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NUCLEAR WASTE PROJECT**

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**NEOTECTONICS OF THE SOUTHERN AMARGOSA DESERT,
NYE COUNTY, NEVADA AND INYO COUNTY, CALIFORNIA**

BY

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MAY, 1991

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University of Nevada

Reno

**Neotectonics of the southern Amargosa Desert,
Nye County, Nevada and Inyo County, California**

**A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Geology.**

by

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May, 1991

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July 3, 1991

Carl Johnson
Administrator of Technical Programs
State of Nevada
Nuclear Waste Projects Office

Dear Carl:

Enclosed is a copy of Diane Donovan's newly completed Master of Science thesis, entitled, "Neotectonics of the southern Amargosa Desert, Nye County, Nevada and Inyo County, California," which was supported by Task 5 and the General Task of the Yucca Mountain Project of the Center for Neotectonic Studies, UNR, with funds provided by your office.

Diane's work includes the first detailed map of Quaternary faults in the southern Amargosa Desert, an area immediately to the south of Yucca Mountain. She identified evidence for three major zones of Quaternary fault activity, including the NE-trending Rock Valley Extension, the N-trending Ash Meadows fault zone, and the NW-trending Amargosa River fault zone. The relations of these fault zones to other known regional faults are uncertain, but Diane has discussed several alternatives that should be considered with regard to the neotectonic setting of Yucca Mountain. Her work emphasizes the importance of further detailed studies of these faults and the Quaternary stratigraphy of southern Amargosa Valley to establish the timing and interactions of the various fault zones near Yucca Mountain.

This is the first of three recently completed theses on neotectonics and active faulting supported by Task 5 that I will soon be sending to you, as soon as we have completed copying them. These studies provide an important body of new information about the neotectonic framework of the Yucca Mountain region. We are grateful for the support provided by your office that made these studies possible.

With best regards,

A handwritten signature in cursive script, reading "Rich Schweickert". The signature is written in dark ink and is positioned above the printed name.

Richard A. Schweickert
Professor of Geology

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ABSTRACT

A complex pattern of active faults occurs in the southern Amargosa Desert, southern Nye County, Nevada. These faults can be grouped into three main fault systems: (1) a NE-striking zone of faults that forms the southwest extension of the left-lateral Rock Valley fault zone, in the much larger Spotted Range-Mine Mountain structural zone, (2) a N-striking fault zone coinciding with a NNW-trending alignment of springs that is either a northward continuation of a fault along the west side of the Resting Spring Range or a N-striking branch fault of the Pahrump fault system, and (3) a NW-striking fault zone which is parallel to the Pahrump fault system, but is offset approximately 5 km with a left step in southern Ash Meadows.

These three fault zones suggest extension is occurring in an E-W direction, which is compatible with the ~N10W structural grain prevalent in the Death Valley extensional region to the west.

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(all located in back pocket)

CHAPTER 1

Introduction

1.1 Motivation

This study was done to assist in evaluating the seismic hazard of the southern Amargosa Desert, a region south of and adjacent to Yucca Mountain and the Nevada Test Site (NTS). Yucca Mountain has been proposed by the U.S. Department of Energy as a potential site for the nation's first high-level nuclear waste repository. Along with studies of local and regional seismic risk associated with the repository site, analyses of volcanic hazards, and studies of hydrologic and economic potential are being conducted by the U.S. Department of Energy to obtain licensing for the site by the U.S. Nuclear Regulatory Commission. This study was supported by the Nevada Nuclear Waste Project Office which is conducting a site assessment program independent from that of the U.S. Department of Energy.

1.2 Purpose and scope of study

The main purpose of this study was to evaluate the extent of Quaternary faulting in the southern Amargosa Desert, based on tectonic geomorphology and limited trenching studies across Quaternary faults. Secondary goals were to develop a tectonic model for the study area

Figure 1-1.
Location map of the southern Amargosa Desert showing study area, distribution of Paleozoic and Cenozoic rocks, and NNW spring alignment in the Ash Meadows area.

based on the observed fault pattern and to assess the seismic hazard of the area.

From late 1987 to 1990, detailed analyses of aerial photographs and field studies were completed in part of the southern Amargosa Desert extending from longitude 116°15'W to 116°30'W and from latitude 36°15'N to 36°40'N, a total of 900 sq. km (Figure 1-1). The aerial photography consists of 44 flight lines of 1:12,000 scale, low-sun-angle photographs (approximately 1622 photos). Twenty-nine of the 44 flight lines cover the area between longitude 116°00'W and 116°45'W and latitude 36°15'N to 36°45'N. Fifteen of the 44 flight lines cover the area between longitude 116°45'W and 116°55'W and latitude 36°45'N to 37°00'N. Six hundred of the 1600 photos were analyzed on three separate occasions to recheck interpretations. The results of this analysis are shown on Plate 1 on which faults and annotations derived from these 600 air photos were transferred. The remaining 1000 photos were reviewed to detect major faults outside the field area.

1.3 Previous Work

Hydrologic and hydrogeologic issues were the primary motivation for previous research in the southern Amargosa Desert. The studies include: Loeltz (1960), Walker (1963), Walker and Eakin (1963), Naff

(1973), Winograd and Thordarson (1975), Dudley and Larson (1976), Claassen (1985), and Bedinger and others (1989). Ash Meadows, in the southeast corner of the southern Amargosa Desert (Fig. 1-1), with 30 natural springs, is considered to be the largest oasis in the U.S., and has attracted studies of the origin of the springs, variations in flow rate, temperature, geochemistry, extent of the recharge area, and depth and lithology of the aquifer.

Since the mid-1980's, Winograd studied the Devil's Hole area in Ash Meadows, where he and other workers obtained a continuous record of ^{18}O variations from a 14 cm-thick calcite vein dated from 50 Ka to 500 Ka. The resultant ^{18}O curve from Devil's Hole closely resembles ^{18}O curves of marine and Antarctic ice cores. The Devil's Hole curve, however, differs from the marine and Antarctic ^{18}O curves by 7 Ka to 17 Ka during the last glacial interval, and may have important implications concerning the credibility of the Milankovich theory when compared to the well-established marine and Antarctic records (Winograd and others, 1988).

Denny and Drewes (1963) provided the first detailed description of stratigraphy and structure in the southern Amargosa Desert. Their 1:62,500-scale map shows Quaternary and Tertiary deposits subdivided into playa, alluvial fan, and spring deposits, together with dune sand. They mapped a portion of the central section of the Ash Meadows fault

(described in this report). Burchfiel (1966) mapped the Lathrop Wells 15' Quadrangle, just north of the Ash Meadows Quadrangle.

More detailed mapping by Naff (1973) emphasized the hydrogeology of Ash Meadows. Naff subdivided the major units of Denny and Drewes (1963) into multiple subunits and added a unit of manmade deposits, designated Qm. He also identified the central section of the Ash Meadows fault in section 2, T18S, R50E and section 26, T17S, R50E (Plate 1), and noted that "a normal fault...displaces older pediment gravels with a vertical throw of at least 20 feet". Naff (1973) also observed a large, west-side down, normal fault at Fairbanks Butte, having "(a displacement) between limestone caps (of at least) 100 feet". Additionally, Naff mapped two other N-striking, normal faults in Quaternary deposits in sections 19 and 21, T17S, R50E (Plate 1).

Mehring and Warren (1976) conducted a detailed study of marsh and dune deposits in the Carson Slough (Fig. 3-5 and Plate 1) that included exploratory trench studies and a ^{14}C -dated chronology of deposits going back 5000 ybp. Their main conclusion was that over the past 5000 years, the spring-fed marshes of Ash Meadows have been ephemeral features controlled or altered by eolian deposition (Mehring and Warren, 1976). Archeological chronology was also involved in their study since Ash Meadows is an early man site. This research was continued during the summer of 1989 by Stephanie

Livingston and Fred Niles of Desert Research Institute, who focussed on archeological aspects of the area using exploratory trench studies of several dune sites.

The most recent noteworthy study is that of Hay and others (1986), who subdivided Pliocene rocks of northern Ash Meadows into three lithofacies, separated on the basis of the presence or absence of Mg-clays, montmorillonite, limestone and/or dolomite. They also studied the isotope geochemistry of the Pliocene deposits. The results of their study have implications for Pliocene climates and depositional environments.

1.4 Physiography

1.4.1 Physiographic location

The Amargosa Desert is an 85 km-long, 30 km-wide, NW-trending valley that occurs in the Walker Lane belt of southern Nevada (Figure 1-2). It is in the Great Basin physiographic province, but differs from typical Basin and Range valleys in that it is a drained basin with eroded Quaternary deposits. The Amargosa Desert is bounded on its south end by the Greenwater and Resting Spring Ranges. The Funeral Mountains are west of the area; to the north are the Bullfrog Hills, Bare Mountain, Crater Flat, and Yucca Mountain. The Amargosa Desert is bounded on the east by the Specter Range, northern Spring Mountains, and the

Figure 1-2.

Map showing topographic features of the region around the Amargosa Desert. AH = Alexander Hills; AMV = Amargosa Valley; AR = Amargosa Ridges; AV = Avawatz Mts.; BF = Bullfrog Hills; CF = Crater Flat; CN = Confidence Hills; EM = Eagle Mountain; FC = Furnace Creek Wash; IH = Ibx Hills; K = Kingston Range; MM = Montgomery Mountains; N = Nopah Range; NDV = Northern Death Valley; RS = Resting Spring Range; SDV = Southern Death Valley; SH = Sheephead Pass; SR = Specter Range; SPR = Spring Mountains; ST = Stewart Valley; OV = Oasis Valley; YM = Yucca Mountain (from Wright, 1988).

Montgomery Mountains. A branch of the Montgomery Mountains, designated the Amargosa Ridges, trends northwest into the southern Amargosa Desert (Figure 1-2).

The Amargosa Desert is drained by the Amargosa River, which flows from near Oasis Valley, north of Beatty, along a southerly course to the Alexander Hills (Figure 1-2). It then turns 180° at the southern tip of the Black Mountains and flows north into Death Valley where it terminates at Badwater, California. Water from springs at Ash Meadows joins the Amargosa River during the winter months when flowing water does not evaporate as rapidly as in the summer.

1.4.2 Climate

The Amargosa Desert has an arid climate with low precipitation and humidity, and high temperature and evaporation rates in the summer. Summer and winter precipitation at Lathrop Wells are 1.7 and 6.2 cm, respectively (Naff, 1973). Recorded extremes in annual temperature for Lathrop Wells range from 115°F to 5°F (Walker and Eakin, 1963). Evaporation reaches up to 250 cm/yr (Dudley and Larson, 1976).

1.4.3 Vegetation

Creosote, mesquite (restricted to sand dunes and the banks of the Amargosa River) and small shrubs are the dominant vegetation of the Amargosa Desert, with the exception of Ash Meadows.

Ash Meadows was established as a National Wildlife Refuge in 1984, providing habitat for at least 26 plants and animals found nowhere else. Ash Meadows is host to the greatest concentration of endemic species in the U.S., which are supported by 18,000 acre-feet of water per year issuing from natural springs within the area (Walker and Eakin, 1963). As a result, biologic research on indigenous desert pupfish and many rare plants dominates over other scientific studies in the area.

1.5 Regional tectonic setting

The southern Amargosa Desert is in the western part of the Basin and Range structural province. Cenozoic extension accommodated by normal and strike-slip faults characterizes the western part of the Basin and Range. Estimates of active extension, based on very long baseline interferometry (VLBI) vary from approximately 10 mm/yr in a N45W direction (Argus and Gordon, 1989) to 9.7 ± 2.1 mm/yr in a N56W ± 10 direction (Minster and Jordan, 1987).

Bimodal basaltic and rhyolitic volcanism accompanied Basin and Range extension (Christiansen and McKee, 1978). Most notably, the mid-Miocene development of the Southwest Nevada volcanic field near Yucca Mountain included the activation and subsidence of the Crater Flat-Prospector Pass caldera complex and west-dipping normal faults at

Yucca Mountain (Carr, 1988) (Figure 1-3).

Large magnitude late Cenozoic extension in the southern Great Basin was accomplished by low-angle detachment faulting that

Figure 1-3.
The Southwest Nevada volcanic field and its relation to faults in the Yucca Mountain area. From Carr (1988).

continues at present (Hamilton, 1988). Wernicke and others (1988) argued that extension across the southern Basin and Range totalled at least 200%, and may have been as much as 300%. According to Hamilton (1988), extension occurred on west-dipping detachment faults that initiated during the Middle Miocene at the Nevada Test Site, late Miocene in the Bullfrog Hills, Pliocene in the Funeral Mountains, and are currently active in Death Valley (Hamilton, 1988).

The present eastern limit of major active deformation is along the east side of Death Valley and is marked by NW-trending right slip faults separated by N-trending normal faults (Hamilton, 1988).

The Amargosa Desert is also within the Walker Lane belt (Figure 1-4), an anomalous area of diverse topography and strike-slip faulting, contained within a NW-trending zone in the western part of the Basin and Range structural province (Stewart, 1988).

Stewart (1988) divided the Walker Lane belt into nine structural blocks, each characterized by a distinct and separate structural style (Figure 1-4). The southern Amargosa Desert occurs near the boundaries of four of these structural blocks:

(1) The Spotted Range-Mine Mountain block is a 30-60 km wide zone characterized by NE-trending left-lateral faults. The Rock Valley fault is part of this system and, as documented here, cuts Quaternary deposits in the southern Amargosa Desert.

Figure 1-4.

Regional structural blocks and major faults in the Walker Lane belt, from Stewart (1988). Arrows indicate relative movement on strike-slip faults. Structural blocks described herein include: SPOTTED RANGE-MINE MOUNTAIN BLOCK (highlighted in orange): MM = Mine Mt.; W = Wahmonie; RV = Rock Valley; CS = Cane Spring; YF = Yucca-Frenchman. SPRING MOUNTAINS BLOCK (green): LVV = Las Vegas Valley. INYO-MONO BLOCK (blue): KC = Kern Canyon; I = Independence; WM = White Mountain; OV = Owens Valley; FC = Furnace Creek; PV = Panamint Valley; DV = Death Valley; G = Garlock; SV = Stewart Valley; P = Pahrump. GOLDFIELD BLOCK (yellow). The Amargosa Desert is outlined in red.

(2) The Spring Mountains block is a relatively coherent block composed of the regionally anomalous mountain mass of the Spring Mountains. It is bounded on the southwest by the Pahrump fault, on the northwest by the Spotted Range-Mine Mountain block, on the northeast by the Las Vegas Valley shear zone and on the southeast by the Lake Mead fault zone.

(3) The Inyo-Mono block is a large, triangular section of the Walker Lane that lies south of the Excelsior-Coaldale section, east of the Sierra Nevada, and west of the Furnace Creek fault zone. This area is characterized by high relief, abrupt linear mountain fronts, major NW-striking right-lateral faults, and high rates of ongoing extension.

(4) The Goldfield block is characterized by a lack of throughgoing northwest-trending strike-slip faults and a scarcity of major basin-range faults. The paucity of faults in the northern half of the Amargosa Desert is consistent with this characterization.

CHAPTER 2

Stratigraphy

2.1 Introduction

This chapter outlines the stratigraphy of basin-fill deposits of late Cenozoic age in the southern Amargosa Desert (Figure 2-1). Rocks surrounding the basin are primarily Paleozoic limestone, dolomite, shale, and quartzite. Mesozoic and lower Tertiary rocks are absent in the study area. However, Miocene tuffs are widespread north of State Hwy 95, in the Yucca Mountain area, and Miocene (?) sandstones are present in the southern Ash Meadows area. Pliocene and Pleistocene limestone, dolomite, and Mg-clay deposits are common throughout the southern Amargosa Desert and especially northern Ash Meadows. Quaternary sediments are mainly of fluvial, modern spring, and eolian origin.

Much of the stratigraphic work described herein was done by others. The object of this chapter is to integrate and supplement existing work to provide a complete overview of the rock record of the southern Amargosa Desert. Ages of units described in this chapter are summarized in Figure 2-2.

2.2 Paleozoic rocks (Pz)

Paleozoic rocks are exposed in four general locations within the study area (Figure 2-1): 1) the southern tip of the Funeral Mountains, 2) the northern tip of the Resting Spring Range, 3) some low hills in

Figure 2-1.

Generalized geologic map of the southern Amargosa Desert.
Paleozoic rocks are shown in black.

the Ash Meadows area, dubbed the Amargosa Ridges by W. J. Carr (1987), and 4) the Specter Range and Skeleton Hills.

2.2.1 Southeast spur of the Funeral Mountains

The information below is from Denny and Drewes (1965).

Southeast-dipping Paleozoic rocks include the Devonian-Silurian Hidden Valley Dolomite in the northern part of the southeast spur of the Funeral Mountains and Mississippian strata in the southern tip of the spur.

The Hidden Valley Dolomite consists of approximately 150 m of medium-gray dolomite with minor amounts of chert. The Lost Burro Formation conformably overlies the Hidden Valley Dolomite and consists of 600-900 m of light- to medium-gray dolomite that contains some clastic limestone. Lying conformably on the Lost Burro Formation, the Lower Mississippian Tin Mountain limestone is 140 m thick and consists of dark-gray cherty limestone. The Mississippian Perdido Formation(?), the stratigraphically highest Paleozoic unit in this area, consists of cherty limestone.

2.2.2 Paleozoic rocks of the northern Resting Spring Range

The highest point in the northern Resting Spring Range is Shadow Mountain, which is underlain by south and southeastward dipping quartzite and minor amounts of micaceous shale and quartz-pebble conglomerate (Denny and Drewes, 1965). This exposure is thought to

Figure 2-2.
Cenozoic stratigraphic units in the southern Amargosa Desert. See text for discussion. DNAG 1983 time scale is used.

include both Precambrian Stirling Quartzite and the Lower Cambrian Wood Canyon Formation (Burchfiel and others, 1983).

Undated, possibly Middle to Upper Cambrian limestone and dolomite lies at the western base of Shadow Mountain in a small fault block (Denny and Drewes, 1965).

2.2.3 Amargosa Ridges

The Amargosa Ridges consist almost entirely of the Banded Mountain Member of the Bonanza King Formation of Middle and Late Cambrian age (Barnes and Palmer, 1961). At the very northwestern tip of the Amargosa Ridges, the Upper Cambrian Dunderberg Shale Member of the Nopah Formation and its lower contact with the Papoose Lake Member of the Bonanza King Formation are exposed (Barnes and Christiansen, 1967). The Banded Mountain Member is about 450 m thick in the Amargosa Ridges and consists almost entirely of limestone and subordinate dolomite with some siltstone, fine-grained sandstone, and minor shale in the lowest part (Carr, 1987). These units strike predominantly NNW and dip gently (20° - 30°) to the NNE and WSW.

An isolated hill, called "Fairbanks" on topographic maps, which is surrounded by Quaternary sediments, is eight kilometers north of the Amargosa Ridges. This hill is composed of unnamed Devonian and Silurian dolomite and Devonian Nevada Formation that dip gently (30 degrees) to the west (Burchfiel, 1966).

2.2.4 Paleozoic rocks of the Striped Hills and Skeleton Hills

The Striped Hills and Skeleton Hills lie near the northeast edge of the study area. The information below is from Burchfiel (1966). The Skeleton Hills consist mostly of the Banded Mountain and Papoose Lake Members of the Bonanza King Formation, with minor exposures of Lower to Middle Cambrian Carrara Formation, and Precambrian Stirling Quartzite. The Striped Hills contain abundant outcrops of both Bonanza King Formation (both members) and the Nopah Formation, consisting of a lower shale, a middle limestone, and an upper dolomite member. Minor amounts of Wood Canyon and Carrara Formations, and the Devonian Nevada Formation also occur here.

2.3 Tertiary rocks (Tt)

2.3.1 Introduction

Tertiary rocks have been described by 1) Denny and Drewes (1965) along the flanks of both the southern Funeral Mountains and the northern Resting Spring Range, 2) Naff (1973) and Denny and Drewes (1965) in a northwest trending area in southern Ash Meadows, and 3) Swadley (1983) and Swadley and Carr (1987) in the Lathrop Wells and Big Dune Quadrangles, respectively. The following integrates the rock descriptions of these authors.

2.3.2 Tertiary rocks of the Funeral Mountains

Tertiary rocks in the southeastern end of the Funeral Mountains have been divided into seven units, most of which are Miocene in age (Cemen and others, 1985). From the base upward, these consist of: a lower fanglomerate, lower shale, lower limestone, lower conglomerate, upper limestone and shale, upper fanglomerate and upper conglomerate. This entire sequence is similar to a section of Oligocene Titus Canyon Formation described by Cornwall and Kleinhampl (1964) in the Bullfrog Hills and may also be the Titus Canyon Formation of Stock and Bode (1935) in the Death Valley area (Naff, 1973). The aggregate thickness of these rocks is at least 1000 m (Naff, 1973).

2.3.3 Tertiary rocks of the northern Resting Spring Range

Approximately 900 m of fanglomerates and finer-grained clastic rocks of Tertiary age overlie Cambrian rocks west and north of Shadow Mountain. Approximately 3 km north of Shadow Mountain, a reddish-brown fanglomerate forms low hills where it rests unconformably on Cambrian strata (Denny and Drewes, 1965). This fanglomerate is similar to fanglomerates comprising the basal units of the Titus Canyon Formation in the Funeral Mountains to the west (Naff, 1973).

2.3.4 Tertiary rocks within the basin

2.3.4.1 Miocene(?) sedimentary rocks (Ts)

Miocene(?) sandstones, claystones, and minor tuffs with extreme lateral and vertical variation are exposed in a northwest-trending belt

in southern Ash Meadows. In one outcrop midway along this belt of exposures, medium-grained, olive green sand with alternating beds showing parallel laminations, ripple marks, and mudcracks is interbedded with rust-colored silts that have local liesegang banding.

Figure 2-3.
Steeply south dipping Miocene (?) sedimentary rocks (Ts) in southern Ash Meadows. View to east.

These rocks dip steeply, alternately to the south and north, and define E-W-trending folds (Figure 2-3). Naff (1973) suggested possible stratigraphic correlations either with sedimentary rocks interbedded with the upper Miocene Paintbrush Tuff in the Yucca Mountain area, or with the lower Pliocene Furnace Creek Formation (5.3 to 6.5 Ma; Fleck,

1970) to the south. These are the "late Tertiary Valley Fill" deposits of Naff (1973), who inferred a playa lake depositional environment for these "thin-bedded, variably light-colored sediments that are combined with a high clay content".

2.3.4.2 Tertiary fluvial gravel (Tg)

This unit is a poorly exposed gravel on a low ridge in the southeast part of the Lathrop Wells Quadrangle. The gravel is poorly sorted, with a silty, sandy matrix and contains subrounded to well-rounded cobbles. It is locally well-cemented with calcrete. It is also characterized by well-rounded boulders as much as 0.6 m in diameter that are largely quartzite and argillite with lesser amounts of limestone, dolomite, and volcanic and plutonic rocks (Swadley, 1983).

2.3.4.3 Pliocene and lower Pleistocene marsh deposits (QTld)

Spring-related polestrian carbonate rocks are widespread throughout the southern Amargosa Desert and especially Ash Meadows. Swadley (1983) and Swadley and Carr (1987) mapped these Pliocene deposits as QTld: lacustrine marl, silt, and limestone. They postulated that a lacustrine environment is indicated by the pattern of scattered exposures of QTld along the margin of the Amargosa Desert, designated "approximate limit of Lake Amargosa" on Swadley and Carr's (1987) map.

It is doubtful that a lake existed here during the late Tertiary and early Quaternary because the presumed lake limit crosses contours that span greater than 130 m in elevation (707 m to 854 m). Also, the Amargosa Desert slopes southward at an average gradient of 3.8 m/km, although whether this is the original gradient or a result of Pleistocene deformation has not been established. Hay and others (1986) found no evidence of shoreline sediments or deep-water clays of a large lake. Additional evidence against a "Lake Amargosa" is the fact that the Amargosa basin had an outlet, at least intermittently, as indicated by the lack of evaporites (Hay and others, 1986).

A more probable and widely accepted interpretation is that these deposits (QTld) had a palestrian origin. Scattered erosional remnants of resistant calcareous marl and limestone are more likely the result of zones of subaqueous spring discharge than remnants of a lake bottom.

Although lateral and vertical variations persist throughout this unit (Naff, 1973), the thickness exceeds 130 m in northernmost Ash Meadows (T17S, R50E, section 16) (Plate 1). This unit varies from thick beds of white, chalky, calcareous marl to thin lenses of dense, fenestral limestone. This unit also contains small calcareous cylinders representing calcified plant stems and insect burrows. Swadley (1983) noted the occurrence of diatoms in this unit. The most impure marl has

a high fraction of quartz silt, rock fragments and clay, along with calcite.

Major outcrops of unit QTld are cut and truncated by 1) the NW-striking fault zone, north and east of the Amargosa River, 2) the NE-striking fault zone (T16S, R49E and R50E), and 3) the N-striking fault zone in Ash Meadows. An extensive exposure of this unit occurs in the

Figure 2-4.

Pliocene and lower Pleistocene limestone, dolomite, montmorillonite, and magnesium clays in northern Ash Meadows. These are divided into three lithofacies designated Tpa, Tld, and Tpl, each reflecting variations in $\delta^{18}\text{O}$ values.

East Playa, north and east of Ash Meadows (Figure 2-4) (Hay and others, 1986).

Hay and others (1986) divided these deposits into three pleistocene lithofacies, designated Tpa, Tld, and Tpl (Figure 2-4) on the basis of relative amounts of limestone, dolomite, montmorillonite, and magnesium clays (such as smectite and sepiolite). According to Hay and others (1986), carbonate minerals within these three lithofacies have stable isotopic compositions that vary with changes in depositional environment. For example, Tpa limestones having low ^{18}O values (+16.6) were deposited in or near areas of spring discharge; Tld limestones have higher ^{18}O values (+18.8) reflecting recrystallization in the vadose zone; and Tpl deposits reflect evaporative concentrations in playas with ^{18}O values of +20.3 to +24.3 (calcite to dolomite, respectively) (Hay and others, 1986).

Compositional variations within the East Playa deposits and along the western margin of East Playa may reflect changes in groundwater sources and changes in climate during the Pliocene. Silicification of carbonate deposits was likely the direct result of seepage along fault zones in East Playa changing from an initial low-silica Ash Meadows-type groundwater to a high-silica water, derived from volcanic rocks (Hay and others, 1986). A similar change in the composition of groundwater seepage is recorded in caliche breccias within this unit,

along the western margin of the basin. This change may be attributed to decreased precipitation about 2.5 Ma which reduced recharge from nearby carbonate rocks relative to that from more distant sources in volcanic rocks to the north (Hay and others, 1986).

Several radiometric ages on ashes and tuffs of unit QTld range from about 2 to 4 Ma (Hay and others, 1986). An age of just less than 4.0 Ma for the oldest of these deposits was inferred from a structural relation to faulted basalts at the outlet of the basin by Hoover (1985). The faulted basalts are believed to correlate with 4.0 Ma basalts in the Greenwater Range. A biotitic rhyolite tuff exposed in several localities in northern Ash Meadows yielded a date of 3.2 Ma by K-Ar and fission track methods and probably correlates with a biotitic rhyolite ash dated at 3.15 Ma near the base of the lacustrine sequence in Searles Lake, 100 km to the southwest (Hay and others, 1986). A pyroxene dacite tuff near the top of the sequence in northern Ash Meadows yielded a zircon fission-track age of 2.1 ± 0.4 Ma (Hay and others, 1986). Hoover and others (1981) dated ash beds in the middle of this unit at 2.95 Ma and 3.1 Ma. A Pearlette-type ash bed sampled within this unit was reported by Swadley (1983) as greater than 800 Ka, based on its thorium content.

2.4 Quaternary deposits

2.4.1 Introduction

Quaternary sediments of the southern Amargosa Desert signal a fundamental change from a wetter to a dryer climate. Prior to the Quaternary, the sources of water for fluvial deposition included local seeps, springs and surface runoff. During the Quaternary, the source of water changed to predominantly surface runoff derived from large drainages such as the Amargosa River, Fortymile Wash, Carson Slough, and Rock Valley Wash. Spring discharge decreased to its present 38,000 m³ per day during the Quaternary, and deposition of limestone, marl, and other spring deposits, continued to a lesser extent than previously.

2.4.2 Pleistocene alluvium (QTa)

Limited exposures of poorly sorted gravel, with angular to subrounded clasts, forms dissected fans that crop out along the flanks of Yucca Mountain and Little Skull Mountain. This gravel also forms rounded ridges and isolated mounds in the southeast quarter of the Lathrop Wells Quadrangle, and overlies Paleozoic rocks within the Funeral Mountains. Drill hole data in Yucca Flat indicate thicknesses ranging from 32 m to 150 m (Hoover and others, 1981).

This unit includes only minor amounts of sand and finer material and contains clasts several meters in diameter. QTa typically forms ballenas, but on flat surfaces it locally develops a dense, varnished

desert pavement (Swadley, 1983). The lack of fine material and the absence of bedding suggest deposition occurred largely by debris flows (Swadley, 1983).

Outcrops are commonly heavily cemented with a dense calcrete (stage IV of Giles and others, 1966) 3 m or more in thickness, which is laminated in the upper part (Swadley, 1983).

Ash beds in QTld units below QTa have been dated at 2.95 Ma and 3.1 Ma and the Bishop ash (730 Ka) has been found near the basal part of Q2e, which overlies unit QTa (Hoover and others, 1981). Pedologic and geologic evidence indicate that unit QTa is probably between 0.9 and 1.1 Ma in age (Hoover and others, 1981).

2.4.3 Spring Deposits

A thin (1 to 7 m thick) sheet of limestone, gravel, and sand lies above older spring-derived pleistocene deposits of Pliocene and Pleistocene age. Figure 2-5 shows the contact as a slight angular unconformity (NW1/4, section 26, T17S, R50E; Plate 1). This deposit is of limited areal extent (and therefore is not included on Figure 2-1). Thick exposures of this deposit (where it caps Fairbanks Butte) suggest that it was spring deposited (Denny and Drewes, 1965). Lobate spring deposits overlap desert pavement on ridges "just west of Devil's Hole" according to Naff (1973) and Denny and Drewes (1965). In addition to white silty marl, this deposit contains light brown travertine and casts

Figure 2-5.

An angular unconformity separates gently east dipping Plio Pleistocene polestrian deposits below from horizontal upper Quaternary polestrian deposits. Photographed in NW1/4, section 26, T17S, R50E. View to north.

of marsh plant stems. Some plant stems in the present spring pools at Ash Meadows have algal coatings which may eventually develop into casts like those observed in this unit.

2.4.4 Fluvial deposits

Several separate fluvial deposits were mapped by Swadley (1983)

and Swadley and Carr (1987) in the Lathrop Wells and Big Dune Quadrangles. Both studies divided fluvial deposits into four Pleistocene and four Holocene fluvial units. This mapping scheme was adapted from Hoover and others (1981).

2.4.4.1 Pleistocene fluvial deposits (Q2a)

Swadley (1983) and Swadley and Carr (1987) subdivided Pleistocene fluvial deposits into four subunits, designated Q2b, Q2c, Q2bc, and Q2s, derived from mapping by Hoover and others (1981). These subdivisions are based on lithology, geomorphology, depositional environment, and soil development. The four subunits are shown collectively as one unit (Q2a) in Figure 2-1 but are described separately here. Figure 2-6, from Swadley (1983), illustrates stratigraphic relations of the Q2a and Q1a subunits.

Q2s, a fluvial sheet sand deposit, consists mostly of sand and gravel. It forms thin sheetlike deposits along larger drainages and on the lower parts of Q2bc alluvial fans (described below). Soil characteristics include a vesicular A horizon, a poorly to well developed argillic B horizon, and a thin, poorly developed C horizon. Q2s has a smooth surface, largely undissected, with a poor to moderately developed desert pavement. This deposit was dated by the U-trend method as 480 +/- 90 Ka to 270 +/- 90 Ka (Swadley and others, 1984). Q2s is probably equal to upper Q2c but older than Q2b.

Figure 2-6.
Hypothetical cross-section showing relations of the Quaternary and
Tertiary deposits of the Lathrop Wells Quadrangle. From Swadley
(1983).

Units Q2b, Q2c, and Q2bc are composed primarily of gravel, sand, and silt, with varying degrees of soil development and topographic position. Q2c merges downslope into Q2b forming the middle to upper parts of extensive fans deposited on and downslope from QTa fans. Soils developed on this unit have a stage IV carbonate accumulation with a moderately developed C horizon (stage III); an argillic B horizon that is overlain by a thick vesicular A horizon. A densely packed desert pavement on Q2c has a well-developed black desert varnish. In addition to fluvial deposits, unit Q2c also includes debris flows. An age of 740 Ka was inferred for the lower part of Q2c in the NTS area based on its interbedded relationship with the lowest part of Q2e (Pleistocene eolian deposits, described below) which includes beds of Bishop ash (Swadley and Carr, 1987). An U-trend age for soil of unit Q2c is 270 Ka (Swadley and others, 1984).

Unit Q2b occurs as terraces along some washes cut into Q2s surfaces and also comprises the lower parts of alluvial fans below bedrock hills, merging upslope into unit Q2c. Soil formed on Q2b has a vesicular A horizon, a cambic B horizon with stage I carbonate accumulation (Swadley and Carr, 1987). Desert pavement is loosely to moderately packed (Swadley and Carr, 1987). A minimum age of approximately 160 Ka has been inferred for this unit based on U-trend ages of samples of Q2b from the Yucca Mountain area (Swadley and

others, 1984).

Q2bc was mapped by Swadley (1983) as a combined unit of Q2b and Q2c, where these two units could not be distinguished. Unless otherwise noted, the above information is derived from Swadley (1983).

2.4.4.2 Holocene fluvial deposits (Q1a)

Holocene units are separated from Pleistocene units by a regional unconformity (Hoover, 1981). The boundary for the regional unconformity is the A horizon and overlying desert pavement developed on the Pleistocene units. Holocene units were deposited in newly entrenched drainages and the outer edges of alluvial fans following a period of erosional dissection which deepened many of the larger drainages (Hoover, 1981). Some fluvial deposition left sheet sand deposits above Pleistocene units.

Swadley (1983) and Swadley and Carr (1987) divided Holocene fluvial sediments into four separate subunits, designated Q1a, Q1ab, Q1c, and Q1s, a scheme similar to that of Hoover (1981). Fluvial sheet sand deposits (Q1s) consist of sand, are pale yellowish brown, fine- to medium-grained, moderately well sorted and silty; they contain scattered pebbles and gravel lenses. This unit covers much of the area west of Ash Meadows and throughout the Amargosa Desert where it forms flat and smooth thin sheets with almost no developed drainages.

It also forms remnant terrace deposits in coalescing fans along lower slopes of the Funeral Mountains and the Resting Spring Range (Swadley and Carr, 1987). Soil development is limited to minor carbonate leaching; locally a loosely packed pavement is developed.

Three of the four subunits, Q1a, Q1ab, Q1c, are composed of a mixture of interbedded gravel, sand, and silt, poorly to moderately well-sorted, and poorly to well-bedded. Q1c forms terrace remnants along the larger drainages and probably underlies Q1s south of Fortymile Wash. The Q1c surface is smooth with stage I carbonate accumulation and a weakly developed C horizon.

Q1ab is similar to Q1c but has no soil or pavement development and commonly exhibits a highly dissected, bar and swale topography. This unit also forms fluvial terraces 1-2 m above the floor of modern washes.

Q1a occurs at the bottom of modern washes, commonly as braided deposits; maximum thickness is probably less than 5 m. A Holocene age has been inferred for these deposits by Hoover and others (1981) based on limited soil development and on correlation with Holocene deposits of nearby areas. Unless otherwise noted, the above information is from Swadley (1983).

2.4.5 Eolian deposits (Q2e and Q1e)

Eolian deposits in the southern Amargosa Desert occur as sand

ramps on the flanks of hills (Skeleton Hills area), as an isolated sand mountain (Big Dune), or as parabolic dunes (Ash Meadows).

Along the southeastern flanks of the Skeleton Hills/Striped Hills/Fairbanks Hill, dunes occur as sand ramps where they blanket Paleozoic rocks in these areas. Swadley (1983) distinguished both a Pleistocene (Q2e) and Holocene (Q1e) unit on his map, with Q2e deposits being much more widespread (approximately 15:1) than the Q1e deposits, indicating that eolian deposition has decreased substantially in the Holocene. Where exposed, Q1e and Q2e deposits form a sand ramp contact with Paleozoic rocks. Swadley (1983) reported lenses of Bishop ash in the basal part of Q2e.

Big Dune lies in the north-central Amargosa Desert (northwest of Figure 2-1), and is worth noting because of its large size and accumulation of sand. Nowhere else near the field area do sand mountains occur. Swadley and Carr (1987) mapped this 80 m thick eolian deposit as Holocene in age, and noted that the sand was derived from Pleistocene eolian deposits and Holocene fluvial deposits.

Several large parabolic dunes in Ash Meadows are aligned with convexity facing north, implying a prevalent wind direction from the south. These dunes form multiple, discontinuous, north-trending sand ridges, ranging from approximately 1 to 8 m high. The largest of these sand ridges acts as a dam for small ponds and marshes along its east

arm (sections 4 and 9, T18S, R50E; Plate 1). The dunes are anchored by vegetation such as mesquite (although dunes do not occur where the most extensive mesquite groves are located). Dune sand is interbedded with peat in the Carson Slough which indicates that dunes have encroached on marsh areas in the past. Radiocarbon dating in Ash Meadows indicates that dunes have been sporadically active over the past 5000 years (Mehring, 1971).

2.4.6 Cultivated deposits (Qm)

Areas of man-altered deposits are common throughout Ash Meadows and include fields cultivated for agricultural purposes, cattle, and peat mining. Naff (1973) mapped these extensive areas as Qm. This unit is worth noting because of the difficulty it poses in identifying tectonic geomorphology in some areas of Ash Meadows (but not shown in Figure 2-1)

CHAPTER 3

Active faulting

3.1 Introduction

A complex pattern of faults within the southern Amargosa Desert can be divided into three main fault zones: 1) a NE-striking zone, which is possibly the SW extension of the Rock Valley fault, 2) a NW-striking zone, including the Amargosa River fault, a possible en echelon northwest extension of the Pahrump fault zone, and 3) a roughly N-striking zone in Ash Meadows, designated the Ash Meadows fault zone (Figure 3-1). Backhoe excavations were made across faults of NE and N-trends to reveal details of faulting to a depth of 2 m. Trench 1 (TR1) and Trench 2 (TR2) were constructed across the Rock Valley fault extension (Plates 2 and 3). Trench 3 (TR3) and Trench 4 (TR4) were excavated across the Ash Meadows fault zone (Plates 4 and 5).

In this thesis, *fault* denotes a single trace; *zone* is more than one fault grouped with similar orientation; *subzone* is a group of faults within a zone that have an orientation that deviates at least 10° from that of the zone in which it belongs; and *sections* are subdivided within zones based on discontinuities in geomorphic expression and changes in strike.

Most faults were detected with the use of 1:12,000 low-sun-

Figure 3-1.
Generalized Quaternary fault map of the southern Amargosa Desert.
NE-striking zone in red; NW-striking zone in green; and N-striking zone
in blue.

angle (LSA) aerial photography. Few of these faults are observable on 1:60,000 AMS series 109 air photos or on multiple bandwidths of Landsat photography.

3.2 Extension of the Rock Valley fault in the southern Amargosa Desert

The Rock Valley fault is the longest trace in the 30-60 km wide, NE-trending, dominantly left-lateral Spotted Range-Mine Mountain zone. The Spotted Range-Mine Mountain structural zone extends 55 km northeast of the Amargosa Desert and is truncated by the NW-striking Yucca-Frenchman fault zone (Carr, 1984). Other faults in this zone include the Mine Mountain fault and the Cane Springs fault. The Rock Valley fault is the southeasternmost fault in the Spotted Range-Mine Mountain structural zone and is now believed to extend southwest into the southern Amargosa Desert (Figure 3-2).

Along the Rock Valley fault, Paleozoic and Tertiary strata are offset a few kilometers in a left-lateral sense (Barnes and others, 1982). The Rock Valley fault is an active fault with distinct scarps in Quaternary alluvium and a seismicity concentrated at its northeast end (Rogers and others, 1983).

The fault considered to be the extension of the Rock Valley fault zone terminates in section 33, T16S, R49E, approximately 3.5 km

Figure 3-2.
 Spotted Range-Mine Mountain structural zone, including Quaternary faults (hachured lines). From Carr (1984).

northeast of the Amargosa River fault zone (Plate 1). This southwestern extension is 9 km long, strikes N62E, and is a narrower, more concentrated (though more discontinuous) zone of scarps than the fault zone in Rock Valley. The southwestern extension of the Rock Valley fault in the southern Amargosa Desert is approximately 1-2 km wide compared to a 6 km wide zone of faulting through Rock Valley. A 3-4 km discontinuity exists in the surface expression of the Rock

Valley fault from section 20 to sections 3 and 4, T16S, R50E. This discontinuity occurs near the northward projection of the Ash Meadows fault zone (described later).

Geomorphic features along the Rock Valley extension generally consist of NE-trending scarps that face both northwest and southeast (Figure 3-3). However, one NW-trending scarp at the southwest termination of the fault faces southwest. Scarps in this area are not necessarily tectonic in origin. They occur at the contact between resistant strata and less resistant material and may be largely erosional in origin.

A 2 km stretch of the fault in sections 26 and 34, T16S, R49E (Figure 3-3) is delineated by a lithologic contact between units QT1d on the northwest side of the fault and Q1a on the southeast side. Elsewhere, tonal lineaments and linear drainages dominate the geomorphic character of this fault.

In sections 18 through 20, T16S, R50E (near scarp profiles P6-P8 on Figure 3-3; see also Appendix A), a 2 km wide zone of vegetation alignments, troughs, scarps, and tonal lineaments marks the fault. Scarp profiles P6, P7, and P8 were measured across a northwest-facing scarp in section 19 in this area (Figure 3-3 and Appendix A).

Three short (0.2 km-long) tonal lineaments trending approximately east-west and two north-trending troughs in sections

Figure 3-3.
Detailed fault map showing extension of the Rock Valley fault into the southern Amargosa Desert.

18 and 19 deviate from the northeast trend. The easternmost N-trending trough, which is 1.75 km long, is truncated on its south end by a NE-trending vegetation alignment.

The youngest deposits cut by faulting are Holocene in age.

3.2.1 Trench descriptions

Two backhoe excavations were cut across the Rock Valley extension; locations of trenches TR1 and TR2 are shown on Plate 1 and Figure 3-3. Evidence of recent fault activity is only suggestive in trench TR2. Trench TR1 was probably not constructed across the main trace of the fault, although it revealed stratigraphic units somewhat similar to those in trench TR2.

Yount and others (1987) excavated two trenches across the Rock Valley fault at Road 28-03 in the NTS, 25 km northeast of the Amargosa Desert. These trenches revealed at least two episodes of movement during the late(?) Quaternary, the most recent of which cut a surficial deposit dated by the U-trend method at 31 ± 10 Ka to 38 ± 10 Ka (Fox and Carr, 1989). The strike-slip component of displacement could not be determined, but dip-slip displacement attributed to the most recent episode of faulting ranged from less than 5 cm to 32 cm, down to the north (Yount and others, 1987).

3.2.1.1 Trench TR1

Trench TR1 exposes a gently dipping ($10-20^\circ$), south-facing

pedogenic calcrete surface (unit TR1C) that cuts across both units exposed on the NW side of the trench (unit TR1A and TR1B) (Plate 2).

Unit TR1A is a silica-cemented pebble gravel, containing a buried soil (Btkcb) that grades into a small fluvial paleochannel. The paleochannel is truncated by unit TR1C.

Unit TR1B is a fining upwards, carbonate-cemented pebble gravel containing insect burrows and plant stems within its upper 10 cm.

The calcrete layer of unit TR1C contains large fractures and voids infilled with poorly indurated pebble gravel.

Units TR1B and TR1C are most likely part of unit Q1a, hence are of Holocene age.

3.2.1.2 Trench TR2

Trench TR2 was excavated across the Rock Valley extension where QTld is juxtaposed against Q1a (Plate 3).

As with TR1, the northwest end of trench TR2 exposed a silica-cemented alluvium consisting of clasts of mafic volcanic rocks and felsic intrusive rocks (TR2A). In addition, insect burrows and plant stem casts are contained in the alluvium along with remnants of well-indurated pedogenic calcrete within the upper 10 cm and on the surface above this unit. TR2A is possibly correlative with TR1A as they both consist of older silica-cemented alluvium located on the northwest ends of trenches TR2 and TR1, respectively. The exhumed pedogenic

calcrete of unit TR2A is a resistant cap rock on the underlying silica-cemented alluvium, creating a prominent non-tectonic scarp in the vicinity of the fault where juxtaposed against less resistant strata, or where cut by streams.

Unit TR2B is the oldest unit observed in the trench on the southeast side of the fault. It is a poorly-indurated cobble gravel with stage II-III carbonate accumulation. This unit is truncated in several places: at meters 23 and 26 (Plate 3), with a possible paleochannel or graben occurring between these two truncations; and at meter 12.3, which may either represent the actual fault trace or the edge of another fluvial channel.

Unit TR2C is a light gray, moderately-indurated, carbonate- and silica-cemented pebble alluvium that grades laterally into unit TR2D at meter 15.5 (Plate 3). TR2C is capped in two places by a 1-3 mm thick, continuous layer of dense silica. This layer of silica is probably a Bqm paleosol horizon.

Unit TR2D is a white, extremely well-indurated pebble alluvium, cemented with calcium carbonate and opaline silica (stage VI). It grades laterally into unit TR2C at meter 15.5. Unit TR2D forms two distinct and separate "layers", both dipping approximately 20° to the SE (Plate 3). The northwesternmost layer extends to the ground surface where it forms a 30 cm wide white line of CaCO_3 - and SiO_2 -cemented

alluvium extending continuously for several meters along the surface, approximately 1-2 m SE of the scarp.

There are at least two reasonable explanations for the origin of unit TR2D:

A. Pedogenic:

Two dense Bkqm horizons developed within the soil profile and then underwent either progressive or episodic tectonic tilting due to close proximity to the fault. More likely, these two calcrete soil horizons might have developed on a scarp, in situ, without subsequent tectonic tilting.

B. Hydrologic:

Another possibility involves a rise in the water table due to one or more tectonic or climatic events. This might cause groundwater to flow upward along fault-related fractures onto the surface, thus locally altering the surface alluvium.

The carbonate and opaline silica that formed within fractures (and as soil horizons) are most likely of pedogenic origin (see discussion in section 3.5.1). It is also remotely possible that ascending waters, as a warm or cold spring, could have formed the carbonate and opaline silica deposits. That this could have occurred is evidenced by the present shallow groundwater table (approximately 30 m) and is inferred to have been shallower during the last pluvial period,

approximately 12,000 ybp.

Unit TR2E is a light gray, CaCO_3 -cemented (stage II-III) alluvium containing numerous buried soil horizons.

Unit TR2F is loose, pebbly channel fill with stage II carbonate accumulation.

In trench TR2, the fault is delineated by a 16 m wide zone of vertical fractures. These are lined with carbonate and opaline silica. These fractures are truncated by unit TR2E northwest of meter 18.8; southeast of that point, they continue upward into unit TR2E, but are truncated by overlying unit TR2F. The localized truncation of fractures between meter 10 and meter 18.8 may be due to fluvial channeling. Fractures beyond meter 18.8 are truncated by unit TR2F, a younger fluvial channel deposit. The fractures are oriented 25° counter clockwise (CCW) to the main trace of the fault and may be extensional in origin (see section 3.5.1 and Figure 3-12)

3.3 Amargosa River fault zone

The Amargosa River fault zone is parallel to and approximately 4 km northeast of the Amargosa River, and extends approximately 15 km from section 17, T17S, R49E to section 16, T18S, R50E along a strike of N48W (Figure 3-4).

Surface expression of the Amargosa River fault zone includes a 7

km wide, discontinuous zone of NW-trending vegetation alignments, troughs, tonal lineaments, linear drainages, and both northeast-facing and southwest-facing scarps. A 3 km wide break in this fault zone occurs between sections 9 and 7, T18S, R50E (Plate 1).

The Amargosa River fault zone truncates a secondary, N-striking zone of faults that lies to the southeast. This secondary zone of faults possibly extends as far south as section 35, T25N, R5E in Inyo County, California (Plate 1), and consists of a 1.5 to 2.5 km wide zone of west-facing scarps in unit QTld and some ponded alluvium. Three secondary faults are also expressed in places as tonal lineaments, vegetation alignments, and troughs. A small, N-striking graben in section 16, T17S, R49E, is the only N-trending feature of this secondary fault system that extends north of the Amargosa River fault. This N-striking zone of faults has sparse surface expression south of the California-Nevada border, but may extend southward to link with faults along the west flank of the Resting Spring Range.

The Amargosa River fault zone extends at least as far southeast as section 16, T18S, R50E (Plate 1), approximately to the Ash Meadows fault zone (and spring alignment). In fact, an apparent discontinuity in the Ash Meadows fault zone occurs where the Amargosa River fault projects southeast. Between this point in Ash Meadows and Stewart Valley, 20 km to the southeast (off the SE corner of Plate 1), no

Figure 3-4.
Detailed fault map showing NW-striking Amargosa River fault and
subsidiary N-striking faults.

tectonic geomorphic evidence for faulting has been observed. The youngest deposits cut by faulting are Holocene in age.

Scarp profile 3, measured across the westernmost N-striking fault in the SW1/4 of section 28, T17S, R49E (Figure 3-4 and Appendix A), shows the degraded nature typical of scarps in this area. The degraded nature of the scarp may be due to a low rate of tectonic activity along this fault.

Evidence that the Amargosa River fault zone is related to the Pahrump fault zone is that both strike parallel to the state line (N50W) and are observed to be almost continuous along this orientation. Because the Pahrump fault zone is a right-slip fault zone (Hoffard, 1990), the Amargosa River fault zone is inferred to be right-slip.

Other evidence for right-slip on the Amargosa River fault includes: (1) offset of the 150 m isopach of Lower Cambrian Zabriskie Quartzite across the Pahrump Fault (also known as the Stewart Valley fault through Stewart Valley (Stewart and others, 1968), and (2) a compressional left step between the Stewart Valley portion of the Pahrump fault zone and the Amargosa River fault. The compressional left step is marked by E-W-trending folds in section 1, T18S, R49E, and sections 5, 9, and 16 of T18S, R50E (Fig. 2-1). All folds occur in unit Ts and therefore may be as old as Miocene.

3.4 Ash Meadows fault zone and NW-trending spring alignment

The Ash Meadows fault zone is subdivided into three sections based on discontinuities in geomorphic expression and changes in strike. The central section, within Ash Meadows, is juxtaposed upon the N24W-trending spring alignment (Figure 3-7). The entire 4 km wide, discontinuous, Ash Meadows fault zone extends approximately 30 km southward from section 24, T16S, R50E to join with faults along the west side of the Resting Spring Range.

All faults on which the amount and direction of slip could be determined are dominantly normal dip-slip. Evidence includes a graben in section 9, T25N, R6E, Inyo County, California (Figure 3-11, and Plate 1), a gouge zone exposed in trench TR3 with slickensides having a 90° rake, and west-facing scarps that contain younger material in the hanging wall.

The youngest deposits cut by faulting in this zone are late Pleistocene.

3.4.1 Northern section

The northernmost section consists of two separate subzones of faults that intersect near Fairbanks Spring in section 9, T17S, R50E (Figure 3-5). The westernmost subzone in this section strikes N18W, and includes a relatively continuous series of linear west-facing scarps mostly in Holocene alluvium (Q1a). The subzone terminates

Figure 3-5.
Detailed fault map showing the northern section of the Ash Meadows fault zone.

northward in the SW1/4 of section 28, T16S, R50E. If it were to continue to the Rock Valley fault zone, 2.8 km to the north, it would project through at the apparent discontinuity of the Rock Valley fault extension in section 20, T16S, R50E (see section 3.2). This subzone of faults is continuous with, but strikes more northerly than (N18W vs N24W), the spring alignment that terminates at Fairbanks Spring.

Several small east- and west-facing scarps, linear drainages, troughs, and vegetation alignments form a discontinuous, approximately N18W-striking series of faults about 1 km east of the main trace of this subzone. The west edge of this subzone of smaller scarps is aligned with the escarpment on the west side of Fairbanks Butte in the SW1/4 of section 3, T17S, R50E (Figure 3-6).

A 3.2 Ma tuff is displaced 50 m, west-side-down along this fault segment west of Fairbanks Butte (Hay and others, 1986). This suggests a 0.016 mm/yr average vertical slip rate, although the amount of displacement distributed between the two faults within this N18W-striking subzone is unclear.

The easternmost subzone in this northern section is a 3 km wide, 7 km long discontinuous subzone of small N28E-trending scarps, linear drainages, tonal lineaments, troughs, and vegetation alignments. This diffuse subzone of faults extends northeast from Fairbanks Spring to section 13, T17S, R50E where several small, N-trending surface

Figure 3-6.

Photograph of Fairbanks Butte, looking north. Trace of fault in SW1/4 of section 3, T17S, R50E, cuts the left side of the escarpment.

features indicative of faults occur. It is unknown whether this subzone is a NE branch fault of the Ash Meadows fault zone or a SW-striking branch of the Rock Valley fault.

The discontinuous surface expression of faults between the north and central segments of the N-striking zone may be due to active erosion in the Carson Slough (Figure 3-5).

3.4.2 Central section

Thirty springs aligned approximately N24W occur in Ash Meadows in the central section of the Ash Meadows fault zone (Figure 3-7). Water that issues from the springs flows through a highly-fractured, Paleozoic carbonate aquifer that has a large recharge area possibly extending as far as Pahrnagat Valley, approximately 140 km to the northeast (Figure 3-8) (Winograd and others, 1988). Water from this regional aquifer flows into a local aquifer of fractured Tertiary limestone and travertine. The local aquifer is juxtaposed against a Tertiary aquitard along a buried normal fault, thus forcing the groundwater to the surface as springs. This normal fault is the Gravity fault of Healy and Miller (1975), so named for a geophysical survey that located it (Fig. 3-7). It may be the same fault that displaces sediments 50 m at Fairbanks Butte by the fact that they occur along the same trend.

Devil's Hole, which is east of the spring alignment and the Gravity fault, is a solution cavity in the Bonanza King Formation which provides a "window into the water table" where it is possible to see into the regional Paleozoic aquifer (Doty and Huckins, 1987). Tectonic-related surface features associated with the spring alignment are discontinuous, N-S to N10W-striking, west-facing scarps in Q2a and QTld deposits. These surface features extend from the SE1/4 of section 21, T17S, R50E southward to the NE1/4 of section 11, T18S,

R50E, in a zone approximately 5 km long and 3 km wide. Only one surface fault in this section is actually coincident with a spring. It occurs in the center of section 35, T17S, R50E, approximately 1 km WNW of Devil's Hole.

Figure 3-8.
General direction of groundwater flow in the south-central Great Basin
(from Winograd and others, 1988).

Two scarp profiles were measured in Q2a sediments, across the long scarp in the south part of section 26, T17S, R50E (scarp profiles P11 and P12, Appendix A). The scarps are 0.35 and 1.2 m high, respectively.

The 1 km long fault SW of Devil's Hole in section 2, T18S, R50E, is a fault-line scarp in alluvial units, caused by juxtaposition of two different lithologies (Q2a and QTld), having different resistance to erosion. It is not possible to determine amount of slip of the most recent event(s), however, because an unknown amount of the footwall has been eroded. In this case, scarp profiles P1 and P2 only provide erosional scarp heights because relief along the fault is caused by differential erosion. This fault is a west-side-down normal fault because of its continuation with and similarity in strike to west-facing scarps to the north.

At the south end of the central section, an apparent discontinuity occurs across a 3 km right step to the southern section of the Ash Meadows fault zone in section 16, T18S, R50E. This discontinuity is approximately coincident with the southeast projection of the Amargosa River fault zone.

3.4.2.1 Trench TR3

Trench TR3 exposes a fault that places white altered clay (QTld) against greenish-gray, carbonate-cemented cobble alluvium (Q2a)

(Plate 4). This contact forms a 55° west-dipping, west-side-down, narrow fault zone with slickensides having a 90° rake, indicating normal dip-slip movement. This is in agreement with other evidence indicative of normal faulting such as the west-facing scarp farther north in the vicinity of trench TR4.

Unit TR3A consists of discrete zones of alternating white and dark gray silty clay with carbonate cement. The unit comprises the entire footwall of the fault in this location.

Unit TR3B is exposed at the bottom of the trench, west of the fault. It is a poorly bedded, white clayey silt with carbonate cement.

Unit TR3C is a light gray cobble alluvium, moderately indurated with carbonate cement. It contains cobble-sized clasts of gray limestone, probably derived from outcrops of the Bonanza King Formation in the Amargosa Ridges to the east, and white altered clay of unit TR3A.

The clay (TR3A) is assumed to be equivalent to similar clay units of Hay and others (1986) mapped to the north of this area, which are 2 to 4 Ma (QTld). Unit TR3C was mapped as Holocene by Naff (1975) and Pleistocene to Recent by Denny and Drewes (1963). It is probably late Pleistocene in age, based on soil development and degree of induration relative to Q1a units.

The amount of vertical separation on the fault exceeds 2 m (depth

of the excavation). An approximate estimate of vertical throw on this fault can be obtained by projecting remnant surfaces of unit TR3C, 200 m to the east, to the trench site. This suggests greater than 3 m of vertical throw, which is greater than the scarp height in the area of TR4.

3.4.2.2 Trench TR4

Trench TR4 was constructed across a conspicuous, N-striking scarp of 1.2 m height in cobble alluvium (Q2a) possibly derived from the Bonanza King Formation (Plate 5).

The trench exposed a 58° west-dipping, west-side-down fault zone that is 0.5 m wide. A thick accumulation of gypsum crystals (>40 cm thick) occurs along the fault. No direct evidence for sense of slip was observed. Based on the slickensides observed in trench TR3, and younger on older stratigraphic relations across the fault in trench TR4, dip-slip displacement is inferred.

Unit TR4A has discrete, alternating zones of moderately-indurated white and dark gray silty clay that is carbonate-cemented. It is probably stratigraphically equivalent to unit QTld.

Unit TR4B overlies TR4A in a sharp contact on the upthrown side of the fault at the east end of the trench. It consists of a pale brown cobble alluvium containing clasts mostly of Bonanza King limestone and occasional pebble-sized clasts of white clay, probably derived

from unit TR4A. It also occurs at the base of the west end of the trench, on the downthrown side of the fault.

Unit TR4C is a brown clayey sand that contains 1-2 cm long crystals of gypsum along with areas pedogenically altered to white carbonate concretions 1-2 cm in diameter. TR4C is actually the thick A and B horizon of a soil developed on unit TR4B but is designated on Plate 5 as a separate unit.

Other evidence for faulting includes three small extensional fissures, presumably once exposed at the surface, infilled with eolian silt and fine sand. These fissures occur at the break in slope of the scarp above the fault. Also, within the fault zone itself, cobbles are aligned with their long axes parallel to the fault plane.

The west end of the trench was excavated to an additional 0.8 m, totalling 2.7 m deep, in an attempt to find unit TR4A. No clay was found, requiring a vertical separation of the top of unit TR4A in excess of 2.5 m.

Two soils were described in some detail: Soil TR4-1 on the downthrown side of the fault (Table 3-1 and Figure 3-9) and soil TR4-2 on the upthrown side of the fault (Table 3-2) (Plate 5). Both soils have formed on a Q2a surface and both contain Av horizons. The thickness of soil TR4-1 is 170 cm; soil TR4-2 is approximately 109 cm thick. One outstanding feature of soil TR4-1 is the 37 cm thick Btky horizon

which is described as a separate lithologic unit (TR4C) on Plate 5. This soil is unusual because of its thickness, long acicular blades of gypsum and cylindroids of CaCO_3 . A 17 cm thick Btky soil horizon was exposed in soil TR4-2.

The Harden or Profile Development Index (PDI) method was utilized on these two soils in an attempt to approximate the age of the

Figure 3-9.

Photograph of soil TR4-1 on the downdropped side of the fault between meters 3 and 4. Note the white cylindroids of CaCO_3 .

surface. It was hoped that an age estimate of the surface cut by the fault would give a maximum age for the most recent rupture event.

The PDI converts soil properties described in the field to numeric data in order to evaluate development of a soil property relative to its state in the parent material (Harden, 1982). These quantified soil properties are summed into a single number, the "profile index", which is then correlated directly to a soil age. This correlation, derived from the Merced River chronosequence of central

Figure 3-10.
 Logarithmic plot of profile development index vs time. From
 Harden (1982).

California, is presented in Figure 3-10. Since the climate of central California is cooler and wetter than southern Nevada and parent

material and vegetation are much different, there is some question about direct applicability using the California profile index vs time graph in southern Nevada.

Since soils form during periods of tectonic stability, they ideally can also be used to estimate times of tectonic disturbance by recording the differences in development between soils formed on the upthrown (stable) block and the downdropped (buried) block and on colluvium shed from the scarp during and after faulting events. The base of each soil may possibly be used as a piercing point for measuring normal offset across the fault. Amount of offset across the fault using this method is approximately 155 cm.

The PDI for the thick (170 cm) soil on the downthrown side of the fault (soil TR4-1) suggests an age between 10,000 and 40,000 ybp. The PDI suggests an age between 100 and 1000 ybp for soil TR4-2. The lower PDI for soil TR4-2 resulted in an estimated surface age that is at least an order of magnitude less than the suggested surface age of soil TR4-1. PDI numbers are derived in Tables 3-3 and 3-4. Soil TR4-2 may be thin near the fault scarp because the erosion rate could have increased due to scarp degradation. This results in an anomalously young age for soil TR4-2. The thickness of soil TR4-1 (170 cm), may be the result of an accumulation of one or more colluvial wedges on the downthrown side of the fault. However, because no clear boundary

TABLE 3-1

Soil description for TR4-1

Located 1/4 mi north of Mary Scott Spring in TR4 on an alluvial fan across a N-trending fault scarp; surface Q2a; good desert pavement development with 95% coverage, no varnish; slope 2°; aspect: west; vegetation: saltbrush, creosote, other small scrub, average 150 cm apart; moisture status is dry.

No.	Horizon	Depth cm	Lower Bndry	Moist Color	Dry Color	Texture	Structure	Consistence		
								Dry	Moist	Wet
1	Av1	0-8	cw	10YR6/3	10YR7/2	scl	2csbk	h	fi	s/po
2 ^a	Av2	8-14	cw	10YR6/3	10YR7/3	scl	2msbk	vh	vfi	ss/ps
3	Bt	14-23	gw	10YR5/4	10YR6/3	cl	2cabk	sh	vfr	ss/ps
4 ^b	Btk	23-33	cw	10YR5/4	10YR6/3	cl	1msbk	sh	vfr	s/ps
5 ^c	Btky	33-70	aw	7.5YR4/4	7.5YR5/4	scl	2vcpr	so	lo	s/ps
6	2Btk	70-104	dw	10YR5/4	10YR6/6	sl	1mabk	h	vfr	ss/ps
7	3Btk	104-170	--	7.5YR5/4	7.5YR6/4	ls	mf	lo	lo	so/ps

No.	Roots	Pores	Clay		Secondary CaCO ₃ /SiO ₂	Est. %		Stickiness	Plasticity
			Films	pH		Grv.	Cob.		
1	---	3vf	---	8.0	es	~30	~10	vs	p
2	2f	3vf	vlm	8.0	es	~15		vs	p
3	2f	2vf	vlm	8.0	es	< 5		s	p
4	2f	---	---	8.2	es	15		s	p
5 ^d	1f	---	---	8.1	es (stagell+)	5-10		s	p
6	---	3vf	---		ev	40	20	ss	ps
7 ^d	1vf	---	---		ev	40	40	ss	po

Comments: ^a Locally platy structure. ^b Dry color is mixed with 7.5YR4/4. ^c Long acicular needles and blades of gypsum occur throughout this horizon. ^d Cylindroids of CaCO₃.

TABLE 3-2

Soil description for TR4-2

Located 1/4 mi north of Mary Scott Spring in TR4 on an alluvial fan across a N-trending fault scarp; surface Q2a; good desert pavement development with 95% coverage, no varnish; slope 2 °; aspect: west; vegetation: saltbrush, creosote, other small scrub, average 150 cm apart; moisture status is dry.

No.	Horizon	Depth cm	Lower Bndry	Moist Color	Dry Color	Texture	Structure	<u>Consistence</u>		
								Dry	Moist	Wet
1 ^a	Av1	0-11	cw	10YR4/3	10YR7/3	scl	2csbk	sh	vfr	ss/ps
2	Av2	11-22	cw	10YR4/3	10YR7/3	cl	2msbk	sh	fr	s/ps
3	Bky	22-32	ca	7.5YR6/4	7.5YR7/3	sl	1mpl	sh	vfr	ss/ps
4	Bk	32-64	gs	7.5YR6/4	7.5YR6/2	sl	1mabk	sh	vfr	ss/ps
5	2Bk	64-92	as	10YR6/3	10YR7/3	s	m	lo	lo	so/po
6 ^{ac}	Btky	92-109	dw	10YR8/2	10YR7/3	c	2msbk	vh	efi	vs/p
7	BC	109-	--	7.5YR5/4	7.5YR4/4					

No.	Clay			Secondary CaCO ₃ /SiO ₂	Est.%		Stickiness	Plasticity
	Roots	Pores	Films pH		Grv.	Cob.		
1	1f	3f	---	es	~5 (w/thin pvmt)		vs	p
2	2vf	1vf	---	es	20		s	p
3 ^b	1vf	---	---	ev (stage I)	50+		s	p
4 ^b	---	---	---	ev (stage I)	50+		s	ps
5 ^b	---	---	---	ev	70+		ss	po
6	---	2vf	---	ev	--		s	p
7	---	---	---	--	--			

Comments: ^a Locally platy structure. ^b With nodules of CaCO₃. ^c Long acicular needles and blades of gypsum occur in the upper 10 cm of this horizon.

TABLE 3-3

Derivation of a Profile Development Index (PDI) for **soil TR4-1** using the Harden Index (Harden, 1982).

		<u>Harden Index number</u>						
		Av1	Av2	Bt	Btk	Btky	2Btk	3Btk
Clay films	(Xf)	---	20	20	---	---	---	---
Texture	(Xt)	50	50	45	45	40	20	10
Rubification	(Xr)	0	0	10	10	40	40	40
Structure	(Xs)	30	30	30	20	40	20	0
Dry Consistence	(Xd)	30	40	20	20	10	30	0
Moist Consist.	(Xm)	30	40	10	10	0	10	0
Value	(Xv)	10	10	30	30	50	30	30
pH	(XpH)	---	---	---	---	---	---	---

<u>Normalized Data</u>							
Xf	---	0	0	---	---	---	---
Xt	0.55	0.55	0.50	0.50	0.44	0.22	0
Xr	0	0	0.05	0.05	0.21	0.21	0.21
Xs	0.50	0.50	0.50	0.33	0.66	0.33	0
Xd	0.30	0.40	0.20	0.20	0.10	0.30	0
Xm	0.30	0.40	0.10	0.10	0	0.10	0
Xv	0.14	0.14	0.43	0.43	0.71	0.43	0.43
XpH	---	---	---	---	---	---	---

<u>Index Results</u>							
Sum normalized properties	1.79	1.99	1.78	1.61	2.12	1.59	0.64
Divide by no. of properties	0.29	0.28	0.25	0.27	0.35	0.26	0.11
Multiply by horiz. thickness	2.39	1.70	2.29	2.68	13.07	9.01	7.04

Sum horizon products through soil profile = Profile Development Index (PDI)

$$\text{PDI} = 38.18$$

TABLE 3-4

Derivation of a Profile Development Index (PDI) for **soil TR4-2** using the Harden Index (Harden, 1982).

		<u>Harden Index number</u>					
		Av1	Av2	Bky	Bk	2Bk	Btky
Clay films	(Xf)	---	---	---	---	---	---
Texture	(Xt)	50	45	40	30	10	60
Rubification	(Xr)	0	0	30	30	0	0
Structure	(Xs)	30	30	15	20	0	30
Dry Consistence	(Xd)	20	20	20	20	0	40
Moist Consist.	(Xm)	10	20	10	10	0	50
Value	(Xv)	30	30	10	20	10	0
pH	(XpH)	---	---	---	---	---	---

Normalized Data

Xf	---	---	---	---	---	---
Xt	0.55	0.50	0.44	0.33	0.11	0.66
Xr	0	0	0.16	0.16	0	0
Xs	0.50	0.50	0.25	0.33	0	0.50
Xd	0.20	0.20	0.20	0.20	0	0.40
Xm	0.10	0.20	0.10	0.10	0	0.50
Xv	0.43	0.43	0.14	0.28	0.14	0
XpH	---	---	---	---	---	---

Index Results

Sum normalized properties	1.78	1.83	1.29	1.40	0.25	2.06
Divide by no. of properties	0.29	0.30	0.21	0.23	0.04	0.34
Multiply by horiz. thickness	3.26	3.35	2.15	7.47	1.12	5.84

Sum horizon products through soil profile = Profile Development Index (PDI)

$$\text{PDI} = 17.35$$

between possible colluvial wedges has been observed, an alternate hypothesis is proposed: An amount of dust equivalent to the thickness of the hypothesized colluvial wedge could have been illuviated into the soil on the west side of the fault. This alternative hypothesis, however, leaves no explanation for the lack of an equivalent amount of illuviated material on the east side of the fault. According to Peterson (1988), the presence of an Av horizon is a major criterion for separating Pleistocene from Holocene surfaces in the NTS. The presence of an Av horizon indicates a Pleistocene deposit (no Av on Holocene deposits). Av thickness, however, is irrelevant with respect to the age of a deposit (Taylor, 1986). The presence of Av horizons on soils TR4-1 and TR4-2 supports a pre-Holocene age for both soils. A pre-Holocene age would obviously invalidate the 100-1000 ybp age for soil TR4-2.

Remnants of the Btky horizon in soil profile TR4-1 also occur on the footwall block in soil profile TR4-2, indicating that displacement post-dates soil development within this unit.

The argillic horizon of soil TR4-1 at least superficially is similar to a stratigraphically equivalent unit in the Rock Valley 2 trench (Yount and others, 1987) dated by uranium trend at 38,000 ybp (Yount, written communication, 1989).

3.4.3 Southern section

The southern section of the Ash Meadows fault zone extends southward from section 16, T18S, R50E, along the western range front of the Resting Spring Range, at least as far south as the southern Resting Spring Range (McKittrick, 1988) (Figure 3-11 and Figure 5-1). On Plate 1, evidence of surface ruptures was mapped as far south as air photo coverage allowed, in section 20, T25N, R6E, Inyo County, California. The N-striking faults along the southern spur of the Funeral Mountains may belong to this fault zone (Plate 1). If this is the case, the width of the fault zone would be approximately 12.5 km. Considering only the faults along the west side of the Resting Spring Range, the width of the fault zone is 3.5 km. The fault zone is characterized by N-striking, discontinuous scarps, tonal lineaments, and vegetation alignments on an alluvial fan composed of units Tt and Q2a.

Scarp profile P9 (Appendix A) was measured across the east-facing scarp of the graben in section 9, T25N, R6E (Inyo County, California). The graben strikes N12W. The graben provides further evidence that the Ash Meadows fault zone is an E-W extensional zone.

3.5 Interpretation of Quaternary fault features

3.5.1 Rock Valley extension

Figure 3-12 shows an equal-area projection of poles of carbonate-

and silica-coated fractures that delineate the fault in trench TR2. Most fractures strike approximately N25E, 25° counter clockwise (CCW) from the N50E orientation of geomorphic features along the fault at this location.

It is unclear whether these fractures are extension fractures or riedel shears. Extension fractures are defined as fractures that form in response to simple shear at about 45° CCW to the main fault (Biddle and Christie-Blick, 1985).

Two sets of riedel shears, or secondary shear fractures, can be associated with a strike-slip fault. One set is oriented at $\phi/2$; the other at $90^\circ - \phi/2$, CCW to the main strike-slip fault. ϕ is the internal coefficient of friction, commonly taken to be 30°. Therefore, riedel shears are commonly oriented at 15° to 75° CCW to the main strike-slip fault (Biddle and Christie-Blick, 1985).

It is difficult to determine the best hypothesis based on orientation of fractures alone: An orientation of 25° (trench TR2) falls between the 15° riedel shear and 45° extension fracture orientations. Because no evidence for shearing was found along these fractures, riedel shearing may be ruled out in favor of an extension fracture hypothesis for the origin of the fractures in trench TR2. These probable extension fractures are aligned in a left-slip orientation on the Rock Valley fault extension.

Figure 3-12.
Lower hemisphere equal-area projection of poles to carbonate- and
silica-coated fractures in trench TR2.

An unresolved debate is currently ongoing which may have implications for carbonate and opaline deposits in trench TR1 and trench TR2. The opaline silica and carbonate deposits of trench TR2 and trench 14 look very similar. The origin of a large vein-like deposit of calcite and opaline silica in trench 14 across the Bow Ridge fault in the vicinity of Yucca Mountain, NTS has led to some debate. This argument has led to considerations of a pedogenic vs. spring origin for the trench 14 deposit. The field, chemical, mineralogical, biological, petrographic, and isotopic data thus far acquired are all consistent with a pedogenic origin for the Trench 14 deposit (Taylor and Huckins, 1986). This analogous situation of the trench TR2 deposits to those of trench 14, an area of probable pedogenic calcite and silica, may be sufficient evidence in which to eliminate a hydrologic interpretation for unit TR2D in trench TR2 (see section 3.2.1.2, p. 46)

3.5.2 Amargosa River fault zone

The Amargosa River fault zone is here interpreted to be the northwest extension of the Pahrump fault zone, a 75 km long right-slip fault that extends southward at least to the south end of Mesquite Valley, south of Pahrump Valley (Hoffard, 1990). Reasons for this hypothesis include its near connection with the Pahrump fault zone across a left step in Stewart Valley and southern Ash Meadows. Also, the Pahrump fault zone and the Amargosa River fault zone have the

same orientation.

It is unclear, based on the above geomorphic data and fault orientation, whether the secondary N-striking zone of faults that is truncated on its north end by the Amargosa River fault zone is a normal dip-slip system resulting from right-slip movement along the Amargosa River fault. These N-striking faults may represent large-scale extension fractures, oriented 45° clockwise to the right-slip Amargosa River fault zone. This situation may be analogous to the possible extension fracture hypothesis observed in trench TR2.

It is also possible that the Amargosa River fault is an "accommodation zone" or transfer fault between normal fault zones to the northeast and southwest of the Amargosa River fault. The first model is the more likely, however, because of its probable link with the Pahrump zone to the southeast.

3.5.3 Ash Meadows fault zone

Evidence in trench TR4 suggests more than one rupture event based on a 1.2 m scarp height in unit Q2a and a greater than 2.7 m displacement of Q2a below the scarp. If 1.2 m approximates the characteristic displacement on this fault, a total displacement of greater than 2.7 m, divided by the characteristic displacement, results in two earthquake events.

The central and northern sections of the Ash Meadows fault zone,

north of section 11, T18S, R50E, may either be a northern extension of the range front fault along the western Resting Spring Range (McKittrick, 1988) or a NNW-striking branch fault of the NW-striking Pahrump fault zone (Figure 7-1). Evidence that supports this includes the association with the spring alignment which does not intersect the southern section. N-striking faults in the central and northern sections of the Ash Meadows fault zone may be extension faults for this supposed NNW-striking, right-slip Pahrump fault zone extension.

CHAPTER 4

Geophysical Data

4.1 Gravity Data

Several gravity lows occur within the southern Amargosa Desert, north of Stewart Valley. Three small gravity lows are aligned in a northwest orientation, a fourth low occurs in the area of the East Playa to the east of the northwest alignment, and a fifth low lies along the state line near the Amargosa River fault (Healey and others, 1980) (Figure 4-1). Three of these gravity lows are aligned with a strong gravity gradient along the eastern front of Bare Mountain. According to Wright (1988), each gravity low corresponds to a fault-controlled sedimentary basin.

The two basins within Ash Meadows are elongated and aligned approximately N45W. The third and most northerly basin along the same trend is elongate N40E and is superimposed upon the Rock Valley extension. The gravity low in the vicinity of East Playa has no preferred elongation, while the gravity low on the state line is elongate N45W, parallel to the state line. In the northern Ash Meadows area, a poorly defined negative, WSW-facing gravity gradient occurs along the eastern edge of the closed gravity lows of Ash Meadows (described above). This WSW-facing gravity gradient coincides with

Figure 4-1.
Bouguer gravity map of the southern Amargosa Desert and surrounding region. Contour interval = 5 milligals. From Wright, 1988.

the NNW-trending groundwater barrier (Winograd and Thordarson, 1975). This gravity gradient is also on trend with a strong ENE-facing gravity gradient that is the expression of the faulted eastern range front of Bare Mountain. Healey and Miller (1965) interpreted this steep gravity gradient at Bare Mountain to have resulted from 365 m to 1065 m down-to-the-east vertical displacement, increasing from south (365 m) to north (1065 m).

In addition, an ENE-facing gravity gradient lies just east of the Funeral Mountains range front. This ENE-facing gradient is aligned with a more diffuse ENE-facing gradient in the central Amargosa Desert, linking it to the strong ENE-facing gravity gradient of Bare Mountain (Figure 4-1). The Bare Mountain gravity high and the gravity high over the Funeral Mountains were interpreted by Snyder and Carr (1984) to result from a "continuous block of dense, metamorphosed Precambrian and Paleozoic rocks that stretches across much of the Walker Lane from the eastern edge of Death Valley to Bare Mountain".

Three-dimensional gravity modeling indicates that the volcanic rocks in the Crater Flat area extend to at least 2500 m below sea level. This great thickness of low density volcanic rocks filled graben-like structures and old calderas that are a possible source area for the Crater Flat Tuff (Snyder and Carr, 1984). These linear gravity lows, flanked by gravity highs, provide evidence for a large graben within the

Death Valley-Pancake Range belt (Carr, 1984) that locally extends from the Timber Mountain caldera complex and is superposed on Crater Flat basalts (Snyder and Carr, 1984).

Basin-fill thicknesses, as determined from gravity data, assuming density contrasts of 0.5 (2.70-2.20) and 0.7 (2.70-2.00) gm/cc, are 1065 m and 700 m, respectively, for an area that extends from the Funeral Mountains to Bare Mountain (Healey and Miller, 1965). Within the gravity low of southern Ash Meadows, exposures of deformed Miocene sedimentary rocks crop out (see section 2.3.4.1). These are the oldest known sedimentary rocks within the basin. An ash bed low in the sedimentary fill of Ash Meadows is radiometrically dated (K/Ar biotite) at 13.2 +/- .04 Ma (R.E. Drake, cited in Cemen, 1983). This is a minimum age for the opening of the basin.

It is important to note that gravity lows in the southern Amargosa Desert probably represent Tertiary basin geometry and do not necessarily reflect Quaternary fault patterns. However, these gravity lows define a basin geometry that probably influenced the resultant Quaternary fault pattern.

Pull-apart basins are delineated by several closed negative gravity anomalies aligned along Death Valley (Figure 4-1). Gravity data (Wright, 1988) of Pahrump Valley, Amargosa Desert, and Crater Flat suggests a pattern of N-trending basins that may be associated with

normal and strike-slip faults and related pull-apart basins. A well-known example of this structural pattern is the connection between north-striking normal faults and northwest-striking right-lateral faults of Death Valley (Stewart, 1983).

As discussed in Chapter 6, two rift models may be defined on the basis of negative gravity anomalies (Wright, 1988) (Figure 4-2). One model links this rift zone to the central Death Valley plutonic-volcanic field to the south (Greenwater volcanic center of Carr, 1984); the second model suggests the rift zone includes the negative gravity closures of Stewart Valley and Pahrump Valley (Wright, 1988) (Figure 4-2). Both models assume that the southern Amargosa Desert and Crater Flat are parts of a NNW-trending rift zone (Figure 4-2). Carr (1984) and Wright (1988) argued that the groundwater barrier and the eastern range front of Bare Mountain are the eastern and western boundaries (respectively) of the rift zone.

4.2 Seismic Refraction Studies

A seismic refraction study of deep crust and mantle structure beneath Yucca Mountain and vicinity was conducted by Hoffman and Mooney (1984). It included a line of seismic stations that extended south from Lathrop Wells to Death Valley Junction (Figure 4-3). The resultant seismic profile recorded a crust-mantle reflection and two

Figure 4-2.

Alternate rift models superposed on Bouguer gravity map of the southern Amargosa Desert and surrounding region. AMB=Ash Meadows Basin; PVB=Pahrump Valley pull-apart basin; SVB=Stewart Valley pull-apart basin. From Wright, 1988.

intra-crustal reflections. An average line through this profile gives a depth-to-basement of 1.5 km. Estimated velocities and their depths are illustrated in Figure 4-4 with two reflections at 24 km and 30 km depth. The crust-mantle boundary is estimated at 35 km between a change in mantle velocity from 6.6 km/s above, to 7.8 km/s below 35 km (Hoffman and Mooney, 1984).

Seismic refraction data from the Crater Flat area recorded the greatest depth-to-basement of the entire survey. A depth-to-basement greater than 3 km exists beneath eastern Crater Flat and western Yucca Mountain, with a graben-like structure in the basement (Hoffman and Mooney, 1984). This estimate of depth-to-basement is somewhat deeper than the 1700 m to 2400 m basin-fill thickness estimated by Healey and Miller (1965) for the same area. Nonetheless, the >3 km estimate for Crater Flat is almost double the 1.5 km depth-to-basement estimate for the southern Amargosa Desert.

Ackermann and others (1988) made a seismic refraction profile between northern Crater Flat and the southern Amargosa Desert. Their interpretation of seismic refraction velocity sections indicates a maximum thickness of 3.2 km for volcanic rocks within the caldera complex of Crater Flat (Ackermann and others, 1988). The depth of the highest velocity interface for this crustal section shallows toward the Amargosa Desert from Crater Flat, from a depth of 2.2 km below sea

Figure 4-3.
Recorder and shot locations for nuclear event deployments. Recorder site locations are indicated by dots and nuclear events by stars. From Hoffman and Mooney, 1984.

Figure 4-4.
Estimated velocities and their depths for a seismic refraction profile across the southern Amargosa Desert.

level to <1.0 km below sea level.

4.3 Seismicity

Hildenbrand and others (1988) compiled seismicity data for the period from August, 1978, to December, 1986, with a range of local magnitude from $M_L=0$ to 4 (Figure 4-5). Their map showed a concentration of microseismicity along the Mine Mountain-Spotted Range structural zone. Several clusters of microearthquakes also occurred just north of the southwest extension of the Rock Valley fault

EXPLANATION

- Earthquake epicenters
- Magnitude
- $M > 3$
 - $2 < M \leq 3$
 - $1 < M \leq 2$
 - $M \leq 1$
- Quaternary fault

Figure 4-5.

Epicenters for earthquakes occurring from August 1978 through December 1986 in the southern Amargosa Desert and surrounding region. From Hildenbrand and others, 1988.

zone in the vicinity of Lathrop Wells. In addition, an elongate concentration of small ($2 < M_L < 3$) seismic events occurred along the eastern front of the Funeral Mountains, just southwest of the southwest terminus of the Rock Valley fault zone. This cluster of events could also be interpreted as being associated with the Amargosa River fault. In either case, this cluster was in the vicinity of both fault termini. A random and diffuse scatter of microearthquakes ($0 < M_L < 3$) characterizes all other areas of the southern Amargosa Desert for the given time window. The presence of microseismicity within the southern Amargosa Desert is positive evidence that faults within the basin are active.

CHAPTER 5

Seismic Hazard Analysis

5.1 Introduction

Due to the proximity of the southern Amargosa Desert to Yucca Mountain, an attempt is herein made to deduce its seismic hazard potential. An investigation of the magnitudes of potential earthquakes that could be produced from faults at and near Yucca Mountain is imperative for engineering design considerations of the proposed high-level nuclear waste repository. Although quantitative data on slip rates and recurrence intervals are not available, geomorphic data permit a first approximation of potential earthquake magnitudes for the southern Amargosa Desert.

5.2 Approaches to seismic hazard analysis

A number of approaches to the problem of seismic risk can be considered, including study and comparison of surface active faults associated with historical surface ruptures, and the examination of historical records and seismological data (dePolo and Slemmons, 1990). In the southern Amargosa Desert, no documented felt historical earthquakes have occurred and so comparisons of surface ruptures with seismic data are not possible.

The paleoseismic approach is essentially an extension of the

historical record and involves the identification and characterization of prehistoric earthquake events. This is usually accomplished by detailed study of the geological record at locations directly along seismic sources. Techniques involved can include multiple trenching studies, tectonic geomorphic studies, and detailed mapping of surficial geology. It is important to note that there can be large uncertainties with the paleoseismic approach, especially when data from only one site are used (dePolo and Slemmons, 1990).

The source characterization approach involves analyzing the physical characteristics of potential seismic sources, such as the fault-surface rupture length, and assigning a correlative earthquake size (dePolo and Slemmons, 1990). This approach is utilized in this chapter.

The relative-comparison approach compares the source in question with similar seismic sources. It uses factors such as tectonic regime, type of displacement, size of the seismogenic zone and length of an earthquake segment (dePolo and Slemmons, 1990).

The regional approach, which involves estimating an earthquake size by reviewing the seismotectonic data of a region, was not utilized.

5.3 Seismic hazard estimates

Several types of seismic hazard estimates are used for the determination of design earthquakes, which are faults or fault systems

characterized seismologically for engineering and design purposes.

The maximum earthquake (also termed probabilistic earthquake) is defined as the largest earthquake expected to occur over a given time interval or exposure time (dePolo and Slemmons, 1990). Common examples of exposure time are 100, 1000, or 10,000 years. This estimate is dependent on recurrence interval data.

The maximum credible earthquake is the largest earthquake that appears capable of recurring in an area or along a fault (dePolo and Slemmons, 1990). It is distinguished from the maximum earthquake by being time-independent.

The characteristic earthquake model is based on the assumption that the distribution of slip associated with an event along a fault segment is repeated in successive events (Schwartz and Coppersmith, 1984). This model assumes that faults tend to generate essentially similar sized earthquakes having a relatively narrow range of magnitudes near the maximum (Schwartz and Coppersmith, 1984). This estimate requires that a fault system be subdivided into discrete segments and that slip rates and recurrence intervals of each segment be known.

Maximum background (floating) earthquakes are those from unidentified sources and/or between larger seismogenic structures. Although larger floating, or random, earthquakes can have magnitudes

of up to 5.0 to 6.5, the determination of sources associated with these earthquakes is difficult (dePolo and Slemmons, 1990). This is a situation inherent within any seismotectonic regime and therefore must be considered.

This seismic hazard study utilizes the maximum credible earthquake estimate and an altered version of the characteristic earthquake, the "Basin-Range earthquake".

Basin-Range earthquakes are defined from historical earthquakes that have occurred within the Basin and Range province. dePolo and others (1991) studied 11 historical earthquakes within the Basin and Range province and discovered that nine of the eleven events ruptured multiple segments, with several ruptures extending beyond distinct fault zone discontinuities. The dePolo and others (1991) study indicates that earthquake ruptures within extensional tectonic regimes may not be confined to individual segments and yet, Albee and Smith (1966) argued that individual historical earthquakes rarely rupture entire fault zones. These two studies suggest that earthquake rupture length for a single event lies somewhere in between an individual segment length and an entire fault zone.

Another characteristic of the Basin-Range earthquake is that many of the largest events (>7.2) involved complex, widely distributed rupture patterns (e.g. 1915 Pleasant Valley, 1932 Cedar Mountain, and

1954 Fairview Peak earthquakes) (dePolo and others, 1989). Therefore, simple earthquake segmentation models are inadequate for evaluating larger earthquakes in the Basin and Range province (dePolo and others, 1989).

Several reasons for this apparent Basin and Range seismotectonic uniqueness include: 1) decoupling and detachment faulting in the mid to upper crust, 2) heterogeneous, highly tectonized crust with preexisting structures and fabrics, and varying lithologies, (3) strike-slip displacement components that cut across pre-existing structural grain or that splay upward (flower structure), and 4) triggering of multiple ruptures by exceeding failure thresholds of adjacent faults (dePolo and others, 1989).

In this study, a Basin-Range earthquake is defined as one that ruptures multiple segments but not the entire defined fault zone. For example, the Basin-Range earthquake multiple segment is that which includes two or more pre-defined segments as in segments A-C and B-D on the Rock Valley fault zone or segments D-F and E-G on the Amargosa River fault zone/Pahrump fault zone (Figure 5-1).

5.4 Fault parameters used for the southern Amargosa Desert

Parameters used to determine potential earthquake magnitudes for faults in the southern Amargosa Desert include fault rupture length,

maximum displacement, and surface area.

5.4.1 Fault rupture-length estimates

Fault length measurements used in the southern Amargosa Desert are either potential maximum rupture lengths (for example, the entire length of the Pahrump or Rock Valley fault systems), or more conservative estimates that consider multiple segment ruptures (the Basin-Range earthquake rupture zone).

Earthquake segmentation involves the identification and characterization of discontinuities along fault zones which potentially act as barriers to earthquake ruptures (dePolo and others, 1991). Earthquake segments within fault zones are defined using several criteria. Characteristics identified as rupture endpoints, hence segment endpoints, are as follows (specific segment terminations or divisions from Figure 5-1 are identified with each characteristic): 1) fault termination (A,D,G), 2) changes in trace complexity (B,C,E,F), 3) cross faults and folds (C,E,D), 4) en echelon stepovers (E,F), 5) fault branches (C,F,G), 6) gaps (E,F), 7) basin boundaries (F,B).

Consideration of historic surface ruptures such as the 1915 Pleasant Valley and the 1983 Borah Peak earthquakes illustrates that estimating earthquake potential based on subdividing long fault systems into segments may not represent the true earthquake potential. For example, the 1915 Pleasant Valley earthquake ruptured

across four and possibly five structural or geometric segments (dePolo and others, 1991). The 1983 Borah Peak event is an example of fault rupture that did not occur along pre-defined segments that are based on surface characteristics. The 1983 rupture not only broke portions of three pre-defined segments, but possibly formed new ruptures in an area not previously defined as part of the fault zone (Freeman and others, 1986).

5.4.2 Maximum fault displacement

Fault displacement, where known, is determined from probable single event maximum scarp heights. No lateral offsets for strike slip faults have been observed in the study area; fault plane displacement measurements used are dip-slip.

Maximum displacement is measured at the west-facing scarp at TR4 (scarp profile P12). This and other non-maximum measurements are presented in Table 5-1.

5.4.3 Fault width

Fault width calculations assume two possible maximum earthquake focal depths: 11 km and 16 km (Rogers and others, 1983). These are based on southern Great Basin earthquake focal depths with the highest frequency of occurrence within the seismogenic zone.

For surface rupture to occur, an earthquake originating at a depth of 15 km is probably required to be at least a magnitude of 6.0 because

Figure 5-1
Regional Quaternary fault map for use in seismic hazard analysis.
From Donovan (1990), Hoffard (1990), McKittrick(1988), and Yount
(1987).

an earthquake source volume radius of at least 15 km would be required (Albee and Smith, 1966). This is based on the assumption that a small earthquake has a nearly spherical source volume and no surface rupture will occur unless the depth of the center of the sphere is less than half the diameter, which is represented by the long axis of the aftershock volume (Albee and Smith, 1966).

Fault width is also dependent on dip of the fault plane. Because the seismogenic depth is constrained between 11 km and 16 km, the shallower the dip on the fault plane, the larger the fault width. Except for the Ash Meadows fault zone for which a dip of 55° is assigned and therefore a width of 13.4-19.5 km, faults are assumed to have a vertical dip (90°). This is a reasonable assumption for predominantly strike-slip faults such as the Rock Valley fault zone, the Pahrump fault zone, and their extensions into the southern Amargosa Desert. Table 5-1 summarizes fault parameters used for the following source characterization approach to developing a seismic risk analysis for the study area.

5.5 Earthquake size - fault parameter correlations

Once the length of a potential earthquake rupture is determined, empirical correlation is used to transform the length parameter into an earthquake size. Most correlations assume earthquake size is linearly

Table 5-1

Fault parameters used in source characterization analysis. Parameters for length are derived from Figure 5-1.

FAULT SYSTEMS

	AMFZ ¹	RVFZ ²	PFZ ³
LENGTH (km):			
Maximum	26.5	68.0 (A-D)	79.0 (D-G)
Multiple segment ⁴	not calculated	38.0 (A-C) 51.0 (B-D)	40.0 (D-F) 57.5 (E-G)
Dip of fault plane	55°	90°	90°
Width (km)	13.4,19.5	11.0,16.0	11.0,16.0
AREA (km ²):			
Maximum	365,517	748,1088	869,1264
Multiple segment ⁴	not calculated	[418,608] ⁵ [561,816] ⁷	[440,640] ⁶ [633,920] ⁸
DISPLACEMENT (m):			
Maximum	1.2	no data	no data
Average	0.35		

1/Ash meadows fault zone

2/Rock Valley fault zone

3/Pahrump fault zone

4/Considered here to be the length of a
Basin-Range earthquake rupture

5/Segment A-C

6/Segment D-F

7/Segment B-D

8/Segment E-G

proportional to the logarithm of length (dePolo and Slemmons, 1990).

5.5.1 Regression formulas

A variety of formulas or regression analyses have been developed from these empirically derived earthquake size vs. length correlations. Most data are analyzed separately according to type of fault displacement and/or tectonic regime. For example, the relation between surface-wave magnitude (M_s) and surface-rupture length (L) for historic earthquakes of the Basin and Range (dePolo and others, 1990) is

$$M_s = 5.2 + 1.2 (\log L)$$

Regressions used in this study are empirical relationships by Slemmons (1977, 1982, 1988), Wesnousky (1986), Bonilla and others (1984), and dePolo and others (1990). These regressions are presented in Table 5-2.

5.5.2 Logic trees

Uncertainties in the resultant data set used for seismic source characterization can be clarified with application of the data set to logic trees. Logic trees allow different data values to be incorporated into the compilation of a single resultant value. Individual input values are weighted according to degrees of uncertainty associated with each

data value. The more parameters, interpretations, and models that can be incorporated into a logic tree and weighted according to respective values, the more statistically reliable will be the final output value (Kulkarni and others, 1988; dePolo, 1989).

Earthquake magnitude estimates shown in Figures 5-2 through 5-4 are partly derived from logic trees in Appendix B. A magnitude is estimated for each of the fault parameters outlined in Table 5-1 using regression equations in Table 5-2. For example, using Rock Valley fault parameters, a maximum fault length of 51 km would give a surface magnitude value of 7.2 derived from input values utilizing nine of the eleven regressions in Table 5-2 (Figure B4, Appendix B). Each of these regression equations are weighted for each segment length according to the following criteria: one point for being used, one point for using data from extensional tectonic regimes, one point if the sense of displacement implied in the regression is appropriate for the fault zone being analyzed, and one point for a regression that applies data from the Basin and Range (dePolo, 1989). Each total is normalized and then multiplied by its estimated earthquake magnitude value.

Each value derived from logic trees in Appendix B is then combined with a magnitude estimate of another fault parameter on the same fault for a final logic tree (Figures 5-2 through 5-4).

Table 5-2

Regressions derived from empirical relationships of fault length/area/displacement vs. magnitude.

LENGTH:1. Slemmons and others (1989):

All Data	<i>all</i>	SAA	$M_s = 5.39 + 1.03 (\log L)$	$R^2 = 0.83$	$SD = 0.30$
	<i>ss</i>	SAS	$M_s = 5.50 + 0.95 (\log L)$	$R^2 = 0.87$	$SD = 0.22$
	<i>dip</i>	SAD	$M_s = 5.10 + 1.25 (\log L)$	$R^2 = 0.79$	$SD = 0.34$

Ext. Data	<i>all</i>	SEA	$M_s = 5.48 + 0.93 (\log L)$	$R^2 = 0.71$	$SD = 0.29$
	<i>ss</i>	SES	$M_s = 5.17 + 1.12 (\log L)$	$R^2 = 0.82$	$SD = 0.25$
	<i>dip</i>	SED	$M_s = 5.57 + 0.87 (\log L)$	$R^2 = 0.55$	$SD = 0.35$

2. Bonilla and others (1984):

	<i>ss</i>	BSS	$M_s = 6.24 + 0.619 (\log L)$	$R^2 = 0.498$	$SD = 0.293$
West. N. Amer.		BNA	$M_s = 5.17 + 1.237 (\log L)$	$R^2 = 0.700$	$SD = 0.324$
	<i>all</i>	BAA	$M_s = 6.04 + 0.708 (\log L)$	$R^2 = 0.438$	$SD = 0.306$

3. Wesnousky (1986):

	<i>all</i>	WES	$M_s = 5.133 + 1.153 (\log L)$
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4. dePolo and others (1990):

Basin & Range		DBRL	$M_s = 5.2 + 1.2 (\log L)$	$R^2 = 0.68$	$SD = 0.3$
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DISPLACEMENT:5. Slemmons (1982):

	<i>all</i>	SDA	$M_s = 6.821 + 0.847 (\log D)$	$R^2 = 0.550$	$SD = 0.378$
	<i>normal</i>	SDN	$M_s = 6.668 + 0.750 (\log D)$	$R^2 = 0.500$	$SD = 0.340$

6. Bonilla and others (1984):

	<i>ss</i>	BDS	$M_s = 7.00 + 0.782 (\log D)$	$R^2 = 0.376$	$SD = 0.331$
West. N. Amer.		BDN	$M_s = 6.98 + 0.742 (\log D)$	$R^2 = 0.454$	$SD = 0.442$
	<i>all</i>	BDA	$M_s = 6.95 + 0.723 (\log D)$	$R^2 = 0.398$	$SD = 0.323$

7. dePolo (1989):

Basin & Range		DDB	$M_s = 6.8 + 0.8 (\log D)$	$R^2 = 0.88$	$SD = 0.2$
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TABLE 5-2 cont'd

AREA:

<u>8. Wyss (1979):</u>				
WYA	$M_s=4.15 + \log A$	$R^2=NA$	$SD=0.3$	
<u>9. Singh and others (1980):</u>				
SIA	$M_s=4.532 + 0.887 (\log A)$	$R^2=0.91$	$SD=0.344$	
<u>10. Bonilla and others (1984):</u>				
BOA	$M_s=4.96 + 0.823 (\log A)$	$R^2=0.46$	$SD=0.342$	

5.6 Seismic hazard of individual fault systems**5.6.1 Ash Meadows fault zone**

The maximum length of the Ash Meadows fault zone is measured from the northern termination of this fault zone at the Rock Valley fault extension southward through Ash Meadows, to its southern termination at the southern section (Plate 1 and Figure 3-11). Only maximum length is considered here because subdivision into segments would yield segment lengths of less than 10 km which is less than the depth of the seismogenic zone in this area.

Maximum displacement is measured from the west-facing scarp at trench TR4 (see scarp profile P12, Figure A12). Average displacement is considered to be approximately 0.35 m, also measured

across the scarp at trench TR4 (profile P11, Figure A11).

Magnitude estimates for length, area, and displacement are given equal weight in Figure 5-2. A final magnitude of M_s 6.9 is derived for this fault (Figure 5-2).

Paleoseismic evidence for multiple events on the north-striking fault system in Ash Meadows is shown in exploratory trench TR4, where white altered clay is displaced more than 2.5 m within the trench with the surface above this trench being displaced 1.2 m. The scarp height, 1.2 m, is assumed to be the "characteristic displacement" along this fault; the displacement exposed within TR4 potentially represents more than two 1.2 m paleoseismic events.

5.6.2 Rock Valley fault zone

The Rock Valley fault zone extends from its SW extension in the southern Amargosa Desert to its NE termination at point A on Fig. 5-1 in the Nevada Test Site. A left step occurs between the SW extension and the remainder of the Rock Valley fault zone, north of Hwy 95. The fault also branches into two discrete zones north of Hwy 95 near C (Figure 5-1). Three possible rupture lengths are considered in the logic tree for this fault zone (Figure 5-3): A-D (the maximum length of the Rock Valley fault zone), A-C, and B-D (Figure 5-1). A higher weight is assigned to B-D (0.4) than A-C (0.3) because B-D includes segments of

Figure 5-2.
Logic tree for the Ash Meadows fault zone.

the fault that have well-defined scarps. Segment A-B (within A-C) is inferred with no evidence of previous surface rupture. The entire fault zone (A-D) is assigned a weight of 0.3 because an earthquake is unlikely to rupture an entire fault zone within the Basin and Range (see section 5.3). Magnitude estimates of length and area are given equal weight. A final magnitude of M_s 7.2 is derived for this fault (Figure 5-3).

5.6.3 Pahrump fault zone and the Amargosa River fault zone

Three fault length measurements are considered for the Pahrump fault and its extension into the southern Amargosa Desert (Amargosa River fault zone). One fault length extends for 79.0 km, from the Pahrump fault zone at G (Figure 5-1), in a northwest direction to the northwest termination of the Amargosa River fault at D. This maximum fault length has a large discontinuity where evidence for NW-striking faulting is absent between F and E. The fault also takes a 3.5 km left step at this discontinuity.

Three possible rupture lengths are considered in the logic tree for this fault zone (Figure 5-3): D-G (see above paragraph), D-F, and E-G. A weight of 0.2 is assigned to D-G because of the unlikely event that an earthquake will rupture across the gap defined by E-F (Figure 5-1). Magnitude estimates of length and area are given equal weight. A final magnitude estimate of M_s 7.2 is calculated for this fault (Figure 5-4).

Figure 5-3.
Logic tree for the Rock Valley fault zone.

Figure 5-4.
Logic tree for the Pahrump fault zone and Amargosa River fault zone.

5.7 Conclusion

Three main fault zones in the southern Amargosa Desert are capable of generating M_s 6.9 (Ash Meadows fault zone) to M_s 7.2 (Rock Valley and Amargosa River/Pahrump fault zones) earthquakes when taking into account their various fault dimensions.

CHAPTER 6

Discussion of Regional Tectonic Models

Two regional tectonic contexts in which to view fault patterns in the southern Amargosa Desert are: 1) the Death Valley extensional system and 2) the Walker Lane belt. The southern Amargosa Desert has structural features that fit both regional tectonic provinces.

6.1 Death Valley extensional region

The Death Valley extensional region extends from the Spring Mountains westward to the Sierra Nevada and from latitude 34°N to about 37°N in a roughly triangular zone (Figure 1-4). This region appears to be the most actively extending portion of the entire Basin and Range province.

According to Hamilton (1988), the Death Valley extensional region has extended in a WNW-ESE direction as the Sierra Nevada has pulled away from the central Basin and Range along a west-dipping detachment fault system that underlies the Death Valley extensional region. This movement resulted in a westward migration of active extension. An isostatic "rebound front" developed immediately behind the westward-moving hanging wall of the main detachment fault. The rebound front developed as the eastern part of this area was

progressively unroofed, starting at the breakaway zone along the western side of the Spring Mountains and continuing to its present longitude at the Black Mountains in Death Valley. The result is that areas east of this front are no longer undergoing rapid extension and are seismically and tectonically quieter than actively extending areas to the west (Figure 6-1). In addition, the overall rate of extension has slowed significantly from an estimated rate of 20-30 mm/yr, 4-14 Ma ago, to its current rate of <10 mm/yr (Wernicke and others, 1988). The Amargosa Desert is behind the rebound front and within the region of less extension (Figure 6-1). Quaternary faults occurring in the southern Amargosa Desert are less active than Quaternary faults within the Death Valley extensional region.

Active right-lateral strike-slip faults may be as important as detachment faults in the region but their role in extension is not clear. Burchfiel and others (1987) argued that strike-slip faults in the Death Valley extensional region are transfer zones that accommodate different amounts of extension among different crustal blocks.

A contrasting hypothesis is that the Death Valley extensional region is currently pulling apart in a N45W direction, thus requiring NW-striking faults in the area to be pure right-slip faults (Caskey, 1990). According to this hypothesis, this new extension direction, along with the high topographic relief within the region, was initiated 3-4 Ma

Figure 6-1.
Idealized E-W cross section of the Death Valley extensional region showing isostatic rebound of lower plate of main detachment. After Hamilton (1988) and Wernicke and others (1989).

(Caskey, 1990; Nitchman, 1990). This hypothesis is based on data from Very Long Baseline Interferometry (VLBI) that suggests a current extension direction of N45W at a rate of 10 mm/yr (Argus and Gordon, 1989).

Wright (1988) argued that negative gravity anomalies are associated with strike-slip faults and pull-apart basins in the Death Valley extensional region. According to Wright (1988), several lines of

evidence strongly suggest that: 1) in a belt which includes Death Valley on the southwest and Pahrump Valley/Amargosa Desert on the northeast, NW-striking right-slip and N-striking normal faults are the principal expressions of crustal failure in the shaping of the present basins and ranges (many of which are delineated by strong gravity gradients and connecting negative gravity anomalies), 2) this region was divided into blocks bounded by these faults 16 to 14 Ma ago, 3) each block evolved with separate deformational and thermal histories, and 4) detachment faults are unconnected, younger features that have originated within the individual blocks. This last point contrasts with the idea that many individual detachment faults sole into a single basal detachment (Wernicke, 1988).

Burchfiel and Stewart (1966) were first to recognize southern Death Valley as a pull-apart basin with the north-striking normal faults in central Death Valley providing a right-step connection between the zones of active NW-striking, right-slip faults of the southern Death Valley fault zone and the Furnace Creek fault zone. Pull-apart basins may be widespread within the Death Valley extensional region, and may include the Saline Valley/Hunter Mtn. fault/Panamint Valley system to the west, and possibly Pahrump Valley and Ash Meadows to the east. According to Wright (1988), the Pahrump fault zone connects with faults that define Stewart Valley and the Stewart

Valley pull-apart basin. Stewart Valley coincides with a strong negative gravity anomaly and is succeeded to the northwest by three other negative anomalies that may delineate three other pull-apart basins (Wright, 1988).

Some of the ideas that follow are also discussed briefly in section 4.1. Carr (1988) delineated a rift zone in the eastern Death Valley extensional region that is defined mainly by negative gravity anomalies. According to Carr (1988), the "Kawich-Greenwater volcano-tectonic rift" extends from the Timber Mountain-Oasis Valley caldera complexes, through the Crater Flat-Prospector Pass complexes and southern Amargosa Desert, to the Death Valley plutonic-volcanic field (also known as the Greenwater volcanic center). In the southern Amargosa Desert, this rift zone is expressed by an alignment of negative gravity anomalies (Figure 4-1) and by exposures of Miocene sedimentary rocks of the Ash Meadows basin (Wright, 1988).

Wright (1988) proposed an alternate model which partly incorporates ideas of Carr (1984), and suggested a linkage between the Pahrump fault zone and Carr's rift zone (Figure 4-2). This rift zone would extend northwestward from Pahrump Valley, through Stewart Valley, in a continuous alignment of faults and apparent fault-related negative gravity anomalies and gravity gradients, connecting with the rift zone of the Amargosa Desert (Wright, 1988).

This idea is consistent with the concept of a NNW-striking dextral fault proposed by Schweickert (1989) extending from Pahrump Valley, through Stewart Valley, Ash Meadows, and into Crater Flat. This idea is based on several lines of evidence including a possible 26 km dextral offset of NW-vergent, recumbent Mesozoic folds between Bare Mountain and the Striped Hills. Schweickert (1989) cited the negative gravity anomalies in the southern Amargosa Desert that extend from Stewart Valley to Crater Flat as noted by Wright (1988) and the NNW spring alignment in Ash Meadows as occurring along this regional-scale dextral fault. Most displacement would have predated the 14-10 Ma ashflow tuffs and calderas of the Yucca Mountain region (Schweickert, 1989).

In addition, the southern Amargosa Desert is situated in a N-trending zone of basaltic volcanism, designated the Death Valley-Pancake Range belt (Carr, 1984). According to Carr (1984), this volcanic zone has greater structural-topographic expression, more Quaternary faulting, seismic activity, and geophysical anomalies than adjacent areas. This idea is supported by observations of Quaternary faulting in the southern Amargosa Desert and its near absence in regions to the north, in Sarcobatus Flat, and beyond. Quaternary faulting was in one case coincident with basaltic eruptions at Crater Flat, probably at about 1 Ma (Carr and others, 1983; Swadley and

Hoover, 1983).

Evidence cited in Section 1.5 and in this chapter suggests that the extension direction in the Death Valley extensional region over the past 14 Ma could have been between E-W to N45W. The discussions outlined above indicate that a general reduction of extensional tectonic activity in the region east of Death Valley occurred throughout the late Cenozoic. Carr (1988) attributed the low rate of tectonic activity during the Pliocene and Quaternary in this region to waning volcanism and to the mechanical effects of very thick accumulations of volcanic rock.

Patterns of Quaternary faulting in the southern Amargosa Desert appear to be similar to fault patterns in the Death Valley extensional region even though active extension east of the Black Mountains has slowed significantly.

6.2 Walker Lane belt

As noted earlier, the Walker Lane belt, as described by Stewart (1988), is the region lying between the Sierra Nevada on the west and the region of typical basin and range topography on the east. The Walker Lane belt is characterized by NW-striking right-slip and NE-striking left-slip faults. The southern Amargosa Desert partially overlaps into the Spotted Range-Mine Mountain structural block, Inyo-

Mono block, Goldfield block, and the Spring Mountains structural block (Stewart, 1988) (see Section 1.5).

The pattern of NW-striking right-slip faults and NE-striking left-slip faults typical of the Walker Lane zone also occurs in the southern Amargosa Desert and Pahrump Valley. Although there is no direct evidence for direction of slip on the Amargosa River fault, the NW-striking right-slip Pahrump fault appears to step left to the Amargosa River fault across a compressional zone in the southern Amargosa Desert. The NE-striking, left-slip Rock Valley fault continues southwest into the southern Amargosa Desert. This pattern of faulting suggests that E-W extension has occurred during the Quaternary. This is substantiated by the presence of the normal, west-side-down Ash Meadows fault zone.

CHAPTER 7

Summary and conclusions

Three main fault zones are represented by the Quaternary fault pattern in the southern Amargosa Desert. The NE-striking Rock Valley extension is interpreted as a left-lateral strike slip zone based on SiO_2 - and CO_3 -filled extension fractures oriented 25° to the main fault trace in trench TR2. The NW-striking Amargosa River fault zone is inferred to be a right-slip zone based on the interpretation that it is related to the right-slip Pahrump fault. A subsidiary, N-striking zone of faults is truncated on the north by the Amargosa River fault zone. These are probably normal faults due to their east- and west-facing scarps and their parallelism with the normal dip-slip Ash Meadows fault zone. Evidence for normal faulting on the Ash Meadows fault zone includes consistently west-facing scarps along the central segment of this fault, an exposed fault plane in trench TR3 with down-dip slickensides and younger on older stratigraphic relations across this fault in both trench TR3 and trench TR4.

The orientations of these three fault systems, together with their inferred sense of Quaternary displacement, are consistent with a strain ellipse model with maximum extension oriented roughly E-W (Figure 7-1).

Figure 7-1.

Diagrammatic representation of alternative models of faulting in the southern Amargosa Desert showing strain ellipse. See text for discussion. Strain ellipse from Christie-Blick and Biddle (1985).

The E-W extension direction is further supported in two alternate tectonic models by the presence of the NE-striking, left-slip Rock Valley extension and the NW-striking, right-slip Amargosa River fault zone (Figure 7-1). In both models, a compressional left step occurs

between the Pahrump fault zone and the Amargosa River fault zone. Model 1 shows the Pahrump fault zone continuing with the spring alignment in Ash Meadows, but crossing the Ash Meadows fault zone. In this model, the southern section of the Ash Meadows fault zone is continuous with the central and northern sections. Model 2 shows the Pahrump fault zone continuing with the spring alignment and the Ash Meadows fault zone. In this model, the southern section of the Ash Meadows fault zone is not continuous with the central and northern sections.

The southern Amargosa Desert spans two tectonic provinces: The Death Valley extensional region and the Walker Lane belt. The Death Valley extensional region is characterized by a westward migration of extension, resulting in isostatic uplift from progressive unroofing of the hanging wall in a detachment fault behind a "rebound front" (Hamilton, 1988). This process is ongoing at the longitude of the Black Mountains where the Mormon Point turtleback faults are exposed. This style of extension previously may have opened up the basin that is now the Amargosa Desert where sediments have been accumulating at least since the Miocene (unit Ts). More recently, rates of tectonic activity have slowed significantly due to the position of the Amargosa Desert behind the active rebound front.

The Walker Lane influence can be seen in the pattern of strike-

slip faults within the southern Amargosa Desert. The NW-striking, inferred right-slip and NE-striking, left-slip fault pattern typical of the Walker Lane belt occurs in the pattern of strike-slip faults within the southern Amargosa Desert.

Negative gravity anomalies occur as a series of small closures along an approximate N40W trend. These anomalies are aligned with negative gravity closures in Pahrump Valley to the south and Crater Flat to the north and may delineate a continuous line of basins in the eastern Death Valley extensional system, and which may be the expression of a rift zone in basement rocks (Carr, 1988). The rift zone would include the Timber Mountain-Prospector Pass caldera complex, north of Crater Flat and the Greenwater volcanics to the south. This rift zone appears to be a zone of concentrated Quaternary faulting, seismicity, and anomalous gravity. It is important to note that although this rift zone is pre-Quaternary, it may control Quaternary structures, such as the Ash Meadows fault zone.

The fact that microseismicity occurs within the southern Amargosa Desert basin suggests that the potential for fault rupture exists. [The seismic hazard for the southern Amargosa Desert is assessed at M_s 6.9 to M_s 7.2 for the newly classified "Basin-Range earthquake". The Basin-Range earthquake estimate concerns earthquakes that will rupture multiple pre-defined segments within a

fault zone.

Recommendations for future research:

Future research in the southern Amargosa Desert should include detailed mapping of Quaternary or Cenozoic units. This type of study would aid in determining an accurate chronology of faulting in the area. This study should include large-scale (1:12,000) mapping, and additional dating of Quaternary units using isotopic and radiogenic dating techniques. A study of soil stratigraphy of Q2a and Q1a units would be useful for segregating these units on a 1:12,000 map.

In addition to a detailed study of stratigraphy, more trench studies are necessary across mapped faults to determine ages of recent faulting events and to determine sense of slip. This would be an especially useful study on the NW-striking Amargosa River fault zone since existing data for sense of slip is limited.

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APPENDIX A

Scarp profiles

Profile P1
 Measured with
 slope stick and brunton

Figure A1.

E-facing faultline scarp in alluvium and clay. Arrow indicates location of fault
 and 13° maximum slope angle. The profile is located approximately 100 m south of
 trench TR3 which exposes a fault plane dipping 55° to the west.

Location of profile: SE1/4 section 2, T18S, R50E.

---- Profile P2
 Measured with
 slope stick and brunton

Figure A2.
 E-facing faultline scarp in alluvium and clay. Arrow indicates approximate
 location of fault and 8° maximum slope. Location of profile:
 SE1/4 section 2, T18S, R50E.

Figure A3.

W-facing, highly degraded fault scarp of the N-striking secondary fault zone associated with the Amargosa River fault zone. Fault possibly occurs between arrows. Long arrow indicates location of 3.5° maximum slope angle. Location of profile: SW1/4 of section 28, T17S, R49E.

Profile P4
 Measured with
 slope stick and brunton

Figure A4.

SE-facing erosional scarp in alluvium and calcrete, delineating approximate
 location of the Rock Valley fault extension; measured approximately 50 m
 southwest of trench TR2; arrow indicates location of 14° maximum slope angle.
 Location of profile: NW1/4 of section 34, T16S, R49E.

+--+ Profile P5
 Measured with
 slope stick and brunton

Figure A5.

SE-facing erosional scarp in alluvium and calcrete, delineating approximate
 location of Rock Valley fault extension; measured approximately 100 m northeast
 of trench TR2. Arrow indicates location of 8° maximum slope angle. Location of
 profile: NW1/4 of section 34, T16S, R49E.

Profile P6
 Measured with
 slope stick and brunton

Figure A6.
 NW-facing fault scarp in alluvium; delineating location of fault of the
 Rock Valley fault extension. Arrow indicates location of 6° maximum
 slope angle. Location of profile: SW1/4 of section 19, T17S, R49E.

Profile P7
 Measured with
 slope stick and brunton

Figure A7.
 NW-facing fault scarp in alluvium, delineating fault of the Rock Valley
 fault extension. Arrow indicates location of 5° maximum slope angle.
 Location of profile: SW1/4 of section 19, T17S, R49E.

--- Profile P8
 Measured with
 slope stick and brunton

Figure A8.

NW-facing multi-faceted fault scarp in alluvium, delineating possible
 multi-faulting events on fault of the Rock Valley fault extension. Arrows
 indicate locations of maximum slope angles (6.5° each). Location of profiles:
 NE1/4 of section 19, T17S, R49E.

Figure A9.
E-facing, highly degraded fault scarp of N-striking graben of Ash Meadows
fault zone. Arrow indicates 2° maximum slope angle. Location of profile:
SE1/4 of section 9, T25N, R6E.

Figure A10.
 W-facing fault scarp of N-striking graben of Ash Meadows fault zone.
 Arrow indicates location of 4° maximum slope angle. Location of profile:
 NE1/4 of section 9, T25N, R6E.

Profile P11
 Measured with
 slope stick and brunton

Figure A11.
 W-facing fault scarp in alluvium, delineating location of fault of the
 Ash Meadows fault zone. Arrow indicates location of 10.5° maximum
 slope angle. Located approximately 200 m south of trench TR4 in
 NW1/4 of section 35, T17S, R50E.

--- Profile P12
 Measured with
 slope stick and brunton

Figure A12.
 W-facing fault scarp in alluvium, delineating trace of fault of Ash Meadows
 fault zone. Arrow indicates location of 12.5° maximum slope angle. Profile
 is located approximately 100 m north of trench TR4 in
 NW1/4 of section 26, T17S, R50E.

APPENDIX B

Logic Trees

Figure B1.
Logic tree for the maximum length of the Ash Meadows fault zone
using regression calculations from Table 5-2.

Figure B2.

Logic trees for the fault area of the Ash Meadows fault zone using regression calculations from Table 5-2. Fault widths of 11 km and 16 km are considered.

Figure B3.
Logic tree for maximum displacement of the Ash Meadows fault zone
using regression calculations from Table 5-2.

Figure B4.

Logic trees for the maximum length (A-D) and two possible multiple segment lengths (A-C and B-D) of the Rock Valley fault zone. These logic trees use regression calculations from Table 5-2.

Figure B5.

Logic trees for the maximum area (A-D) and two possible multiple segment areas (A-C and B-D) of the Rock Valley fault zone. Fault widths of 11 km and 16 km are considered. Regression calculations from Table 5-2 are used.

Figure B6.

Logic trees for the maximum length (D-G) and two possible multiple segment lengths (D-F and E-G) of the Amargosa River and Pahrump fault zones. These logic trees use regression calculations from Table 5-2.

Figure B7.

Logic trees for the maximum area (D-G) and two possible multiple segment areas (D-F and E-G) of the Amargosa River and Pahrump fault zones. Fault widths of 11 km and 16 km are used. See regression calculations in Table 5-2.

NORTHWEST

PLATE 2

TRENCH 1 - Rock Valley fault

ick Valley fault

TR1A

Very pale brown (10YR 8/3) alluvium (pebble gravel) with discrete zones of well indurated alluvium, cemented with SiO₂. contains at least one buried soil toward the top of this unit, also has a small fluvial channel cut into alluvium.

TR1B

Very pale brown (10YR 7/3) pebbly alluvium, mainly volcanic clast, in carbonate cement, strongly cemented toward base. Scollitus burrows on ground surface above this unit.

TR1C

White (10YR 8/2) carbonate cemented alluvium, fractures within this unit are infilled with non-indurated pebbly alluvium, probably equivalent to unit TR1B.

AST WALL

Q1a

Ground surface

LEVEL LINE

Unit TR1C

buried soil

paleochannel

10

11

12

13

14

15

16

Very pale brown (10YR 8/3) alluvium (pebble gravel) with discrete zones of well indurated alluvium, cemented with SiO_2 ; contains at least one buried soil toward the top of this unit, also has a small fluvial channel cut into alluvium.

Very pale brown (10YR 7/3) pebbly alluvium, mostly volcanic clasts in carbonate cement, strongly cemented toward base; scotinus burrows on ground surface above this unit.

White (10YR 8/2) carbonate cemented alluvium, fractures within this unit are infilled with non-indurated pebbly alluvium, probably equivalent to unit TR1B.

SOUTHEAST

Q1a

nd surface

Unit TR1C

paleochannel

12

13

14

15

16

17

18

NORTHWEST

PLATE 3

5

6

7

8

9

10

11

R

U

TRENCH 2 - Rock Valley fault

ley fault

TR2A

White (10YR 8/2) SiO₂ cemented alluvium, coarse sand, low pebble sized mafic volcanics and fine sand felsic intrusives, channel deposits on surface (near 1m) contain boulder sized pieces of well indurated pedogenic calcrete, scambur burrows prevalent on ground surface above this unit. This unit is also mapped unit Q1a.

TR2B

Poorly indurated cobble gravel, stage II-III carbonate accumulation, this unit appears to be truncated either by channeling or faulting at meters 12, 23, and 26.

TR2C

Light gray (10YR 7/2) alluvium indurated with SiO₂ and CaCO₃ cement, stage 2 carbonate accumulation on clasts, this unit appears to be capped by a 1-3 mm thick coating of opaline silica, calcite and opaline silica-filled extension fractures are common.

TR2D

White, grading from 10YR 8/1 (CaCO₃) to 10YR 8/2 (SiO₂), extremely well indurated alluvium, cemented with high % of both CaCO₃ and SiO₂ (stage VI carbonate accumulation), this unit is tilted 20° to the SE and exposed at the surface as a white line striking N4, possibly defining the RVFZ here.

TR2E

Light gray (10YR 7/2), poorly indurated, CaCO₃ cemented alluvium, CaCO₃ coated grains common (stage II-III carbonate accumulation), includes numerous buried soils.

TR2F

Loose channel fill, mostly pebble size, weak platy soil structure with stage II carbonate accumulation and some clay films.

1.
2.
3.
4.

2
23
24

SOUTHEAST

WEST

PLATE 4

TRENCH 3 - Rooker I

- Rooker Road fault

1. altered clay II and dark gray altered clay I
 mapped equivalent to mapped in 1971 and 1974

alternately colored, poorly bedded, clay II content

alternately colored, moderately bedded, clay II content
 white clay, poorly bedded, equivalent to mapped in 1971 and 1974

W

Participants: Thomas Sawyer, Ma

STRATIGRAPHIC

Unit A	Brown, very fine sand with p to medium roots and few co
Unit B	Light brown, very fine sand and large blocky structure
Unit C	Light tan, very fine sand filled with concentrically small charcoal fragments at
Unit D	Light brown, fine sand w finely cross-bedded lamina
Unit E	Light brown, very fine sand

LOG OF TRENCH AT EXCAVATION SITE 3

s: Thomas Sawyer, Marith Reheis, and John Caskey

STRATIGRAPHIC UNITS

very fine sand with platy structure; numerous fine
ium roots and few coarse roots.

brown, very fine sand with compound large platy
rge blocky structure and numerous fine roots.

tan, very fine sand and silt; massive; root casts
with concentrically layered clay and silt and
charcoal fragments are common.

brown, fine sand with little silt; massive to
cross-bedded lamina.

—	Str
—	Fra
—	Pla

VATION SITE 3

EXPLANATION

- Stratigraphic contact; dashed where inferred
- /// Fractures; dashed where inferred
- ⌘ Plant

PLATE V

EXPLANATION

mic contact; dashed where inferred

dashed where inferred

Participants: Thomas Sawyer, 1

STRATIGRAPHY

Unit A	Brown, very fine sand with to medium roots and few c
Unit B	Light brown, very fine s and large blocky structur
Unit C	Light tan, very fine sand filled with concentrical small charcoal fragments
Unit D	Light brown, fine sand finely cross-bedded lamir
Unit E	Light tan, very fine sar fragments are common.
Unit F	Light brown, discontinuou sand with platy structure occur within the unit.
Unit G	Light brown, massive unit sand with minor silt to v
Unit H	Light brown, coarse to fi well-indurated, with in: gravel-sized clasts.
Unit I	light brown, fine sand wi cross-bedded lamina.

ants: Thomas Sawyer, Marith Reheis, and John Caskey

STRATIGRAPHIC UNITS

own, very fine sand with platy structure; numerous fine medium roots and few coarse roots.

ght brown, very fine sand with compound large platy and large blocky structure and numerous fine roots.

ght tan, very fine sand and silt; massive; root casts filled with concentrically layered clay and silt and all charcoal fragments are common.

ght brown, fine sand with little silt; massive to finely cross-bedded lamina.

ght tan, very fine sand and silt; massive; charcoal fragments are common.

ght brown, discontinuous layer of silt and very fine sand with platy structure. Numerous charcoal fragments occur within the unit.

ght brown, massive unit that grades upwards from medium sand and with minor silt to very fine sand and silt.

ght brown, coarse to fine sand; massive; moderately to well-indurated, with infrequent well-rounded granitic gravel-sized clasts.

ght brown, fine sand with minor silt; massive to finely cross-bedded lamina.

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vertical

EXPLANATION

- Stratigraphic contact; dashed where inferred
- Fractures; dashed where inferred
- Plant

PROCEDURES

The trench wall was cleaned with hand tools, brushes, and compressed air. This procedure was occasionally repeated to provide fresh exposures. A horizontal baseline or datum was constructed along the wall from heavy nails and sturdy string. The horizontality of the datum was determined with a line level and a clear plastic tube open at both ends and partially filled with water, i.e., the water levels in the tube seek the horizontal. The datum was demarcated at one meter intervals. Key stratigraphic contacts and geologic structures were delineated by nails and colored flagging. The trench was logged by measuring along, and vertically from the datum to contacts and structures.

20

24

- - 2

EXPLANATION

contact; dashed where inferred

shed where inferred

PROCEDURES

cleaned with hand tools, brushes, and procedure was occasionally repeated to
 3. A horizontal baseline or datum was
 all from heavy nails and sturdy string.
 e datum was determined with a line level
 e open at both ends and partially filled
 ter levels in the tube seek the horizontal.
 at one meter intervals. Key stratigraphic
 structures were delineated by nails and
 trench was logged by measuring along, and
 m to contacts and structures.

EVIDENCE OF QUARRYING

QUATERNARY FAULTING IN THE INYO AND NYE COUNTIES, CALIF

BY
DIANE DONOVAN
1990

IN THE SOUTHERN AMARGOSA I , CALIFORNIA AND NEVADA

BY
DONOVAN
990

OSA DESERT,

SW EXTENSION

AMARGOSA RIVER FAULT Z

ZONE

NORTHERN SECTION

36°30'

CENTRAL SECTION

MAP EXPLANATION

Features indicative of fault recency/location:

- bt - ballena offset or truncated
- dd - deflected drainage
- ld - linear drainage
- s - scarp in late Tertiary/Quaternary alluvium
- sa - saddle
- sc - scarp expressed as a channel edge
- t - tonal lineament
- tr - trough
- v - vegetation alignment

Traces of late Tertiary/Quaternary faults based on surface low-sun-angle photography and in the field. Solid line indicate dashed line indicates a faulted feature of less certainty, dotted ball indicates direction scarp faces.

spring

very subtle t
in alluvium

Kelley's Well

Gravel Pit

s in alluvium
Radio Telephone Sta.

Death Valley Junction

Airstrip

s across drainage
s across drainage

on tures,

dd - deflected drainage

ld - linear drainage

s - scarp in late Tertiary/Quaternary alluvium

sa - saddle

sc - scarp expressed as a channel edge

t - tonal lineament

tr - trough

v - vegetation alignment

Traces of late Tertiary/Quaternary faults based on surface features observed in low-sun-angle photography and in the field. Solid line indicates well-defined fault; dashed line indicates a faulted feature of less certainty, dotted where concealed. Ball indicates direction scarp faces.

spring

END

**DATE
FILMED**

10 / 7 / 93