Stateline fault system: A new component of the Miocene-Quaternary Eastern California shear zone

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Notes
ABSTRACT

The Eastern California shear zone is an active, north-northwest–trending zone of intraplate right-lateral shear that absorbs ~25% of Pacific-North America relative plate motion. The Stateline fault system (SFS), which includes several previously recognized, discontinuously exposed Quaternary structures along the California-Nevada border, is in this paper defined as a continuous, 200-km–long zone of active dextral shear that includes (from south to north) the Mesquite, Pahrump, and Amargosa Valley segments. Recognition of this system expands the known extent of the Eastern California shear zone ~50 km to the east-northeast from its traditionally recognized boundary along the Death Valley fault system. Proximal volcanic and rock avalanche deposits offset across the Mesquite segment of the SFS indicate 30 ± 4 km of slip on this structure since 13.1 ± 0.2 Ma. This offset is an order of magnitude larger than previous estimates across this section of the SFS, but it is consistent with larger offsets previously proposed for the central and northern sections. The total offset and averaged slip rate since mid-Miocene time (2.3 ± 0.35 mm/yr) are similar to those of other major faults across this portion of the Basin and Range, which, in turn, accommodates an additional 2–3 mm/yr of displacement of the Sierran block relative to North America (Bennett et al., 2003). The Eastern California shear zone is superimposed on the strongly transtensional central Basin and Range province, which began to evolve in the early Miocene as the Pacific-North America transform boundary began to grow (Atwater and Stock, 1998; Wernicke, 1992). Quantitative reconstructions of the continental geology show that from 16 to 6 Ma, prior to the opening of the Gulf of California and development of the San Andreas system, ~50% of Pacific-North America motion (~20 mm/yr) was accommodated in the Basin and Range (Wernicke et al., 1988; Dickinson and Wernicke, 1997; Wernicke and Snow, 1998; McQuarrie and Wernicke, 2005). After 6 Ma, Basin and Range average displacement rate and contribution to the total strain budget decreased by a factor of two, as a result of more coastwise relative plate motion (less extensional component) and more effective localization of strain along the San Andreas system (Atwater and Stock, 1998; Oskin and Stock, 2003). The shear zone thus represents an overprint of a relatively slow, diffuse, transform system on the older transtensional system, and has been a key locale for studying the spatial and temporal distribution of slip in an active fault system (e.g., Reheis and Dixon, 1996; Lee et al., 2001; Snow and Wernicke, 2000; Dixon et al., 2003; Wernicke et al., 2004; Faulds et al., 2005; Wensnousky, 2005).

Recent analyses of geodetic data from continuous Global Positioning System (GPS) stations spanning the Eastern California shear zone suggest that the eastern limit of dextral Pacific-North America shear between latitudes 35° N and 37° N lies to the east of Death Valley along the California-Nevada state line (Fig. 1A; Wernicke et al., 2004; Hill and Blewitt, 2006). These results indicate the potential existence of a dextral fault ~50 km east of the easternmost fault considered in previous tectonic models of this region (e.g., Snow and Wernicke, 2000; Miller et al., 2001; Dixon et al., 2003). A northwest-southeast–trending zone

INTRODUCTION

Pacific-North America plate motion is accommodated across a broad zone of faulting on the western margin of the continental United States. The San Andreas fault system absorbs the greatest portion of the 48 mm/yr of relative plate motion (~35 mm/yr; e.g., Minster and Jordan, 1987; Bennett et al., 2003). Most of the remainder is accommodated by the Eastern California shear zone, a diffuse array of primarily north-west-striking faults to the east and south of Sierra Nevada/Great Valley microplate (Dokka and Travis, 1990). This relatively young (<6-Ma) system of predominantly right-lateral, strike-slip faults currently accommodates ~9 mm/yr of north-northwest motion of the Sierra Nevada/Great Valley microplate relative to the eastern Great Basin, which, in turn, accommodates an additional 2–3 mm/yr of displacement of the Sierran block relative to North America (Bennett et al., 2003). The Eastern California shear zone is superimposed on the strongly transtensional central Basin and Range province, which began to evolve in the early Miocene as the Pacific-North America transform boundary began to grow (Atwater and Stock, 1998; Wernicke, 1992). Quantitative reconstructions of the continental geology show that from 16 to 6 Ma, prior to the opening of the Gulf of California and development of the San Andreas system, ~50% of Pacific-North America motion (~20 mm/yr) was accommodated in the Basin and Range (Wernicke et al., 1988; Dickinson and Wernicke, 1997; Wernicke and Snow, 1998; McQuarrie and Wernicke, 2005). After 6 Ma, Basin and Range average displacement rate and contribution to the total strain budget decreased by a factor of two, as a result of more coastwise relative plate motion (less extensional component) and more effective localization of strain along the San Andreas system (Atwater and Stock, 1998; Oskin and Stock, 2003). The shear zone thus represents an overprint of a relatively slow, diffuse, transform system on the older transtensional system, and has been a key locale for studying the spatial and temporal distribution of slip in an active fault system (e.g., Reheis and Dixon, 1996; Lee et al., 2001; Snow and Wernicke, 2000; Dixon et al., 2003; Wernicke et al., 2004; Faulds et al., 2005; Wensnousky, 2005).

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of discontinuously exposed dextral faults has been described, extending some 200 km along the California-Nevada border, from the town of Primm, Nevada, in the south, to as far north as the town of Beatty, Nevada (Figs. 1B and 1C; e.g., Schweickert and Lahren, 1997), consistent with the new geodetic observations. This zone of faulting is defined in this paper as the Stateline fault system (SFS), and comprises the previously described Pahrump fault (Piety, 1995; Anderson, 1998), Pahrump fault zone (Liggett and Childs, 1973; Stewart, 1988; Wright, 1989) and Pahrump Valley fault zone (Hoffard, 1991; dePolo, 1998); Stewart Valley fault (Stewart et al., 1968; Burchfiel et al., 1983; Carr, 1984); Amargosa River fault zone (Donovan, 1991; Anderson et al., 1995; Piety, 1995; dePolo, 1998); and Stateline fault (Hewett, 1956) (SFS; Figs. 1B and 1C).

Because no equivalent active structures are described in the region immediately northeast of the SFS, and because geodetic movements throughout this region are stable at the limit of detection (~0.2 mm/yr level; Bennett et al., 2003), we interpret the SFS as the northeasternmost component of the Eastern California shear zone between latitudes 35° N and 37° N. It has received little attention by workers focusing on understanding the long- and short-term strain distribution in the shear zone (Bo, 2005; Dixon et al., 2003; Dixon et al., 1995; Dokka and Macaluso, 2001; Oldow, 2003), in part because, unlike other major dextral faults across this region, most of its trace is developed in poorly consolidated, late Quaternary lacustrine deposits and is therefore obscured by late Holocene erosion. We partition its trace into three primary segments separated by contractional (left) step-overs, which, from south to north, include the Mesquite, Pahrump, and Amargosa segments (Fig. 1C).

Previous estimates of offset across the SFS include ~3 km on the Mesquite segment (Walker et al., 1995); a range of ~10 km (Burchfiel et al., 1983) to 15–19 km (R.L. Christiansen, personal communication in Stewart et al., 1968) on the Pahrump segment; and 25–45 km on the Amargosa segment (Poole and Sandberg, 1977; Schweickert and Lahren, 1997; Stevens, 1991; Cooper et al., 1982). All of these estimates are based on offsets of pre-Cenozoic markers, such as Paleozoic isopachs and facies boundaries or Mesozoic contractional structural elements (Fig. 1A). Uncertainties in the locations and original geometries of these markers and their pre-Cenozoic age limit their usefulness for making quantitative estimates of Cenozoic slip rate (Schweickert and Lahren, 1997; Snow and Wernicke, 2000). Such estimates generally require the identification of offset, late Cenozoic, proximal sedimentary and volcanic deposits from their sources (e.g., Rowland et al., 1990; Topping, 1993; Niemi et al., 2001; Fryxell and Duebendorfer, 2005).

Limited evidence exists for Quaternary offset along the SFS; however, this may be due to the easily eroded nature of the playa deposits through which the fault is mostly developed and the lack of quantitative age data on Quaternary deposits in the region (e.g., Anderson, 1998). The Amargosa segment of the SFS is believed to have ruptured in the Holocene on the basis of fault scarp morphology (Piety, 1995), while two separate rupture events on the Pahrump segment are presumably Holocene in age (Anderson et al., 1995; Menges et al., 2003). Holocene activity is broadly ascribed to the SFS on the basis of fault-scarp morphology on the eastern side of the Nopah Range (Schmidt and Davidson, 1999), and geophysical studies indicate displacement along the full 60-km length of the Pahrump segment (Shields et al., 1997; Louie et al., 1998). High-resolution, Airborne Laser Swath Mapping (ALSM) of the Pahrump segment of the SFS (Niemi et al., 2005) suggests fault offsets are developed in sediment believed to be late Quaternary in age (dePolo et al., 2003). The Late Quaternary slip rate on the SFS is estimated to be less than 0.2 mm/yr (Anderson, 1998) but greater than 0.1 mm/yr, the latter figure based on geophysical images of an offset spring mound along the Pahrump segment of the fault (Louie et al., 1998). Seismic hazards analyses of the Yucca Mountain Nuclear Waste Repository assign a slip-rate estimate of 0.005–0.07 mm/yr to the Pahrump segment of the SFS and 0.01–0.05 mm/yr to the Amargosa segment (Stepp et al., 2001). These slip rates are presumed to average slip-over Late Pleistocene or early Holocene time, and are based largely on the geomorphic characteristics of the fault zone and the estimated ages of geological deposits that have been disrupted by faulting (e.g., Anderson, 1998). To date, no post-Miocene geological markers offset by the SFS yield both unambiguous displacement data and reliable, absolute age control.

Present-day rates of deformation are based on analysis of GPS data from the Basin and Range Geodetic Network (BARGEN; Wernicke et al., 2004; Hill and Blewitt, 2006), which spans the Amargosa segment of the SFS well to the east of the Death Valley fault zone. Shear strain rates in this region are greater than can be explained by far-field effects of the Death Valley fault zone, according to dislocation models with nominal fault-slip rates and locking depths (Wernicke et al., 2004; Hill and Blewitt, 2006). The geodetic data and reasonable fault parameters applied to Eastern California shear zone faults suggest...
0.7–1.2 mm/yr of right-lateral shear is accommodated on structures to the east of the Death Valley fault zone. This shear may be localized on the Amargosa segment, or distributed on several other known fault strands in the region, but the geodetic data cannot be explained by any models of the shear zone that do not include the SFS or an equivalent suite of structures (Hill and Blewitt, 2006).

We present new evidence showing that 13.1 ± 0.2 Ma proximal volcanic deposits and associated rock avalanches southwest of the northeastern trace of the Mesquite segment of the SFS at Black Butte are dextrally offset 30 ± 4 km from their source region, northeast of the fault at Devil Peak in the southern Spring Mountains (Fig. 1B). Combined with previous estimates, this result establishes the SFS as a major late Cenozoic structure, comparable in offset and length to the Death Valley, Panamint Valley-Hunter Mountain, and Owens Valley fault systems (Fig. 1A; Table DR1). The time-averaged slip rate on the SFS since 13.1 ± 0.2 Ma of 2.3 ± 0.35 mm/yr is ~20% of the total geodetic, right-lateral displacement rate observed across the western basin and Range today (e.g., Bennett et al., 2003), but is two to three times the ~1 mm/yr geodetic rate measured across the Amargosa segment and environs (Wernicke et al., 2004; Hill and Blewitt, 2006), and twenty times higher than existing estimates based on geologic observations of any portion of the SFS (Anderson, 1998). Thus, the role of the SFS in accommodating contemporary plate boundary deformation is unclear. Furthermore, this result is an important new constraint on the spatial and temporal distribution of strain within the Eastern California shear zone and of the long-term seismic hazard predicted for Las Vegas, Pahrump, and the proposed high-level nuclear waste facility at Yucca Mountain.

GEOLeGIC SETTING

Devil Peak

Devil Peak is a small (~2.5-km diameter) hypabyssal rhyolite dome that intruded into Paleozoic carbonate strata of the southwestern Pahrump Valley and is composed of ~1000 m of northeast-dipping sedimentary and volcanic strata (Fig. 1B and Plate 1; Hewett, 1956). The southwest flank of Black Butte is composed of a series of Cenozoic volcaniclastic and lacustrine sediments overlain by massive, cliff-forming Paleozoic carbonate megabreccia deposits, separated along a sharp contact containing prominent linear scour marks and striations (cf. Figures 4 and 7 of Davis and Friedmann, 2005). The megabreccias are commonly composed of a series of Mississippian Monte Cristo and Cambrian Nopah and Bonanza King formations (the latter two are mapped together as Goodsprings Dolomite by Hewett, 1956). These units comprise the hanging wall of the Sultan thrust (Plate 1A; Hewett, 1956). West-directed collapse of the hanging wall of the Sultan thrust, in response to tilting and uplift due to emplacement of the Devil Peak rhyolites, is the most likely mechanism for the emplacement of the megabreccia, although similar slide sheets to the east of Devil Peak in the Shadow Valley basin have no such apparent direct cause and are presumed to be related to regional detachment faulting (Davis and Friedmann, 2005). The megabreccia and volcanic units now unconformably overlie Cambrian through Permian strata deformed around the rhyolite dome during the early stages of the rhyolite dome emplacement (Plate 1A; Walker et al., 1981; Massachusetts Institute of Technology (MIT) field camps, 2002, 2003, unpublished map).

Black Butte

Black Butte is a 200-m–high, northwest-trending ridge located at the center of southernmost Pahrump Valley and is composed of ~1000 m of northeast-dipping sedimentary and volcanic strata (Fig. 1B and Plate 1; Hewett, 1956). The southwest flank of Black Butte is composed of a series of Cenozoic volcaniclastic and lacustrine sediments overlain by massive, cliff-forming Paleozoic carbonate megabreccia deposits, separated along a sharp contact containing prominent linear scour marks and striations (cf. Figures 4 and 7 of Davis and Friedmann, 2005). The megabreccias are predominantly composed of Mississippian Monte Cristo Formation (Hewett, 1956), with subordinate amounts of the Devonian Sultan Formation and Cambrian Nopah and/or Bonanza King formations (Plate 1B), and contain intact blocks >1 km in maximum dimension. Interbedded with the megabreccia are white- and tan-weathering, lacustrine strata that locally contain ash and gypsum. The megabreccia deposits are resistant and hold up the crest of the butte. The northeastern flank of the butte is composed of progressively thinner and more discontinuous megabreccia sheets and interbedded lacustrine and pyroclastic deposits that grade upsection into obsidian rock avalanche deposits with a pumiceous matrix (Fig. 2B). The obsidian blocks are up to 1 m in maximum dimension, are angular, unsorted, and ungraded, and show no sign of reworking, indicating deposition proximal to source.

Geochemical and Geochronological Analyses

Strong similarities in appearance and composition of the volcanic units at each locality, and the fact that the megabreccia and rock avalanche sheets in both places are derived from the same Paleozoic units, suggest correlation of these two sections and therefore restoration of the deposits at Black Butte to a position within a few kilometers of the rhyolite dome at the time of its emplacement (Fig. 3). To test this hypothesis, U/Pb ages on zircons were determined for silicic ash in both sections, and from stony rhyolite of the rhyolite dome. In addition, geochemical analyses were performed on obsidian glass blocks from both the Devil Peak and Black Butte sections.

Obsidian block rims were trimmed to remove hydrothermally altered glass, and fragments of the block cores were sent to Activation Laboratories for trace-element analysis. Trace-element compositions of Black Butte and Devil Peak samples (Tables DR2–DR4) are compared with other well-characterized obsidian sources from the USA (McDonald et al., 1992; Table DR5). These comparisons reveal strong similarities between the Black Butte and Devil Peak obsidian samples and distinct differences from other localities, especially in concentrations of Cr, Sr, Sn, Ba, Ce, and Eu (Fig. 4 and Table DR5). Data from the Black Butte and Devil Peak samples were also compared to a more limited suite of trace-element data obtained from Devil Peak obsidian samples as part of an archaeological obsidian source characterization study (Shackley, 1994). Surprisingly, trace-element data collected during the archaeological study reveal distinct differences in Sr, Ba, and Ce concentrations between obsidian samples from the west and east sides of Devil Peak (Shackley, 1994; Table DR5). These differences are interpreted to result from variations in wall-rock composition and hydrothermal activity during intrusion of the Devil Peak rhyolite (Shackley, 1994). Unsurprisingly, the Devil Peak obsidian samples collected from the west side of Devil Peak and characterized as part of this study share similar Sr, Ba, and Ce concentrations to previously characterized samples from the west side of Devil Peak (Table DR5). However, the Black Butte samples analyzed as part of this study also

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Figure 2. Photographs of proximal volcanic facies and slide blocks at Black Butte and Devil Peak. (A) View to the southeast of block and ash flow (Tba) overlying air-fall tuff (Taf—volcanic units mapped together as Tr on Plate 1) and megabreccia deposits of Paleozoic carbonates (Tb) along the northeast flank of Black Butte. All units are dipping steeply to the northeast. (B) View to the north from the Umpire Perlite Mine (Plate 1A) volcanic units associated with Devil Peak. Block and ash flow (Tba) is overlain locally by a thick obsidian (Tof—dark unit on ridge crest in foreground). Undifferentiated Paleozoic carbonates (Pzu) form the skyline ridge in the background. (C) Panoramic view of Black Butte from the southwest toward the northeast showing the sharp contact between smooth slopes underlain by Tertiary lacustrine deposits and overlying cliff-forming Mississippian carbonates. (D) View of sharp basalt contact between Mississippian Monte Cristo Formation and Tertiary lacustrine deposits, southeast edge of Black Butte. (E) Tilted Mississippian slide block overlying Tertiary lacustrine deposits along southeast edge of Black Butte (photographs D and E by Kevin Mahan).
yield Sr, Ba, and Ce concentrations that indicate a source on the west side of Devil Peak. The difference in trace-element concentrations found in obsidian samples from either side of Devil Peak, combined with the striking similarity in trace-element concentrations between the Black Butte obsidian sample and obsidian flows located on the west side of Devil Peak, strongly suggest a single source for obsidian breccias now located on the west side of Devil Peak and at Black Butte.

U-Pb geochronological analyses were undertaken on individual zircon grains collected from both Black Butte and Devil Peak (Table DR2). The analyses were performed using a Cameca IMS 1270 ion microprobe at the University of California, Los Angeles, SIMS (Secondary Ion Mass Spectrometer) Facility. Age spectra of the three samples are statistically indistinguishable from one another (Fig. 5; Table DR6), and are consistent with previous age determinations on the Devil Peak rhyolite using the K-Ar method (Armstrong, 1966). The age of the Devil Peak rhyolite, based on the U/Pb data, is 13.1 ± 0.2 Ma, synchronous with the emplacement of silicic eruptive products located at Black Butte and to the west of the intrusion itself.
DISCUSSION

Correlation of Black Butte and Devil Peak Sections

Based on the similarities of the volcanoclastic stratigraphic succession at Black Butte and Devil Peak, and the proximal nature of the source for each, we propose to restore the section currently exposed at Black Butte adjacent to the western edge of the Devil Peak intrusion at 13.1 ± 0.2 Ma. The association of a “point deposit,” such as a rock avalanche or megabreccia deposit, with a “point source,” provides one of the best constraints on tectonic transport in the absence of more discrete piercing lines (Topping, 1993; Fryxell and Duebendorfer, 2005). The total amount of offset of the Black Butte deposits from the Devil Peak source depends on the run-out length and direction of the rock avalanche deposits (e.g., Topping, 1993). Based on exposures of the megabreccia at Black Butte, we conservatively estimate the maximum megabreccia sheet to have a volume of ~0.5 km³ (Plate 1B). Using empirical relationships between rock avalanche volume and run-out distance, we estimate that the Black Butte rock avalanche traveled between 3 and 10 km (Scheidegger, 1973; Hsu, 1975; Li, 1983; Ui, 1983; Topping, 1993; Fryxell and Duebendorfer, 2005). The present-day distribution of megabreccia deposits at Devil Peak and the topographic bowl that resulted from the emplacement of the Devil Peak rhyolite (Plate 1A) lead us to a preferred interpretation of ~3–4 km of west-southwest–directed run out, followed by 30 km of right-lateral offset along the SFS. Topography created by the rhyolite intrusion constrains run-out orientation to lie between southwest and northwest. Given this range of permissible run-out orientations, total dextral offset of the deposits along the SFS ranges between 26 and 34 km.

We therefore suggest that 30 ± 4 km of right-lateral slip has been accommodated on the SFS since mid-Miocene time. The minimum, long-term, time-averaged slip rate on the SFS, then, is 2.3 ± 0.35 mm/yr, assuming that the SFS initiated at or before 13.1 ± 0.2 Ma. However, if displacement on the SFS is limited to a shorter time period than the past 13 ± 0.2 Ma, the slip rate on the fault would increase proportionally. For example, if the development of the SFS is related to the opening of the Gulf of California and the concomitant initiation of shear across the Eastern California shear zone, then the 30 ± 4 km of offset may have been accommodated in the past 6–10 Myr (e.g., Snow and Wernicke, 2000; Oskin et al., 2001), yielding slip rates on the SFS of 3–5 mm/yr, respectively.

Slip-Rate Discrepancy

Both contemporary motions derived from GPS geodesy across the Amargosa segment of the SFS of 0.7–1.2 mm/yr (Wernicke et al., 2004; Hill and Blewitt, 2006) and Holocene rates of 0.1–0.2 mm/yr determined from geologic observations (Anderson, 1998) are much smaller than the above estimates of long-term slip rate on the SFS. Allowing for the possibility that some of the contemporary motion in this area is related to elastic strain accumulation on the northern Death Valley fault zone and other faults to the west (Dixon et al., 2003), the discrepancy is even more striking. This disagreement between the short-term geodetic and the long-term geologic slip rates is not entirely unexpected, since such discrepancies have been observed at several localities across normal and strike-slip fault systems within the Basin and Range and Mojave regions (Peltzer et al., 2001; McClusky et al., 2001; Oskin and Iriondo, 2004; Oskin et al., 2007; Friedrich et al., 2003; Wernicke et al., 2000; Friedrich et al., 2004; Niemi et al., 2004). We have identified four possibilities that may explain the observed discrepancies in the slip rate. First, it is possible that the present ~1-mm/yr (or less) geodetic slip-rate and ~0.1-mm/yr geologic slip-rate determinations represent a transient period of slow slip on the SFS, while strain is temporarily transferred to other faults within the Eastern California shear zone. Strain is continuing to accumulate on the SFS, but seismic strain release has been limited through the Holocene. Such a scenario may indicate that seismic strain release on the SFS is clustered on timescales of thousands or tens of thousands of years, while long-term slip rates on
the SFS vary on hundreds of thousands or million-year timescales (e.g., Friedrich et al., 2003; Niemi et al., 2004).

Alternatively, faults across the Eastern California shear zone may have developed sequentially from east to west, such that strain localization along the SFS occurred early in the development of the shear zone, but the high strain rates that the SFS must once have accommodated have now migrated permanently to younger faults to the west as the Eastern California shear zone has evolved. The SFS, then, would be analogous to the San Gabriel or Miller Creek-Palomas faults in California; these faults accommodated rapid slip rates (and significant displacements) early in the development of the San Andreas transform system, but are now thought to be mostly or completely inactive (Powell, 1993; Petersen and Wesnousky, 1994; Wakabayashi, 1999). Evidence of Holocene displacement on the Amargosa and Pahrump segments of the SFS would then be the manifestation of infrequent seismic events on these faults.

Geologic fault slip rates on the SFS may also be underestimated due to poor exposure of fault scarps developed in unconsolidated Quaternary sediments and a lack of quantitative age constraints on faulted sediments. Significant discrepancies between geodetic and geologic slip rates in the western Mojave Desert (Peltzer et al., 2001; Oskin and Iriondo, 2004) have been reduced but not eliminated by further investigations into long-term geologic slip rates on the faults that comprise the Eastern California shear zone in this region (Oskin et al., 2007). A spring mound imaged by geophysical methods at the southern end of Stewart Valley has been offset ~18 m in a dextral sense (Louie et al., 1998). The age of the spring mound is not directly constrained, but based on ages of exposed spring mounds in the region, it could be as young as 10 ka (Quade et al., 1995). If so, the Holocene slip rate on the SFS could be as high as 1.8 mm/yr (Louie et al., 1998), in closer agreement with both short- and long-term geologic slip rates.

Finally, the difference between geodetic and geologic slip rates may be related to the latitudinal position of the various measurements. The geodetic observations thus far constrain the slip rate on the Amargosa segment, while the geologic observations presented in this paper pertain to the Pahrump and Mesquite segments (Fig. 1B). For example, it is possible that slip on the Mesquite and Pahrump segments of the SFS is transferred westward to the Death Valley-Furnace Creek fault zone via an extension of the observed left (compressional) step-over between the Pahrump and Amargosa segments (Fig. 1B). In such a scenario, the difference in the geodetic and geologic rates would reflect an along-strike change in displacement rate on the SFS. Continuous GPS stations recently installed across Amargosa and Pahrump valleys will help to distinguish between these alternatives, while further work to better constrain the Holocene slip rate on all three segments of the SFS is being undertaken.

Irrespective of tighter constraints on the temporal and spatial pattern of deformation along the SFS, the magnitude of slip accommodated on this fault since mid-Miocene time indicates that it is integral to understanding the initiation and development of the Eastern California shear zone. The observed 30 ± 4 km of slip on the SFS is greater than the amount of Tertiary dextral slip on either the Owens Valley fault (~3–20 km; e.g., Lee et al., 2001; although total slip since Cretaceous time may approach 65 km; Kylander-Clark et al., 2005), or the Panamint Valley-Hunter Mountain fault (8–10 km; Burchfiel et al., 1987), and is only slightly less than the total Tertiary right-lateral slip on the northern Death Valley-Fish Lake Valley fault (40–50 km; McKee, 1968; Reheis and Sawyer, 1997).

Seismic Hazards

The SFS, as defined in this paper, lies within 50 km of metropolitan Las Vegas, cuts directly through the rapidly growing city of Pahrump, Nevada, and passes within 25 km of the proposed nuclear waste repository site at Yucca Mountain. Velocity measurements from space-based geodesy indicate a substantially higher slip rate than is indicated by the Quaternary faulting history on the SFS (Wernicke et al., 2004; Hill and Blewitt, 2006), and the long-term slip rates and displacement on the SFS since Miocene time presented in this study reinforce the geodetic results. In terms of assessment of seismic hazards for the Pahrump Valley region, both the slip rate and the total displacement determined through this study are important. The former is of greatest importance to the cities of Pahrump and Las Vegas. Although available evidence suggests that earthquakes greater than Magnitude 7 occur on the SFS (Menges et al., 2003), recurrence intervals on the SFS have been estimated to be >10 ka (Anderson, 1998; Menges et al., 2003), suggesting a low probability for a large earthquake associated with the fault system. If the long-term slip rate obtained from the offset of the volcanic succession along the SFS is representative of the average rate of slip on the SFS, then the probability of a large event would increase significantly.

Additional geologic and geodetic work looking at the present slip-rate distribution and Quaternary slip history of the SFS is ongoing and will address the question of spatial and temporal slip-rate variations for this fault system.

CONCLUSIONS

Successions of volcanic and sedimentary rock currently separated across the Stateline fault zone are correlated on the basis of stratigraphic similarity, geochemical fingerprint, and geochronologic age. This correlation establishes displacement along the Stateline fault of 30 ± 4 km since mid-Miocene (13.1 ± 0.2 Ma) time, although we note that additional, pre-13-Ma displacement could have occurred. The long-term slip rate of 2.3 ± 0.35 mm/yr on the Stateline fault implied by this correlation requires reconsideration of neotectonic activity on this fault, and may suggest reassessment of the hazard potential this fault poses for towns in southwestern Nevada and for the nuclear waste repository at Yucca Mountain. The total slip on the SFS determined by this study implies that the SFS is an integral structure in the development of the Eastern California shear zone and increases to four the number of major dextral faults that should be considered in tectonic models of the shear zone between latitudes 35° N and 37° N. The discrepancy between geodetic and long-term geologic slip rates on the SFS is opposite that observed across other portions of the Eastern California shear zone and underscores the importance of deriving fault-slip rates on multiple temporal scales as key to understanding the evolution of a complex intracratonic transform zone.

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Plate 1 (A) and (B)

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