Chapter 10

Quaternary Faulting on the Southern Crater Flat Fault

By Emily M. Taylor

Contents

Abstract

Two trenches, excavated across projections of the Southern Crater Flat Fault, expose middle Pleistocene to lower Holocene alluvium and fine-grained eolian deposits that record at least three surface-rupturing paleoearthquakes. On the basis of thermoluminescence analyses of fine-grained alluvial materials and U-series analyses of opaline silica sampled from the inner rinds of clasts, the most recent faulting event probably occurred 6–2 ka, the penultimate faulting event 40–10 ka, and an earlier faulting event 250–130 ka. Minimum recurrence intervals are about 5–90 k.y. The maximum total vertical-slip rate on the Southern Crater Flat Fault is estimated at 0.002 mm/yr.

Introduction

The Southern Crater Flat Fault is a down-to-the-west normal fault that is best exposed in a 2-km-long segment south of Stagecoach Road (fig. 2), where for some distance it is traceable as a well-defined scarp forming the bedrock (basalt)-alluvium contact (see chap. 3; Simonds and others, 1995). Quaternary faulting relations were studied in two trenches, CFF–T1 and CFF–T1A (figs. 2, 42), which were excavated in surficial deposits that intersect the fault trend at sites 0.5 to 1.0 km north of Stagecoach Road. Trench CFF–T1 is located on a subtle, rounded alluvium-disrupting scarp that forms a distinctive lineament on aerial photographs. Trench CFF–T1A, 100 m to the south, is located on a surface immediately adjacent to a drainage where the fault is exposed.

Stratigraphic correlations between trenches CFF–T1 (pl. 18) and CFF–T1A (pl. 17) are difficult, even though they are not far apart and the Quaternary deposits involved in the faulting are of similar age. One reason for the observed differences is that the aggradation sequence exposed in trench CFF–T1 was affected by a small drainage on the hanging wall. Another factor may be that not all segments of the Southern Crater Flat Fault were activated simultaneously during each of the three faulting events. For example, segments of the fault may have been triggered by movement on other nearby faults, such as the Windy Wash Fault that has parallel and (or) similar orientations (see chap. 3, fig. 4). The near-verticality and planarity of the fault in both exposures and the absence of bifurcating fractures toward the surface indicate a strike-slip component of movement, which can also result in stratigraphic variations along strike and add to the difficulties in correlating faulting events between the two trenches.

Stratigraphy

Trenches CFF–T1 (pl. 18) and CFF–T1A (pl. 17) expose Quaternary deposits of largely alluvial gravel, with minor amounts of fine-grained eolian sand. The development of distinctive soil horizons, commonly separated by erosional unconformities and capped by eolian deposits, has created stratigraphic markers that are extremely useful for paleoseismic interpretations. Characteristics of the Quaternary lithologic units that were differentiated in each of the trenches are listed in tables 28 and 29.

Five samples of secondary opaline silica inner rinds on clasts and one sample of a younger soil were collected from trench CFF–T1A (pl. 17) for U-series and thermoluminescence analysis, respectively. Estimated rounded ages of various units, listed in table 30, are unit 2B, 9 ka (sample TL–61); unit 3K, 40–70 ka (sample HD 1959); unit 3Bk, 120–130 ka (sample HD 1958); and unit 4, 200–350 ka (avg ~250 ka; samples HD 1957, HD 1961). In terms of the standard Quaternary stratigraphic framework for the Yucca Mountain area (fig. 3), these ages indicate that unit 2 correlates most closely with unit Qa5, unit 3 with unit Qa3, and unit 4 with unit Qa2.

Paleoseismology

Trenches CFF–T1 (pl. 18) and CFF–T1A (pl. 17) expose the Southern Crater Flat Fault and provide evidence for at least three faulting events that may have caused surface ruptures during the Quaternary. These paleoearthquakes occurred in the past ~250 k.y., with a total measured offset of 24 to 65 cm, resulting in a maximum vertical slip rate of 0.002 mm/yr. The most recent faulting event offsets the Av soil horizon, which could be as young as 3 ka. Fault-plane striae on Quaternary deposits were not available to estimate net tectonic slip. The estimated slip for each faulting event is therefore for vertical slip only and is made by correcting for

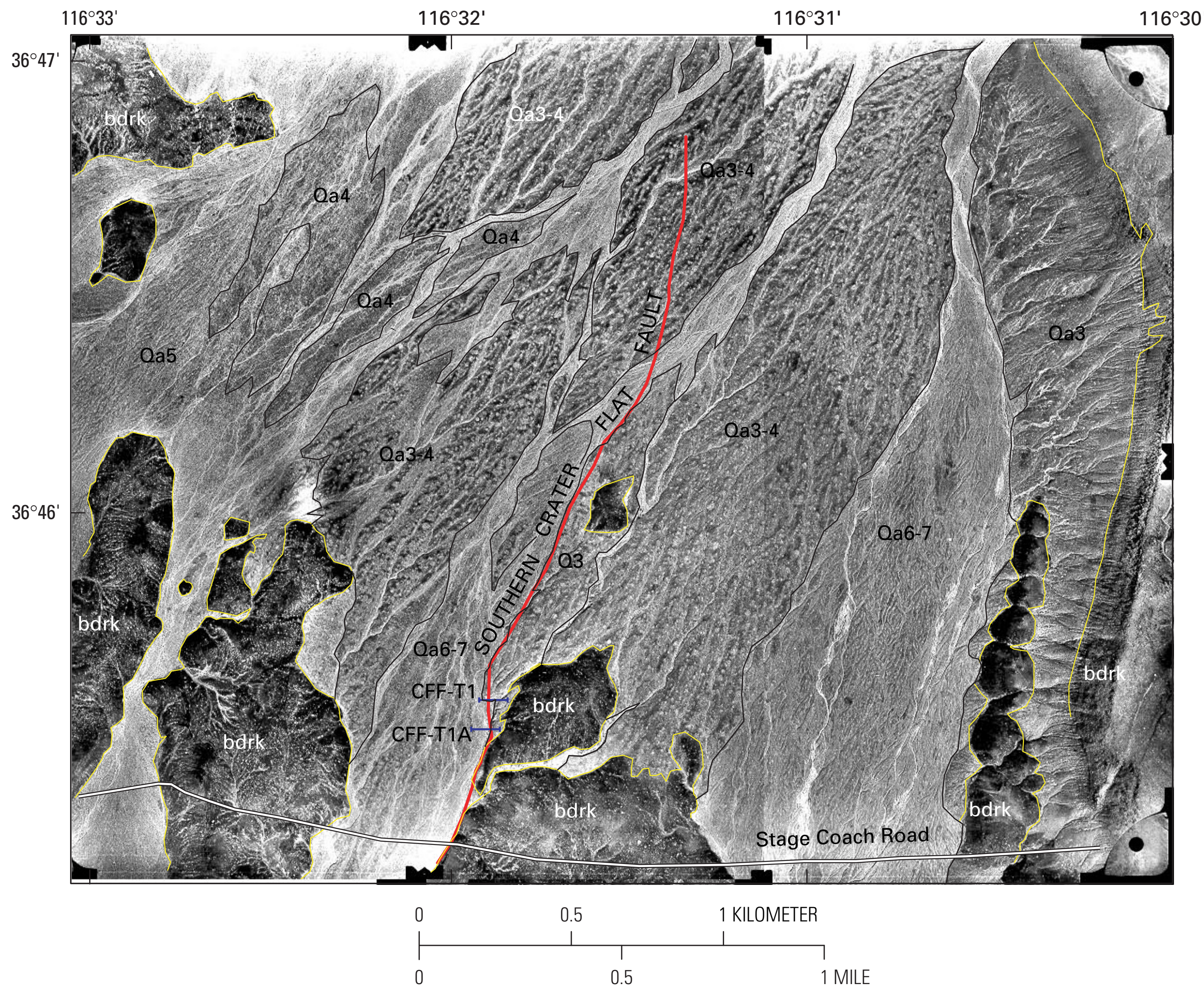

Figure 42. Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada (figs. 1, 2), showing distribution of surficial deposits and locations of trenches CFF–T1 and CFF–T1A (pls. 17, 18; fig. 2). Red line, projection of the Southern Crater Flat Fault; yellow line, bedrock-alluvium contact. Map units refer to standard sequences of Quaternary surficial deposits at Yucca Mountain (table 2).

Table 28. Soil and stratigraphic units exposed on the north wall of trench CFF–T1A across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 18 and figures 1, 2, and 42 for locations. Colors from Munsell Soil Color Charts (Munsell Color Co., Inc., 1992). See table 14 for explanation of abbreviations. Do., ditto]

Field No., horizon, boundary	Unit	Dry color (<2-mm fraction)	Moist color (<2-mm fraction)	Texture	Structure (primary and secondary)	Consistence (dry, wet)	Clay films	Secondary carbonate (gravel and disseminated)	Gravel content (volume percent)	Parent material and lithology (sorting, angularity, bedding, imbrication, and support)	Miscellaneous (roots, pores, SiO_2, oxidation, concretions, salts)
Hanging-wall and footwall units											
1, Av, as	1	10YR 7.5/3	10YR 4/3	L-SiL	3 vco sbk, 2° 3 f-co sbk to sg	shss, ps	0	0, ev	5 (gr)	Well sorted, subangular, nonbedded, nonimbricated, matrix supported.	Continuous vesicles, 1° eolian.
2, Bk1, cs	1	10YR 8/3	10YR 5/4	L	2 m-co abk, 2° sg	lo-shss, ps	0	I, ev	40 (pb gr)	Moderately well sorted, subangular, nonbedded, nonimbricated, matrix supported.	– – –
3, 2Btwk, as (14 on footwall)	2	10YR 7/3	10YR 4/3	SL	1 m sbk	lo-shso, po	0	I–, ev	25 (cb pb gr)	Poorly sorted, subangular, nonbedded, nonimbricated, matrix supported.	– – –
Hanging-wall units											
21, 2Bwk2, as	2	7.5–10YR 7/3	10YR 4/3	SL	sg	lovss, ps	0	I–, filaments, e	70 (cb pb gr)	Moderately well sorted, subangular, nonbedded, nonimbricated, matrix supported.	– – –
4, 3K, gw (15 on footwall)	3	10YR 7/2.5	10YR 5/3	LS	3 vco abk, 2° sg	lo-ehso, po	0	II+, ev	80 (cb pb gr)	do --------------------	– – –
5, 3Bk, as (16 and 17 on footwall)	3	10YR 8/2	10YR 5/4	LS	3 co sbk where cemented, 2° sg	lo-vhso, po	0	I, II+ in lenses ≤10 cm wide, ev	75 (cb pb gr)	Moderately well sorted, subangular, moderately well bedded, imbricated in lenses, clast supported except in cemented lenses.	– – –
5.5, 4Bkb1, as (18 on footwall)	4	10YR 7/2	10YR 5/3	LS	sg	lo-vhso,po	0	II+ in lenses	70 (cb pb gr)	Moderately well sorted, subangular, moderately well bedded, nonimbricated, clast supported.	– – –
6, 5Bkb1, bottom of trench (19 on footwall)	4	10YR 7.5/2	10YR 5/3	LS	sg, 3 f sbk where cemented	lo-vhso, po	0	II+, ev	70 (cb pb gr, few ≤8 cm)	Moderately well sorted, subrounded, nonbedded, nonimbricated, matrix supported.	– – –
Fault-zone units											
7, FZ1–1, as (1 and 2 on hanging wall and footwall)	FZ	10YR 6/2	10YR 4/3	L	3 m-co sbk	shvss, vsp	0	I–, ev	25 (pb gr)	Moderately well sorted, subangular to subrounded, nonbedded, nonimbricated, matrix supported.	Fault-related colluvial wedge, preserved Av soil horizon in places.

Table 28. Soil and stratigraphic units exposed on the north wall of trench CFF–T1A across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada—Continued

Field No., horizon, boundary	Unit	Dry color (<2-mm fraction)	Moist color (<2-mm fraction)	Texture	Structure (primary and secondary)	Consistence (dry, wet)	Clay films	Secondary carbonate (gravel and disseminated)	Gravel content (volume percent)	Parent material and lithology (sorting, angularity, bedding, imbrication, and support)	Miscellaneous (roots, pores, SiO_2, oxidation, concretions, salts)
Fault-zone units											
8, FZ1–2, as, erosional unconformity	FZ	10YR 6.5/3	10YR 4/3	L-SiL	2 co sbk-abk	so-shvss, po	0	I, ev	30 (pb gr)	do --------------------	Offset buried Av+Bk soil horizon preserved in places.
9, FZ2, aw, event horizon?, erosional unconformity		10YR 6/2	10YR 4/3	SL	3 m-co sbk	sovss, vsp	0	I, filaments, e	30 (pb gr with few cb)	do --------------------	Gravel fill eroded into lower unit.
10, FZ3–1, cs, event horizon (4 and 5 on hanging wall; 15, 16, and 17 on footwall)	FZ	10YR 6.5/2	10YR 4/3	SL	sg	loso, po	0	II, ev	70 (pb gr)	Moderately well sorted, subangular, nonbedded, nonimbricated, matrix supported.	– – –
11, FZ3–2, aw erosional unconformity	FZ	10YR 6/2	10YR 4/4	LS	sg	loso, po	0	I, ev	70 (cb gr)	Poorly sorted, subrounded, moderately well bedded, nonimbricated, matrix supported.	– – –
12, FZ3–3, aw, event horizon (6 on hanging wall; 18 and 19 on footwall)	FZ	10YR 7/2	10YR 4.5/3	LS	3 f-m abk, 2° sg	ehso,po	0	II, ev	– –	Poorly sorted except in lenses, subangular to subrounded, moderately well to nonbedded, nonimbricated, matrix supported.	Stages 1and 2 silica. This unit is very localized and not exposed on the south wall.
13, FZ4, bottom of trench	FZ	10YR 7/2	10YR 5/3	LS	2 f-m sbk, 2° sg	ehso, po	0	I+, ev	80 (cb pb gr)	Poorly sorted, subrounded to subangular, moderately well bedded, nonimbricated, matrix supported.	Stage I silica.
20, fracture fill, bottom of trench	Fracture fill	10YR 7/2	10YR 5/3	SL	sg	loso, po	0	I (numerous rotated clasts), ev	50 (cb pb gr)	Nonsorted, subangular to subrounded nonbedded, nonimbricated, matrix supported.	– – –
Footwall units											
14, 2Btwk cw (3 on hanging wall)	2	7.5YR 7/2	7.5YR 4/4	SL	3 m-co sbk	sovss, vsp	0	0, ev	50 (pb gr)	Poorly sorted, subangular, nonbedded, nonimbricated, matrix supported.	Horizon is eroded by a channel in center of the footwall.
15, 3K cs (4 on hanging wall)	3	10YR 7/2	10YR 5/2	LS	3 co pl, 2° m	ehso, po	0	III, ev	90 (cb pb gr)	Moderately well sorted, subangular, moderately well bedded, nonimbricated, matrix supported.	– – –

Table 28. Soil and stratigraphic units exposed on the north wall of trench CFF–T1A across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada—Continued

Field No., horizon, boundary	Unit	Dry color (<2-mm fraction)	Moist color (<2-mm fraction)	Texture	Structure (primary and secondary)	Consistence (dry, wet)	Clay films	Secondary carbonate (gravel and disseminated)	Gravel content (volume percent)	Parent material and lithology (sorting, angularity, bedding, imbrication, and support)	Miscellaneous (roots, pores, SiO_2, oxidation, concretions, salts)
						Footwall units					
16, 3Bk1 cs (top of 5 on hanging wall)	3	10YR 7/2	10YR 4/3	LS	sg except in cemented lenses	lo-hso, po	0	I with lenses of III, e	85 (cb pb gr)	Poorly sorted, subrounded, moderately well bedded, nonimbricated, matrix supported.	– – –
17, 3Bk2 as (bottom of 5 on hanging wall)	3	10YR 6/2	10YR 4/3	LS	sg	loso, po	0	I, ev	80 (pb gr)	Moderately well sorted, subrounded, moderately well bedded, imbricated in places, clast supported.	– – –
18, 4Bk1b1 cs (6 on hanging wall)	4	10YR 8/2	7.5YR 5/4	SL	m	ehso, po	0	III to IV–, I on gravel, ev	80 (pb cb gr)	Poorly sorted, subangular to subrounded, nonbedded, nonimbricated, matrix supported.	– – –
19, 4Bk2b1 (bottom of 6 on hanging wall) (not sampled)	4	10YR 8/3	7.5YR 5.5/4	LS	3 f sbk, 2° m	ehso, po	0	I+, ev	70 (pb gr)	Moderately well sorted, angular, nonbedded, moderately imbricated, matrix supported.	Secondary carbonate infiltrated into basalt bedrock.
19, 4K+R, bottom of trench	4	10YR 7.5/3	10YR 5/4	LS	sg	loso, po	0	I, ev	70 (pb gr)	Moderately well sorted, subrounded, weakly bedded, locally well imbricated, matrix supported.	Secondary carbonate infiltrated into basalt bedrock. Stage I silica

Table 29. Soil and stratigraphic units exposed on the north wall of trench CFF–T1 across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 17 and figures 1, 2, and 42 for locations. Colors from Munsell Soil Color Charts (Munsell Color Co., Inc., 1992). See table 14 for explanation of abbreviations. Do., ditto]

Field No., horizon, boundary	Unit	Dry color (<2-mm fraction)	Moist color (<2-mm fraction)	Texture	Structure (primary and secondary)	Consistence (dry, wet)	Clay films	Secondary carbonate (gravel and disseminated)	Gravel content (volume percent)	Parent material and lithology (sorting, angularity, bedding, imbrication, and support)	Miscellaneous (roots, pores, SiO_2, oxidation, concretions, salts
Hanging-wall and footwall units											
1, Av, as	1	10YR 7/3	10YR 5/4	SL	3 co pl, 2° 1 f-co sbk	shvss, vsp	0	0, e	10 (pb gr)	Well sorted, subangular, nonbedded, nonimbricated, matrix supported.	– – –
2, Bk, cs	1	10YR 8/3	10YR 4/3	SL	1 m-co sbk, 2° sg	sovss, po	0	I–, ev	40 (pb gr)	do ----------------------	– – –
3, 2Btkwb1, cw	2	7.5YR 7/3	10YR 4/4	SL	3 f sbk, 2° sg	soso, po	0	0, ev	40 (pb gr)	do ----------------------	– – –
Hanging-wall units											
4, 3K, aw (erosional unconformity)	3	10YR 7/2	10YR 5/3	LS	sg, 3 pl in places	ehso, po	0	II+, ev	80 (cb pb gr, few bd)	Nonsorted, subangular to subrounded, nonbedded, nonimbricated, matrix supported.	– – –
5, 4K, ac	4	10YR 8/3	10YR 5/3	LS	3 vco pl to m	ehso, po	0	III–IV (less developed adjacent to fault zone), ev	80 (pb gr)	Moderately well sorted, subrounded, nonbedded, nonimbricated, matrix supported.	– – –
6, 4Bk, ac	4	10YR 7/2	10YR 5/4	LS	1 f sbk, 2° sg	loso, po	0	I–II (better developed in lenses), ev	80 (cb pb gr, few bd)	Poorly sorted, subangular, moderately well bedded, nonimbricated, matrix supported.	– – –
7, 5Bk1b1, cw	5	10YR 7/3	10YR 3/4	SL	3 f-m abk	hso, po	0	I– (increasing toward base), ev	60 (pb gr, few cb)	Moderately well sorted, subrounded, poorly bedded, nonimbricated, matrix supported.	Well-preserved argillic B soil horizon, in places, at top of unit.
8, k25B b1, as	5	10YR 7/2	10YR 6/3	SL	sg	loso, po	0	I+ (better developed near top), ev	80 (cb pb gr)	do -----------------	– – –
9, 6Bk1b2, bottom of trench	6	10YR 7/2	10YR 6/3	LS	3 co-vco pl (in lenses), 2° 1 co-f sbk	h-ehso, po	0	I, ev	80 (pb gr)	Moderately well sorted, subangular, poorly bedded, nonimbricated, matrix supported.	– – –

Table 29. Soil and stratigraphic units exposed on the north wall of trench CFF–T1 across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada—Continued

Field No., horizon, boundary	Unit	Dry color (<2-mm fraction)	Moist color (<2-mm fraction)	Texture	Structure (primary and secondary)	Consistence (dry, wet)	Clay films	Secondary carbonate (gravel and disseminated)	Gravel content (volume percent)	Parent material and lithology (sorting, angularity, bedding, imbrication, and support)	Miscellaneous (roots, pores, SiO_2, oxidation, concretions, salts
						Fault-zone units					
14, FZ (N. 4°–6° E) 13–40 cm wide	FZ	10YR 6.5/3	10YR 4/4	LS	sg	loso, po	0	I, with frequent rotated clasts, ev	40–80 (pb gr, few bd)	Poorly sorted, subrounded, nonbedded, nonimbricated, matrix supported.	Many vertically oriented clasts lining fracture fill. No vertically oriented carbonate laminae.
						Footwall units					
11, 3K, cw	3 (FW)	10YR 7/2.5	10YR 7.5/ 4.5	LS	3 vco pl in places, 2° sg	ehso, po	0	II, ev	80 (cb pb gr)	Moderately well sorted, subrounded, nonbedded, nonimbricated, matrix supported.	– – –
12, 3Bk1, as	3 (FW)	10YR 7/2	7.5YR 4/3	LS	sg	lo-ehso, po	0	II+ to III (in lenses), ev	80 (cb pb gr)	Moderately well sorted, subrounded to subangular, nonbedded, nonimbricated, matrix supported.	– – –
13, 4Ckn, bottom of trench	4 (FW)	10YR 8/3	10YR 4.5/3	LS	sg	loso, po	0	II+ to III	80 (cb pb gr)	Moderately well sorted, subangular, nonbedded, imbricated in places, clast supported.	Stage 1 silica. Clean channel gravel.

Table 30. Numerical ages of deposits exposed in trench CFF–T1A across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada.

[See plate 18 and figures 1, 2, and 42 for locations. Samples: HD (error limits, ±2σ), U-series analyses by J.B. Paces; TL–61 (error limits, ±2σ), thermoluminescence analysis by S.A. Mahan]

Trench (pl. 17)	Sample	Unit and material sampled	Estimated age (ka)
CFF–T1A	TL–61	2, 2Bw soil horizon---------------	9±1
	HD 1956	4, clast rind-----------------------	263±16, 311±35, 352±26
	HD 1957	4, clast rind-----------------------	210±12, 236±13, 247±12
	HD 1958	3, 3Bk soil horizon, clast rind---	120±5, 125±15, 128±6
	HD 1959	3, 3K soil horizon-----------------	40±2, 49±2, 60±9
	HD 1961	4, clast rind-----------------------	260+∞/–110, 348±178

backtilting on the hanging wall and erosion on the footwall, where applicable. The estimated vertical slip for each faulting event is generally accurate to within ±10 cm.

Trench CFF–T1A (pl.17) provides a less ambiguous paleoseismic history than trench CFF–T1 (pl. 18). Age control exists on the deposits in trench CFF–T1A, and the units on the hanging wall and footwall are correlative. In the following discussions, trench CFF–T1A is therefore described first, and comparisons are then made with trench CFF–T1.

Trench CFF–T1A

In trench CFF–T1A (pl. 17), the Southern Crater Flat Fault is defined by two strands, 1.5 m apart, that bound an alluvium-filled graben in the intervening zone. Bedrock (basalt), exposed in the footwall, is in contact with down-faulted Quaternary deposits in the hanging wall to the west. The surficial units (1, 2, 3, and so on, pl. 17; table 28) are in an alternating sequence of alluvium and fine-grained eolian deposits. Individual units, generally separated by unconformities, are characterized by weakly cemented fine-grained materials at the top underlain by carbonate-cemented soil horizons that cap unconsolidated, matrix-supported gravel forming the base. Soils in the hanging wall appear to be less well developed than in the footwall. On the soils in the footwall, secondary carbonate accumulated in the uppermost 1 m of the deposits, which are relatively stable, with little aggradation and (or) erosion taking place. In contrast, aggradation of materials along a still-existing drainage channel that traverses the hanging wall resulted in the accumulation of thicker deposits on that (west) side of the fault (pl. 17) and the subsequent distribution of secondary carbonate through the upper 2 to 3 m of the deposit.

The two fault strands exposed in the trench cut to different depositional units or levels in the Quaternary sequence, and the observed stratigraphic relations provide a basis for estimating the number and relative timing of faulting events, as described below.

Event Z

The most recent faulting event recorded in the surficial deposits exposed in trench CFF–T1A (pl. 17) occurred on the strand that defines the eastern margin of the graben (pl. 17). This strand is the only splay that disrupts the surface soil in unit 1, including the Av soil horizon. Units FZ1–1 and FZ1–2 contain light-colored, weakly cemented Bk and Av soil-horizon materials that slumped adjacent to the fault and were subsequently buried by eolian deposits. Because the fault extends upward to near the ground surface and the overlying soils are poorly developed, the faulting event (Z) must have occurred relatively recently. Av soil horizons at the surface in the Yucca Mountain area (figs. 1, 2) generally range in age from 2 to 6 ka, and a thermoluminescence analysis of one sample (TL–61, table 30) collected in the fine-grained unit 2 (pl. 17), which was also offset, yielded a maximum estimated date for event Z of 9±1 ka. Therefore, surface rupture of the Av soil horizon occurred 9–2 ka (preferred value, 6–2 ka). About 18 to 20 cm of vertical offset that was measured at the top of unit 2 is assumed to represent the offset from event Z.

Event Y

Event Y occurred along the two splays of the Southern Crater Flat Fault that bound the graben (pl. 17). The western strand is marked by a truncated fissure fill that was enlarged during this faulting event and displaced all units except the modern soil (units 1, 2). The western splay did not fracture during event Z. Material appears to have been deposited into the graben before event Y, and was then rotated during the faulting event. This surface-rupturing paleoearthquake offset the moderately well developed K soil horizon ($CaCO_3$ stage II+–III morphology) developed on unit 3. The K soil horizon is preserved on the hanging wall (3K), the graben (FZ3–1), and the footwall (3K). Secondary carbonate in the 3K soil horizon (unit 3) was dated (U-series) as 40–70 ka (sample HD 1959, table 30). Unit 3 contains some black ash, which is tentatively correlated with the eruption of the nearby Lathrop Wells volcanic center (fig. 1) at 77±6 ka (Heizler and others, 1999). Ages of 120–130 ka (sample HD 1958, table 30) were also estimated from unit 3 at depth (3Bk soil horizon). Because the 3K soil horizon was formed before being displaced by event Y, this event is assumed to have occurred after 40 ka but before the paleochannel was deposited by approximately 9 ka (sample TL–61, table 30).

After event Y, a channel (unit 2) was eroded into the 3K soil horizon developed on unit 3 and removed evidence of the surface offset produced by the event. The Btwk soil horizon developed on unit 2 is preserved east of the margin of the paleochannel, where it was not eroded. These uncertainties make measurement of the offset difficult, but it is estimated at 5 to 15 cm (preferred value, 10 cm on the western fault splay), on the basis of projecting the contact between units 2 and 3 on the footwall westward across the fault zone and measuring the offset with the same contact on the hanging wall. This offset was then compared with the offset at the base of the 3K soil horizon across the fault zone.

Event X

Event X displaced units 4 and 5 and also occurred along the two graben-bounding fault splays. Fractures on the eastern splay are truncated at the top of a buried soil on unit 4. Material tilted eastward into the 1.5-m-wide graben between the exposed faults. Unit 4 is rotated and preserved in the base of the graben. Ages of secondary carbonate and opaline silica on inner rinds were estimated at 250 ka (average for unit 4; samples HD 1957, HD 1961, table 30) and 260–350 ka (unit 5; sample HD 1956, table 30), providing minimum ages for the deposits. Displacement occurred after the carbonate was in place, thus the U-series analyses provide a maximum estimated date of 250 ka for event X. Because the fractures are truncated by unit 3, which has a minimum estimated age of 120–130 ka (sample HD 1958, table 30), the event is dated at no earlier than 250 – 130 ka. Subsequently, alluvium (unit 3) appears to have been rapidly deposited, thereby preserving the nearly vertical, well-cemented small fault scarp. The offset from this event is estimated at 17 to 32 cm (preferred value, 20 cm), resulting in an estimated total offset exposed in trench CFF–T1A (pl. 17) of 24 to 65 cm (preferred value, 48 cm) and a maximum vertical-slip rate of 0.002 mm/yr.

Summary of Depositional and Faulting Events

A series of schematic cross sections showing the sequential development of the structures exposed on the north wall of trench CFF–T1A (pl. 17) is shown in figure 43. The various stages, from oldest to youngest, are summarized as follows:

1. Alluvium (units 4, 5) accumulated on or adjacent to the bedrock scarp. Infiltrated silt capped and weakly cemented the alluvium, and a soil, characterized by a Bk horizon, developed on the surface. Event X displaced units 4 and 5, which were rotated into the graben.
2. Alluvium (unit 3) accumulated on the scarp and in the graben, and a soil (3K horizon) developed on the surface.
3. Event Y displaced the moderately well developed K soil horizon on top of unit 3. A fault fissure formed on the western fault strand, and unit 3 was rotated into the graben. The K soil horizon was preserved in the graben (unit FZ3–1).
4. A channel (unit 2) cut into the K soil horizon on top of unit 3 and eroded the surface offset recorded by event Y. Fine eolian sand and silt accumulated on the surface and infiltrated the underlying deposit. Incipient Bk and Bt soil horizons formed, capped by an Av soil horizon at the surface.
5. Event Z offset the modern soil. Av and Bk soil-horizon materials slumped against the fault and were buried by fine-grained eolian materials.

Trench CFF–T1

Quaternary deposits exposed in trench CFF–T1 (pl. 18), which are morphologically similar to those exposed in trench CFF–T1A, appear to record a comparable depositional history and are assumed to be contemporaneous. The buried soils are similarly characterized by weakly cemented fine-grained material above a zone cemented by secondary carbonate, and by a deeper zone of unconsolidated matrix-supported gravel. On the basis of the abundance of fine-grained materials and the morphology of the secondary carbonate, each soil is estimated to represent at least 10 k.y. of surface exposure. The buried soils are capped by erosional unconformities.

The fault is marked by a single fissure fill, as much as 40 cm wide, that narrows to a single fracture at the surface. No additional strands of the fault are present; however, discontinuous fractures were observed. The fault exposed in trench CFF–T1 (pl. 18) is oriented N. 4°–6° E., unlike the general trend of the fault strand exposed in trench CFF–T1A that is oriented N. 15°–28° E.

Event Z

Evidence for event Z includes a single fracture that penetrates the surface. Although the Av soil horizon (pl. 18) is not clearly offset, the Bk soil horizon, immediately below the Av soil horizon, is thickened in the fault zone and on the hanging wall, a relation that is interpreted to indicate a faulting event with an estimated offset of 5 to 10 cm. Such a small displacement at the surface may have healed rapidly, leaving no Av soil-horizon material apparently offset or buried. On the basis of a correlation of soil properties to those exposed in trench CFF–T1A (pl. 17), the surface rupture is dated at 9–2 ka (preferred value, 4–3 ka).

Event Y

Event Y displaced units 3 through 6 approximately 5 to 10 cm. Unit 3 is capped by a well-developed 3K soil horizon

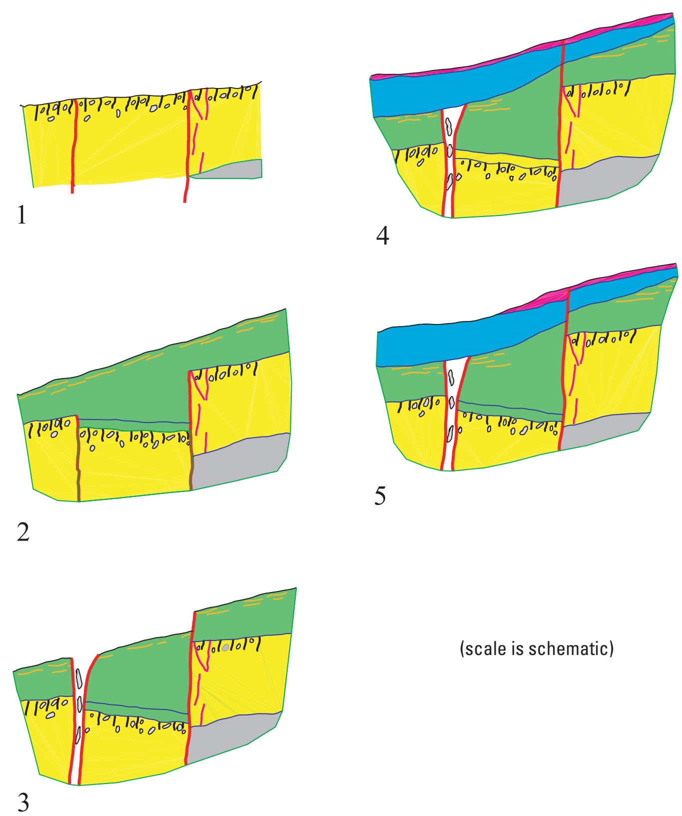

Figure 43. Schematic diagrams illustrating sequential development (stages 1–5) of structures on north wall of trench CFF–T1A (pl. 17; figs. 2, 42) across the Southern Crater Flat Fault in the Yucca Mountain area, southwestern Nevada (figs. 1, 2).

that formed before being displaced by this event. On the basis of correlating soil development with the dated units exposed in trench CFF–T1A (pl. 17), event Y is dated at later than 40 ka.

Event X

Event X displaced units 5 and 6 about 10 to 15 cm. Unit 5 has a minimum estimated age of 263±16 ka (sample HD 1956, table 30). A total offset of 20 to 40 cm, measured on the top of unit 5 in the deposits exposed in trench CFF–T1 (pl. 18), provides a maximum fault-slip rate of 0.002 mm/yr.

Summary

Geologic relations exposed in trenches CFF–T1A and CFF–T1 indicate that at least three surface-rupturing paleoearthquakes occurred on the Southern Crater Flat Fault during middle Pleistocene to early Holocene time. On the basis of thermoluminescence analyses of fine-grained alluvium and U-series analyses of secondary carbonate and opaline silica sampled from the inner rinds of clasts, event Z probably occurred 4–3 ka, event Y 40–10 ka, and event X 250–130 ka. Minimum recurrence intervals are about 5 to 90 k.y., and the maximum total vertical-slip rate is estimated at 0.002 mm/yr.