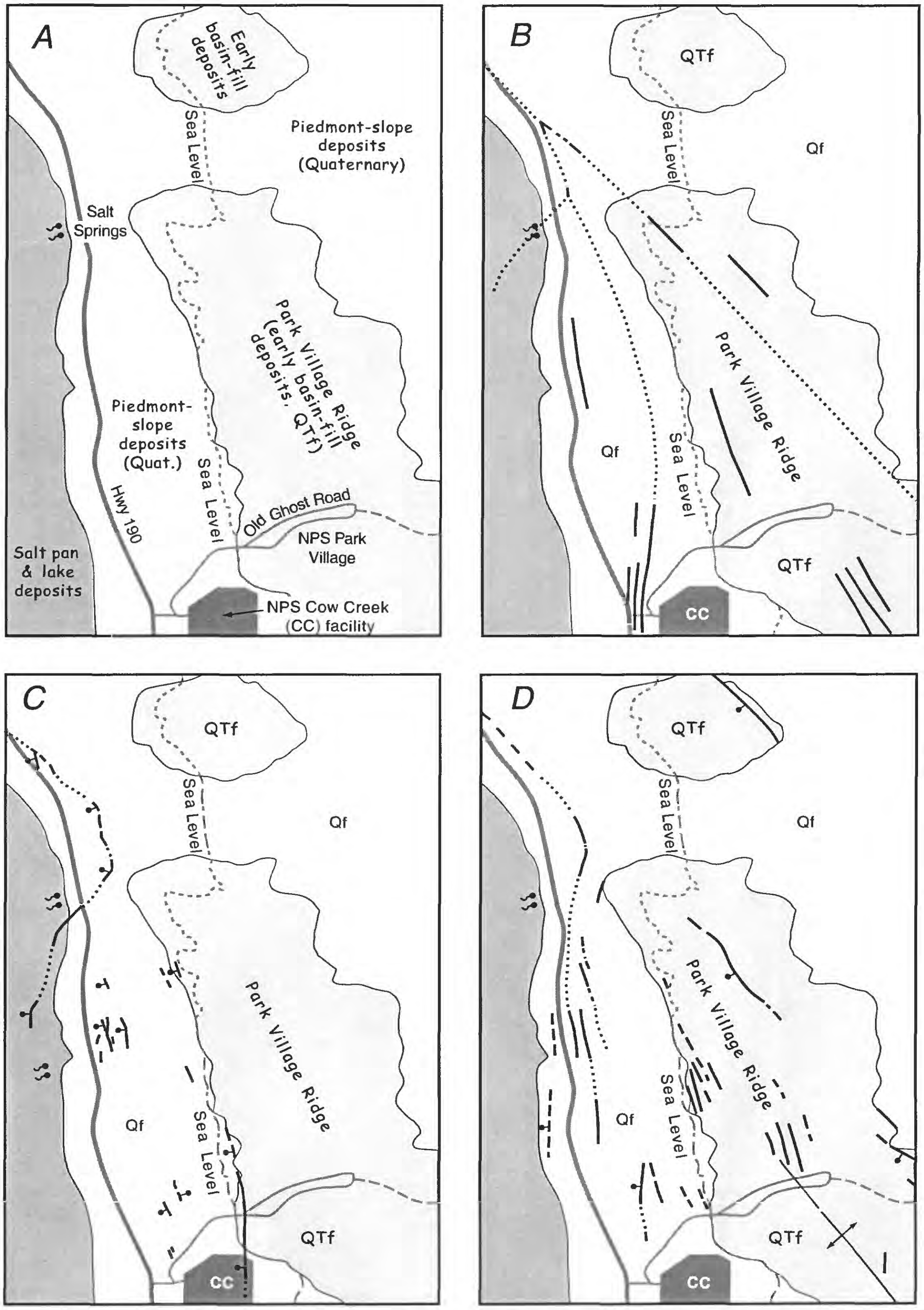

Figure 6. Quaternary fault maps of the Cow Creek area: (A) index map of area; (B) Hunt and Mabey (1966; no displacement sense shown); (C) Brogan and others (1991); (D) Wright and Troxel (1993). Abbreviations: CC, Cow Creek facility; Qf, undifferentiated Quaternary deposits; QTf, early basin-fill deposits of Funeral and Furnace Creek Formations.

facility are somewhat generalized on their map, but they did not show a fundamental fault traversing the facility.

Surficial Deposits (Quaternary)

In contrast to the tilted basin-fill sediment that underlies Park Village Ridge, the areas to the west are entirely covered by surficial deposits. These deposits are largely unconsolidated and rest unconformably on older basin-fill deposits as seen in exposures on the northern half of the Old Ghost complex. Most of the surficial deposits are comprised of alluvial-fan gravel of varying ages and character (fig. 4). The gravel is typically 1 to 5 m thick and is of fluvial (sandy gravel and gravelly sand) and debris-flow (silty gravel) origin, which is typical of alluvial fans in desert environments. These gravels include little or no fine-grained surficial sediment, except for a capping (mantle) of desert loess that is incorporated into 5- to 20-cm-thick vesicular A (soil) horizons.

Most previous mapping of surficial deposits in Death Valley is of a reconnaissance nature and used a four-fold stratigraphic division. This scheme originated with the fine early mapping of Hunt and Mabey (1966) and was accepted and utilized by Wright and Troxel (1993). For detailed studies such as this one, further subdivison can be accomplished on the basis of geomorphic and soil characteristics as outlined by Klinger and Piety (1996, table 2). For example, Dorn and others (1987), Moring (1986), and Klinger and Piety (1996) all proposed multifold division (table 1) of the upper three units (Q4 through Q2) first established by Hunt and Mabey (1966).

In this study, we are using the stratigraphic column of Klinger and Piety (1996) with minor modifications (see table 1). For example our youngest unit (Q4) represents their alluvial units Q4a (historic) and Q4b (0.1-2.0 ka). These units can be separated with detailed study, but neither are faulted at the sites we studied, thus we mapped Q4 as an undifferentiated unit (fig. 4). Unit Q4 forms the youngest part of the landscape, which represents recurrent debris-flow and flooding events during intense rainstorms. The surface of unit Q4 has original or slightly modified surface morphology (bar and swale topography), displays no desert varnish to light desert varnish on poorly developed desert pavement, and lacks zonal soils (see Klinger and Piety, 1996, table 2). About 50 percent of the alluvial-fan landscape on the piedmont-slope west of Park Village Ridge is formed by alluvium of unit Q4 (fig. 4).

Alluvial unit Q3 and its two subunits (Q3c and Q3ab of increasing age) form about 30 percent of the alluvial-fan landscape on the piedmont-slope west of Park Village Ridge (fig. 4). Subunit Q3ab is an undivided equivalent of Klinger and Piety's (1996) units Q3a and Q3b, and unit Q3 is an undivided equivalent of Klinger and Piety's (1996) units Q3a, Q3b, and Q3c. The surfaces underlain by subunits of Q3 are characterized by subdued bar and swale topography (typically equal portions), medium to dark desert varnish on well-developed desert pavements, medium to thick vesicular A horizons, and weakly developed zonal soils on subunit Q3ab.

Of the four basic units, the most easily differentiated are Q3 and Q2 owing to the conspicuous differences in surface tone and geomorphic expression. Unit Q2, which is entirely pre-Holocene, has been subdivided into three subunits: Q2c, Q2b, and Q2x on the basis of topographic position, geomorphic preservation, and their characteristically dark-varnished desert pavement. Q2c and Q2b are the most extensive of the three subunits on the piedmont of the Cow Creek area. These two units form the remaining 20 percent of the piedmont. The subdivision of unit Q3, which span a potential time interval of 700,000 years, is primarily based on soil development. Sparse exposures of soils in the Cow Creek area make these subdivisions tenuous.

Subunit Q2a, which is Klinger and Piety's (1996) oldest subdivision of unit Q2, was not mapped as a *bona fide* unit in the Cow Creek area. Aerial photographs of the Park Village Ridge (see location on fig. 6) indicate several levels of erosion surfaces that appear to be capped by thin (<1 m) to moderate (1-5 m) thickness of gravel (unit Q2x, table 1) reworked from the primarily conglomeratic upper part of the Funeral Formation (QTf). This conglomerate is the likely source of the gravel preserved on these Q2x remnants. These surfaces project westward into the air (see Hunt, 1975, fig. 5) and do not appear to have ever been of wide extent. They are probably equivalent to unit Q2a of Klinger and Piety (1996).

Table 1. Correlation of Quaternary alluvial units as they apply to the Cow Creek area
[Modified from table 1 of Klinger and Piety, 1996]

Time Terms and Age Limits		This Study (Cow Creek area)	Klinger and Piety (1996) (Death Valley)	Wright and Troxel (1993) (North-central Death Valley)	Dorn and others (1987) (Hanaupah fan, Death Valley)	Moring (1986) (Northern Death Valley)	Hunt and Mabey (1966) (Death Valley)
HOLOCENE	Holocene (0-10 ka)	Q4	Q4b (historic)		Modern		
			Q4a (0.1-2 ka)	Qg4	Q4c (0.5-2.5 ka)	Qf4	Qg4
					Q4b (2-4.5 ka)	Qf3	
		Q3c	Q3c (2-4 ka)	Qg3			Qg3
		Q3	Q3b (4-8 ka)		Q4a (6-11 ka)		
		Q3ab	Q3a (8-12 ka)				
PLEISTOCENE	Late (10-130 ka)	Q2c	Q2c (12-70 ka)	Qg2	Q3 (13-50 ka)	Qf2c Qf2b Qf2a	Qg2
		Q2b	Q2b (70-200 ka)		Q2a/Q2b (110-190 ka)		
	Middle (130-730 ka)	Q2x	Q2a (400-730 ka)		Q1/Q1b (>500->800)		
						Qf1	
	Early (730 ka-1.6 Ma)	Q1 (not mapped)	Q1 (>1200 ka; 1.2 Ma)	Qg1			QTg1 (Funeral Fm., upper part)
		QTf (Funeral Fm., coarse upper part, fine lower part)		QTfs (Funeral Fm.)			

Notes: For this study, we mapped unit Q3 as an undivided equivalent of Klinger and Piety's (1996) units Q3c, Q3b, and Q3a; unit Q3ab as an undivided equivalent of Klinger and Piety's (1996) units Q3b and Q3a; unit Q2x as probably correlative with their unit Q2a; unit Q1 was not mapped in the area.

However, no effort was made to map this unit in detail, and we did not see exposures of soils developed on these eroded surfaces, so the correlation of subunit Q2x and Q2a is somewhat questionable.

The oldest of the four basic surficial units is Q1. It has not been mapped within the Cow Creek area, but unpublished mapping by Janet Slate (USGS—Denver) in the Beatty ½° x 1° sheet shows remnants of unit Q1 east of the Park Village Ridge, as does the mapping of Hunt and Mabey (1966, unit QTg1) and Wright and Troxel (1993, unit Qg1). Unit Q1 displays almost no original surface geomorphology, having been deeply dissected from a Q2-like form into ballinas (whalebacks). The surfaces are heavily varnished and have well-developed desert pavements on stable landscapes. The soils are typically very well developed having advanced stages (IV+) of calcium carbonate morphology (see Klinger and Piety, 1996, for landscape morphology; Machette, 1985, for stages of carbonate morphology).

There is sparse numeric age control for the surficial geologic deposits, either in the Cow Creek area or the whole of Death Valley. Klinger and Piety (1996) rely mainly on correlation to other stratigraphic sequences in the Southwest and to assumptions about climatically controlled depositional sequences. Klinger and Piety's (1996) subdivision of units Q4 and Q3 seem reasonable and their age estimates are based on a few radiocarbon dates and thermoluminescence age estimates. Their suggested ages for the subunits of Q2 are uncontrolled by reliable age determinations. Unit Q2c for example, is estimated to be 12-70 ka, a time interval which encompasses the later half of the late Pleistocene (roughly 10-130 ka), whereas unit Q2b (70-200 ka) encompasses the first half of the late Pleistocene and a small portion of the middle Pleistocene (roughly 130-730 ka). If climatic changes control deposition and erosion of alluvial units in Death Valley, which is a basic tenant of most Quaternary stratigraphic sequences, then unit Q2b should probably consist of several subunits itself.

Erosional History

It seems likely that erosion of Park Village Ridge and the underlying sediment was caused by one or more high stands of Lake Manly, which filled Death Valley intermittently during the middle to late Pleistocene. There are numerous lacustrine shorelines etched across the western face of Park Village Ridge (plate 1, see also Hunt, 1975, fig. 5). The western face of Park Village Ridge and the cliff areas east and southeast of the Cow Creek facility are supported by the resistant conglomeratic upper part of the Funeral Formation, whereas the underlying fine-grained part is easily eroded. Thus, the steep slopes in these areas are probably a combined result of the protective conglomeratic caprock and lacustrine erosion of the underlying fine-grained sediment.

Lake Manly is the distal sump into which Owens River discharged after traversing and overflowing the chain of pluvial lakes between Death Valley and Mono Lake (Blackwelder, 1933; Smith, 1976). The long-accepted paradigm that Death Valley's lacustrine shorelines are the result of a deep (ca. 500 ft) latest Pleistocene (ca. 35-10 ka) is currently being debated on the basis of new uranium-series dating of lacustrine tufas at Badwater and deep cores from the basin (Ku and others, 1998) and thermoluminescence dating of lacustrine (?) silts in a high-level spit northeast of Beatty Junction (see Klinger and Piety, 1996). This debate will take years of research to resolve, but there is clear geologic evidence for one or more lakes that were sufficiently deep to bury the Park Village Ridge (see Hunt and Mabey, 1966; Klinger and Piety, 1996, etc.). The main question is at what time(s) did these lakes bury the ridge and cause reworking of the gravelly part of the Funeral Formation. At whatever times this occurred, the lakes probably had a profound effect on shaping the geomorphology of the Cow Creek area—everything from forming the steep cliff east of the pool to eroding the western face of the ridge and etching the tens of shorelines that are obvious on aerial photographs and on the ground.

STRUCTURE, FAULTS, AND EARTHQUAKES

During our first site visit in May 1998, the senior author proposed to the NPS that one or more faults could extend through the eastern margin of the Cow Creek facility (fig. 4). This assertion was made on the basis of several published geologic maps that show surficial faulting to the east and north-northwest of the facility. In addition, our photogeologic reconnaissance had identified several lineaments that project towards the facility. Thus, several lines of geologic evidence suggested that faults or zones of faults could extend through the facility and directly impact potential building sites. Conversely, although Death Valley is generally considered to be a region of potential seismic activity, its past century of history is not marked by an unusual number of earthquakes, the largest being in the magnitude 4-5 range (see following discussion). Thus the presence of faults, both locally and regionally, and the generally aseismic character of the valley presented a paradox. Our best explanation for this paradox is that large earthquakes that cause surface deformation along the Death Valley and Furnace Creek fault zones occur infrequently and are separated by relatively aseismic episodes.

Structural Problems in the Area

A fault zone was shown along the eastern margin of the Cow Creek facility by Brogan and others (1991) on their 1:62,500-scale map, but not by Wright and Troxel (1993) based on 1:48,000-scale mapping (fig. 6). In as much as Brogan and others' (1991) mapping concentrated on surficial evidence of late Quaternary faulting, we believed that such a fault could exist at the facility. The gross physiography of the site suggested the presence of a fault zone defined by a primary NNW-striking normal (?) fault along the eastern margin of the facility. This fault would truncate the high-level piedmont surfaces (Q2x) that extend from the Cow Creek facility east and northeast to the Park Village. These high surfaces are formed on conglomerates of the upper part of the Funeral Formation (Pliocene to Pleistocene), whereas the underlying fine-grained sediment forms that east-bounding slope of the facility. The few springs that seep from the slope could be concentrated within this hypothetical fault zone. About 100 feet (30 m) west of this "main fault" there is a series of low hills (anomalous topography) that could be formed by an antithetic fault (west-bounding fault of the 30-m-wide zone). The resultant graben could extend north-northwest to Old Ghost Road, and south-southeast of the Cow Creek facility.

If the fault zone existed as described, then the present swimming pool (fire-fighting water supply) would lie within the graben, and all of the three new buildings would have been along or close to the western (antithetic) fault (plate 1). To complicate matters more, there was a possibility of an additional more western (third) fault as suggested by the topography, which has been greatly modified in the 65 years since the Cow Creek facility was established. Existence of these faults could not be proven without subsurface investigations (trenching, see following discussion). In the course of our field review with the NPS staff, we discussed minimum setbacks from the fault zone, appropriate use of the proposed building sites, and alternate sites that exist within the immediate area. Although the eastern part of the area (figs. 3 and 4) was their first choice, alternate sites for the new Curator's and Natural History Association buildings were considered west of the present elementary school (north of the Resources Management Office, plate 1) and in the Salt Pan Vista area (south of the Resources Management Office, fig. 4 and plate 1). The former site has some potential flood problems that NPS had previously identified, and thus was considered less desirable. The main problem with the Salt Pan Vista area was its visibility from the road. Nevertheless, by mid-summer 1998, the NPS had focused on Salt Pan Vista as the probable location for the above mentioned buildings, as well as for the future location of the existing maintenance yard and facilities.

Mapped Quaternary Faults

As previously mentioned, Brogan and others (1991) were the first to show a fault traversing the Cow Creek facility (fig. 6C). They mapped a north-south fault through the pool area of the facility (see Brogan and others, 1991, plate 2) and extended it north along the western margin of Park Village Ridge. They considered the western margin of the ridge to be fault controlled, but the field evidence is not compelling to us. Our detailed geologic mapping of the site (see plate 1) reveals north- and north-east-striking young faults, but the apparent path of this young deformation skirts the western margin of the Cow Creek facility. We suspect that Brogan and others (1991) were mislead by photogeologic identification of some north-trending non-tectonic lineaments area caused by erosional etching of gentle east-dipping beds that hold up the slope (western limb of the aforementioned syncline) and by cultural features such as buried water pipes, old roads and trails. Our field inspection failed to confirm the existence of a fault with the eastern part of the facility as mapped by Brogan and others (1991).

The most recent fault mapping in the area is that of Klinger and Piety (1996), however their detailed investigations concentrated on the Furnace Creek and Death Valley fault zones instead of the transition area in between. Their map of the transition zone (Klinger and Piety, 1996, fig. 14, scale about 1:250,00), which is reproduced above as figure 4, shows a late Quaternary (<15 ka) pattern of faulting that includes selected elements of Hunt and Mabey (1996), Wright and Troxel (1993), and Brogan and others (1991) mapping. Interestingly, Klinger and Piety (1996) also included a fairly long north-south-trending fault that projects through the eastern part of the Cow Creek facility; we suspect that this structure was inferred from the steep western margin of Park Village Ridge and supported by Brogan and others' (1966) mapping.

In summary, geologic mapping dating from 1965 to 1996, at intermediate scales of 1:48,000 to 1:96,000 have noted the presence of Quaternary faults at the Cow Creek facility, on the piedmont-slope northwest of the facility, and within older deposits on Park Village Ridge (fig. 6). As discussed later, we (1) confirm the presence of many piedmont faults near the facility, (2) cannot find evidence of young movement on any faults within the facility including the north-south fault suggested by both Brogan and others (1991) and Klinger and Piety (1996), and (3) have not investigated the faults within Park Village Ridge because they are not associated with deposits that record stratigraphic evidence of young movement.

Recent Earthquakes

Death Valley has a relatively sparse record of historic earthquakes with most of the felt ground motion coming from earthquakes originating in clusters around the margin of the Park, or more distant earthquakes in the Basin and Range Province of southern Nevada and southeastern California. The U.S. Geological Survey's earthquake catalog of the Death Valley region for the past century (since 1900), which is plotted in figure 7, shows relatively few magnitude 4 or larger earthquakes within the (new) boundary of the Park, and only a single magnitude 5 earthquake near Scotty's Castle. Admittedly, the best earthquake locations and magnitude estimates are from the past 30 years as a result of better monitoring and the implementation of a dense network at the Nevada Test Site and for the Yucca Mountain project, in the past several decades. Nevertheless, no significant increase in earthquake locations or concentrations have been noted within the valley in the past several decades.

Five M 4-5 earthquakes have occurred south and west of the Cow Creek facility as shown on figure 7. Three of these occurred beneath the Furnace Creek area, a fourth was farther east near Texas Springs, and the fifth was farther north, about 5 km south of Titus Canyon. These earthquakes were large enough to be felt and but could only cause minor damage: they are clearly minor events unrelated to surface faulting. The single M 5 earthquake that occurred within the Park was at its northern boundary, about 7 km southeast of Scotty's Castle on the Nevada/California state boundary. No other M 5+ earthquakes, which are easily recorded by regional and the U.S. National Seismic Network, are known to have occurred within the Park's boundary during the past century. Thus, earthquakes within the Park have been mainly of M 4-5, and only five M 4+ events have occurred in the century, which relates to a return rate of about one M 4+ event every 20 years. The minimum threshold for surface faulting is probably an earthquake of about M 6—somewhere between about 30 (M 4) and 1000 times stronger (M 6) than those felt in the Park so far this century.

There have been substantially more large-size earthquakes around the margins of the Park than within it (fig. 7). Since 1968, three M 6.0-6.5 earthquakes occurred in a tight cluster located about 90 km northeast of the Cow Creek facility in Nevada and a fourth event, M 6.2, occurred in another cluster located about 105 km northeast of the facility in California. These four earthquakes were large enough to have been associated with localized ground ruptures, although none was reported. A third small cluster of M 5-6 earthquakes occurred about 85 km southwest of the facility. In summary, all of these M 6-6.5 earthquakes were far enough away that the associated ground motion was greatly attenuated (reduced) at the facility.

The relative quiescence of the Furnace Creek and Death Valley fault zones as illustrated in figure 7 suggests that they currently are aseismic, a behavior common for Basin and Range faults. For example, the Wasatch fault zone, a major Quaternary fault that extends about 385 km across northern and central Utah on the eastern margin of the Basin and Range, has a similar history of seismicity. No earthquakes larger than M 5 have been definitively located on the Wasatch fault zone (Arabasz and others, 1992). However, extensive paleoseismic studies (see Machette and others, 1992a) have indicated that the fault has been the source of repeated M 7+ earthquakes on the average of once every 400 years during the past 5,000-6,000 years (Machette and others, 1991, 1992b). Thus, aseismic behavior of large surface-rupturing fault zones, such as the Furnace Creek and Death Valley, should be viewed as an anomalous yet characteristic pattern that is typical of the longer (century to millennium scale) paleoseismic record.

SITE INVESTIGATIONS

Three sites at the Cow Creek facility were investigated by trenching: two using a backhoe (Salt Pan Vista and Ridgecrest) and a third by hand excavation (Old Ghost). The backhoe trenches were 1.5 to 3 m deep and penetrated alluvial deposits and the underlying lacustrine or basin-fill deposits. The Salt Pan Vista (SPV) and Ridgecrest (RC) trenches were excavated to search for evidence of Quaternary deformation. The hand-dug trench (OG) at the Old Ghost site was dug to expose faults northwest of the facility

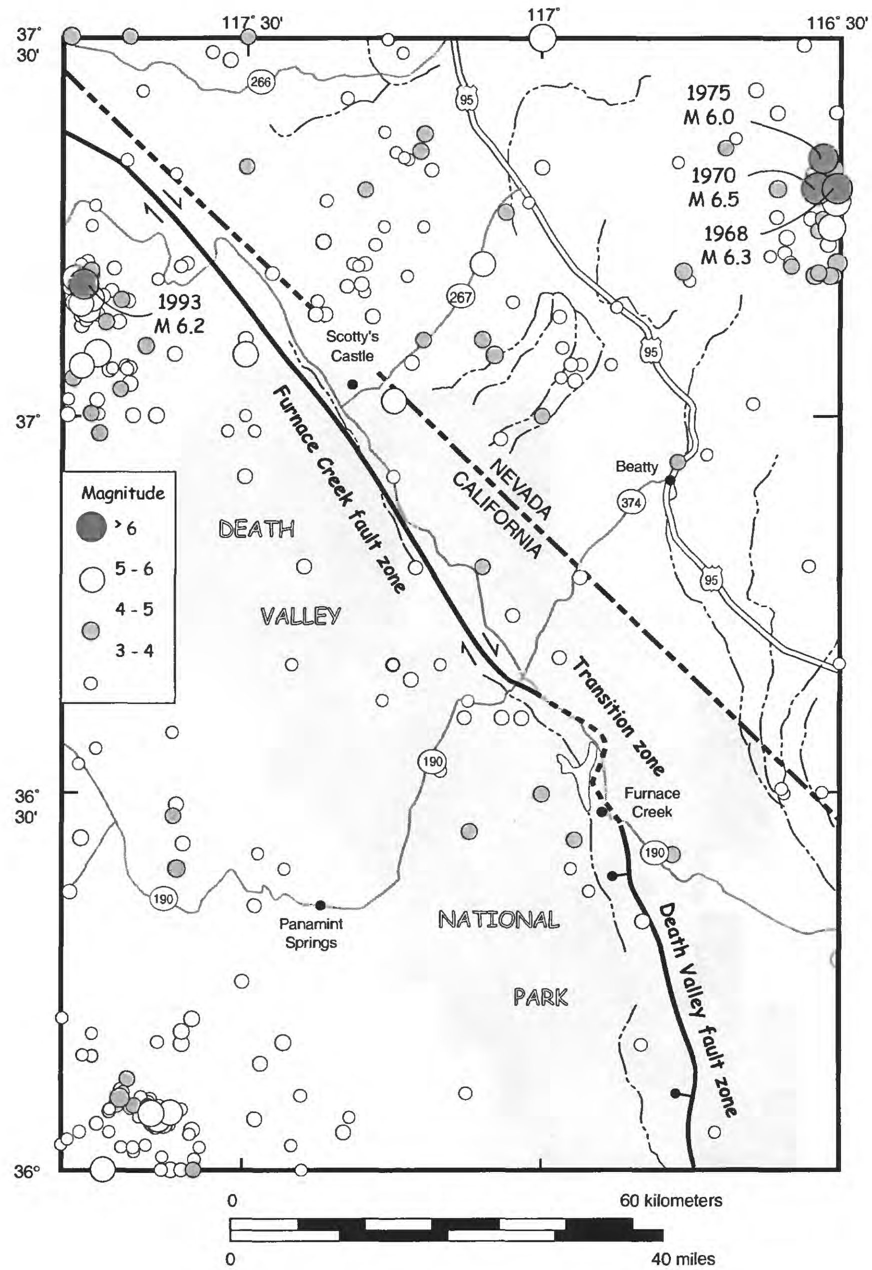

Figure 7. Locations of M >3 earthquakes since 1900 in the Death Valley region. Earthquake locations from search of U.S. Geological Survey WWW catalog (http://wwwneic.cr.usgs.gov). The four largest historic earthquakes (labeled by date) have occurred in areas of seismic clustering not associated with the Death Valley and Furnace Creek fault zones.

and determine the number of earthquakes that formed them. In addition, we hoped to date the faulting, but no suitable materials were found.

Salt Pan Vista Site and Trench

The Salt Pan Vista trench was excavated on a broad, alluvial fan that forms a piedmont west of the maintenance yard. Salt Pan Vista is an informal NPS name for this area in the lower portion of the Cow Creek facility. This area affords an excellent view (vista) of the salt pan that occupies Cottonball Basin, the northern of three subbasins within the main portion of Death Valley. The surface of the alluvial fan that forms Salt Pan Vista has been modified by 60 years of discontinuous use, most recently as the site of temporary (trailer) housing for NPS staff. These trailers were removed in 1997, and replaced with new permanent housing at the Park Village. At present, Salt Pan Vista is characterized by shallow cut and fills that provided level terraces for the trailer housing. Several generations of roads traverse the site, so locating the SPV trench (fig. 8) provided some challenges in terms of finding undisturbed materials. Our primary objective was to provide clearance for the proposed footprint of the new Museum Curator's Building; a secondary objective was to find the least disturbed site for excavation.

The SPV trench was located just north of the access road to the former trailers (see fig. 4, plate 1) and just west of the most western of the trailer sites where modification of the alluvial surface has occurred. It appears that there has been <0.5 m of disturbance here, but enough to disturb the existing desert pavement, varnish, and underlying soil. Small remnants of the original surface are preserved along the northern and western margins of the fan. The morphology, desert varnish and development of pavement on these surface remnants suggest that Salt Pan Vista is underlain by one of the Q3 subunits. Salt Pan Vista is not as old as the surface underlying the Natural Resources Management building (about 200 m north of the SPV trench), which we mapped as unit Q2c. Thus, Salt Pan Vista is mapped as the surface of unit Q3ab, an undivided unit equivalent to Klinger and Piety's (1996) units Q3a and Q3b. If this correlation is correct, unit Q3ab should have been deposited between 4 ka and 12 ka (in middle Holocene to latest Pleistocene time). If faults that cut unit Q3c (2-4 ka) of the Old Ghost alluvial-fan sequence extend south and east across Salt Pan Vista, they should be conspicuous in the SPV trench.

Figure 8. Photograph showing excavation of the Salt Pan Vista (SPV) trench. View to southwest with Cottonball Basin in the middle distance.

The SPV trench exposed three basic units: two upper units comprised of alluvial (sandy gravel) and debris-flow deposits (silty gravel), and an underlying lacustrine deposit (clayey to sandy silt) that is related to a moderately deep cycle of Lake Manly (see plate 2 for a complete description of units 1-3.)

The upper unit (1) is comprised of primarily fluvial sandy gravel but perhaps 25 percent is debris-flow gravel. By mapping overlapping layers and lenses of gravel that represent a single geologic unit (Q3c, plate 1), we were able to extend relatively continuous markers across the entire trench and show that no faults cut these units.

The age of unit 1 (undeformed) is unknown, but we suspect that it is latest Pleistocene to middle Holocene (see plates 1 and 2). As mentioned previously, remnants of its surface have moderately developed varnish on a discontinuous (75 percent) pavement of cobbles. This is similar to surface morphologies for units Q3b or Q3a. In addition, there is evidence of a weakly developed zonal soil beneath the least disturbed surfaces cut by the trench. The soil is characterized by 6- to 8-cm-thick silty Av (vesicular A) horizon over a weakly developed (stage I) Bk (calcareous B) horizon with minor gypsum. The underlying material (C horizon) is oxidized to about 50 cm depth, but there is little pedogenic carbonate development associated with the C horizon. This degree of soil development is consistent with unit Q3b of Klinger and Piety (1996) and suggests an early (?) Holocene age.

The upper part of unit 2 is characterized by a slightly oxidized sandy pebble gravel (fig. 9); the oxidation may represent a weakly developed soil that formed at the surface prior to burial by unit 1. If so, unit 2 may be equivalent to unit Q3a of Klinger and Piety (1996). The debris-flow layers in unit 2 contain abundant rip-up clasts derived from the Funeral Formation to the east. The upper contact is slightly wavy but sharp, indicating little or no erosion prior to burial by unit 1. Conversely, the basal contact of unit 2 is irregular and sharp, and represents an unconformity on unit 3.

As in unit 1, layers and lenses of gravel in unit 2 were mapped to provide lateral continuity (plate 2). They are primarily of debris-flow origin, are commonly discontinuous, and either fill channels or construct levees. Most of the unit is comprised of silty clast-supported gravel, but as much as 40 percent of the unit may be of fluvial origin. Over the relatively short distance we exposed unit 2, we found no evidence for faults. Thus faulting does not appear to have affected this site during or after deposition of Q3ab in the latest Pleistocene to early Holocene.

Unit 3 was exposed over a distance of about 4 m in the deepest part of the SPV trench (plate 2). No faults were found in this small exposure. Unit 3 is fine grained and gravel free, suggesting deposition in a lacustrine environment, although no shells or other megafossils were found to support this interpretation. The material is an unbedded clayey to sandy silt; it is relatively dense, compact, and light gray in color, but oxidizes to a light yellowish brown on exposure (all characteristics of lake deposits). Samples taken for paleomagnetic analysis (fig. 10) indicate that the silt is normally magnitized. These data are consistent with deposition during the predominantly normal magnetic direction of the Bruhnes magnetic chron (1n, 0-780 ka), but from this data we could not preclude that the lake deposits were deposited before 780 ka during one of many earlier normal magnetic chrons or subchrons (see Cande and Kent, 1992). If the sample was reversely magnitized, then there would be a high probability of it being older than 780 ka. Two samples of unit 3 were taken from the trench for thermoluminescence dating; sample SPV-2 (plate 2) was sent to Dr. Steven Forman at the University of Chicago for analysis. The preliminary age estimate (S. Forman, written commun., March 11, 1999) for the sample is >100 ka (Lab no. UIC-679), and the sample may be luminescence saturated (*i.e.*, reflect an infinite age). The elevation of the sample is about 40 m above Badwater (-282 ft) and about 30 m above Cottonball Basin, which is directly west of the site, the lake sediment is related to a moderately deep (>40 m) cycle of Lake Manly. From the viewpoint of preservation of the lake deposits at the land surface prior to burial by unit 2, we thought that it would have been deposited during a latest Pleistocene (10-130 ka) phase of Lake Manly. However considering the TL age estimate, it appears that unit 3 was deposited in a pre-100 ka lake phase, perhaps during oxygen-isotope stage IV (older than 130 ka). Further analyses are required to make a final age determination and to correlate the sediment to a specific stand of Lake Manly.

Figure 9. Photograph of units 2 and 3 on south wall of SPV trench. Tape measure is 2 m long. Upper end is at unit 1/2 contact. Fine-grained sediment is unit 3.

In conclusion, we found no evidence for surface deformation related to latest Pleistocene or Holocene faulting at the Salt Pan Vista site. Lineaments mapped to the southeast (plate 1) that trend northwest toward the site are probably not related to faulting, they may be of fluvial origin. Also, there is no evidence that the faults that displace the Old Ghost alluvial-fan complex (1 km to the north) extend to the south through Salt Pan Vista. It appears that the path of young faulting skirts the western margin of the Cow Creek facility; although we cannot preclude the possibility that older (pre-latest Pleistocene) faults exist beneath the facility in early basin-fill deposits. If such faults are present, there is no evidence preserved at the surface or in the SPV trench for young movement on them.

Figure 10. Close up photograph of contact between units 2 and 3 in the SPV trench, south wall. Unit 2 shows crude parallel bedding and unconformable relations with unit 3. TL sample SPV-2 is from hole near knife.

Ridgecrest Site and Trench

Ridgecrest is an informal term we use for a narrow ridge (and local drainage divide) between exposed basin-fill deposits on the eastern margin of the facility near the pool (fig. 11) and an incised stream channel south of the Cow Creek facility (fig. 4). Cutting along the north margin of the channel directly has exposed fine-grained deposits of the Funeral Formation (QTf, plate 1) from the cliff area (east of the pool) to the western side of the California DOT facility, about 300 m west of the Ridgecrest (RC) trench. The crest of the ridge lies about 12 m above the channel, and about 5 m below a remnant of older alluvium that we correlate with unit Q2b. On the basis of its topographic position, soils development, and stratigraphic relations with Salt Pan Vista to the west, we have mapped the alluvial units underling the Ridgecrest as unit Q2c. This stratigraphic call is discussed below.

Figure 11. View to south of pool (and palm trees) on eastern margin of the Cow Creek facility. The Ridgecrest (RC) site is just beyond the palms, in middle distance.

Our primary objective for excavating the RC site was to assess the validity of a SSE-trending fault zone that Brogan and others (1991) had mapped along the eastern margin of the Cow Creek facility. This assessment was needed to provide clearance for possible building sites and relocation of the maintenance yard to the eastern margin of the Cow Creek facility. As previously mentioned, the gross topography and geomorphology of this area suggested the presence of a graben controlled by a primary (normal) fault along the eastern slope of the facility and an antithetic (normal) fault on the western side of a graben, within which the pool is located. The Ridgecrest site is within the suspected position of this fault zone.

To minimize surface disturbance, the Ridgecrest trench was excavated along an old track (road) that had provided access to an abandoned water storage building above the pool. Although the road had not been used for years, its location was clearly seen from disturbance of the desert pavement. The Ridgecrest trench was placed adjacent to the eastern (faulted?) end of an isolated 5-m-high ridge of Q2b gravel in order to document assess the presence of the proposed antithetic graben-bounding fault. At first, the Ridgecrest area and it associated surface (to the west) appeared to be underlain by a thin lag of alluvium, but upon excavation we found eolian, debris-flow, and fluvial deposits.

The RC trench exposed four units (plate 2): an eolian(?) sand and silt unit (1), two intermediate units (2, upper; 3, middle) comprised of alluvial and debris-flow gravels, and a basal calcrete duripan (calcium-carbonate-enriched crust) that appears to be formed on older alluvium (unit 4, lower) and possibly early basin-fill deposits (QTf).

Surprisingly, the uppermost unit (1) in the RC trench consists of eolian deposits. The surface of the unit has an eroded desert pavement and thin (1-3 cm) Av horizon that we thought would be the upper part of an underlying fluvial unit. However, beneath this thin cap of gravel and silt we found a 40- to 75-cm-thick mantle of silt and fine sand, which because of its fine-grained character, lack of bedding and coarse layers, and position high in the landscape, is considered to be of eolian origin.

This eolian unit has a 20- to 50-cm-thick Btyk horizon (B horizon with clay accumulation as well as gypsum and calcium carbonate) that reflects relatively weak soil development. The Btyk horizon has prismatic structure (3-6 cm diameter peds) and is noticeably oxidized (7.5*YR* colors) compared to the underlying parent material (Cu horizon, 10*YR* colors), which is a slightly calcareous silty fine-grained sand. Two samples of the Cu horizon (unit 1) were taken from the trench for thermoluminescence dating; sample RC-2 (plate 2) was sent to Dr. Steven Forman at the University of Chicago for analysis. The preliminary age estimate (S. Forman, written commun., March 11, 1999) for the sample is 15±4 ka (Lab no. UIC-680). Further analyses are required to make a final age determination. The weak development of the Av/Btyk soil profile and probable latest Pleistocene age for unit 1, suggests that units 2 and 3 form a package that is roughly equivalent to Klinger and Piety's (1996) unit Q2c (12-70 ka, table 2). If these units were displaced, there would be evidence of faulting in late Pleistocene or possibly Holocene time.

Unit 2 is a massive, poorly stratified sandy gravel and gravelly sand. The upper part is matrix-supported, suggesting a debris-flow origin. The lower part consists of crudely to moderately bedded sandy gravel of fluvial origin. The upper and lower contacts of unit 2 and most of its bedding planes are subparallel to the land surface and undeformed by faults. Unit 3 is primarily fluvial gravel with a stone line at the top, suggesting that unit 2 is unconformable on unit 3. Unit 3 is generally finer grained than unit 2, has more laterally continuous beds and bedding planes, and is also parallel to the surface. Again, throughout the length of the trench, there is no evidence of deformation of unit 3. The basal contact of unit 3 is marked by a prominent stone line and downward coarsening of clasts (to pebble and medium cobble size), indicating an unconformity with unit 4.

The lowest unit (4) exposed in the Ridgecrest trench is a firmly cemented duricrust composed of calcrete. The calcrete is formed in a massive to poorly bedded pebble gravel to gravelly sand. The best stratification is in beds of pea-size gravel. From the limited exposures, we believe that unit 4 consists of mixed fluvial and debris-flow deposits that might be equivalent to the basal part of the gravel that forms the 5-m-high ridge to the south of the trench. We correlate this ridge-forming gravel with Klinger and Piety's (1996) unit Q2b (70-200 ka, see table 1), which is quite extensive in the northern part of the Old Ghost alluvial-fan complex. The calcrete in unit 4 may could be either pedogenic or a ground water in origin—not enough of the unit was exposed to choose between the two origin. We sampled a rather dense, laminated portion of the calcrete (RC-X, pl. 2) for uranium-series analysis, but the sample was unsuitable for dating owing to excessive thorium content (James Paces, USGS, oral commun., 1999).

In conclusion, we found no evidence for faulting of Pleistocene or Holocene deposits at the Ridgecrest site. Faults mapped by Brogan and others (1991) on the basis of aerial photo analysis are probably lineaments related to east-dipping bedding planes exposed in the fine-grained facies of the Furnace Creek Formation. Springs that seep from the eastern slope of the facility appear to be associated with coarse (sandy conglomerate) beds in the upper part of the predominately fine grained facies of the Furnace Creek Formation. The anomalous topography in this area is not related to faulting but instead to stream capture and erosion of non-resistant beds in the Funeral Formation. It appears that the path of young faulting skirts the western margin of the Cow Creek facility, although we cannot preclude the possibility that inactive, older (pre-late Pleistocene) faults exist in basin-fill deposits beneath the facility. If such faults are present, there is no evidence preserved at the surface or in the RC trench for young movement on them.

Old Ghost Site and Trench

Most of the previous geologic mapping in the area shows fault to the north Cow Creek facility, specifically on the Old Ghost alluvial-fan complex. Of the available mapping (see fig. 6), it's our view that Wright and Troxel's (1993) mapping is the most accurate in depicting the local fault pattern, but it is still incomplete and rather simplified owing to its intermediate scale (1:48,000). Our more detailed mapping (at 1:2,000 scale) of a small area north of the facility (fig. 12) reveals considerably more surface rupturing, rupturing in both north-south and northeast-southwest trends, and clear evidence for repeated movement on faults that displace pre-Holocene surfaces (units Q2c and Q2b) on the north margin of the Old Ghost alluvial-fan complex. Such improvements in fault locations are to be expected owing to the focused nature of our investigations and the large scale of our aerial photos and base map.

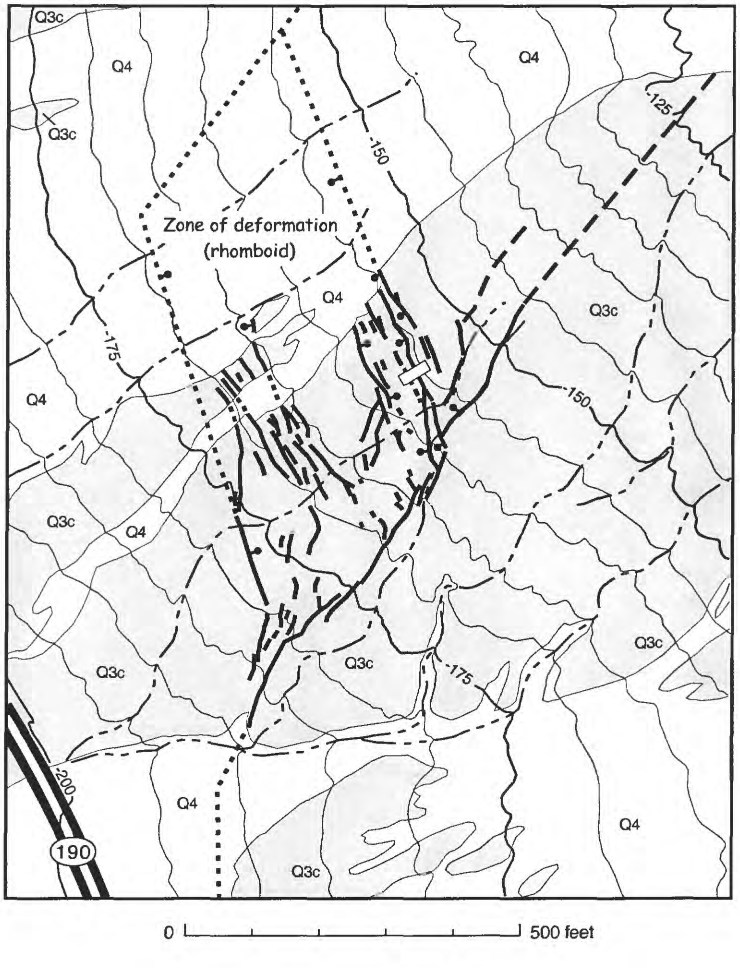

Figure 12. Detailed map of surficial geology and fault scarps on Old Ghost (OG) alluvial-fan complex. OG trench site shown by white box. Refer to text or plate 1 for explanation of units.

We were fascinated by the apparent youthfulness of the fault scarps that are preserved on parts of the Old Ghost alluvial-fan complex, particularly those surfaces that we mapped as being underlain by unit Q3c. We found no evidence for displacement of unit Q4 (or its subunits Q4a and Q4b), thus precluding extremely young offset (*i.e.*, historic to several hundred years). However, the steep slopes associated with the scarps on unit Q3c, which are typically <1 m high, suggests that they were formed in the late Holocene (see following discussion of age estimates for these scarps). In order to obtain additional stratigraphic evidence for their timing, in particular whether or not they formed in a single (?) faulting event, we hand-dug a small trench across the main fault scarp (fig. 13) at the Old Ghost site (fig. 4), where it is about 1.0 m high.

At this locality the fault zone is marked by a main scarp (80-100 cm high), an antithetic scarp (10-20 cm high), a shallow intervening graben, and numerous (10-20) filled fissures (5-10 cm wide). About 70 percent of the fissures are west of (below) the graben, about 25 are within the graben, and the remaining 5 percent are east of (above) the main fault. In the summer and fall of 1998, the fissures were easily recognized owing to profuse, but dead vegetation that grew preferentially in the fine-grained fill of fissures. The spring of 1998 was one of the wettest on records in Death Valley, with about 5.5 inches of precipitation (about 4 times normal) falling between July 1997 and June 1998 (the weather year). In drier years, these fissures would have been detectable, but not obvious.

The hand-dug trench was about 1 m deep and 2.8 m long (plate 2, Old Ghost trench). The upper end was at the crest of the scarp and it extended about 75 cm past the toe of the scarp, thereby guaranteeing exposure of all fault planes that are related to formation of the main fault scarp (fig. 14). Two basic types

Figure 13. Photograph of the trench at Old Ghost site. This hand dug excavation was about 1-1.5 m deep and 2.5 m long (plate 2). The Cow Creek facility is in the distance.

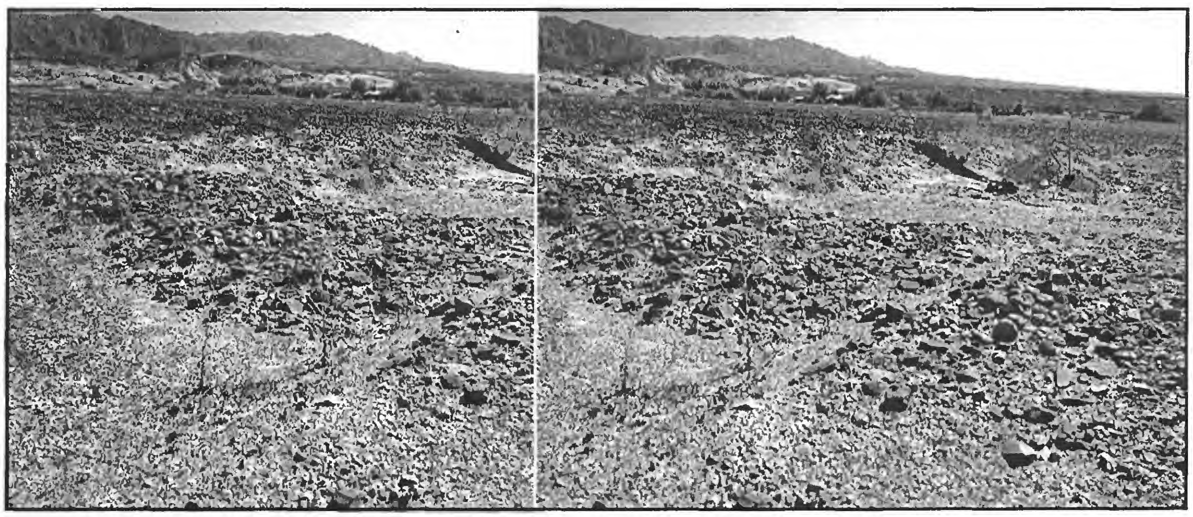

Figure 14. Stereo pair image of main (1-m-high) fault scarp at Old Ghost site. Trench is in middle ground; Cow Creek facility is in background. View is toward the south-southeast.

of deposits were exposed: post-faulting colluvial deposits (units 1 and 2) derived from the erosion of the fault scarp, and alluvial and debris-flow deposits (unit 3) that underlie and form the Q3c surface. These deposits are much alike in texture and lithology inasmuch as units 1 and 2 were derived from unit 3; however, both unit 1 and 2 are unbedded to poorly bedded, less cohesive, and somewhat finer grained than unit 3.

The post-faulting colluvial deposits in the trench were mapped as a debris facies (unit 2) resulting from gravitational collapse of the initial scarp, and a wash facies (unit 1) resulting from sheetwash and creep processes (see Wallace, 1977). Unit 1 is the more recent deposit, and it is still accumulating today. The older (lower) debris facies (unit 2) is an unsorted, massive sandy cobble gravel that fills two fissures and forms a colluvial wedge. The upper wash facies (unit 1) is an unsorted, poorly (crudely) bedded sandy pebble to cobble gravel that forms an elongate envelope (mantle) across the entire scarp; it pinches out at the crest and toe of the scarp. A weak 3- to 5-cm-thick Av (silt-rich) horizon has formed on the lower half of the wash facies, indicating rapid accumulation of eolian dust on the scarp slope. No faults or fractures were recognized within units 1 or 2, thus demonstrating that the entire colluvium (units 1 and 2) postdates the faulting.

The faulted alluvial and debris-flow deposits (unit 3) that we correlate with geologic map unit Q3c are crudely bedded, but the contacts between alternating fine- and coarse-grained layers are subparallel to the original ground surface and to one another. The surface of this unit is marked by a 5- to 6-cm-thick Av horizon that can be traced scarpward (east) to within about 20 cm of the western most of two major fault planes. The Av is barely noticeable near the fault (F2), owing to disturbance by adjacent faulting and scarp debris that collapsed on the former land surface. Nevertheless, the silty texture and vesicular character of the Av is a fairly characteristic marker of the pre-faulting land surface.

Four faults were mapped in the trench, but only the eastern (upslope) two have substantial displacement. Fault F1 (at 40-50 cm horizontal on plate 2) forms a 5- to 10-cm-wide fissure in the upper 50 cm of the trench and has enough displacement (vertical and possibly horizontal) that individual gravel layers cannot be matched across the fault. Likewise, fault F2 (at 75-80 cm horizontal) forms a single plane of displacement, the upper 25 cm of which has collapsed slightly to form a vertical free face that is buried by unit 1. As with F1, individual gravel layers cannot be matched across F2. The net offset on F1 and F2 is about 1 m as determined by the stratigraphic separation between the Av horizon on the scarp crest and on the downthrown block (at 90-100 cm horizontal). Fault F3 (at about 110 cm horizontal) appears to be a minor fault that accommodates warping of the buried Av horizon. Similarly, F4 (at 130-150 cm horizontal) is a small displacement reverse fault that caused minor (2-3 cm) folding of the buried Av horizon. In combination, F3 and F4 form a small horst (uplifted block) that is expressed as a fold in the Av horizon, but there is no net displacement of the Av horizon west of F2.

The presence of a single deposit of colluvium (units 1 and 2) is evidence that only one faulting event formed the scarp on unit Q3c. No deposits related to a second (older) faulting event were found within the upper meter of unit 3 (mapping unit Q3c), and the stratigraphic throw on the top of unit 3 is roughly equivalent to the scarp height (see Appendix B; plate 2, scarp profile CC-2B). Both of these observations demand a single faulting event that post-dates stabilization of unit Q3c and formation of the Av horizon, which is now buried. Klinger and Piety (1996) suggested that their unit Q3c was deposited between 200 and 2,000 yrs ago; we favor the older portion of this range (>1,000 yrs ago) owing to the burial of a well developed Av horizon, which must have required several hundred years (or more) to form after stabilization of the Q3c surface. Unfortunately, no datable charcoal or other organic matter was found within Q3c, and the Av horizon was too disrupted and thin for thermoluminescence dating.

Time of Faulting at the Old Ghost Site

There are several methods for determining the time at which a prehistoric faulting event occurred. The first is a stratigraphic approach that relies on age determinations from faulted and unfaulted deposits, thereby bracketing the probable time of a faulting event. If appropriate materials are present (charcoal, organic matter, volcanic ash, eolian sand or silt, etc.), this method may limit the time of faulting to as little as several hundred years (see for example, Machette and others, 1991). More commonly, however, the chronologic (age) data provide limits of a thousand years or more or are couched in stratigraphic terms, such as older than Q4b (200-2000 years) and younger than Q3c (2000-4000 years) (as in this case).

The second method for determining the timing of a prehistoric faulting event is a geomorphic approach that relies on a systematic degradation of fault-generated topography (fault scarps) through time. This approach is known as "morphometric analysis" and it relies on known calibration points from dated late Pleistocene and Holocene scarps (fault scarps, shorelines, and fluvial-terrace scarps) in the Basin and Range Province. The analysis yields an estimate of the time of scarp formation, rather than bracketing the time of the event. Used in conjunction with the stratigraphic approach, this technique yields a non-evasive, but powerful tool that is relatively easy to apply. Bucknam and Anderson (1979) were the first to champion this empirical approach to scarp morphology, building on fundamental observations that Bob Wallace made from fault scarps and lacustrine shorelines in northwestern Nevada (Wallace, 1977). Many investigators have used this approach in the past 20 years (see Machette, 1989, for a review), but a second more quantitative approach based on the diffusion equation has gained favor with modelers (Nash, 1980, 1987; Hanks, 1998). Analyses based on the empirical approach are presented briefly here in order to estimate the actual time of the youngest faulting event recorded at the Old Ghost site. The diffusion-equation approach can not be applied at this site owing to non-equilibrium conditions—scarps larger than 1 m on the Old Ghost alluvial-fan complex have maximum slope angles that are above the angle of repose (ca. 33°) for unconsolidated sand and gravels, and thus cannot be effectively modeled.

Scarp morphology data were collected from three topographic traverses (Appendix A, tables 1-3) perpendicular to the graben that is formed on unit Q3c of the Old Ghost (OG) fan (plate 1). The traverses crossed the antithetic and main faults, as well as a small displacement synthetic fault about 5 m above the main fault. These three profiles were designated as CC-1, CC-2, and CC-3 for the Cow Creek area (plate 2). From the long profiles, we identified five small scarps (3 main and 2 smaller sympathetic) for analysis. In addition, we collected a short profile (DV-3) across a small (<1-m-high) scarp formed on unit Q3 (undivided), and short (DV-2) and long (DV-1) profiles across a large (ca. 7-m-high) scarp on the much older Q2b. These latter profiles are located 245-440 m (about 800-1450 ft) north of the OG trench site, as shown on plate 1. Their main purpose was to document the amount of displacement recorded on units Q3 and Q2b, and to demonstrate that the path of young faulting extends north and northeast of the facility on the Old Ghost alluvial-fan complex.

The main parameters used for Bucknam and Anderson's (1979) empirical analysis of fault-scarp morphology are maximum scarp-slope angle (θ, in degrees) and scarp height (SH, in meters). In addition, diffusion-equation analysis of fault-scarp morphology uses the far-field (fan) slope angle (γ, in degrees) and surface offset (SO, in meters) associated with the scarp, so these values were also calculated. In the empirical analysis, morphometric data for scarps of the same age will plot as linear fields with values for maximum scarp-slope angle (y-axis) increasing as scarp height (x-axis) increases. Bucknam and Anderson (1979) showed that four sets of scarps (three fault scarps and the Bonneville shoreline) behave in a regular fashion, with the older scarps plotting to the right (more degraded) and younger scarps plotting to the left (less degraded, see fig. 5 of Bucknam and Anderson, 1979). Data for the Cow Creek scarps are shown in figure 15, along with calibration lines for the Fish Springs scarp (ca. 2 ka), the Drum Mountains scarp (7-10 ka), and the highest shoreline of Lake Bonneville (14.5 ka). (See Machette, 1989, for discussion of calibration lines and treatment of morphometric data.)

The apparent youthfulness of the Cow Creek scarps is obvious from the empirical data shown on figure 15. The Cow Creek scarps are clearly younger that those of the 2-ka Fish Springs fault, but the question is how much younger? The larger of the Cow Creek scarps (which are only about 1 m high) have maximum slope angles that are at or exceed the angle of repose (commonly taken as 33° for unconsolidated sandy gravel). No free faces (near vertical elements; Wallace, 1977) were observed along the scarps.

In order to estimate a time of formation for the Cow Creek scarps, we fit an exponential scale to the data shown in figure 15. We fixed the Fish Creek data at 2.0±0.5 ka, the Drum Mountains data at 8.5±1.5, and the Bonneville data at 14.5±0.5 ka; the assigned error limits reflect varying degrees of geologic uncertainty with the individual data sets. Figure 16 shows the results of our analysis. We plotted time of formation on the x-axis (log scale) and scarp height on the y-axis (log scale) for the three sets of calibration data using 12° and 26° maximum scarp-slope angles as control points (see fig. 15). We then fit lines through the data that minimized their variation (gray lines, fig. 16). Finally, for the Cow Creek scarps, we plotted the anticipated scarp heights at 12° and 26° maximum slope angles (data from fig. 15) on the appropriate lines of best fit. The predicted time of formation of the Cow Creek scarps is about 400±100 years. To this, you must add the amount of time required for the vertical scarps to collapse to the angle of repose, which we estimate to be 100-200 years for these size scarps in the Basin and Range Province. Thus, the time of most recent faulting on the Old Ghost fan complex is roughly estimated to be 500-600 years ago. This estimate reflects a minimum time because the empirical approach compares the Death Valley scarps with similar features formed in the northern Basin and Range Province, where the climate is cooler and considerably moister (8-12 inches of annual precipitation).

There are a multitude of problems associated with estimating the time of formation of these scarps, the most significant being the climatically controlled rates of diffusivity (scarp modification) in Death Valley's hyperarid late Holocene climate. These scarps most likely degraded slower than comparable-size scarps in the Basin and Range Province, so the empirical comparisons are likely flawed. Recent

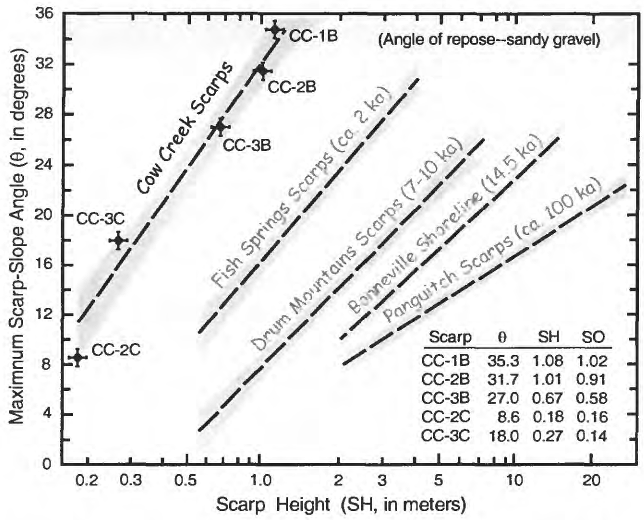

Figure 15. Morphometric data for fault scarps at the Old Ghost site. Abbreviations: θ, maximum scarp-slope angle; SH, scarp height (m); and SO, surface offset (m).

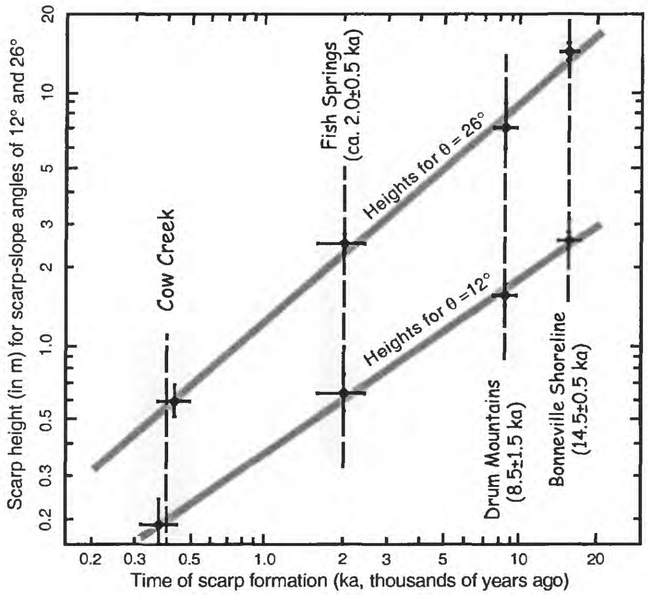

Figure 16. Data for estimating time of formation of Cow Creek scarp at Old Ghost site.

analysis of dated fault scarps in Israel's Dead Sea rift (Enzel and others, 1994; Enzel and others, 1996) yielded five diffusivity (k) rates, the most appropriate being a lower limit of about 0.4 m^2/ka (see Hanks, 1998, table 2.6.3-2 for a compilation of published diffusivity rates). Diffusivity rates for scarps in the Basin and Range Province are commonly around 1.1 m^2/ka, although Hanks (1998) cited a value of 0.64 m^2/ka for some small (1 m) shorelines of Lake Bonneville. For estimating the age of the Cow Creek fault scarps, we expect that they may have degraded at rates of 0.4-0.64 m^2/ka. The 0.64 m^2/ka rate would yield a minimum scarp age as stated above (400 years, plus 100-200 years for collapse), whereas the 0.4 m^2/ka rate would yield a maximum age about 1.6 times greater, or 740-840 years (400 x 1.6, plus 100-200 years). In summary, the morphometric analysis of the <1-m-high scarps on the Old Ghost alluvial-fan complex yields estimates of 500-600 years (minimum) to 740-840 years (maximum) for the time of the most recent faulting event.

PALEOSEISMOLOGY OF THE COW CREEK AREA

Despite the presence of surficial faulting on the Old Ghost alluvial-fan complex north of the Cow Creek facility, and lineaments seen on aerial photographs to the south of the facility, our exploratory trenches on Salt Pan Vista and the Ridgecrest failed to show any evidence of late Quaternary faulting. This result is not surprising in that no evidence of fault scarps were found within the facility during our brief reconnaissance, or from aerial photographs of the facility. However, owing to extensive modification of nearly all ground surfaces with the facility, we could not exclude the possibility of surface faulting prior to trenching.

We found that the proposed building sites, both at the Ridgecrest area south of the pool and on Salt Pan Vista, had no evidence of surface rupturing, and thus should not be precluded as construction sites. It appears that the path of active faulting, at least in the late Pleistocene (10-130 ka) and Holocene (0-10 ka) has been around the facility. Clear evidence of young faulting, perhaps only 500 to 840 years ago, exists at the Old Ghost site, just ½ km north of the facility. This faulting extends to the north, away from the facility, and to the southwest, west of the facility.

The detailed fault pattern on the Old Ghost fan is one of a series of right-stepping rhomboids (fig. 12), the east and west sides being defined by prominent normal faults, and the north and south sides being defined by subdued normal or strike-slip (?) faults. The latter faults are typically parallel or subparallel to drainage channels, making their recognition difficult. This pattern, although most apparent at the Old Ghost site, is also seen to the north on older deposits (unit Q2b, plate 1). The right-stepping pattern may allow motion to be transferred from basin-margin faults that are mapped along the western boundary of Park Village Ridge onto similar faults that extend south through and around the Mustard Hills and that ultimately connect to the Death Valley fault zone near Furnace Creek (see Hunt and Mabey, 1966, plate 1).

One might argue that future faulting could occur along the eastern margin of the facility, where others have drawn faults that bound the west margin of Park Village Ridge (see fig. 4). However, we believe that the most recent faulting in the area has been on the Old Ghost fan, and there is clear evidence of a long history of movement on faults in this same zone. For example, the small (<1-m-high) scarps at the Old Ghost site continue to the north, but are buried for several hundred meters (width) by late Holocene and historic alluvium (map unit Q4). From there north, the recent faulting is superposed on a 7-m-high scarp formed on unit Q2b, which according to Klinger and Piety (1996) is 70-200 k.y. (table 1). We can prove young movement on these large scarps because a young (Q3) fan inset within the older materials is offset about 50 cm (see profile DV-3, plate 2).

Farther north and east, there are several scarp-like features preserved on the Q2b surface (see profile DV-1, plate 2). These features have very gentle slopes (commonly <5°) and were of questionable origin when we first saw them in the field. We considered that they may be shoreline features of Lake Manly, similar to those seen to the east on aerial photographs (see also Hunt, 1975, fig. 5). However, these old, gentle scarps (see profile DV-1C, plate 2) have small ruptures across them as seen best under low-sun angle illumination (early morning at this site). The ruptures are typically only centimeters high, but they disrupt the well-developed desert pavement of unit Q2b. The preservation of such subtle features on the old scarps demands relatively young (*i.e.*, Holocene) movement.

What does the relationship between the small and large scarps on the Old Ghost fan complex say about the long-term history of faulting at the Cow Creek facility? First, they prove that faulting has continued to take a consistent path around the facility for at least 70 k.y. and perhaps a lot longer (*i.e.*, 200 k.y.). Secondly, if one considers the offset associated with the young scarps (CC-1 to -3 and DV-3) to be characteristic of surface rupturing events in this area, then the age and size of all the scarps can be used to make rough estimates of the repeat time (recurrence interval) for faulting and the rate of offset (slip rate) on the faults.

The large fault scarps (DV-1A and DV-2, plate 2) are clearly the result of multiple rupturing events. The scarps are about 7 m high, but the young rupture is located at the base of these scarps, suggesting that as much as half of the scarps may be buried by younger debris (Q3 and Q4). This inference is supported by the scarp profiles, which show a gentle west-dipping slope above the scarps, and a relatively flat, nearly horizontal (to backtilted) slope below the scarps. This relation is common in that the downdropped fault block becomes the preferred site for alluvial deposition, whereas the upper block becomes progressively entrenched as the local streams seek to maintain an equilibrium gradient across the faults.

Thus, for the purposes of discussion, let us consider several conditions. First, the 7-m scarp heights represent the minimum surface offset for unit Q2b. Second, the average prehistoric rupture along the fault had about ⅔ m of surface offset (see scarp profiles, plate 2). If these conditions (assumptions) are correct, then there must have been at least ten surface rupturing events (table 2) at a minimum. The age of unit Q2b is considered to be 70-200 ka by Klinger and Piety (1996), although this inference has not been substantiated by numerical dating. In the second case, if the 7-m scarp height represents just half of the surface offset (14 m) for unit Q2b, then there could have been about 20 surface rupturing events (or even more smaller events). These two cases, which are shown on table 2, describe the bounds on the probable amounts of offset and duration of faulting. Finally, the third (preferred) case results in the most geologically reasonable estimate for the likely long-term slip rate (0.1 mm/yr) and average recurrence intervals (6,700 years) for this particular fault zone.

Faulting at the Old Ghost site could be related to any of three scenarios: (1) sympathetic or actual movement related to faulting on the southern end of the Furnace Creek fault zone, (2) sympathetic or actual movement related to faulting on the northern end of the Death Valley fault zone, or (3) independent movement on faults within the transition zone unrelated to the larger fault zones. Deciding which of these three possibilities is correct or most likely is not possible without a better understanding of the chronology of young faulting on each of the major fault zones. At this time, little is known about the paleoseismicity of those faults adjacent to the Cow Creek facility. The timing of the most recent event on the Death Valley fault zone is unknown, but Klinger and Piety (1996) estimate an average recurrence interval (R.I.) of about 1-2 k.y. The estimated 500-840 year old movement at Cow Creek is

Table 2. Possible slip rates and recurrence intervals for fault scarps on unit Q2b, Old Ghost alluvial-fan complex.
[mid., preferred value in mid range]

Duration of faulting (yrs)	Offset (in mm)	Slip rate (in mm/yr)	† R.I. (in yrs) (1 m events)
1) Short, <70,000	<14,000 (max.)	0.2 (max.)	3,500 (min.)
2) Long, <200,000	>7,000 (min.)	0.035 (min.)	20,000 (max.)
3) Mid, *ca.* 100,000	10,000 (mid.)	0.10 (mid.)	6,700 (mid.)

† Note: Recurrence interval (R.I.) is based on net offset and inferred 2/3-m slip per event. If slip at this site averaged less (i.e., 1/2 m), then the number of events increases and recurrence interval decreases, proportionately.

probably not coincident with Klinger's (1999) most recent documented offset on the Furnace Creek fault zone, which is dated at about 300 yrs ago from a site just north of the Grapevine Ranger Station. However, the Cow Creek scarps could be related to run-over (distal rupture) from an earlier event on either adjacent fault zone. Conversely, we cannot discount the possibility that the Cow Creek scarps are related to earthquakes on faults of the transition zone that are largely independent of the Death Valley and Furnace Creek fault zones.

In addition to the possible interactions between the three fault zones discussed above, the Cow Creek facility is subject to strong ground motion from two or three different sources. Large earthquakes (M >6) associated with ground rupture on the Death Valley and Furnace Creek fault zones could cause strong ground motion at the site. In addition, movement on faults within the transition zone could also strong local ground motion because of the short distances to an epicenter. Thus, although surface rupturing at the site may only occur occasionally (*i.e.*, every 5-30 k.y.; table 2), ground shaking from the more active Death Valley and Furnace Creek fault zones constitute an additional hazard (see following discussion). Klinger and Piety (1999, field trip stop 1) estimated that the return period for ground-rupturing earthquakes on the Death Valley fault zone at Willow Creek to be between 1-2 k.y., and that the average vertical slip rate has been 1.3 to 2.6 mm/yr since the middle Holocene. Clearly the Death Valley fault zone is an order of magnitude more active than faults within the transition zone. If the same paleoseismic rates apply to the Furnace Creek fault zone (which has an even higher slip rate), then the Cow Creek facility is probably subjected to strong ground motion from adjacent faults on at least once every 500 to 1,000 years or less (*i.e.*, two major fault zones each having 1-2 k.y. return times).

SEISMIC HAZARDS AT THE COW CREEK FACILITY

The most recent USGS probabilistic seismic-hazards map of the region (see Frankel and others, 1997) shows that almost the entire length of Death Valley has a 10 percent probably of experiencing >0.4 g ground acceleration (to as much as 0.6 g) in the next 50 years (fig. 17). The input parameters for Frankel and others' (1997) map were based on preliminary paleoseismic data (as of 1995) for the Furnace Creek and Death Valley fault zones (Frankel and others, 1996). They used a return time (recurrence interval) of 260 yrs and 337 yrs for the Furnace Creek and Death Valley fault zones, respectively, based on slip rates of 5 and 4 mm/yr and maximum magnitude earthquakes of Mw 7.2 and Mw 6.9 (respectively).

These >0.4 to 0.6 g acceleration levels are comparable with that predicted for close-in sites along the San Andreas and other major strike-slip faults in southern California. Adobe buildings, such as the historic ones currently occupied by NPS employees at the Cow Creek facility, might sustain damage at as little as 0.2 g shaking, whereas buildings of wood- to steel-frame construction perform better, but still could suffer significant damage at the 0.5 g level.

The high levels of anticipated ground motion in Death Valley may seem anomalous considering that little significant seismic activity has occurred within the valley since 1900, with most local earthquakes being at M 3-4 or less. This low level of historical seismicity maybe a result of the short observation window for seismicity in Death Valley (ca. 100 years) and the aseismic nature of some major faults in the Basin and Range Province. Similar problems exist along the Wasatch fault zone in Utah—the modern level of seismicity along the fault is relatively low, but geologic studies indicate that a major (M >7) surface-rupturing earthquake should occur about once every 400 years on average. Thus, the recent seismicity of the region is likely a poor predictor of future, if rare, surface faulting earthquakes on the Death Valley and Furnace Creek fault zones and the intervening transition zone.

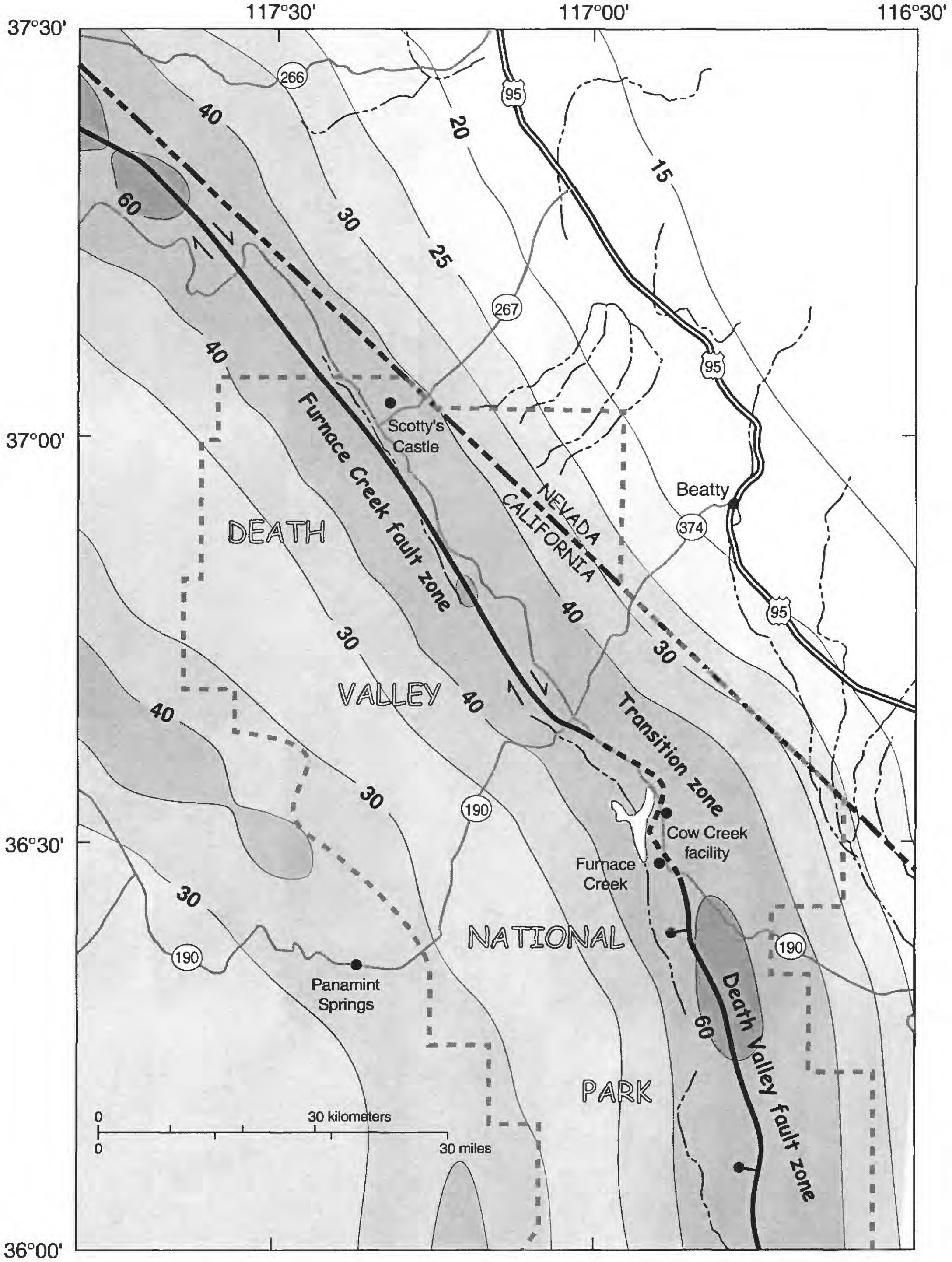

Figure 17. Probabilistic seismic-hazard map for Death Valley National Park and surrounding area. The map shows contours of percent gravitational acceleration (g) that have a 10 percent chance of being exceeded during the next 50 years (*i.e.*, roughly a 100 percent chance of being exceeded during the next 500 years). Data from maps of Frankel and others (1996), contours generated by custom mapping software available at USGS web site (see http://geohazards.cr.usgs.gov/eq/).

RECOMMENDATIONS

As a result of our geologic and seismic-hazard investigations in the Cow Creek area, we have the following comments and recommendations about new building sites and the older building inventory.

(1) We found no evidence of surface ruptures through the Cow Creek facility (historical district). However, young fault movement may be difficult to identify in areas that lack a cover of surficial geologic materials (they typically preserve fault scarps). Basin-fill deposits are mainly exposed in the upper part of facility and most of the surface there has been modified by construction since 1934, so we can not preclude future surface rupturing at the site. Surficial faulting on the nearby Old Ghost site probably occurred between 500 and 840 yrs ago, during the late Holocene.

(2) Since young faulting commonly reactivates existing structures, we believe that future faulting in the Cow Creek area will continue to take a path around the western margin of the facility, as the most recent ruptures did. Thus, we do not expect that surface rupturing would occur at or near the Salt Pan Vista site or along the eastern margin of the facility.

(3) Of the two building sites investigated, Salt Pan Vista is the superior building site. This area is underlain by poorly to moderately indurated sandy gravels that are about 3 m thick. Such material would form a natural, highly compacted pad for buildings or the maintenance facility. The Ridgecrest site, as well as sites both west and south of the pool, may have thin alluvial cover materials, but they basically are underlain by soft sediments of the Funeral Formation. These materials have relatively low density (especially when weathered within about 1 m of the ground surface), often retain high moisture content, and may have moderate to high shrink-swell potential. The above factors may present special engineering challenges if such sites are chosen for construction.

(4) Any new buildings in this area should be designed for ground-motion values as defined in the most recent seismic-hazard guidelines and maps. In the past, relative levels of seismic hazards were defined by zones (increasing from I to IV), which are no longer applicable to federally operated, federally funded, or federally insured structures. Since about 1980, the federal building code maps have been based on two ground-motion contour maps—one relating to long-period (1 sec) ground motions, one to short-period (0.2 sec). Fault ruptures, which were the main focus of our investigations, are an important issue in evaluating seismic hazards in earthquake-prone areas. Although we did not find fault ruptures to be a likely hazard at the site, seismic shaking is be a major concern. Owing to the high activity rates for the Furnace Creek and Death Valley fault zones, the possible levels of ground shaking at the Cow Creek facility and the intervening transition zone would exceed 0.4 g and may approach 0.6 g (60 percent of gravity) as shown on the latest NEHRP probabilistic ground-motion maps (Frankel and others, 1997). The code applicable for Federal sites is the FEMA National Earthquake Hazard Reduction Program (NEHRP) standards "Recommended provisions for seismic construction for new buildings." Maps and provisions can be obtained at BSSC, 1201 L. St. NW, Washington DC 20005 or (202) 289-7800.

(5) Older buildings, especially those of adobe construction within the Cow Creek historic district are especially vulnerable to these levels of ground shaking and may sustain substantial damage at or above 0.2 g. In particular, the Resource Management Center contains a half-dozen NPS staff on a daily basis and the Auto Shop has a similar number of employees in it, although egress from the shop would be easier during a large earthquake.

(6) The potential exists for strong ground shaking at other populated sites within the valley. Recent studies of ground shaking in thick sediment-filled valleys (such as Los Angeles, San Francisco, and Mexico City) suggest that ground motion at certain frequencies may be amplified owing to the thickness and nature of the sedimentary fill. One should note that the predicted ground motions in Death Valley (fig. 17) reflect bedrock sites, not alluvial sites. Inasmuch as the Cow Creek and Furnace Creek areas are within the sediment-filled portion of the valley, the predicted ground motions might be large than expected (*i.e.*, strong amplification) or somewhat less than predicted (*i.e.*, some attenuation). The affects of site amplification can only demonstrated by recording strong ground motion at each site. Nevertheless, every effort should be made to upgrade the existing building inventory to the safest level possible.

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Appendix A, Table 1. Surveying data for scarp profile CC-1							
Slope length, in meters	First rod reading	Second rod reading	Elev. change, in meters	Arcsin of slope, in radians	Slope angle, in degrees	Horizontal distance, in meters	Elevation, in meters
1.00	2.430	2.350	0.080	0.080	4.589	0.997	0.08
1.00	2.350	2.305	0.045	0.045	2.579	1.996	0.13
1.00	2.305	2.280	0.025	0.025	1.433	2.995	0.15
1.00	2.280	2.220	0.060	0.060	3.440	3.994	0.21
1.00	2.220	2.130	0.090	0.090	5.164	4.990	0.30
1.00	2.130	2.075	0.055	0.055	3.153	5.988	0.36
1.00	2.075	2.070	0.005	0.005	0.286	6.988	0.36
0.50	2.070	2.070	0.000	0.000	0.000	7.488	0.36
0.50	2.070	2.050	0.020	0.040	2.292	7.988	0.38
0.50	2.050	2.020	0.030	0.060	3.440	8.487	0.41
0.30	2.020	2.000	0.020	0.067	3.823	8.786	0.43
0.20	2.000	2.005	-0.005	-0.025	-1.433	8.986	0.43
0.20	2.005	2.040	-0.035	-0.176	-10.079	9.183	0.39
0.20	2.040	2.090	-0.050	-0.253	-14.478	9.377	0.34
0.20	2.090	2.110	-0.020	-0.100	-5.739	9.576	0.32
0.20	2.110	2.130	-0.020	-0.100	-5.739	9.775	0.30
0.20	2.130	2.140	-0.010	-0.050	-2.866	9.974	0.29
0.50	2.140	2.150	-0.010	-0.020	-1.146	10.474	0.28
0.50	2.150	2.155	-0.005	-0.010	-0.573	10.974	0.28
0.40	2.155	2.155	0.000	0.000	0.000	11.374	0.28
0.30	2.155	2.105	0.050	0.167	9.594	11.670	0.33
0.30	2.105	2.090	0.015	0.050	2.866	11.970	0.34
0.50	2.090	2.080	0.010	0.020	1.146	12.470	0.35
0.50	2.080	2.090	-0.010	-0.020	-1.146	12.969	0.34
0.50	2.090	2.140	-0.050	-0.100	-5.739	13.467	0.29
0.50	2.140	2.170	-0.030	-0.060	-3.440	13.966	0.26
0.50	2.170	2.170	0.000	0.000	0.000	14.466	0.26
0.50	2.170	2.145	0.025	0.050	2.866	14.965	0.29
1.00	2.145	2.010	0.135	0.135	7.759	15.956	0.42
1.00	2.010	1.990	0.020	0.020	1.146	16.956	0.44
1.00	1.990	1.980	0.010	0.010	0.573	17.956	0.45
1.00	1.980	1.920	0.060	0.060	3.440	18.954	0.51
1.00	1.920	1.890	0.030	0.030	1.719	19.954	0.54
1.00	1.890	1.810	0.080	0.080	4.589	20.951	0.62
1.00	1.810	1.730	0.080	0.080	4.589	21.947	0.70

Appendix A, Table 1—Continued. Surveying data for scarp profile CC-1							
Slope length, in meters	First rod reading	Second rod reading	Elev. change, in meters	Arcsin of slope, in radians	Angle, in degrees	Distance, in meters	Elevation, in meters
1.00	1.730	1.770	-0.040	-0.040	-2.292	22.947	0.66
1.00	1.770	1.820	-0.050	-0.050	-2.866	23.945	0.61
1.00	1.820	1.780	0.040	0.040	2.292	24.945	0.65
0.50	1.780	1.760	0.020	0.040	2.292	25.444	0.67
0.50	1.760	1.700	0.060	0.120	6.892	25.941	0.73
0.50	1.700	1.600	0.100	0.201	11.537	26.430	0.83
0.50	1.600	1.550	0.050	0.100	5.739	26.928	0.88
0.50	1.550	1.500	0.050	0.100	5.739	27.425	0.93
0.50	1.500	1.370	0.130	0.263	15.070	27.908	1.06
0.40	1.370	1.270	0.100	0.253	14.478	28.295	1.16
0.20	1.270	1.240	0.030	0.151	8.627	28.493	1.19
0.20	1.240	1.130	0.110	0.582	33.367	28.660	1.30
0.20	1.130	1.000	0.130	0.708	40.542	28.812	1.43
0.20	1.000	0.900	0.100	0.524	30.000	28.985	1.53
0.20	0.900	0.780	0.120	0.644	36.870	29.145	1.65
0.20	0.780	0.690	0.090	0.467	26.744	29.324	1.74
0.20	0.690	0.650	0.040	0.201	11.537	29.520	1.78
0.20	0.650	0.630	0.020	0.100	5.739	29.719	1.80
0.50	0.630	0.660	-0.030	-0.060	-3.440	30.218	1.77
0.50	0.660	0.620	0.040	0.080	4.589	30.717	1.81
0.50	0.620	0.620	0.000	0.000	0.000	31.217	1.81
0.50	0.620	0.550	0.070	0.140	8.048	31.712	1.88
0.50	0.550	0.490	0.060	0.120	6.892	32.208	1.94
0.50	0.490	0.510	-0.020	-0.040	-2.292	32.708	1.92
1.00	0.510	0.540	-0.030	-0.030	-1.719	33.707	1.89
1.00	0.540	0.440	0.100	0.100	5.739	34.702	1.99
1.00	0.440	0.410	0.030	0.030	1.719	35.702	2.02
1.00	0.410	0.370	0.040	0.040	2.292	36.701	2.06
1.00	0.370	0.260	0.110	0.110	6.315	37.695	2.17
1.00	0.260	0.110	0.150	0.151	8.627	38.683	2.32
1.00	0.110	0.010	0.100	0.100	5.739	39.678	2.42
1.00	0.010	-0.070	0.080	0.080	4.589	40.675	2.50

Appendix A, Table 2. Surveying data for scarp profile CC-2							
Slope length, in meters	First rod reading	Second rod reading	Elevation change, in meters	Arcsin of slope, in radians	Slope angle, in degrees	Distance, in meters	Elevation, in meters
1.00	3.39	3.36	0.03	0.030	1.719	1.000	0.03
1.00	3.36	3.34	0.02	0.020	1.146	1.999	0.05
1.00	3.34	3.33	0.01	0.010	0.573	2.999	0.06
1.00	3.33	3.32	0.01	0.010	0.573	3.999	0.07
1.00	3.32	3.30	0.02	0.020	1.146	4.999	0.09
1.00	3.30	3.21	0.09	0.090	5.164	5.995	0.18
1.00	3.21	3.18	0.03	0.030	1.719	6.995	0.21
1.00	3.18	3.16	0.02	0.020	1.146	7.994	0.23
0.20	3.16	3.14	0.02	0.100	5.739	8.193	0.25
0.20	3.14	3.15	-0.01	-0.050	-2.866	8.393	0.24
0.20	3.15	3.15	0.00	0.000	0.000	8.593	0.24
0.20	3.15	3.18	-0.03	-0.151	-8.627	8.791	0.21
0.10	3.18	3.22	-0.04	-0.412	-23.578	8.882	0.17
0.10	3.22	3.24	-0.02	-0.201	-11.537	8.980	0.15
0.10	3.24	3.26	-0.02	-0.201	-11.537	9.078	0.13
0.10	3.26	3.27	-0.01	-0.100	-5.739	9.178	0.12
0.10	3.27	3.29	-0.02	-0.201	-11.537	9.276	0.10
0.10	3.29	3.30	-0.01	-0.100	-5.739	9.375	0.09
0.20	3.30	3.30	0.00	0.000	0.000	9.575	0.09
0.20	3.30	3.31	-0.01	-0.050	-2.866	9.775	0.08
0.20	3.31	3.31	0.00	0.000	0.000	9.975	0.08
0.50	3.31	3.32	-0.01	-0.020	-1.146	10.475	0.07
0.50	3.32	3.30	0.02	0.040	2.292	10.975	0.09
1.00	3.30	3.25	0.05	0.050	2.866	11.973	0.14
1.00	3.25	3.16	0.09	0.090	5.164	12.969	0.23
1.00	3.16	3.07	0.09	0.090	5.164	13.965	0.32
1.00	3.07	3.06	0.01	0.010	0.573	14.965	0.33
1.00	3.06	3.09	-0.03	-0.030	-1.719	15.965	0.30
1.00	3.09	3.06	0.03	0.030	1.719	16.964	0.33
1.00	3.06	2.98	0.08	0.080	4.589	17.961	0.41
1.00	2.98	2.96	0.02	0.020	1.146	18.961	0.43
1.00	2.96	2.97	-0.01	-0.010	-0.573	19.961	0.42
1.00	2.97	2.95	0.02	0.020	1.146	20.961	0.44
1.00	2.95	2.90	0.05	0.050	2.866	21.959	0.49
1.00	2.90	2.85	0.05	0.050	2.866	22.958	0.54
1.00	2.85	2.83	0.02	0.020	1.146	23.958	0.56
1.00	2.83	2.76	0.07	0.070	4.014	24.956	0.63
0.50	2.76	2.74	0.02	0.040	2.292	25.455	0.65
0.50	2.74	2.69	0.05	0.100	5.739	25.953	0.70

Appendix A, Table 2—Continued. Surveying data for scarp profile CC-2							
Slope length, in meters	First rod reading	Second rod reading	Elevation change, in meters	Arcsin of slope, in radians	Slope angle, in degrees	Distance, in meters	Elevation, in meters
0.50	2.69	2.68	0.01	0.020	1.146	26.453	0.71
0.30	2.68	2.66	0.02	0.067	3.823	26.752	0.73
0.20	2.66	2.64	0.02	0.100	5.739	26.951	0.75
0.50	2.64	2.60	0.04	0.080	4.589	27.449	0.79
0.50	2.60	2.52	0.08	0.161	9.207	27.943	0.87
0.50	2.52	2.39	0.13	0.263	15.070	28.426	1.00
0.30	2.39	2.26	0.13	0.448	25.679	28.696	1.13
0.20	2.26	2.17	0.09	0.467	26.744	28.875	1.22
0.20	2.17	2.08	0.09	0.467	26.744	29.053	1.31
0.20	2.08	1.99	0.09	0.467	26.744	29.232	1.40
0.20	1.99	1.89	0.10	0.524	30.000	29.405	1.50
0.20	1.89	1.78	0.11	0.582	33.367	29.572	1.61
0.20	1.78	1.73	0.05	0.253	14.478	29.766	1.66
0.50	1.73	1.71	0.02	0.040	2.292	30.265	1.68
0.50	1.71	1.66	0.05	0.100	5.739	30.763	1.73
0.50	1.66	1.67	-0.01	-0.020	-1.146	31.263	1.72
0.50	1.67	1.69	-0.02	-0.040	-2.292	31.762	1.70
0.50	1.69	1.70	-0.01	-0.020	-1.146	32.262	1.69
0.50	1.70	1.67	0.03	0.060	3.440	32.761	1.72
0.50	1.67	1.60	0.07	0.140	8.048	33.256	1.79
0.50	1.60	1.52	0.08	0.161	9.207	33.750	1.87
0.50	1.52	1.53	-0.01	-0.020	-1.146	34.250	1.86
0.50	1.53	1.51	0.02	0.040	2.292	34.749	1.88
1.00	1.51	1.43	0.08	0.080	4.589	35.746	1.96
1.00	1.43	1.39	0.04	0.040	2.292	36.745	2.00
1.00	1.39	1.34	0.05	0.050	2.866	37.744	2.05
1.00	1.34	1.30	0.04	0.040	2.292	38.743	2.09
1.00	1.30	1.20	0.10	0.100	5.739	39.738	2.19
1.00	1.20	1.08	0.12	0.120	6.892	40.731	2.31
1.00	1.08	1.09	-0.01	-0.010	-0.573	41.731	2.30
1.00	1.09	1.11	-0.02	-0.020	-1.146	42.731	2.28
1.00	1.11	1.16	-0.05	-0.050	-2.866	43.730	2.23
1.00	1.16	1.14	0.02	0.020	1.146	44.729	2.25
1.00	1.14	1.01	0.13	0.130	7.470	45.721	2.38
1.00	1.01	0.98	0.03	0.030	1.719	46.720	2.41
1.00	0.98	0.94	0.04	0.040	2.292	47.720	2.45
1.00	0.94	0.90	0.04	0.040	2.292	48.719	2.49
1.00	0.90	0.84	0.06	0.060	3.440	49.717	2.55

Appendix A, Table 3. Surveying data for scarp profile CC-3							
Slope Length in meters	First rod reading	Second rod reading	Elevation change (in meters)	Arcsin A (in radians)	Angle in degrees	Distance in meters	Elevation in meters
1.00	3.37	3.39	-0.02	-0.020	-1.146	1.000	-0.02
1.00	3.39	3.36	0.03	0.030	1.719	1.999	0.01
1.00	3.36	3.27	0.09	0.090	5.164	2.995	0.10
1.00	3.27	3.20	0.07	0.070	4.014	3.993	0.17
1.00	3.20	3.17	0.03	0.030	1.719	4.992	0.20
1.00	3.17	3.12	0.05	0.050	2.866	5.991	0.25
1.00	3.12	2.94	0.18	0.181	10.370	6.975	0.43
0.20	2.94	2.95	-0.01	-0.050	-2.866	7.175	0.42
0.20	2.95	2.97	-0.02	-0.100	-5.739	7.374	0.40
0.20	2.97	3.00	-0.03	-0.151	-8.627	7.571	0.37
0.20	3.00	3.02	-0.02	-0.100	-5.739	7.770	0.35
0.20	3.02	3.08	-0.06	-0.305	-17.458	7.961	0.29
0.20	3.08	3.10	-0.02	-0.100	-5.739	8.160	0.27
0.20	3.10	3.10	0.00	0.000	0.000	8.360	0.27
0.20	3.10	3.09	0.01	0.050	2.866	8.560	0.28
0.20	3.09	3.05	0.04	0.201	11.537	8.756	0.32
0.20	3.05	3.02	0.03	0.151	8.627	8.954	0.35
0.50	3.02	3.02	0.00	0.000	0.000	9.454	0.35
0.50	3.02	2.99	0.03	0.060	3.440	9.953	0.38
1.00	2.99	2.88	0.11	0.110	6.315	10.947	0.49
1.00	2.88	2.83	0.05	0.050	2.866	11.945	0.54
1.00	2.83	2.80	0.03	0.030	1.719	12.945	0.57
1.00	2.80	2.73	0.07	0.070	4.014	13.942	0.64
1.00	2.73	2.69	0.04	0.040	2.292	14.942	0.68
1.00	2.69	2.62	0.07	0.070	4.014	15.939	0.75
1.00	2.62	2.61	0.01	0.010	0.573	16.939	0.76
1.00	2.61	2.59	0.02	0.020	1.146	17.939	0.78
1.00	2.59	2.51	0.08	0.080	4.589	18.936	0.86
1.00	2.51	2.50	0.01	0.010	0.573	19.936	0.87
1.00	2.50	2.45	0.05	0.050	2.866	20.934	0.92
1.00	2.45	2.39	0.06	0.060	3.440	21.933	0.98
1.00	2.39	2.34	0.05	0.050	2.866	22.931	1.03
1.00	2.34	2.29	0.05	0.050	2.866	23.930	1.08
0.50	2.29	2.28	0.01	0.020	1.146	24.430	1.09
0.50	2.28	2.24	0.04	0.080	4.589	24.928	1.13
0.50	2.24	2.16	0.08	0.161	9.207	25.422	1.21
0.50	2.16	2.07	0.09	0.181	10.370	25.914	1.30
0.20	2.07	2.07	0.00	0.000	0.000	26.114	1.30
0.20	2.07	2.03	0.04	0.201	11.537	26.310	1.34
0.20	2.03	1.98	0.05	0.253	14.478	26.503	1.39

Appendix A, Table 3—Continued. Surveying data for scarp profile CC-3							
Slope Length in meters	First rod reading	Second rod reading	Elevation change (in meters)	Arcsin A (in radians)	Angle in degrees	Distance in meters	Elevation in meters
0.20	1.98	1.90	0.08	0.412	23.578	26.687	1.47
0.20	1.90	1.83	0.07	0.358	20.487	26.874	1.54
0.20	1.83	1.71	0.12	0.644	36.870	27.034	1.66
0.20	1.71	1.63	0.08	0.412	23.578	27.217	1.74
0.20	1.63	1.57	0.06	0.305	17.458	27.408	1.80
0.20	1.57	1.55	0.02	0.100	5.739	27.607	1.82
0.20	1.55	1.52	0.03	0.151	8.627	27.805	1.85
0.50	1.52	1.49	0.03	0.060	3.440	28.304	1.88
0.50	1.49	1.45	0.04	0.080	4.589	28.802	1.92
1.00	1.45	1.41	0.04	0.040	2.292	29.802	1.96
1.00	1.41	1.35	0.06	0.060	3.440	30.800	2.02
0.50	1.35	1.28	0.07	0.140	8.048	31.295	2.09
0.50	1.28	1.25	0.03	0.060	3.440	31.794	2.12
0.50	1.25	1.21	0.04	0.080	4.589	32.292	2.16
0.50	1.21	1.18	0.03	0.060	3.440	32.791	2.19
0.50	1.18	1.16	0.02	0.040	2.292	33.291	2.21
0.30	1.16	1.10	0.06	0.201	11.537	33.585	2.27
0.20	1.10	1.11	-0.01	-0.050	-2.866	33.785	2.26
0.20	1.11	1.04	0.07	0.358	20.487	33.972	2.33
0.30	1.04	0.96	0.08	0.270	15.466	34.261	2.41
0.30	0.96	0.92	0.04	0.134	7.662	34.559	2.45
0.20	0.92	0.93	-0.01	-0.050	-2.866	34.758	2.44
0.50	0.93	0.87	0.06	0.120	6.892	35.255	2.50
0.50	0.87	0.85	0.02	0.040	2.292	35.754	2.52
1.00	0.85	0.80	0.05	0.050	2.866	36.753	2.57
1.00	0.80	0.75	0.05	0.050	2.866	37.752	2.62
1.00	0.75	0.69	0.06	0.060	3.440	38.750	2.68
1.00	0.69	0.60	0.09	0.090	5.164	39.746	2.77
1.00	0.60	0.54	0.06	0.060	3.440	40.744	2.83
1.00	0.54	0.50	0.04	0.040	2.292	41.743	2.87
1.00	0.50	0.47	0.03	0.030	1.719	42.743	2.90
1.00	0.47	0.42	0.050	0.050	2.866	43.742	2.95
1.00	0.42	0.37	0.05	0.050	2.866	44.740	3.00
1.00	0.37	0.30	0.07	0.070	4.014	45.738	3.07
1.00	0.30	0.25	0.05	0.050	2.866	46.737	3.12
1.00	0.25	0.20	0.05	0.050	2.866	47.735	3.17
1.00	0.20	0.05	0.15	0.151	8.627	48.724	3.32
1.00	0.05	0.00	0.05	0.050	2.866	49.723	3.37

DATA ENTRY IN SHADED AREA			Date (mo/day/yr):	10/10/98	Created in MS Excel 5.0c on 6/23/97 by Barton Kiburz				
Site or Area		Old Ghost site	Profile azimuth:	068°	Endpoint		Modf'd 11/06/98 by M. Machette		
Fault Name	Cow Creek		Scarp aspect	SW	Coordinates		and R.C. Bucknam, USGS		
Profile/Sta. No.	CC-1		Scarp trend:	154°	Cumulative		*CALCULATIONS (text hidden)*		
Seg.	Dist. (m)	Angle (Deg)	Air Photo No.:	14-9	X	Y		XLR=	0.0
Enter field data here			Pick these points		0	0	Lower	YLR=	0.0
1	1	1.719	1st lower point	0	0.99955	0.029998		XLF=	8.2
2	1	1.146	2nd lower point	9	1.99935	0.049998		YLF=	0.3
3	1	0.573	1st scarp point	44	2.9993	0.059998			
4	1	0.573	2nd scarp point	52	3.99925	0.069999		XSR=	27.9
5	1	1.146	1st upper point	54	4.99905	0.089999	Scarp	YSR=	0.9
6	1	5.164	2nd upper point	77	5.994991	0.180006		XSF=	29.8
7	1	1.719	Scarp Height (SH)	0.84	6.994541	0.210004		YSF=	1.7
8	1	1.146	Surf. Offset (SO)	0.77	7.994341	0.230004			
9	0.2	5.739	Pick these points		8.193339	0.250003		XUR=	30.8
10	0.2	-2.866	Max scarp (θs°)		8.393088	0.240003	Upper	YUR=	1.7
11	0.2	0	Fan slope (θf°)		8.593088	0.240003		XUF=	49.7
12	0.2	-8.627			8.790826	0.210003		YUF=	2.6
13	0.1	-23.578			8.882477	0.170003			
14	0.1	-11.537			8.980457	0.150003		ML=	0.0
15	0.1	-11.537			9.078436	0.130003		MS=	0.4
16	0.1	-5.739			9.177935	0.120003		MU=	0.0
17	0.1	-11.537			9.275915	0.100003		BL=	0.0
18	0.1	-5.739			9.375413	0.090004		BS=	-11.2
19	0.2	0	***Click on chart and pull***		9.575413	0.090004		BU=	0.4
20	0.2	-2.866	***handles to enlarge***		9.775163	0.080004		XUI=	29.8
21	0.2	0			9.975163	0.080004		XLI=	27.9
22	0.5	-1.146			10.47506	0.070003		SH=	0.8
23	0.5	2.292			10.97466	0.09		SO=	0.8
24	1	2.866			11.97341	0.14			
25	1	5.164			12.96935	0.230007			
26	1	5.164			13.96529	0.320014			
27	1	0.573			14.96524	0.330014			
28	1	-1.719			15.96479	0.300016			
29	1	1.719			16.96434	0.330014			
30	1	4.589			17.96114	0.410022			
31	1	1.146			18.96094	0.430022			
32	1	-0.573			19.96089	0.420021			
33	1	1.146			20.96069	0.440021			
34	1	2.866			21.95944	0.490022			
35	1	2.866			22.95819	0.540022			
36	1	1.146			23.95799	0.560022			
37	1	4.014			24.95553	0.630022			
38	0.5	2.292			25.45513	0.650018			
39	0.5	5.739			25.95263	0.700017			
40	0.5	1.146			26.45253	0.710017			
41	0.3	3.823			26.75186	0.730019			
42	0.2	5.739			26.95086	0.750019			
43	0.5	4.589			27.44926	0.790023			
44	0.5	9.207			27.94281	0.870023			
45	0.5	15.07			28.42562	1.000023			
46	0.3	25.679			28.69599	1.130022			
47	0.2	26.744			28.87459	1.220023			
48	0.2	26.744			29.0532	1.310024			
49	0.2	26.744			29.2318	1.400024			
50	0.2	30			29.40501	1.500024			
51	0.2	33.367			29.57204	1.610024			
52	0.2	14.478			29.76569	1.660026			
53	0.5	2.292			30.26529	1.680022			
54	0.5	5.739			30.76279	1.730021			
55	0.5	-1.146			31.26269	1.720021			
56	0.5	-2.292			31.76229	1.700025			
57	0.5	-1.146			32.26219	1.690024			
58	0.5	3.44			32.76128	1.720026			
59	0.5	8.048			33.25636	1.790027			
60	0.5	9.207			33.74992	1.870028			
61	0.5	-1.146			34.24982	1.860028			

62	0.5	2.292			34.74942	1.880024			
63	1	4.589			35.74621	1.960032			
64	1	2.292			36.74541	2.000024			
65	1	2.866			37.74416	2.050025			
66	1	2.292			38.74336	2.090017			
67	1	5.739			39.73835	2.190014			
68	1	6.892			40.73112	2.310012			
69	1	-0.573			41.73107	2.300011			
70	1	-1.146			42.73087	2.280011			
71	1	-2.866			43.72962	2.230011			
72	1	1.146			44.72942	2.250011			
73	1	7.47			45.72094	2.380018			
74	1	1.719			46.72049	2.410016			
75	1	2.292			47.71969	2.450008			
76	1	2.292			48.71889	2.490001			
77	1	3.44			49.71708	2.550004			
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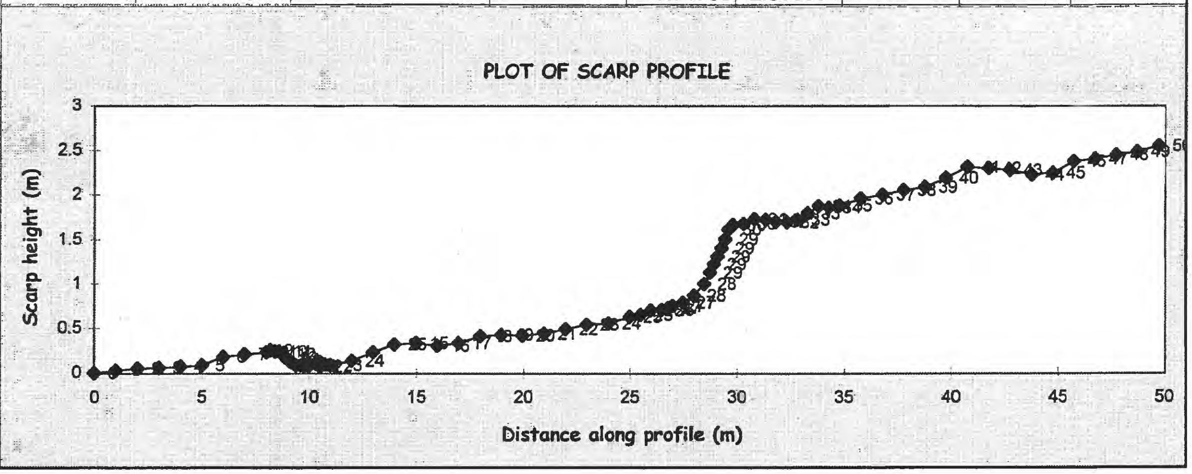

DATA ENTRY IN SHADED AREA			Date (mo/day/yr):	10/10/98	Created in MS Excel 5.0c on 6/23/97 by Barton Kiburz				
Site or Area		Old Ghost site	Profile azimuth:	068°	Endpoint		Modf'd 11/06/98 by M. Machette		
Fault Name		Cow Creek	Scarp aspect	SW	Coordinates		and R.C. Bucknam, USGS		
Profile/Sta. No.		CC-2	Scarp trend:	154°	Cumulative		*CALCULATIONS (text hidden)*		
Seg.	Dist. (m)	Angle (Deg)	Air Photo No.:	149	X	Y		XLR=	0.0
Enter field data here			Pick these points		0	0	Lower	YLR=	0.0
1	1	1.719	1st lower point	0	0.99955	0.029998		XLF=	8.2
2	1	1.146	2nd lower point	9	1.99935	0.049998		YLF=	0.3
3	1	0.573	1st scarp point	44	2.9993	0.059998			
4	1	0.573	2nd scarp point	52	3.99925	0.069999		XSR=	27.9
5	1	1.146	1st upper point	54	4.99905	0.089999	Scarp	YSR=	0.9
6	1	5.164	2nd upper point	77	5.994991	0.180006		XSF=	29.8
7	1	1.719	Scarp Height (SH)	0.84	6.994541	0.210004		YSF=	1.7
8	1	1.146	Surf. Offset (SO)	0.77	7.994341	0.230004			
9	0.2	5.739	Pick these points		8.193339	0.250003		XUR=	30.8
10	0.2	-2.866	Max scarp (θs°)		8.393088	0.240003	Upper	YUR=	1.7
11	0.2	0	Fan slope (θf°)		8.593088	0.240003		XUF=	49.7
12	0.2	-8.627			8.790826	0.210003		YUF=	2.6
13	0.1	-23.578			8.882477	0.170003			
14	0.1	-11.537			8.980457	0.150003		ML=	0.0
15	0.1	-11.537			9.078436	0.130003		MS=	0.4
16	0.1	-5.739			9.177935	0.120003		MU=	0.0
17	0.1	-11.537			9.275915	0.100003		BL=	0.0
18	0.1	-5.739			9.375413	0.090004		BS=	-11.2
19	0.2	0	***Click on chart and pull***		9.575413	0.090004		BU=	0.4
20	0.2	-2.866	***handles to enlarge***		9.775163	0.080004		XUI=	29.8
21	0.2	0			9.975163	0.080004		XLI=	27.9
22	0.5	-1.146			10.47506	0.070003		SH=	0.8
23	0.5	2.292			10.97466	0.09		SO=	0.8
24	1	2.866			11.97341	0.14			
25	1	5.164			12.96935	0.230007			
26	1	5.164			13.96529	0.320014			
27	1	0.573			14.96524	0.330014			
28	1	-1.719			15.96479	0.300016			
29	1	1.719			16.96434	0.330014			
30	1	4.589			17.96114	0.410022			
31	1	1.146			18.96094	0.430022			
32	1	-0.573			19.96089	0.420021			
33	1	1.146			20.96069	0.440021			
34	1	2.866			21.95944	0.490022			
35	1	2.866			22.95819	0.540022			
36	1	1.146			23.95799	0.560022			
37	1	4.014			24.95553	0.630022			
38	0.5	2.292			25.45513	0.650018			
39	0.5	5.739			25.95263	0.700017			
40	0.5	1.146			26.45253	0.710017			
41	0.3	3.823			26.75186	0.730019			
42	0.2	5.739			26.95086	0.750019			
43	0.5	4.589			27.44926	0.790023			
44	0.5	9.207			27.94281	0.870023			
45	0.5	15.07			28.42562	1.000023			
46	0.3	25.679			28.69599	1.130022			
47	0.2	26.744			28.87459	1.220023			
48	0.2	26.744			29.0532	1.310024			
49	0.2	26.744			29.2318	1.400024			
50	0.2	30			29.40501	1.500024			
51	0.2	33.367			29.57204	1.610024			
52	0.2	14.478			29.76569	1.660026			
53	0.5	2.292			30.26529	1.680022			
54	0.5	5.739			30.76279	1.730021			
55	0.5	-1.146			31.26269	1.720021			
56	0.5	-2.292			31.76229	1.700025			
57	0.5	-1.146			32.26219	1.690024			
58	0.5	3.44			32.76128	1.720026			
59	0.5	8.048			33.25636	1.790027			
60	0.5	9.207			33.74992	1.870028			
61	0.5	-1.146			34.24982	1.860028			

62	0.5	2.292		34.74942	1.880024			
63	1	4.589		35.74621	1.960032			
64	1	2.292		36.74541	2.000024			
65	1	2.866		37.74416	2.050025			
66	1	2.292		38.74336	2.090017			
67	1	5.739		39.73835	2.190014			
68	1	6.892		40.73112	2.310012			
69	1	-0.573		41.73107	2.300011			
70	1	-1.146		42.73087	2.280011			
71	1	-2.866		43.72962	2.230011			
72	1	1.146		44.72942	2.250011			
73	1	7.47		45.72094	2.380018			
74	1	1.719		46.72049	2.410016			
75	1	2.292		47.71969	2.450008			
76	1	2.292		48.71889	2.490001			
77	1	3.44		49.71708	2.550004			
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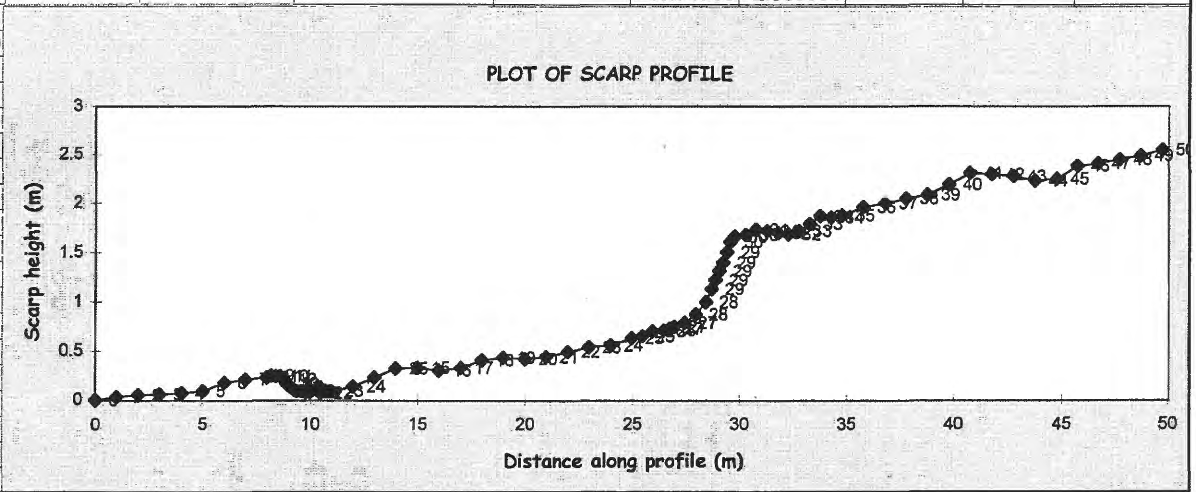

DATA ENTRY IN SHADED AREA			Date (mo/day/yr):	10/10/98	Created in MS Excel 5.0c on 6/23/97 by Barton Kiburz				
Site or Area		Old Ghost site	Profile azimuth:	067°	Endpoint		Modf'd 11/06/98 by M. Machette		
Fault Name		Cow Creek	Scarp aspect	SW	Coordinates		and R.C. Bucknam, USGS		
Profile/Sta. No.		CC-3	Scarp trend:	154	Cumulative		*CALCULATIONS (text hidden)*		
Seg.	Dist. (m)	Angle (Deg)	Air Photo No.:	14-9	X	Y		XLR=	0.0
Enter field data here			Pick these points		0	0	Lower	YLR=	0.0
1	1	-1.146	1st lower point	0	0.9998	-0.02		XLF=	6.0
2	1	1.719	2nd lower point	6	1.99935	0.009998		YLF=	0.3
3	1	5.164	1st scarp point	43	2.995291	0.100004			
4	1	4.014	2nd scarp point	44	3.992838	0.170005		XSR=	27.0
5	1	1.719	1st upper point	69	4.992388	0.200002	Scarp	YSR=	1.7
6	1	2.866	2nd upper point	78	5.991137	0.250003		XSF=	27.2
7	1	10.37	Scarp Height (SH)	0.99	6.974803	0.430007		YSF=	1.7
8	0.2	-2.866	Surf. Offset (SO)	0.87	7.174553	0.420007			
9	0.2	-5.739	Pick these points		7.37355	0.400007		XUR=	40.7
10	0.2	-8.627	Max scarp (θs°)		7.571288	0.370007	Upper	YUR=	2.8
11	0.2	-5.739	Fan slope (θf°)		7.770285	0.350008		XUF=	49.7
12	0.2	-17.458			7.961073	0.290006		YUF=	3.4
13	0.2	-5.739			8.16007	0.270007			
14	0.2	0			8.36007	0.270007		ML=	0.0
15	0.2	2.866			8.55982	0.280007		MS=	0.4
16	0.2	11.537			8.755779	0.320007		MU=	0.1
17	0.2	8.627			8.953516	0.350007		BL=	0.0
18	0.5	0			9.453516	0.350007		BS=	-10.1
19	0.5	3.44	***Click on chart and pull***		9.952615	0.380009		BU=	0.4
20	1	6.315	***handles to enlarge***		10.94655	0.490003		XUI=	28.0
21	1	2.866			11.9453	0.540004		XLI=	25.7
22	1	1.719			12.94485	0.570001		SH=	1.0
23	1	4.014			13.94239	0.640002		SO=	0.9
24	1	2.292			14.94159	0.679994			
25	1	4.014			15.93914	0.749994			
26	1	0.573			16.93909	0.759995			
27	1	1.146			17.93889	0.779995			
28	1	4.589			18.93568	0.860002			
29	1	0.573			19.93563	0.870003			
30	1	2.866			20.93438	0.920003			
31	1	3.44			21.93258	0.980007			
32	1	2.866			22.93133	1.030007			
33	1	2.866			23.93008	1.080007			
34	0.5	1.146			24.42998	1.090007			
35	0.5	4.589			24.92838	1.130011			
36	0.5	9.207			25.42194	1.210012			
37	0.5	10.37			25.91377	1.300014			
38	0.2	0			26.11377	1.300014			
39	0.2	11.537			26.30973	1.340014			
40	0.2	14.478			26.50338	1.390016			
41	0.2	23.578			26.68668	1.470015			
42	0.2	20.487			26.87403	1.540014			
43	0.2	36.87			27.03403	1.660014			
44	0.2	23.578			27.21733	1.740014			
45	0.2	17.458			27.40812	1.800015			
46	0.2	5.739			27.60712	1.820015			
47	0.2	8.627			27.80486	1.850015			
48	0.5	3.44			28.30395	1.880016			
49	0.5	4.589			28.80235	1.92002			
50	1	2.292			29.80155	1.960013			
51	1	3.44			30.79975	2.020016			
52	0.5	8.048			31.29483	2.090017			
53	0.5	3.44			31.79392	2.120019			
54	0.5	4.589			32.29232	2.160023			
55	0.5	3.44			32.79142	2.190024			
56	0.5	2.292			33.29102	2.21002			
57	0.3	11.537			33.58496	2.27002			
58	0.2	-2.866			33.78471	2.26002			
59	0.2	20.487			33.97206	2.330019			
60	0.3	15.466			34.2612	2.410019			
61	0.3	7.662			34.55852	2.450018			

62	0.2	-2.866			34.75827	2.440018			
63	0.5	6.892			35.25466	2.500017			
64	0.5	2.292			35.75426	2.520013			
65	1	2.866			36.753	2.570013			
66	1	2.866			37.75175	2.620014			
67	1	3.44			38.74995	2.680017			
68	1	5.164			39.74589	2.770024			
69	1	3.44			40.74409	2.830027			
70	1	2.292			41.74329	2.870019			
71	1	1.719			42.74284	2.900017			
72	1	2.866			43.74159	2.950017			
73	1	2.866			44.74034	3.000018			
74	1	4.014			45.73789	3.070018			
75	1	2.866			46.73664	3.120018			
76	1	2.866			47.73538	3.170018			
77	1	8.627			48.72407	3.32002			
78	1	2.866			49.72282	3.37002