# Chapter 11

# Quaternary Faulting on the Northern Crater Flat Fault

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## Contents



## Abstract

Quaternary activity on the Northern Crater Flat Fault was studied in a trench that exposes evidence of four or five surface-rupturing paleoearthquakes. The youngest faulting event is estimated to have occurred 6–4 ka, and the oldest about 500 ka. The total net cumulative displacement of the oldest deposits exposed in the trench (estimated age, >500 ka) is about 122 cm, which yields a slip rate of <0.0024 mm/yr. The average earthquake-recurrence interval is estimated at 165 k.y. for three interseismic intervals, or 124 k.y. for four interseismic intervals.

## Introduction and Setting

The Northern Crater Flat Fault is a discontinuous, multistrand, normal to left-oblique-slip fault along the northeast edge of Crater Flat and the northwest flank of Yucca Mountain (figs. 1, 2). Characteristics of the fault are summarized in chapter 3 and were described by Simonds and others (1995).

In general, Quaternary deposits younger than middle Pleistocene are poorly preserved along the Northern Crater Flat Fault (see Faulds and others, 1994). The most extensive, relatively young deposits are on a large, middle to upper Pleistocene alluvial fan (units Qa3/Qa4, table 2). Therefore, to examine the paleoseismic history of the fault in the youngest deposits available, trench CFF–T2 (fig. 2) was excavated where the fault crosses this fan, as well as where it crosses a vegetation lineament that is on line with projections of scarps preserved in older deposits along the fault. An alternative trench (CFF–T2A) was located on a subtle scarp in lower to middle Pleistocene alluvial gravel about 1.5 km north of trench CFF–T2. The deposits in trench CFF–T2A are correlated with either unit Qa1 or unit Qa2 (see Faulds and others, 1994), more likely with unit Qa1, on the basis of the carbonate cementation exposed in the trench and the topographically rounded surface covered with abundant carbonate chips. Estimated ages for units Qa1 and Qa2 are 430–760 ka and 380+350/−110 ka, respectively (see chap. 2).

Both trenches were excavated in spring 1995. Trench CFF–T2 (fig. 2) did not intersect the fault; the vegetation lineament that led to siting of the trench may be a paleoearthquake-related feature, but one that produced no measurable offset of the alluvial fan in that locality. Fault offset was observed in trench CFF–T2A, however, and the Quaternary paleoseismic history of the Northern Crater Flat Fault, as determined from detailed logging and interpretation of the exposed geologic relations, is summarized in this chapter. Because trench CFF–T2A was excavated in lower to middle Pleistocene deposits, the paleoseismic record preserved in the walls of the trench may be incomplete with respect to possibly later faulting events.

## Methods

Trench CFF–T2A (pl. 19) was logged by using field and close-range photogrammetric methods (see chap. 1). Stratigraphic units were described in accordance with standard sedimentologic terminology, and soil descriptions follow the nomenclature of Birkeland (1984) and Machette (1985). Paleoearthquakes were identified on the basis of offset units across the fault, colluvial wedges or fault fissures, and the upward termination of fractures (see chap. 1). U-series and thermoluminescence analyses were used to estimate the ages of stratigraphic units and soils and to date paleoearthquakes. Dating methods are described in chapter 2, and estimated ages of the materials collected in trench CFF–T2A are listed in table 31.

**Table 31.** Numerical ages of deposits exposed in trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 19 and figures 1 and 2 for locations. Samples: TL–62 through TL–64 (error limits, ±2σ), thermoluminescence analyses by S.A. Mahan; HD 1964 and HD 1966 (error limits, ±2σ), U-series analyses by J.B. Paces]

| Trench (pl. 19) | Sample | Unit and material sampled | Estimated age (ka) |
|---|---|---|---|
| CFF–T2A | TL–62 | 6, clast rind---------------- | 5±1 |
| | TL–63 | 4, silty sand---------------- | 84±19 |
| | TL–64 | 4, silty sand---------------- | 495±434 |
| | HD 1964 | 2, clast rind---------------- | >400 |
| | HD 1966 | 5b, clast rind--------------- | 32±2, 493±260 |

# Stratigraphy, Soils, and Structure Exposed in Trench CFF–T2a

Trench CFF–T2A (pl. 19) exposes a sequence of alluvial sandy gravel (units 1–5) and eolian sand (unit 6); unit descriptions are listed in table 32. Units 1, 2, 4, 5, and 6 have characteristics typical of the alluvial gravel deposits around Yucca Mountain; they contain subangular to subrounded clasts of Tertiary volcanic rocks, are generally poorly to moderately well sorted, and range in texture from matrix to clast supported. Units 1, 4, 5, and 6 are present on both the downthrown and upthrown blocks of the fault, whereas units 2 and 3 are present on only the downthrown block. Unit 3 probably resulted from stripping of units 1 and (or) 2 on the upthrown (east) block. Disrupted pods of B soil horizon, which are common in unit 3, are believed to have originated on the upthrown block. Additionally, unit 3 has been extensively bioturbated from burrowing animals and from plant roots, as evidenced by abundant rhizoliths and an irregular base. Unit 2 has a well-developed carbonate soil that is absent on unit 3, and the top of the unit is irregular, indicating a period of erosion before the deposition of unit 3. Subunit 5a is a wedge-shaped deposit, with characteristics indicative of both alluvial and colluvial origins, that accumulated on the downthrown side of a small-displacement fault strand (pl. 19). Subunit 5d, consisting primarily of clasts from unit 5, is interpreted to have been deposited as an upper part of unit 5 that was later broken up to form a "rubble" zone resulting from movement on the directly underlying Northern Crater Flat Fault zone (pl. 19; fig. 44).

Age constraints on the exposed units in trench CFF–T2A include two thermoluminescence analyses of silty sand from unit 4 (samples TL–63, TL–64, pl. 19; table 31) and four U-series analyses of buried silica-carbonate soils that formed units 2 and 5. The two thermoluminescence analyses yielded radically different age estimates of 84±19 ka (sample TL–63) and 495±434 ka (sample TL–64). Although the age of sample TL–64 fits within the estimated ages for units Qa1 and Qa2, the extremely high dose rate for these two samples (8–10 grays/k.y.) indicates that neither estimated age is reliable (S.A. Mahan, oral commun., 2000).

Three moderately well developed silica/carbonate-cemented ($CaCO_3$ stage II–IV morphology) buried soils are exposed in the trench (see soil profiles on pl. 19 and soil descriptions in table 33). The youngest buried soil (b1) is formed on units 4 and 5 on the upthrown block and on units 3 through 5 on the downthrown block. This buried soil probably represents several cycles of erosion and soil formation, and the top forms a conspicuous stripped, irregular boundary with the overlying eolian unit 6 and a modern A soil horizon. U-series estimated ages of the opaline silica component of soil b1 range from 32±2 to 493±260 ka (sample HD 1966, pl. 19, table 31). The second-youngest buried soil (b2) is formed on unit 2 on the downthrown block. On the upthrown block, this soil is probably included as part of the carbonate soil designated b1 or b2. On the basis of a U-series analysis (sample HD 1964, pl. 19; table 31) the age of soil b2 on the downthrown block is estimated at older than 400 ka. The oldest buried soil (b3) is formed on unit 1 on both the upthrown and downthrown blocks.

The main fault zone exposed in trench CFF–T2A (pl. 19) has a flower-shaped geometry that ranges in width from about 0.8 m near the bottom of the trench to 3 m near the top (fig. 44). The central part of the fault zone consists of an intact triangular block of carbonate-cemented unit 5, with two main fissures on either side (fig. 44). The eastern fissure is nearly vertical and appears to extend from unit 5 upward into unit 6; the western fissure has dips ranging from about 10° near the top of the trench, through 40° midway down the trench wall, to vertical at the intersection with the eastern fissure about 1 m above the base of the trench. Fractures parallel both fissures. The central block and both fissures are believed to have formed by lateral shear and by downdropping of units on the west side of the fault. As the west side was downdropped by vertical and (or) lateral shear along the vertical part of the main fault trace, the central block became detached from the main downthrown block and tilted westward. The tilting (1) opened the near-vertical extensional fissure on the east side of the block, (2) opened the shallow fissure (by shear) on the west side, and (3) broke apart the upper part of the central block, thereby creating the rubble zone in subunit 5d. The scarp on the surface corresponds to the western fissure. Both fissures are filled by eolian/colluvial silty sand. A thermoluminescence analysis of a sample (TL–62, pl. 19; table 31) from fill in the western fissure yielded an estimated age of 5±1 ka.

Fractures extend to various stratigraphic levels, away from the main fault trace on both the upthrown and downthrown blocks (fig. 44). Individual fracture sets are difficult to distinguish, although two distinct sets are apparent: one set of shear fractures that terminate at the top of unit 4b on the upthrown block, and one set of primarily extensional fractures that terminate at the top of unit 5.

The downthrown block is backtilted and possibly slightly downwarped. Units 1 through 4 are backtilted and may be slightly convex upward, with the high point near soil profile III (pl. 19). Fractures near the west end of the trench may be related to backtilting or folding. The net cumulative vertical displacements described in the following sections were esti-

**Table 32.** Descriptions of stratigraphic units exposed on the south wall of trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 19 and figures 1 and 2 for locations. Position: DB, downthrown block; UB, upthrown block. Descriptions of upthrown block are from observations made predominantly in the vicinity of soil profile I, and descriptions of downthrown in the vicinity of soil profile III. General lithology (in order from most to least abundant): pbl, pebble (2–60 mm); cbl, cobble (6–26 cm); bld, boulder (>26 cm); snd, sand (<2 mm); slt, silt. Matrix: c, coarse; f, fine; masked, obliterated by pedogenic carbonate; m, medium; pbl, pebble; slt, silt; snd, sand; vc, very coarse; vf, very fine. Cementation: CO3, carbonate; ind, indurated; mod, moderate; non, noncemented; Si, silica; stg, strong; vstg, very strong; wk, weak. Fabric includes degree of sorting and rounding of grains, bedding characteristics, degree of imbrication, type of internal support, and characteristics of lower contact. Deformation: EW, event wedge; F, faulted; FF, fissured. Do., ditto]

| Unit or subunit | Position | General lithology | Clast size (cm) and abundance (vol pct) | Matrix | Cement | Thickness (cm) | Shape | Fabric | Miscellaneous features | Deformation |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UB | pbl snd cbl slt | <22, 70–90 | slt-c snd | $CO_3$, Si, stg | >95 (base not observed) | Tabular --------- | Poorly to moderately well sorted, subrounded, gravel beds continuous and extensive, moderate imbrication down to the east, matrix to clast supported, lower contact not exposed. | Matrix at top of unit contains eolian contribution. | F |
| 4 | UB | snd pbl cbl | <20, 30–80 | f-c snd | $CO_3$, wk-mod | 0–90 (avg 75) | Lenticular tabular. | Poorly to moderately well sorted, subangular to subround, local lenses of cobbles (unit 4a), poor imbrication down to the east, matrix supported, unconformable sharp lower contact. | – – – | F |
| 4a | UB | pbl snd pbl | <29, 60–90 | f-c snd | $CO_3$, wk-mod | 0–35 (avg 20) | Lenticular ------ | Moderately well sorted, subrounded, no bedding or imbrication, clast supported, gradational to sharp lower contact. | – – – | F |
| 4b | UB | pbl cbl snd | <80, 70–90 | f-c snd | $CO_3$, mod | 0–30 (avg 25) | do ----------- | Poorly to moderately well sorted, subangular, poor imbrication down to east, clast supported, sharp to gradational lower contact | – – – | F |
| 4a/4b | UB | pbl snd cbl | <26, 50–70 | f-c snd | $CO_3$, wk-mod | 0–64 (avg 40) | do ----------- | Poorly sorted, subrounded, jumbled appearance with pods of moderately well sorted gravel and some pebble alignment, matrix supported, unconformable sharp lower contact. | – – – | F |
| 5 | UB | pbl cbl snd bld | <53, 85–95 | snd | $CO_3$ and Si, mod-stg | 0–100 (avg 80) | Irregular; assumed to be originally tabular before erosion. | Moderately well to well sorted, subangular to subrounded, bedding that dips east, some crossbedding, moderate to strong imbrication down to the east, some upward grading, clast supported, sharp lower contact. | Top of unit has been stripped by erosion. | F |
| 5a | UB | pbl snd cbl | <29, 85–95 | f-c snd | $CO_3$, mod | 0–18 (avg 14) | Lenticular/ wedge. | Poorly to moderately well sorting, subrounded to subangular, minor bedding, clast supported, gradational to sharp lower contact. | Probably alluvium and colluvium deposited on downthrown side of fault. | EW?, F |

**Table 32.** Descriptions of stratigraphic units exposed on the south wall of trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada—Continued

| Unit or subunit | Position | General lithology | Clast size (cm) and abundance (vol pct) | Matrix | Cement | Thickness (cm) | Shape | Fabric | Miscellaneous features | Deformation |
|---|---|---|---|---|---|---|---|---|---|---|
| 5c | UB | pbl snd cbl | <20, 60–90 | snd | $CO_3$, wk-stg | 0–>180 (avg 120) | Irregular -------- | Moderately well to well sorted, subrounded, distinct bedding, moderate to strong imbrication down to the east, clast supported, gradational to sharp lower contact. | Top of unit has been stripped by erosion. | F |
| 6 | UB | slt pbl cbl | <100, 5–10 | slt-f snd | $CO_3$, wk | 15–90 (avg 20) | Tabular with irregular base. | Well sorted, subrounded to rounded, no bedding or imbrication, laminar carbonate/silica clasts from soil on unit 5 are present in lower part of unit, matrix supported, lower contact is irregular and sharp. | – – – | F |
| 1 | DB | pbl snd slt cbl | <25, 70–90 | f-c snd | $CO_3$, wk-well | >60 (base not exposed) | Top is irregular. | Poorly to well sorted, subangular to subrounded, bedded with poor to moderate imbrication, clast supported, lower contact not exposed. | Matrix at top 20 cm of unit contains eolian contribution. | F |
| 2 | DB | pbl snd cbl | <20, 70–95 | f-c snd | $CO_3$, wk-stg | 0–80 (avg 60) | Irregular; assumed to be originally tabular before erosion/bioturbation. | Poorly to moderately well sorted, subangular to subround, bedded with moderate imbrication down to east, clast supported, sharp lower contact. | Appears to have a sandy unit (1) at base. | F, probably deposited due to paleoearthquake that caused erosion on the UB |
| 3 | DB | slt pbl snd cbl | <15, 20–50 | slt-c snd | $CO_3$, wk-mod | 25–>110 (avg 50) | Tabular/ irregular. | Poorly to well sorted for gravel and slt, respectively, subrounded, no bedding or imbrication, strongly bioturbated, contains carbonate-coated clasts from underlying unit, matrix supported, unconformable, irregular sharp lower contact. | Abundant pods of B soil horizon with 10YR 6/4-7/4 color. | Do. |
| 4 | DB | pbl cbl snd bld | <50, 60–80 | f-c snd | $CO_3$, wk-mod | 50–90 (avg 80) | Tabular --------- | Poorly to well sorted, subangular to subrounded, gravel bedding and sandy-cobble lenses common (see unit 4a), top of unit generally defined by sandy-cobble layer (unit 4b), strong imbrication down to the east, clast supported, sharp lower contact. | Few fragments of B soil horizon present. | F |

**Table 32.** Descriptions of stratigraphic units exposed on the south wall of trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada—Continued

| Unit or subunit | Position | General lithology | Clast size (cm) and abundance (vol pct) | Matrix | Cement | Thickness (cm) | Shape | Fabric | Miscellaneous features | Deformation |
|---|---|---|---|---|---|---|---|---|---|---|
| 4a | DB | snd cbl pbl slt | <200, 70–80 | slt-c snd | $CO_3$, mod | 0–40 (avg 20) | Lenticular ------ | Moderately well to well sorted, subangular to subrounded, no bedding or imbrication, clast supported, sharp lower contact. | Pods of B soil horizon present. | F |
| 4b | DB | snd cbl pbl slt | <200, 70–80 | slt-c snd | $CO_3$, mod | 0–40 (avg 20) | do ----------- | Moderately well to well sorted, subangular to subrounded, no bedding or imbrication, clast supported, sharp lower contact. | do -------------- | F |
| 5 | DB | pbl cbl snd slt bld | <43, 70–90 | slt-c snd | $CO_3$, stg | 0–140 (avg 70) | Wedge, pinching to west; assumed to be tabular before erosion. | Poorly to moderately well sorted, subangular to subrounded, local bedding, moderate imbrication down to east, clast support, sharp lower contact. | Top of unit has been stripped by erosion. | F |
| 5b | DB | cbl snd pbl bld | <40, 80–90 | f-c snd | $CO_3$, mod stg | 0–30 (avg 20) | Lenticular ------ | Moderately well to well sorted, subround, no bedding or imbrication, clast support, gradational to sharp lower contact. | – – – | F |
| 5d | DB | pbl cbl snd slt bld | <43, 70–90 | slt-c snd | $CO_3$, stg | 0–140 (avg 70) | Wedge, pinching to west; assumed to be tabular before erosion | Poorly to moderately well sorted, subangular to subrounded, local bedding, moderate imbrication down to east, clast supported, sharp lower contact. | Unit is the same as unit 5, except that it is a rubble zone created by faulting. | F |
| 6 | DB | slt pbl cbl snd | <20, 5–10 | slt | $CO_3$, wk | 15–40 (avg 20) | Tabular with irregular base. | Well sorted, angular to subangular, no bedding or imbrication, matrix supported, unconformable irregular lower contact. | Carbonate clasts from unit 5 have been pedogenically worked up into this unit; unit appears to redden downward, indicating weak B soil-horizon development. | F |
| Fissure fill | Fault zone | slt snd pbl cbl | <7, 5–10 | slt-c snd | $CO_3$, wk | 0–20 (avg 10) | Fissure with increasing width upward. | Moderately-well sorted, angular to subround, no bedding or imbrication, matrix supported, sharp boundaries. | – – – | FF |

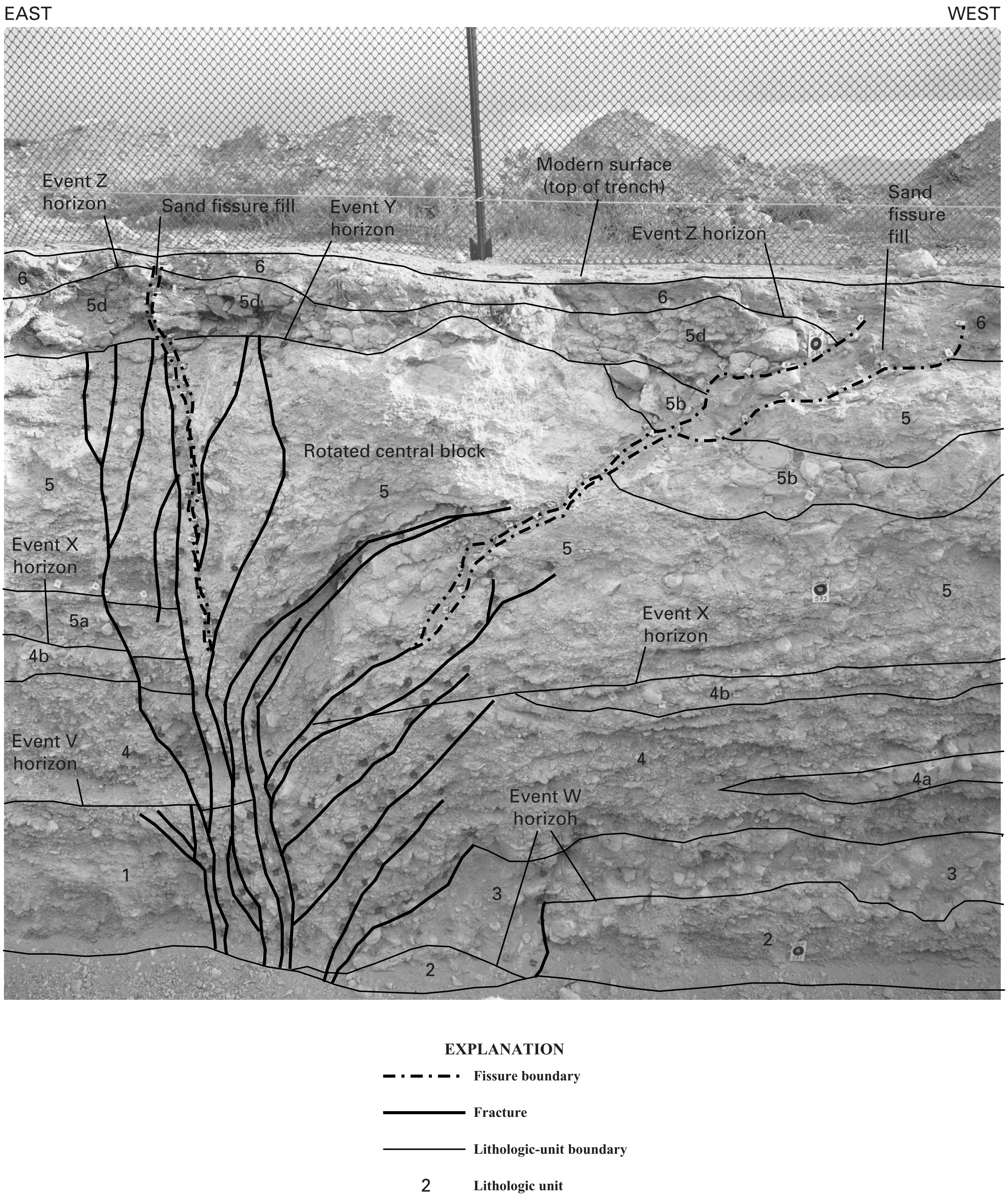




**Figure 44.** Part of south wall of trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada (pl. 19; figs. 1, 2), showing main fault zone, mapped surficial deposits, and event horizons marking Quaternary faulting events (V–Z). Dark spots along some lines are markers that were emplaced to facilitate mapping.

**Table 33.** Descriptions of soil profiles in trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 19 and figures 1 and 2 for locations. See table 3 for soil-horizon terminology. Colors from Munsell Soil Color Charts (Munsell Color Co., Inc., 1992). Texture: lm, loam; slt, silt; snd, sand. Structure—grade: 1, weak; 2, moderate; 3, strong; m, massive; sg, single grain—size: c, coarse; f, fine; m, medium; v, very fine—type: abk, angular blocky; pl, platy; sbk, subangular blocky. Consistence—dry: eh, extremely hard; h, hard; lo, loose; sh, slightly hard; so, soft; vh, very hard—wet: po, nonplastic; ps, slightly plastic; so, nonsticky; ss, slightly sticky. $CO_3$ stage morphology from Birkeland (1984). Effervescence (in cold dilute HCl): e, some; em, moderate; eo, none; es, strong; ev, very strong; vse, very slight. Cementation: ci, indurated; cs, strong; cw, weak. Lower horizon boundary—distinctness: a, abrupt; c, clear; g, gradual—topography: i, irregular; s, smooth; w, wavy. Roots—abundance: 1, few, 2, common; 3, many—size: co, coarse; f, fine; m, medium; vf, very fine—location: frc, fractures; lam, laminae; ped, ped faces; thruout, throughout. Pores—abundance: 1, few; 2, common; 3, many—size: f, fine; m, medium; vf, very fine—shape: i, irregular or interstitial; v, vesicular—location: nod, carbonate nodules; ped, ped faces; thruout, throughout; upper, upper part of soil. Rhizoliths—abundance: 1, few; 2, common; 3, many—size: co, coarse; f, fine—location: thruout, throughout. n.o., not observed]

| Horizon | Depth (cm) | Asso-ciated unit | Color | | Gravel content (vol pct) | Texture | Structure | Consistence | | $CO_3$ morphology stage | Efferves-cence | Cemen-tation | Lower horizon boundary | Roots | Pores | Rhizo-liths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wet | Dry | | | | Dry | Wet | | | | | | | |
| **Soil profile I** | | | | | | | | | | | | | | | | |
| Avk | 0 | 6 | 10YR 6/4–5/4 | 10YR 7/3 | 5–15 | sltlm | 2vf-c sbk | sh | so-ss ps-p | n.o. | es-ev | n.o. | cw | 2 vf-co thruout | 3 vf-f thruout | n.o. |
| 2Bkb1 | 12 | 5c | 10YR 7/3 | 10YR 8/1 | 60–90 | sndlm | 2f-c abk, pl | vh | so-ss po | I–III | es-ev | cs | a-c w | 2 vf-m thruout | n.o. | n.o. |
| 3Bkb1 | 119 | 5 | 10YR 7/3 | 10YR 8/1 | 85–95 | sndlm | 1-2 f-m sbk m | vh | so po | II | es | cs | cw | 1 vf-f thruout | n.o. | 1 f-m thruout |
| 4Bkb1 or 4Bkb2 | 141 | 4 | 10YR 7/3 | 10YR 8/1 | 50–70 | sndlm | 2 f-c sbk m | h-vh | so ss | II | es | cs | a s | 1 vf thruout | 2 vf-f v upper | 2 m-co thruout |
| 5Kqmb2 or 5Kqmb3 | 209 | 1 | 7.5YR 6/6 | 7.5YR 7/4 | 70–90 | sndlm | 2 m-c sbk, pl m | vh | so po | III–III+ | es | ci | n.o. | n.o. | 2 vf-f v upper | n.o. |
| **Soil profile II** | | | | | | | | | | | | | | | | |
| Avk | 0 | 6 | 10YR 6/4–5/4 | 10YR 7/3 | 10–20 | sndlm | 1-2f-m sbk | sh-h | so-po | n.o. | es-ev | n.o. | cw-i | 2vf-m thruout | 3vf-f v | n.o. |
| 2Kqmb1 | 33 | 5 | 10YR 8/2 | 10YR 8/1 | 60–85 | sndlm | m | vh-eh | so po | III–III+ | es | cs-ci | a s | 2 vf-f thruout | n.o. | n.o. |
| 3Bkbl | 130 | 4 | 10YR 7/3 | 10YR 8/1 | 30–80 | sndlm | 1-2 vf-c sbk m | sh | so po | II | es | cw-cs | a s | 2f-m thruout | n.o. | 2 f-m thruout |
| 4Bkqmb2 | 222 | 1 | 10YR 7/3 | 10YR 8/1–8/3 | 70–90 | sndlm | 2-3f-c sbk, pl m | vh-eh | so po | III | es | cs-ci | n.o. | n.o. | 3vf-f top 20 cm | n.o. |
| **Soil profile III** | | | | | | | | | | | | | | | | |
| Avk | 0 | 6 | 10YR 7/3 | 10YR 6/4 | 20–30 | sndlm | 1-2 vf-m sbk | sh-h | so po-ps | n.o. | es-ev | n.o. | a-c w | 2 vf-co thruout | 3 vf-f thruout | n.o. |
| 2Kqmb1 | 30 | 5 | 10YR 8/2–7/2 | 10YR 8/1 | 5–10 | sndlm | 2 m-co sbk, pl m | vh-eh | so po | II–IV | es | cs-ci | c w | 1 vf-f thruout | n.o. | 1 vf-m thruout |
| 3Bkb1 | 76 | 4 | 10YR 7/2 | 10YR 8/1 | 60–80 | sndlm | m | h | so po | II | es | cs | c w | 1 vf-f thruout | n.o. | 1 f-m thruout |
| 4Bkqb1 | 126 | 3 | 10 YR 5/4 | 10YR 6/4–7/4 | 20–50 | sndlm | 2 f-c sbk | so-$CO_3$ vh-$SiO_2$ | so po | I | es-$CO_3$ eo-$SiO_2$ | cs | a-c i | 1 vf-f thruout | 1-2 vf i $SiO_2$ pods | 2 vf-co thruout |
| 5Bkb2 | 180 | 2 | 10YR 7/2 | 10YR 8/1 | 70–95 | sndlm | 1-2 m sbk m | h-vh | so po | I–II | es | cw-ci | c s | 1 vf-f thruout | n.o. | n.o. |
| 6Bkb2 | 246 | 1 | 10YR 7/2 | 10YR 8/1 | 70–90 | sndlm | 1 f-c sbk m | h-vh | so po | II–III | es | cs | a s | n.o. | n.o. | 1 m-co thruout |

EAST WEST


**EXPLANATION**

**Fracture**—Dashed where approximately located

**Lithologic-unit boundary**—Dashed where approximately located

1 **Lithologic unit**

**Figure 45.** Part of south wall of trench CFF–T2A across the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada (pl. 19; figs. 1, 2), showing stratigraphic relations bearing on event X on upthrown block of fault. Dark spots along some lines are markers that were emplaced to facilitate mapping.

**Table 34.** Summary of faulting events on the Northern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 19 and figures 1 and 2 for locations. Displacements and ages are best estimates; reported displacements are generally accurate to within ±10 cm]

| Event | Likelihood of occurrence based on available evidence | Event horizon | Evidence | Vertical displacement at the main fault (cm) | Net cumulative vertical displacement (cm) | Date (ka) |
|---|---|---|---|---|---|---|
| Z | Definite | Within unit 6 (fig. 44). | Units 5 and 5b offset; central block of unit 5 rotated, creating rubble zone (unit 5d) composed of clasts of unit 5 broken apart by rotation or lateral slip; sandy fissure fill terminates within unit 6; scarp at surface. | 20, measured at the top of unit 5. | 0–5; net cumulative vertical displacement for events Z, Y, and X is constrained by net cumulative vertical displacement at top of unit 4b/4, which is near 0. | 6–4, based on 5±1-k.y. estimated thermoluminescence age for sandy fissure fill; <10, based on absence of carbonate cement in sand fissure fill. |
| Y | Moderate | Top of unit 5 (fig. 44). | Multiple fractures on upthrown and downthrown blocks that terminate at or near top of unit 5; fractures show no apparent shear displacement and differ from those related to event Z by having abundant carbonate coating. | 0 | 0 | >10, based on presence of carbonate coatings on fractures; <433, based on estimated minimum age of Quaternary unit Qa1 (table 2). |
| X | Definite | Top of unit 4b/4 (figs. 44, 45). | Fractures that terminate at base of unit 5; displacement of top of unit 4b/4; presence and geometry of unit 5a. | 40; cumulative vertical displacement from events Z, Y, and X measured at the fault on top of unit 4b/4 is about 60 cm. | 0–5 | >400, based on U-series ages for soil from unit 5 (HD 1967, HD 1966); >433, based on estimated minimum age of Quaternary unit Qa1 (table 2). |
| W | High | Top of unit 2 (fig. 44). | Differential displacement between top of unit 2 and base of unit 4; presence of unit 3 only on downthrown block, possibly owing to stripping of unit 2 off upthrown block. | 50, half of estimated 100-cm displacement resulting from events W and V). | 45 | >>433, based on estimated minimum age of Quaternary unit Qa1. |
| V | Moderate | Top of unit 1 (fig. 44). | Differential displacement between top of unit 1 and base of unit 4; presence of unit 2 only on downthrown block, possibly owing to stripping of unit 1 on upthrown block after uplift from event. | 50 | 45 | >>433, based on estimated minimum age of Quaternary unit Qa1. |

mated by removing the effects of backtilting and (or) downwarping adjacent to the fault zone and by projecting event horizons into the fault zone from undeformed sections on the downthrown and upthrown blocks.

## Paleoearthquakes

Stratigraphic and structural evidence for at least four faulting events (Z–W, from youngest to oldest) and, possibly, as many as five faulting events (including an older event V) was observed in trench CFF–T2A (figs. 44, 45). Evidence, displacements, and ages for these faulting events are summarized in table 34.

Uncertainty exists as to whether events V and W were separate occurrences or represent only a single faulting event. The question concerns the relation between stratigraphic units 2 and 3, both of which are now preserved on only the downthrown block (fig. 44). With regard to unit 2 in particular, it cannot be determined whether (1) it was deposited only on the downthrown block as a result of older event V, followed by the deposition of unit 3; or (2) it was initially deposited on both sides of the fault and subsequently eroded off the upthrown block during event W, resulting in the deposition of overlying unit 3 on the downthrown block. Because units 2 and 3 are separated by an unconformity, indicating a difference in age, the evidence favors an interpretation that two faulting events occurred before the deposition of unit 3.

## Quaternary Slip Rate and Average Recurrence Interval

The cumulative vertical displacement of unit 1 on the Northern Crater Flat Fault is about 160 cm in trench CFF–T2A (pl. 19). The net cumulative vertical displacement, as calculated by correcting for backrotation of the downthrown block, is estimated at about 100 cm. To calculate the total net cumulative displacement, the dip and left-oblique slip of the fault must be taken into consideration. The main fault zone exposed in the trench is vertical to near-vertical. Although no slickensides were observed in Quaternary materials to indicate the rake of Quaternary movement, Simonds and others (1995) documented a rake of 55° S. on a bedrock fault plane near the trench site. Using this rake, in combination with a vertical fault and 100 cm of net cumulative vertical displacement, the total net cumulative displacement is estimated at 122 cm. Given the U-series estimated ages for the opaline component of the carbonate soils formed on units 2 through 5 (generally 400–493 ka, pl. 19; table 31), the age of unit 1 is conservatively dated at older than 500 ka. On the basis of an estimated 122 cm of total net cumulative displacement of this unit, a Quaternary fault slip rate of less than 0.0024 mm/yr is calculated.

The minimum age of 500 ka for unit 1, the indication that four or five faulting events (three or four interseismic intervals) occurred after the deposition of unit 1, and an estimated date of 5 ka for the most recent faulting event yield possible average paleoearthquake-recurrence intervals of 165 k.y. (three faulting events) and 124 k.y (four faulting events), assuming that the oldest event (W or V) occurred soon after the deposition of unit 1.

## Relation to the Southern Crater Flat Fault

The relation between the Northern and Southern Crater Flat Faults (see chap. 10) is unclear. Results from mapping (Simonds and others, 1995) and paleoseismic investigations are inconclusive for determining whether these two faults are connected or are separate features. The timing of faulting events, however, is similar enough to allow for possible linkage of the two faults in the subsurface. The most recent event (Z) on each fault occurred within the past 10 k.y.: at 9–2 ka on the Southern Crater Flat Fault and at 6–4 ka on the Northern Crater Flat Fault. Events Y and X on the Southern Crater Flat Fault are estimated at <40 and >250 ka, respectively; events Y and X on the Northern Crater Flat Fault are estimated at 433–10 ka and >433 ka, respectively. Both faults have slip rates of about 0.002 mm/yr; however, this slip rate is based on a much shorter paleoseismic record for the Southern Crater Flat Fault than for the Northern Crater Flat Fault. The paleoseismic record for the Southern Crater Flat Fault covers only about the past 250 k.y., whereas the paleoseismic record on the Northern Crater Flat Fault covers about the past 500 k.y. The difference in record length, but the similarity in slip rates, indicates that the Northern Crater Flat Fault probably has a lower long-term slip rate than does the Southern Crater Flat Fault. This increase in slip rate from north to south in Crater Flat fits with the existing data from other faults (for example, Menges and others, 1994) and the most recent model for the formation of the Crater Flat Basin (Fridrich, 1999; Fridrich and others, 1999), indicating that the basin is opening in a fanlike pattern from north to south, with the pivot point located in the caldera complex north of Yucca Mountain (figs. 1, 2).

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