Recently Active Traces of the Berryessa Fault and Adjacent Sections of the Green Valley Fault Zone, California: A Digital Database

Data Series 710

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2012

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Suggested citation:
Lienkaemper, James J., 2012, Recently active traces of the Berryessa section and adjacent sections of the Green Valley Fault Zone, California: A Digital Database: U.S. Geological Survey Data Series 710, 12 p.

Contents

Recently Active Traces of the Berryessa Fault and Adjacent Sections of the Green Valley Fault Zone, California:A Digital Database

By James J. Lienkaemper

Introduction

This database with accompanying map shows the locations of, and evidence for recent movement on, active traces of the Berryessa Fault, a northern section of the Green Valley Fault. It includes previously unmapped parts of the Green Valley Fault northward from Wooden Valley and of the Hunting Creek Fault southward from Mysterious Valley (figs. 1, 2). The locations and recency of movement of the newly mapped traces are based primarily on geomorphic expression (fig. 3) of the fault as interpreted from large-scale aerial photography. In a few places, evidence of fault creep and offset Holocene strata in natural exposures and in trenches confirms the activity of some of these traces.

This U.S. Geological Survey (USGS) report is formatted both as a digital database for use within a geographic information system (GIS) and for broader public access as map images that may be browsed or downloaded. The text describes the types of scientific observation used in making the map, lists references pertaining to the fault and the evidence of faulting, and provides guidance for the use and the limitations of the map. Locations along the fault are given by distance along the fault from its approximate north end at a major bend in the Hunting Creek Fault (HCF, figs. 1, 2), as defined by the map grid described below in the section entitled "Methodology."

The term "recently active fault trace" is defined here as a fault trace that shows evidence consistent with movement during the Holocene, or approximately the past 10 ka.

The Green Valley Fault in this report constitutes a nearly continuous fault system about 110 km long lying east of the San Andreas Fault and the Hayward-Rodgers Creek-Maacama Fault (fig. 1). South of Wooden Valley (WV, fig. 1), this fault system has generally been called the Green Valley Fault or the Concord-Green Valley Fault (GVF, fig. 1); however, this study shows sufficient continuity of the active fault traces to describe a longer Green Valley Fault northward to Lake Berryessa (LB, fig. 1), where it jogs to the right through a connector fault (fig. 2) to become the eastern trace of the Berryessa Fault. The Berryessa Fault, in turn, makes a right step of 2 to 3 km to the Hunting Creek Fault (fig. 2). Such a minor discontinuity has an approximately 50-percent probability of allowing through-going rupture in any large earthquake (Wesnousky, 2008). Thus, both the Hunting-Creek and Berryessa Faults can be considered sections of the Green Valley Fault for the purposes of seismic hazard evaluation. For simplicity, in this report I refer to the newly mapped traces of the Green Valley Fault (km 10–57, fig. 2) as the northern section of the fault.

Geologic Setting and Fault Mapping

The Green Valley Fault is a major branch of the San Andreas Fault system. Like the San Andreas, the Green Valley Fault is a right-lateral, strike-slip fault, meaning that slip is mainly horizontal, so that objects on the opposite side of the fault from the viewer will move to the viewer's right as slip occurs. For a broader discussion of the basic principles of strike-slip faulting and the relation of the Green Valley Fault to the San Andreas Fault system, see the report by Wallace (1990a).

Frizzell and Brown (1976), Bryant (1982a), and Bryant and Cluett (2002) summarized the geologic setting and previous mapping of the Green Valley Fault and evaluated its apparent recency of movement by geomorphic interpretation of aerial photography. They concluded that the fault probably continues northward of Wooden Valley (WV, fig. 1), but that its exact location is partly concealed here by large landslides. Possibly even more important is that tree cover is extensive here and it obscures much of the fault trace between Wooden Valley and Lake Berryessa. A new tool, lidar (light detection and ranging), has recently become available to analytically image topography beneath the tree canopy, as discussed further below.

Farther north, near Lake Berryessa (LB, fig. 1, 2), Wagner (1975) identified the Pope Creek Fault and the Putah Creek Fault (western and eastern traces, respectively, of the Berryessa Fault), describing them as Quaternary active. North of Lake Berryessa, Bryant (1982b, 1983; see Bryant, 2000) considered that the Hunting Creek Fault possibly connects with the Green Valley Fault, but other than a few well-defined features along the Pope Creek Fault (western trace of the Berryessa Fault) Bryant (1982b, fig. 2b) concluded

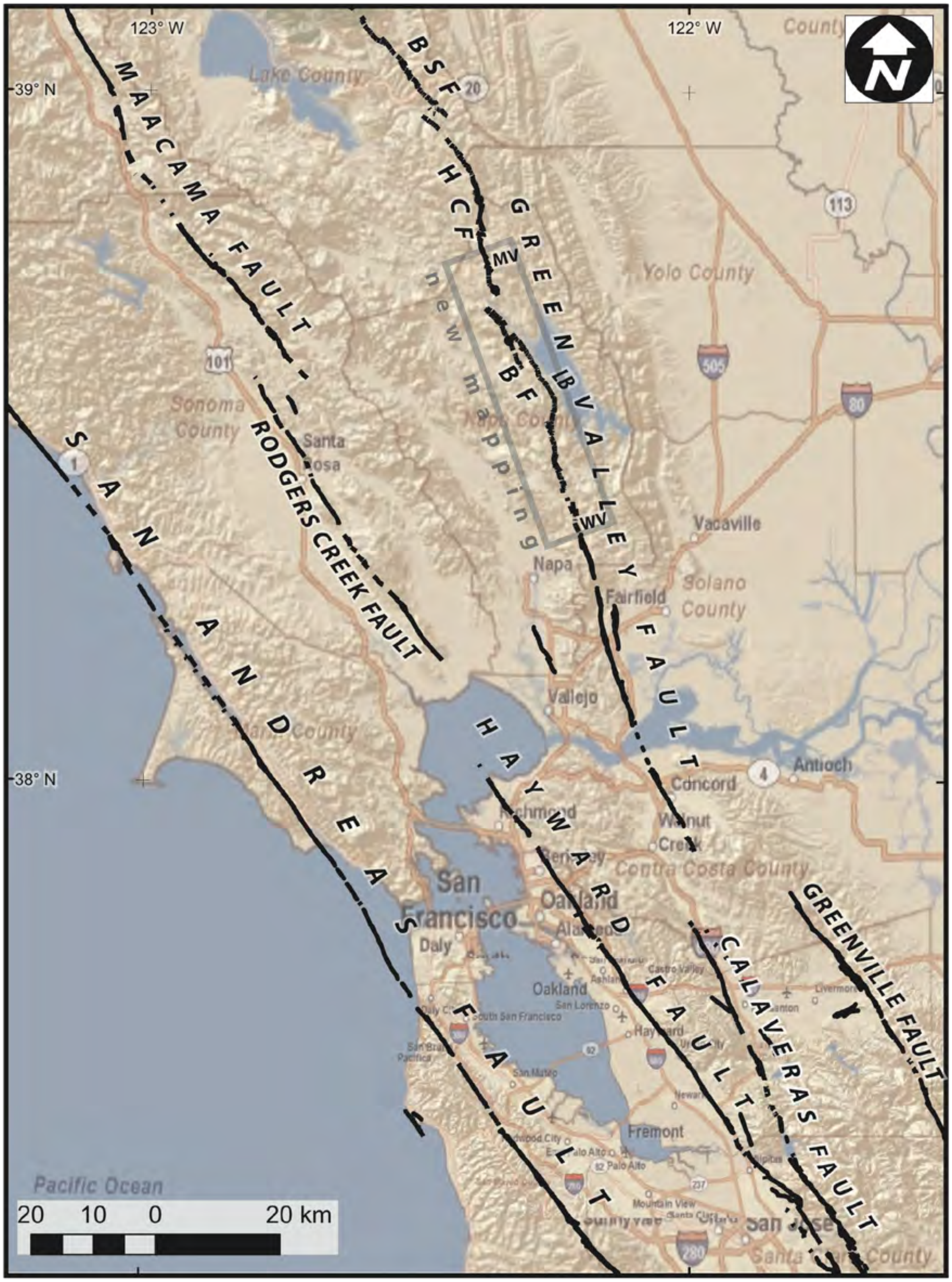

Figure 1. San Francisco Bay area of central California, showing locations of newly mapped traces of the Green Valley Fault in the study area (gray box). (See fig. 2 for larger view and fig. 4 for details). Holocene active faults (black lines) from U.S. Geological Survey and California Geological Survey (2006) except for the Bartlett Springs Fault (BSF; Lienkaemper, 2010), the Berryessa Fault (BF) and adjacent parts Hunting Creek Fault (HCF) south of Wooden Valley (WV), and the Green Valley Fault north of Wooden Valley. LB, Lake Berryessa.

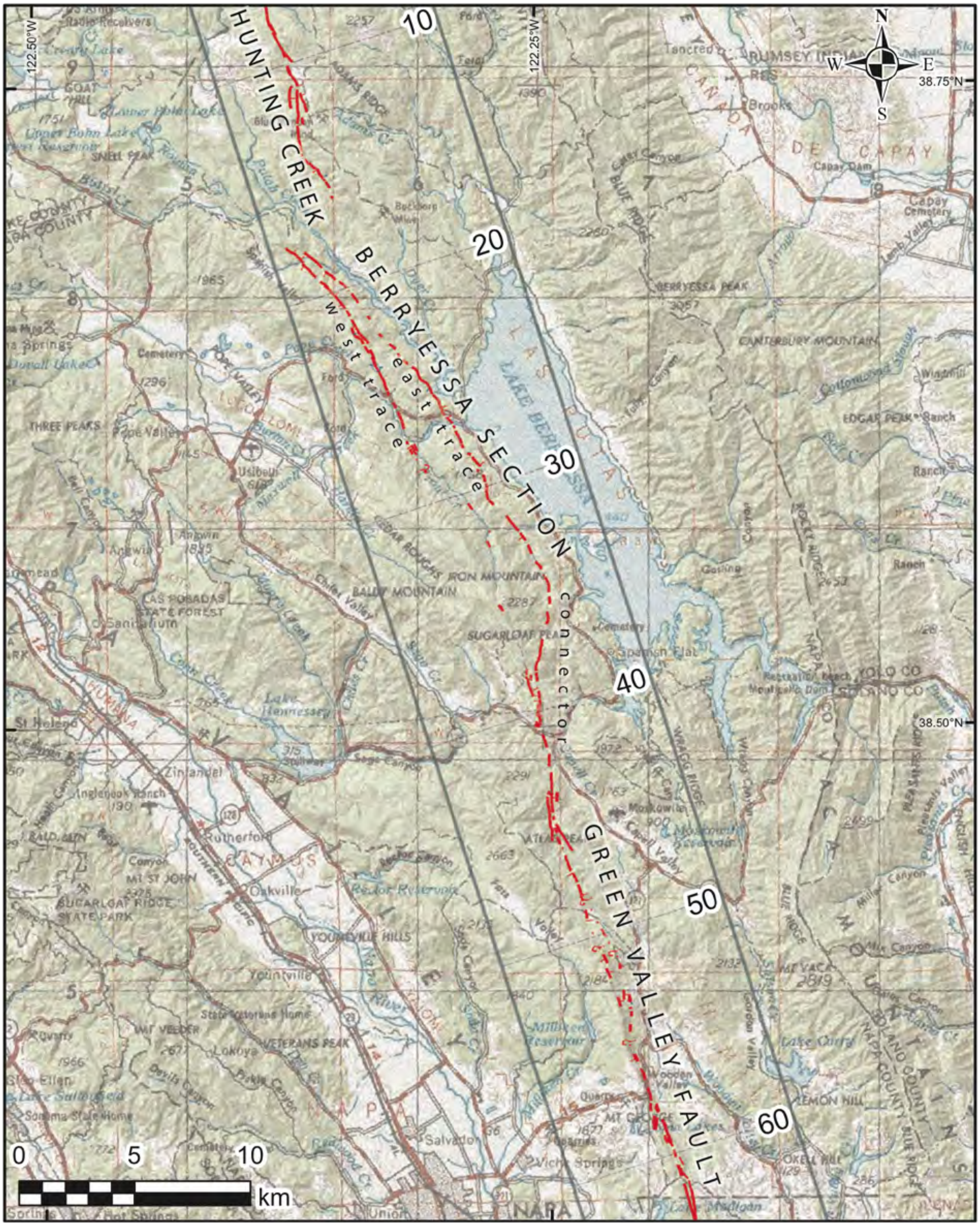

Figure 2. Enlarged view of the study area (fig. 1) showing locations of newly mapped traces of the Green Valley Fault described in this report (km 10 to 57; fig. 4 for details). Red lines, Holocene active faults, south of km 60 (from U.S. Geological Survey and California Geological Geological Survey, 2006) and the Hunting Creek fault north of km 10 (from Lienkaemper, 2010).

that these faults "...are somewhat less well defined and may not have had displacement in Holocene time." Therefore, during that time an apparent gap was present in Holocene fault traces between km 27 and 57 (fig. 2). Detailed geologic mapping within this gap, in the vicinity of Wooden Valley (WV, fig.1) and northward, including the Green Valley Fault, has recently become available (Bezore and others, 2004; Delattre and others, 2006; Wagner and Gutierrez, 2010). This new mapping indicates that dextral slip of 6 to 8 km on the basis of offset of the north edge of the Eastern Sonoma Volcanics between Atlas Peak and Wooden Valley, has occurred sometime within the past 3.9 Ma. Farther north, on the western trace of the Berryessa Fault, I infer 1.8 to 5 km of apparent dextral offset in the southernmost outcrops of some lower units within the Clear Lake Volcanics (~1.3-1.5 Ma; Donnelly-Nolan and others, 1981), as mapped locally by Wagner (1975). Nearby Pope Creek is dextrally offset by 1.8 km, in agreement with the minimum estimate.

To interpret the geomorphic expression of active faulting, I used two sets of 1:12,000-scale aerial photographs: 1996 (USGS-)CFZ and 2010 USGS-BF and three sources of lidar imagery: 2008 GeoEarthScope, 2002 Napa Watershed, and 2011 USGS. Lidar images are especially useful for revealing fault traces previously obscured or concealed under tree canopy and for inferring recency of movement (Haugerud and others, 2003; Hilley and others, 2010). The methodology used to interpret the recency and locations of fault traces is described in more detail below.

Organization of Digital Files

This report is being released primarily as a digital product to be either used directly as a GIS map layer or browsed online (http://pubs.usgs.gov/ds/710/). Nontechnical users may gain an overview of the mapping at a scale of about 1:50,000 or may use virtual globe software for viewing it at any scale desired. More technical users may wish to query the GIS database and develop their own map views of the fault by using either ArcGIS software (proprietary) or ArcReader (free on the Internet). As with all GIS data, the reader must be aware of the scale limitations of each data set. The accuracy of these datasets is

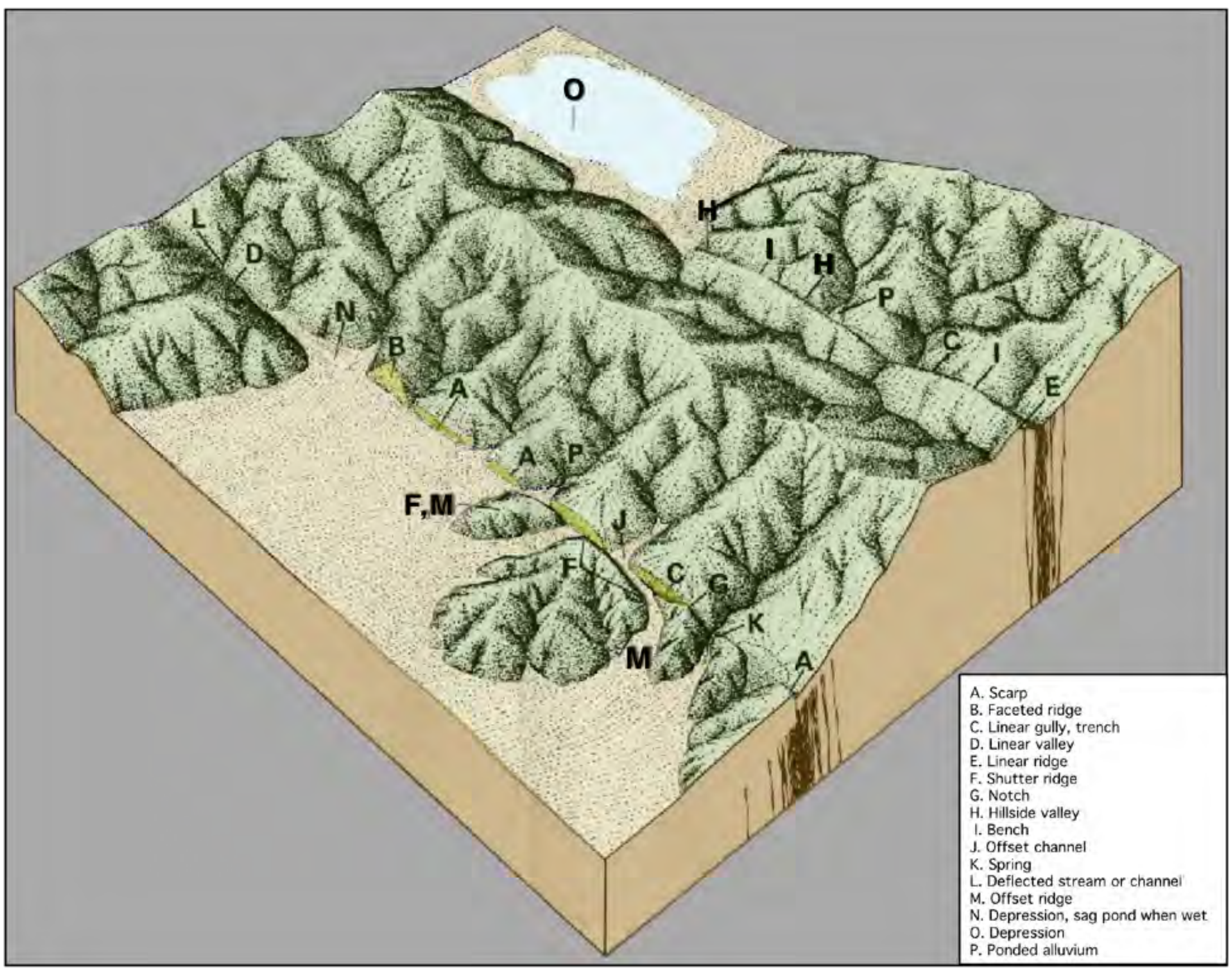

Figure 3. Block diagram showing typical landforms created along recently active faults (after Sharp, 1972)

discussed further below and described in the metadata of each GIS file. Documentation of the database fields is included in the metadata of each GIS file and here.

The projection of all GIS files in the download package is UTM10-WGS84.

Methodology

Map Abbreviations and Kilometer Grid

The fault-strip map takes the approach used by Lienkaemper (1992, 2006) for the Hayward Fault by presenting evidence of faulting in abbreviated labels (fig. 4). For indexing the locations of the features discussed in this report, the map includes a kilometer grid oriented along the approximate average strike of the Green Valley Fault: N. 18° W. (figs. 1, 2, 4). The km 0 mark is located in the large (~18 ± 3°) bend where the main active trace of the Hunting Creek Fault deviates distinctly from the average trend of the Green Valley Fault. Northward of km 0, the Hunting Creek Fault (HCF, fig. 1) begins to align with the Bartlett Springs Fault (BSF, fig. 1; Lienkaemper, 2010, 2011) rather than the Green Valley Fault. This kilometer grid is available in the GIS data package as a shapefile.

Abbreviations for Figure 4

G1	Strongly pronounced feature
G2	Distinct feature
G3	Weakly pronounced feature
?	Additional uncertainty in tectonic origin
af	Alignment of multiple features as listed
as	Arcuate scarp
bfs	Backfacing scarp
bt	Downthrown surface tilting back toward fault
dd	Deflected drainage
df	Depression formed by some aspect of fault deformation, undifferentiated
dr	Sag, depression formed in right stepover of fault trace
ec	*En echelon* cracks in pavement, evidence of creep
fs	Faceted spur
gi	Linear break (or gradual inflection) in slope
hb	Linear hillside bench
hv	Linear hillside valley
lr	Linear ridge
ls	Fault-scarp height enlarged by landsliding
lv	Linear valley or trough
mp	Youngest traces disturbed by human activities. Mapped trace bisects disturbed zone. Location uncertainty (dashed gap in linework) equals half- width of disturbed zone.
n	Notch
pr	Pressure ridge in left stepover
rr	Right-laterally offset ridgeline
rs	Right-laterally offset stream or gully
s	Saddle
sb	Broad linear scarp (implies multiple traces)
sc	Scissorpoint, sense of vertical separation reverses
se	Subsoil exposed
sl	Scarp, linear
sn	Narrow linear scarp (implies dominant trace)
sp	Spring
ss	Swale in saddle
vl	Line of vegetation

Fault Location Inferred from Geomorphic Expression

Geomorphic interpretation, on aerial photographs and lidar images, and in the field, is a critical element in identifying recently active fault traces (Wallace, 1990b). A block diagram (fig. 3) illustrates many of the typical landforms created by strike-slip faulting. Most of these geomorphic features result when horizontal sliding along the fault brings different materials into contact at the fault, for example, bedrock against unconsolidated alluvium or colluvium.

The most visible effect is that fault slip causes abrupt disruptions in the natural drainage system, including interrupted subsurface waterflow, and results in stream offsets and the formation of ponds and springs. Most of the methodology used in this study was previously described by Lienkaemper (1992, 2006) for mapping the Hayward Fault, and so here I summarize only the main ideas, with emphasis on how mapping methods may differ for the Green Valley Fault.

I use a code system (G1, strongly pronounced; G2, distinct; G3, weakly pronounced) to express my overall judgment about the reliability of geomorphic features for accurately locating recent fault traces. Accuracy or location certainty is also estimated quantitatively in the GIS database, which can be depicted on the map by choice of line type.
I tried to apply this methodology similarly in my previous work, despite significant differences in rainfall and terrain between the Hayward Fault and the northern section of the Green Valley Fault. For example, average rainfall along the Hayward Fault (530 mm/yr) is only about two-thirds that of the northern section of the Green Valley Fault (740 mm/yr), and the average elevation of the Hayward Fault is only 80 m, in contrast to 340 m on the northern GVF. Thus, owing to its higher rainfall and steeper slopes, greater rates of erosion and landsliding should be observed on the northern section of the Green Valley Fault, and recent geomorphic features should be more difficult to recognize because of poorer preservation.

Landsliding posed a major challenge to mapping the continuity of active fault traces, requiring initial identification of landslide features to distinguish them from tectonic features. Landslides clearly cause two large gaps in mapping the northern section of the Green Valley Fault (~2 km) near km 21–23 (western trace, fig. 2) and km 49–51 and many

A

Figure 4. Detailed map of active traces of the Berryessa Fault and adjacent parts of the northern Green Valley Fault (box, fig. 1). *A*, Hunting Creek Fault and the Berryessa Fault. *B*, Eastern and western traces of the Berryessa Fault. *C*, Connector between Berryessa and Green Valley sections. *D*, Green Valley Fault. *E*, Southernmost limit of mapping. Abbreviations listed below describe geomorphic features indicative of recent fault slip that were used to infer the approximate locations of these fault traces (see fig. 3). Additional information is available in GIS database.

B

Figure 4. Detailed map of active traces of the Berryessa Fault and adjacent parts of the northern Green Valley Fault (box, fig. 1). *A*, Hunting Creek Fault and the Berryessa Fault. *B*, Eastern and western traces of the Berryessa Fault. *C*, Connector between Berryessa and Green Valley sections. *D*, Green Valley Fault. *E*, Southernmost limit of mapping. Abbreviations listed below describe geomorphic features indicative of recent fault slip that were used to infer the approximate locations of these fault traces (see fig. 3). Additional information is available in GIS database.—Continued

C

Figure 4. Detailed map of active traces of the Berryessa Fault and adjacent parts of the northern Green Valley Fault (box, fig. 1). *A*, Hunting Creek Fault and the Berryessa Fault. *B*, Eastern and western traces of the Berryessa Fault. *C*, Connector between Berryessa and Green Valley sections. *D*, Green Valley Fault. *E*, Southernmost limit of mapping. Abbreviations listed below describe geomorphic features indicative of recent fault slip that were used to infer the approximate locations of these fault traces (see fig. 3). Additional information is available in GIS database.—Continued

D

Figure 4. Detailed map of active traces of the Berryessa Fault and adjacent parts of the northern Green Valley Fault (box, fig. 1). *A*, Hunting Creek Fault and the Berryessa Fault. *B*, Eastern and western traces of the Berryessa Fault. *C*, Connector between Berryessa and Green Valley sections. *D*, Green Valley Fault. *E*, Southernmost limit of mapping. Abbreviations listed below describe geomorphic features indicative of recent fault slip that were used to infer the approximate locations of these fault traces (see fig. 3). Additional information is available in GIS database.—Continued

E

Figure 4. Detailed map of active traces of the Berryessa Fault and adjacent parts of the northern Green Valley Fault (box, fig. 1). *A*, Hunting Creek Fault and the Berryessa Fault. *B*, Eastern and western traces of the Berryessa Fault. *C*, Connector between Berryessa and Green Valley sections. *D*, Green Valley Fault. *E*, Southernmost limit of mapping. Abbreviations listed below describe geomorphic features indicative of recent fault slip that were used to infer the approximate locations of these fault traces (see fig. 3). Additional information is available in GIS database.—Continued

smaller gaps. Between km 29 and 35, extreme rates of erosion and landsliding in melange within the Great Valley Complex (Graymer and others, 2007) in the ravine of Trout Creek may be responsible for the weak or obscure southward continuity of the western trace of the Berryessa Fault. Alternatively the fault may step to the left beneath Trout Creek Ridge to the eastern trace, with surface slip on the western trace of the fault dying out southward of km 39.

Fault Location from Creep Evidence

Fault creep, the common name for aseismic slip observed along the surface trace of a fault, has been recognized along many branches and segments of the San Andreas Fault system (the Calaveras, Concord, Green Valley, Greenville, Hayward, Imperial, Maacama, northern section of the Rodgers Creek, central section of the San Andreas, Sargent, and Superstition Hills Faults). Galehouse and Lienkaemper (2003) summarized creep in northern California. Although USGS recently installed three alinement arrays across the Berryessa Fault, it is still unknown whether the fault exhibits creeping behavior (McFarland and others, 2009). However, the nearest array to the north on the Hunting Creek Fault currently indicates a low creep rate (1.4 ± 0.5 mm/yr; 2007–2011 at site HCHC at km 3.9) as does the next array to the south (1.5 ± 2.4 mm/yr at site GVCL at km 43.3) but with a large uncertainty in its rate (McFarland and others, 2009). Unlike the Hayward Fault, few cultural features cross the northern section of the Green Valley Fault, and so I have not identified any cultural features that indicate creep.

Fault Location from Trenching Evidence

North of the study area, some trenching has been done across the Hunting Creek Fault (HCF, fig. 1; Bryant, 1983; Bryant and Cluett, 2002). In 2011-2012 at km 21.9, USGS excavated four trenches across the western trace of the Berryessa Fault and documented paleoseismic evidence suggesting the age of the most recent earthquake was ~400 ± 100 yr ago (J. J. Lienkaemper, unpublished data, 2012). Thus fragile surface rupture features along the fault trace accompanying that earthquake would by now be considerably degraded, explaining some of the difficulty that earlier workers had in recognizing active fault traces in this remote part of the Green Valley Fault.

Acknowledgments

The USGS National Earthquake Hazards Reduction Program and the U.S. Bureau of Reclamation jointly funded the 2010 aerial photography and fault mapping and 2011–12 trenching. I thank Larry Anderson, Sarah Derouin and Lucy Piety of U.S. Bureau of Reclamation for helping make this work possible. I appreciate the assistance of Salih Cotten and the Shadhiliyya Sufi Center in our paleoseismic study. Reviews of the manuscript and metadata by John Tinsley and Luke Blair improved this report.

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