The San Andreas fault at Wallace Creek, San Luis Obispo County, California

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LOCATION

From either the coast or the interior, Wallace Creek is most easily reached by way of California 58 (Fig. 1). Precisely at the southwestern base of the Temblor Range, leave California 58 and drive southwest on an unmarked paved road about 0.2 mi (0.3 km) to a junction with an unpaved road (Fig. 2). Turn left (south) on this road and follow the San Andreas fault to Wallace Creek.

The unpaved road leading to Wallace Creek is impassable to all vehicles during and immediately following major storms. At all other times, two-wheel- or four-wheel-drive vehicles can be easily driven to within 1,300 ft (400 m) of the site. To avoid the gradual destruction of fragile tectonic landforms, park vehicles along the road near the section 33/34 boundary fence and walk the short distance north to the fault. During the dry season, be careful not to park on dry, flammable vegetation.

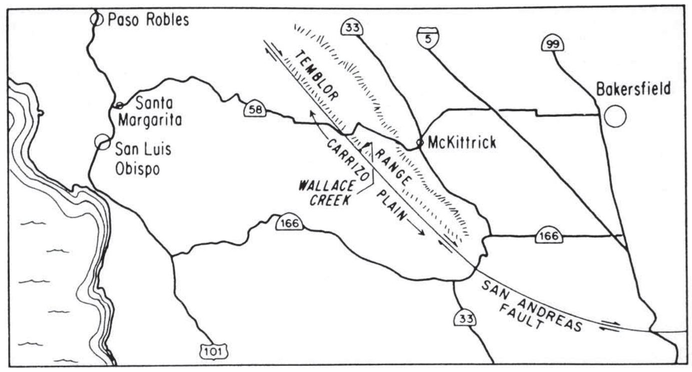

Figure 1. Location of Wallace Creek area. Wallace Creek drains southwestward out of Temblor Range and crosses San Andreas fault as it passes into Carrizo Plain.

SIGNIFICANCE OF THE SITE

Rarely are tectonic landforms as well expressed and as well dated as they are at Wallace Creek. Along this 1.5 mi (2.5 km) length of the San Andreas fault are examples of most of the classic geomorphic features of strike-slip faults, including offset and beheaded channels, shutter ridges, and sags. The smallest features, including right-lateral offsets measuring about 33 ft (10 m), formed in association with the great Fort Tejon earthquake of 1857 (Sieh, 1978). The offsets of larger features, including a 3,700-year-old channel offset 430 ft (130 m), have grown by successive episodes of deformation (Sieh and Jahns, 1984; Wallace, 1968).

Radiometric dating of offset features at this locality demonstrates that the San Andreas fault has been slipping at an average rate of about 1.4 in/yr (34 mm/yr) for at least the past 13,000 years. This rate is only 60 percent of the total relative velocity between the North American and Pacific plates of 2.2 in/yr (56 mm/yr) determined by Minster and Jordan (1978). Hence, a significant fraction of the relative plate motion must be accommodated on other structures, and, contrary to popular belief, the plate boundary cannot be straddled by standing astride the San Andreas fault.

Division of this rate into the amount of offset accumulated during the past three large earthquakes yields recurrence interval estimates ranging between 240 and 450 years. These values are far greater than the current period of dormancy that began following the 1857 earthquake, and a great earthquake will probably not be produced by rupture involving this segment of the fault until at least 2100 A.D.

SITE INFORMATION

The San Andreas fault is perhaps the most famous of all transform faults; certainly it is one of the most accessible. At this locality, features of the surficial trace of this major crustal structure are especially well displayed.

Tectonic Landforms

Figure 3 depicts landforms associated with the fault. Traces of the fault and mappable geologic units have been excluded from this topographic map in order to avoid obscuring the landforms. The location of the fault trace is indicated by small block triangles on the left and right margins of the map. Features discussed in the text are referenced to a 100-m grid marked from left to right on the upper and lower edge of the map.

Offset channels are one of the tectonic landforms most apparent on Figure 3. Between the 300- and 500-m marks is the channel of Wallace Creek, which is offset 430 ft (130 m) along the fault. Farther to the southeast, at the 2,250-m mark, is a younger channel, offset about 65 ft (20 m). Between the 690- and 900-m marks are four very small gullies that are offset about 30 ft (9.5 m).

At the 1,050-m mark is another small gully incised about 1.5 ft (0.5 m) into an alluvial fan. The portion of this gully upstream from the fault is no longer visible in the field. It was buried during a severe storm in February 1978. Prior to its burial, the gully displayed a measurable offset of about 30 ft (9.5 m).

Excellent examples of beheaded channels are at the 100-, 2,800-, 2,000-, and 2,100-m marks. Each of these has been displaced several hundred ft (m) from its source. The history of the

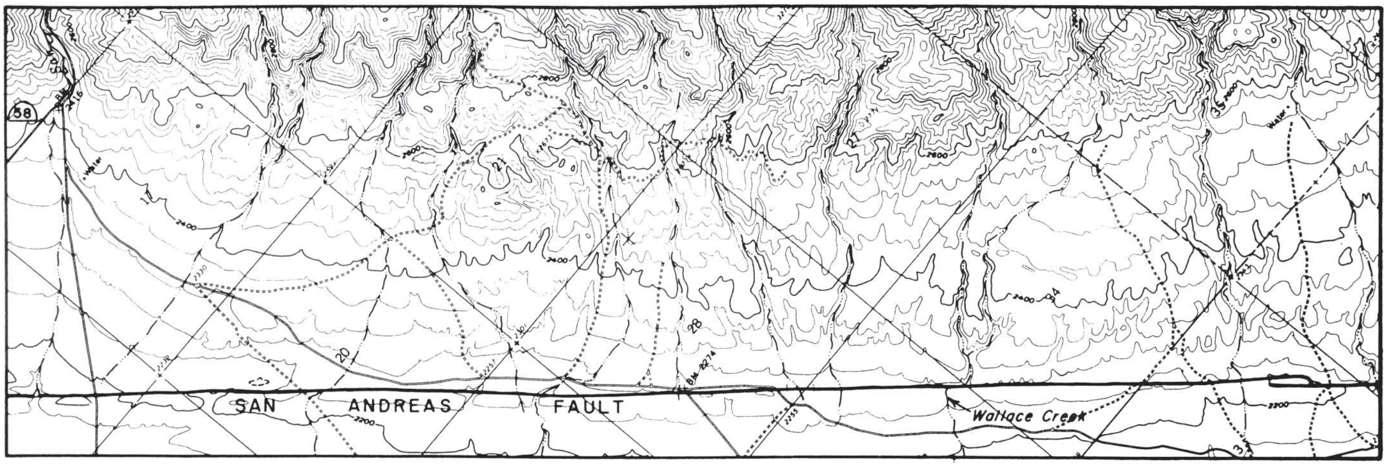

Figure 2. Topographic map of Wallace Creek area showing access roads and San Andreas fault. Location of San Andreas fault mostly from Vedder and Wallace (1970).

TABLE 1. SMALLEST STREAM OFFSETS NEAR WALLACE CREEK AND PROPOSED INTERVALS BETWEEN GREAT EARTHQUAKES (FROM SIEH AND JAHNS, 1984)

Stream Offsets (m)	Number of Measurements	Produced by	Slip associated with earthquake (m)	Proposed Interval Between Events (yr)
$9.5 \pm 0.5 (\pm 1\sigma)$	5	1857 event	$9.5 \pm 0.5 (\pm 1\sigma)$	
				240-320 §
21.8 ± 1.1	4**	1857 plus last prehistoric event	$12.3 + 1.2$*	
				300-440 §
32.8 or 33.5 ± 1.9	3**	1857 plus latest 2 prehistoric events	11.0 or 11.7 ± 2.2†	
				240-450 §

*$21.8 - 9.5 \pm (0.5^2 + 1.1^2)^{1/2}$.
†$32.8 - 21.8 \pm (1.1^2 + 1.9^2)^{1/2}$ or $33.5 - 21.8 \pm (1.1^2 + 1.9^2)^{1/2}$.
§Slip during following earthquake in column 4 divided by average late Holocene slip rate (33.9 ± 2.9 mm/yr).
**Offset gullies are all between Wallace Creek and gully at 900-m mark in Figure 1.

latter two channels is discussed in more detail by Wallace (1968, p.17–18). A smaller, but very distinct, beheaded channel is visible at the 960-m mark. Very probably it was cut by streams that now flow out of the canyon at the 1,040-m mark. Much smaller beheaded gullies are present between the 570- and 870-m marks. These are barely visible in Figure 3, and some are difficult to see and interpret in the field because the channel segments near the fault are choked with debris that has been washed off the fault scarp.

These smallest beheaded and offset channels provide an important clue to the behavior of the San Andreas fault. The smallest measurable dislocations within the map area are small gullies offset about 30 ft (9.5 m). These dislocations probably formed during the great 1857 earthquake, which was produced by fault rupture along a 220-mi (360-km) or somewhat longer segment of the fault in southern California (Sieh, 1978; Agnew and Sieh, 1978). It appears that none of the 30 ft (9.5 m) has accumulated during the 20th century, because fences built across the fault in the Carrizo Plain at about the turn of the century display no offset whatsoever (Brown and Wallace, 1968). Also, the 30-ft (9.5-m) dislocations probably do not represent smaller offsets accumulated during two or more large earthquakes, because small gullies form very frequently in the Carrizo Plain. For example, a new gully formed at the 1,950-m mark in February 1978. It and many older post-1857 gullies in the Carrizo Plain display no offset at all (Sieh, 1978; Wallace, 1968). If large dislocations are produced at intervals of several decades or more, discrete populations of offsets should be observable.

In fact, larger dislocations in this area are rough multiples of the 30-ft (9.5-m) offset (Sieh and Jahns, 1984, Table 1). Several gullies are offset about 80 ft (22 m), and several more are offset about 100 ft (33 m). A logical conclusion is that the 1857 earth-

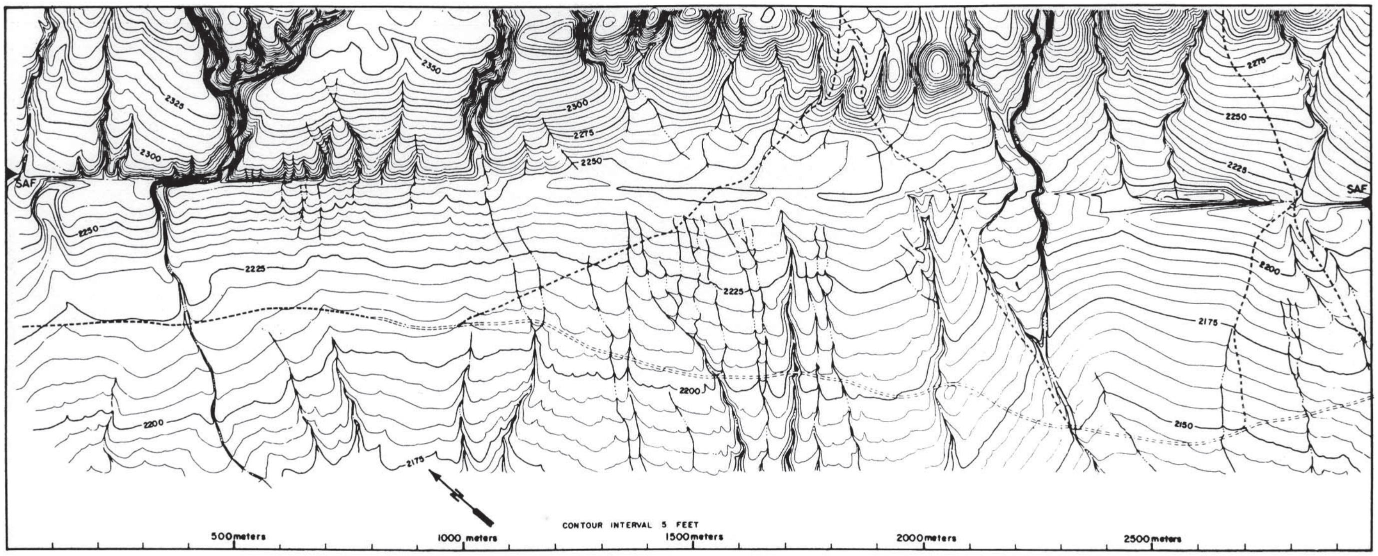

Figure 3. Topographic map of Wallace Creek area illustrates offset and beheaded channels, sag depressions, shutter ridges, and other tectonic landforms produced by recurring strike-slip movement along San Andreas fault. Elevations approximate the National Geodetic Vertical Datum (NGVD 29). Triangles (SAF) at left and right margins mark location of San Andreas fault.

quake was accompanied by about 30 ft (9.5 m) of slip and that its two predecessors were accompanied by about 40 and 36 ft (12.5 and 11 m) of slip.

Shutter ridges of various sizes are well represented along this segment of the fault. The term "shutter ridge" was originally employed by Buwalda (1936, p. 307) to describe topographic highs that had been moved across drainage courses along strike-slip faults. He envisioned these highs or ridges to have been carried by lateral fault slip into positions immediately downstream from existing drainages. The largest shutter ridge at this site can be found between the 1,100- and 1900-m marks. We are uncertain as to the origin of this shutter ridge: It may well represent a broad alluvial fan offset from a source southeast of the 2,300-m mark. Alternatively, it may be a more dynamic feature—perhaps an anticline with a southwest-plunging axial trace that has risen incrementally while being moved laterally over the past several thousand or more years. Smaller shutter ridges, composed of displaced alluvial and colluvial aprons, block the offset gullies between the 620- and 890-m marks.

Sediment is commonly "ponded" behind shutter ridges. A large region of active deposition currently exists upslope of the shutter ridge between the 1,100- and 1,900-m marks. Streams flowing into this region of topographic closure lose their carrying capacity on reaching this area of low gradient and drop their bed load. Three small alluvial fans are clearly visible on the northeastern margin of the depression. Although we have never witnessed it, water may, at times of high discharge, actually pond in this area of topographic closure behind the shutter ridge. This would enable deposition of silty and clayey suspended load as well. Eventually, alluvial fans building southwestward or quiet-water silts and clays filling the basin may be able to overtop the shutter ridge, enabling reestablishment of a fault-crossing drainage there. This drainage would probably cross the fault at the low point in the shutter ridge at the 1,670-m mark, reoccupying the ancient beheaded drainge there. Smaller examples of "ponded" sediment occur immediately upstream from the fault in most of the small drainages between the 680- and 890-m marks. The small right-lateral jogs between the 680- and 890-m marks must result in lesser competence of these ephemeral streams immediately upstream from the fault. Perhaps this is because several meters of length, but virtually no height, are added to the long profile at the time of dislocation. Thus, dislocations add a section of shallower gradient at the fault. Alternatively, substantial losses in stream- or debris-flow velocity may occur at the fault, because the flow must abruptly bend to the right, around the small shutter ridges.

Between the 2,350- and 2700-m marks, two fault traces are arranged en echelon. Dextral slip has resulted in an increase in volume between the overlapping parts of these two faults, and a "sag" or depression has formed as the surface has dropped between the two fault planes. Spectacular evidence of this was evident immediately following a severe storm in mid-February 1978. During that storm, the three major channels that terminate in the sag delivered enough water to form an ephemeral sag pond about 12 ft (3.5 m) deep. Substantial erosion of the northwestern and southeastern channel beds also occurred at that time, and alluvial fans with deltaic fronts formed on the margins of the pond. Along the long margins of the pond, many large, elongate pits, some as much as 10 ft (3 m) deep and long, formed as the ponded water catastrophically drained into open fractures along both fault planes. Fresh pond-facing fault scarplets, up to about 6 in (15 cm) in height, formed along both long margins of the lake as near-surface debris was carried to greater depths by these waters and surficial blocks slumped in to fill the voids. Remnants of the delta fronts, collapse fissures, and fault scarps are still visible at the time of this writing (1985).

Fault scarps of several ages and degrees of activity are present within the area of Figure 3. The continuous high scarp that extends the full length of Figure 3 between zero and 300 m northeast of the fault trace is 30 ft (10 m) high and is still growing between the 490- and 650-m marks. The trace of the fault lies very near its base, and its lower slopes are much steeper than its upper slopes (about 35° versus about 5°). Sieh and Jahns (1984) demonstrated that this scarp has been growing since about 13,000 years ago, when the alluvial fan in which it formed ceased accumulating. The scarp has risen 10 ft (3 m) in the past 3,700 yrs, at an average rate of 0.03 in/yr (0.8 mm/yr). Between the 650- and 1,900-m marks, the fault scarp has either ceased growth or transforms into a broad monocline. This is indicated by several lines of evidence. First, the fault trace at the 1,900-m marks is farther away from the base of the scarp than at the 650-m mark. Second, the scarp is buried by greater volumes of debris toward the southeast (note the large alluvial fans between the 1,320- and 1,900-m marks). Third, the steepness of the lower portion of the scarp diminishes toward the southeast. Thus, this scarp appears to be growing in height northwest of and decreasing in height southeast of the 650-m mark. Thus, the block upstream from the fault appears now to be bulging upward in the northwest and subsiding in the southeast.

The scarps immediately adjacent to the fault trace alternate along strike from northeast-facing to southwest-facing: a common feature of strike-slip faults termed "scissoring." In some localities, scissoring is clearly a result of purely strike-slip offset of a nonplanar ground surface. In the field, for example, scissoring of the fault scarp can be readily observed across the alluvial fan between the 960- and 1,100-m marks. On the northwestern half of the fan the fault scarp faces uphill, whereas on the southeastern half it faces downslope. This is best explained as strike-slip offset of the convex surface of the alluvial fan.

Wallace Creek

The geomorphology and stratigraphy of Wallace Creek, the large, prominent channel between the zero- and 700-m marks has been studied in detail by Sieh and Jahns (1984). By employing surficial geologic mapping, trenching, and radiocarbon dating, they were able to determine the age and evolution of Wallace Creek, and thereby determined a long-term slip-rate for the fault and made estimates of recurrence intervals for large earthquakes there. Between about 19,000 and about 13,000 years ago, the San Andreas fault at Wallace Creek traversed a broad, active alluvial fan (Fig. 4a). The fan surface was aggrading at a rate sufficient to bury fresh fault scarplets soon after their formation. About 13,000 years ago, perhaps due to climatic changes, Wallace Creek cut a channel into the fan and the fan surface ceased aggrading (Fig. 4b).

Subsequently, the fault has progressively offset the channel several hundred ft (m). Twice the channel segment downstream from the fault has been abandoned, and a new downstream segment cut straight across the fault from the upstream segment (Fig. 4c, e). The oldest downstream segment now resides at the minus 10-m mark about 1,500 ft (475 m) away from its upstream continuation and just off the northwest edge of the map of Figure 3. Another former channel of Wallace Creek now lies beheaded at the 100-m mark. It was first cut by Wallace Creek about 10,000 years ago (Fig. 4c). Between 11,000 and 3,700 years ago this channel was offset about 250 m but was able to avoid beheading by maintaining a deep channel segment along to the fault, analogous to the segment of the presently active channel that follows the fault (Fig. 4d). During a period of merely a century or so, alluvium choked this segment of the channel. A terrace 23 ft (7 m) above the modern channel floor near the fault-crossing and between the 450- and 480-m marks is a remnant of the surface of this 3,700-year-old channel filling. This channel aggradation led to abandonment of the old channel and entrenchment of a new channel straight across the fault (Fig. 4e). In the past 3,700 years, this new channel has been offset 430 ft (130 m) to its present configuration (Fig. 4f).

SLIP RATE DURING THE LATE HOLOCENE AND ESTIMATION OF RECURRENCE INTERVALS

Knowing the date of the most recent entrenchment of Wallace Creek and the offset that accumulated since that entrenchment, one can calculate rather precisely a slip rate of 33.9 ±2.9 mm/yr ($\pm 2\sigma$) for the San Andreas fault. The latest prehistoric dislocation of 40.6 ft (12.3 m) is estimated to have occurred between 1540 and 1630 A.D. The previous dislocation of about 36 ft (11 m) may have occurred between 1120 and 1300 A.D. If the interval between large events is indeed as long as is indicated by these estimates, the next event at Wallace Creek should not be anticipated until about 2100 A.D. or even later.

IMPLICATIONS OF THIS SITE FOR KINEMATICS OF SOUTHERN CALIFORNIA

Minster and Jordan (1978) determined from a circumglobal data set that the relative motion of the Pacific and North American plates has averaged about 2.2 in/yr (56 mm/yr) during the past 3 m.y. The geologic record at Wallace Creek shows that, at least during the past 13,000 yr, only about 1.4 in/yr (34 mm/yr) of this has been accommodated by slip along the San Andreas fault. If the 3-m.y. average is assumed to represent the Holocene average rate across the plate boundary as well, then clearly the San Andreas fault is accommodating only 60 percent of the relative plate motion. The reminder of the deformation must be accomplished elsewhere within a broader plate boundary. The San Gregorio–Hosgri fault system, which traverses the coast of central California, may have a late Pleistocene–Holocene slip rate of 0.2 to 0.5 in/yr (6 to 13 mm/yr) (Weber and Lajoie, 1977), and the Basin Ranges, to the east of the San Andreas fault, may

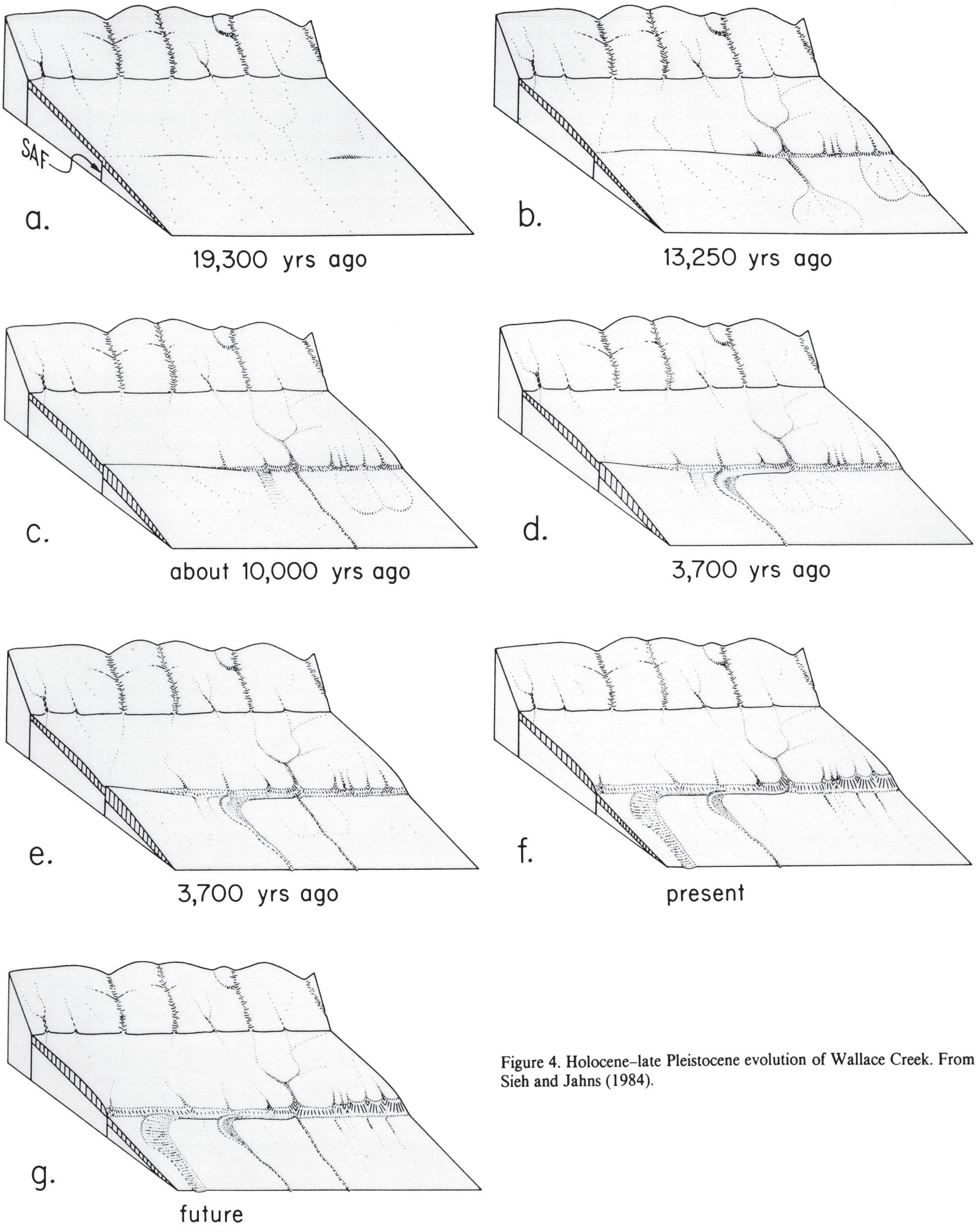

Figure 4. Holocene–late Pleistocene evolution of Wallace Creek. From Sieh and Jahns (1984).

be opening N.35°W. on oblique normal faults at a late Pleistocene–Holocene rate of about 0.3 in/yr (7 mm/yr) (Thompson and Burke, 1973). Most of the 2.24-in/yr (56-mm/yr) plate rate may thus be attributed to the San Andreas, San Gregorio-Hosgri, and Basin Range faults.

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