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Introduction to the Special Issue on Paleoseismology of the San Andreas Fault System

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Purpose

The purpose of this special issue of BSSA is to provide a state-of-the-science compendium of data on the rupture history of the San Andreas fault from recent paleoseismic investigations. The San Andreas fault is the primary boundary fault between the Pacific and North American plates and one of the most thoroughly studied faults in the world. Fourteen articles prepared by 74 authors provide dates of surface ruptures and/or measurements of slip or slip rate at 10 paleoseismic investigation sites along the main trace of the San Andreas fault, at one site on the Hayward fault, and along the northern San Jacinto fault. This issue includes documentation of the longest multicycle earthquake sequence in California—and possibly in North America (14 ruptures at the Wrightwood site). Geographic coverage extends almost along the entire San Andreas fault system, from Bodega Bay in northern California to the Mecca Hills in the Coachella Valley. The issue also includes articles linking paleoseismic data with modern instrumental recordings of ground motion and seismicity.

Data on the earthquake history of the San Andreas fault form the basis of numerous models of fault behavior and calculations of seismic hazard. Despite the relatively large amount of data available for the San Andreas fault, there remain unresolved questions about segmentation, the rupture patterns of large earthquakes, and characteristics of earthquake recurrence. The data presented in this special issue contribute toward understanding the spatial and temporal rupture history of the San Andreas fault over multiple rupture cycles during the last few hundred to few thousand years. This is the timescale of greatest interest for seismic hazard assessments and fault modeling.

Summary

This introduction provides an overview of the issue and summarizes results in simplified, tabular form. Table 1 contains dates of surface ruptures and/or average recurrence intervals reported from 10 sites discussed in this issue. Table 2 includes measurements of slip or slip rate at seven of the locations. The summary tables highlight the data presented in each article and are not intended to be substitutes for the detailed presentation and discussion of data in individual articles. Articles are ordered geographically from north to south, with the exception of the first two.

The first two articles by Toppozada *et al.* and Brune provide a bridge between the instrumental record of earthquakes along the San Andreas fault system and the paleoseismic observations in the rest of this issue. Toppozada *et al.* present a compilation of $M \geq 5.5$ earthquakes along the entire San Andreas fault zone. Most of the San Andreas fault, Hayward fault, and a portion of the San Jacinto fault ruptured between A.D. 1812 and 1906 in large earthquakes with minimal or no instrumental records (Toppozada *et al.* and Brune.). Toppozada *et al.* discuss the incompleteness of the early historic record for $\sim M$ 6 events in key areas such as Parkfield and present an interpretation of the location of the December A.D. 1812 southern California earthquakes based on felt reports. Several other articles in this issue also address the location of the 1812 ruptures based on paleoseismic trench excavations (Lindvall *et al.*, Weldon *et al.*, Biasi *et al.*, Fumal *et al.*, and McGill *et al.*). The A.D. 1868 earthquake on the Hayward fault is discussed by both Toppozada *et al.*, from historic records, and by Lienkaemper *et al.*, from paleoseismic excavations.

Brune analyzes precarious rocks to estimate ground motions from prehistoric, early historic, and recent earthquakes. He provides constraints on shaking near the San Andreas and San Jacinto faults from historic earthquakes in A.D. 1812, 1857, 1899, and 1912, as well as prehistoric ground motions at Banning Pass between the Plunge Creek trench site of McGill *et al.* to the northwest, and the Thousand Palms site of Fumal *et al.* to the southeast.

In northern California, Knudsen *et al.* studied relative sea level changes at Bodega Bay and Bolinas Lagoon. They interpreted several episodes of earthquake-induced subsidence along the north coast section of the San Andreas fault. When combined with results of other paleoseismic investigations in the north coast region, the results suggest that ruptures occurred approximately 700 years ago and 350 years ago, as well as in A.D. 1906.

Lienkaemper *et al.* report the results of paleoseismic excavations at Tysoon's Lagoon (also called Tule Pond) along the Hayward fault, a major branch of the San Andreas fault system in the densely populated east San Francisco Bay area. In addition to describing evidence of the historic 1868 earthquake, they discuss evidence of creep, as well as three prehistoric ruptures.

Two articles discuss rupture characteristics of the San

Table 1
Surface Rupture Dates and Average Recurrence Intervals for Sites on the San Andreas Fault System Discussed in This Issue

Reference	Site	Latitude (N) Longitude (W)	Dates (A.D.)	Average Recurrence (yr)
Knudsen *et al.*	Bodega	38°18 min 49 sec	1906	
	Harbor	123° 1 min 50 sec	After 1600	
			980–1300	
	Bolinas	37° 56 min 2 sec	1906	
	Lagoon	122° 41 min 51 sec	~1250	
Lienkaemper *et al*	Tyson's Lagoon,	37° 33 min 21 sec	1868	130 ± 40
	Hayward fault	121° 58 min 28 sec	1730 (1650–1790)	
			1630 (1530–1740)	
			1470 (1360–1580)	
Young *et al.*	LY4	35° 28 min 9 sec	After 1857	
		120° 1 min 8 sec	1857 (1390–1865)	
			1030–1460	
Lindvall *et al.*	Frazier Mountain	34° 48 min 44 sec	1857	
		118° 54 min 7 sec	1460–1600	
Biasi *et al.*	Pallett Creek	34° 27 min 19 sec	1857	135
	(after Sieh *et al.*)	117° 53 min 14 sec	1812 (1758–1837)	
			1496–1599	
			1343–1370	
			1046–1113	
			1031–1096	
			914–986	
			803–868	
			749–775	
			614–666	
Fumal *et al.*	Wrightwood	34° 22 min 11 sec	1857	105
Biasi *et al.*		117° 40 min 04 sec	1812	
			1647–1717	
			1508–1569	
			1448–1518	
			1191–1305	
			1047–1181	
			957–1056	
			800–881	
			736–811	
			695–740	
			657–722	
			551–681	
			407–628	
McGill *et al.*	Plunge Creek	34° 06 min 57 sec	1510–1730	
		117° 08 min 15 sec	~1450	
Fumal *et al.*	Thousand Palms	33° 55 min 11 sec	>1520–1680	215 ± 25
		116° 18 min 27 sec	1450–1555	
			1170–1290	
			840–1150	
			770–890	
Shifflett *et al.*	Stone Ring Gullies	33° 34 min 23 sec		260 ± 100
		115° 58 min 45 sec		

Andreas fault between Cholame Valley and the Carrizo Plain. Runnerstrom *et al.* report changes in survey section-line lengths and positions of survey monuments spanning the San Andreas fault before and after the A.D. 1857 earthquake. The right-lateral displacement measured by Runnerstrom *et al.* spans approximately 2 km of the fault zone and is significantly greater than the slip reported by Young *et al.* from hand excavations within the fault zone. Young *et al.* measured shorter aperture displacement from the 1857 earthquake and report the approximate date of the penultimate earthquake. They also describe enigmatic tectonic fractures that apparently formed after 1857.

Table 2
Slip and Slip Rate Measurements for Sections of the San Andreas Fault System Discussed in This Issue

Reference	Site	Latitude (N) Longitude (W)	Event Dates (A.D.)	Slip per Event (m)	Slip Rate (mm/yr)
Lienkaemper *et al.*	Tyson's Lagoon, Hayward fault	37° 33 min 21 sec 121° 58 min 28 sec	1868 1730 (1650–1790) 1630 (1530–1740) 1470 (1360–1580)	>0.1–0.2 >0.3 >0.2 >0.45	
Runnerstrom *et al.*	N boundary	35° 32 min 11 sec 120° 5 min 13 sec	1857	16.2 ± 6.0	
	S boundary	35° 31 min 35 sec 120° 4 min 30 sec			
Young *et al.*	LY4	35° 28 min 9 sec 120° 1 min 8 sec	After 1857 1857 (1390–1865) 1030–1460	Fractures 3.0 ± 0.7	
Weldon *et al.*	Wrightwood	34° 22 min 11 sec 117° 40 min 04 sec	1857 pre-1857	1–2 2–4	20–40
Kendrick *et al.*	Northern San Jacinto fault	34° 117° 15 min			≥20
Fumal *et al.*	Thousand Palms	33° 55 min 11 sec 116° 18 min 27 sec			4 ± 2
Shifflett *et al.*	Holocene paleofan	33° 34 min 23 sec 115° 58 min 45 sec			12
	Pleistocene lagoon	(approx.)			5–8

Lindvall *et al.* identified two surface ruptures, including the 1857 earthquake, within the last 500 years at the Frazier Mountain paleoseismic site in the mountainous Big Bend region of the San Andreas fault. They conclude that the penultimate rupture in the Big Bend occurred several centuries earlier, rather than the A.D. 1812 date proposed by Toppozada *et al.* However, they cannot rule out the possibility of rupture on a nearby trace in 1812.

Three companion articles by Weldon *et al.*, Fumal *et al.*, and Biasi *et al.* report evidence of surface rupture and well-constrained dates of 14 earthquakes at the Wrightwood site in the San Gabriel Mountains. This is the longest chronology of large earthquakes from any site in California and possibly all of North America. The length of the record and the number of earthquakes provide a data set large enough for testing models of earthquake recurrence and calculation of seismic hazard with low uncertainties. Weldon *et al.* provide a detailed description of the near-surface structure of the San Andreas fault zone at Wrightwood, the average displacement in the most recent events, and the average slip rate. Fumal *et al.* describe evidence for the earthquakes and constraints on the age of each rupture. Biasi *et al.* present a quantitative analysis of rupture dates and their temporal distribution, as well as conditional probabilities of rupture during the next 30 years. They also apply statistical methods to previously published data from the Pallett Creek paleoseismic site and attempt to quantify the potential for joint rupture of Pallett Creek and Wrightwood in the last 1500 years.

The San Jacinto fault is a major branch of the San Andreas fault system that splays off the main fault southeast of the Wrightwood paleoseismic site. Kendrick *et al.* conducted a study of landscape evolution along the northern San Jacinto fault and applied their methods toward measuring the slip rate of the fault. Their results suggest that the slip rate of the northern San Jacinto fault may be as high as the slip rate of the San Andreas fault in the San Bernardino region.

McGill and colleagues examined the rupture history of the San Bernardino strand of the San Andreas fault at the Plunge Creek paleoseismic site. Much of the article discusses evidence for, and dating of, the most recent earthquake. They address the question of whether or not the A.D. 1812 rupture extended through the site and present evidence that supports a significantly earlier date of most recent rupture. Their results suggest that the 1812 rupture terminated to the northwest, between Plunge Creek and Wrightwood.

An article by Fumal and colleagues documents the occurrence of four or five earthquakes at the Thousand Palms Oasis site on the Mission Creek strand of the San Andreas fault, since A.D. 800. The most recent rupture occurred several centuries ago, prior to historic records. Fumal *et al.* also report a minimum slip rate for the Mission Creek strand of the fault.

The final manuscript by Shifflett *et al.* includes geodetic measurements, analysis of geomorphic features, and dating of offset shorelines and archeological features to estimate the slip rate and average recurrence time for large earthquakes along the southernmost San Andreas fault in the Mecca Hills, Coachella Valley.

Acknowledgments

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