Statewide California Earthquake Center
Final Technical Report
Project 22104

Landers Earthquake scarp after 30 years

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Abstract
The original form and initial modification of earthquake surface rupture are essential information about faulted landscapes. We present data from 30 years of the Emerson fault scarp formed in the 1992 M7.3 Landers, California, earthquake . We combine repeat photography and topographic surveys from 12 site visits (1992-2022). We made numerous topographic surveys with changing technologies (total station, terrestrial laser scanning, and photogrammetry). We also made two excavations in 2022. The scarp-parallel cut exposed fine-grained alluvial fan facies consistent with the current depositional environment. The fault-normal trench exposed a 1-m-wide shear zone juxtaposing indurated silt and sandstone with unconsolidated silt and coarse sand with angular pebbles. 1992 fractures terminate a few cm below the surface. Pre-1992 rupture is suggested by upward-terminating fractures and coarse colluvial material within the downthrown, western side. The 1992 earthquake caused ~5 m right lateral and 1-2 m vertical offset at the Emerson fault site. It lifted a series of 2000-4000 m^2 watersheds. Landscape response is controlled by seasonal rainfall, drainage basin form, substrate induration, and scarp morphology. Fault scarps modified without runoff have rounded and collapsed. The incision signal has propagated 50-70 m upstream (70-80% of total channel length) with meter-deep and dm-wide channels cutting the low relief pre-1992 valley floors. We developed a 3-stage model for post-earthquake landscape response: 1) Reestablish flow paths across simple scarps. Runoff diverts into the fracture network in broadly fractured scarps. 2) Integrate drainage network with small-scale capture events. 3) Extend flowpaths headward via knickzone retreat.

Intellectual Merit
The original form and initial modification of earthquake surface rupture are essential information about faulted landscapes. We present data from 30 years of the Emerson fault scarp formed in the 1992 M7.3 Landers, California, earthquake. We developed a 3-stage model for post-earthquake landscape response: 1) Reestablish flow paths across simple scarps. Runoff diverts into the fracture network in broadly fractured scarps. 2) Integrate drainage network with small-scale capture events. 3) Extend flowpaths headward via knickzone retreat.

Broader Impacts
Understanding the original form and initial modification of earthquake surface rupture is valuable for anticipating hazard from active faults. This project involved a cadre of young mostly women scientists who are taking the lead in this research.

Technical Report Narrative

Overview

The original form and initial modification of earthquake surface rupture are essential information about faulted landscapes. We present data from 30 years of the Emerson fault scarp formed in the 1992 M7.3 Landers, California, earthquake (Figure 1, Table 1). We combine repeat photography and topographic surveys from 12 site visits (1992-2016) with field investigation in 2022.

In 1992, we did analog photography and total station survey (10^3 points measured) (Table 1). By 2008, we used digital photography and terrestrial laser scanning (10^7 points). In 2012, we began to use photogrammetry (10^8 points). In 2022, we added more photos, revisited the survey control network with dGNSS, and performed a UAS survey (10^9 points). We also made two excavations in 2022. The scarp-parallel cut exposed fine-grained alluvial fan facies consistent with the current depositional environment. The fault-normal trench exposed a 1-m-wide shear zone juxtaposing indurated silt and sandstone with unconsolidated silt and coarse sand with angular pebbles. 1992 fractures terminate a few cm below the surface. Pre-1992 rupture is suggested by upward-terminating fractures and coarse colluvial material within the downthrown, western side. The trench logs are still under interpretation and not presented here.

The 1992 earthquake caused ~5 m right lateral and 1-2 m vertical offset at the Emerson fault site. It lifted a series of 2000-4000 m^2 watersheds. Landscape response is controlled by seasonal rainfall, drainage basin form, substrate induration, and scarp morphology. Fault scarps modified without runoff have rounded and collapsed (Figure 2). The incision signal has propagated 50-70 m upstream (70-80% of total channel length) with meter-deep and dm-wide channels cutting the low relief pre-1992 valley floors (Figures 3 and 4). We developed a 3-stage model for post-earthquake landscape response: 1) Reestablish flow paths across simple scarps. Runoff diverts into the fracture network in broadly fractured scarps. 2) Integrate drainage network with small-scale capture events. 3) Extend flowpaths headward via knickzone retreat.

This work is still underway. We have presented it at the 2023 GSA meeting:
Arrowsmith, J R., Rhodes, D. D., Reitman, N., Hatem, A. Powell, J., Schwarz, M., Zuckerman, M., Long term observations of earthquake surface rupture: 30 years after the Landers 1992 earthquake. Geological Society of America Annual Meeting abstract, 60-6, 2023.

Special thanks to the 29 Palms Marine Base for their support.

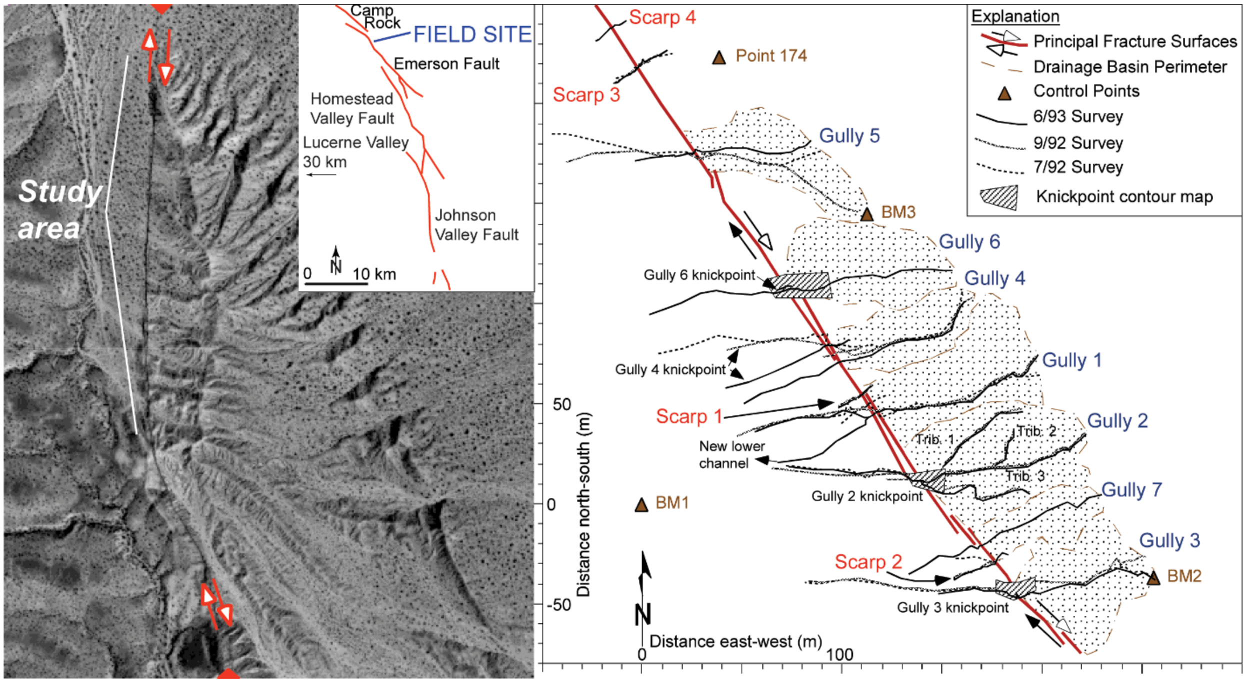

Figure 1. *Field site along the northern Emerson fault which ruptured in the M7.3 1992 Landers earthquake. Left image inset shows the study area location along the rupture zone (red lines). Aerial photograph taken by USGS immediately after the earthquake shows surface rupture trace along uplifting folded basin and alluvial fan sedimentary units and the study area. White rectangles indicate Figure 3 panel locations. At right, the map illustrates the main landforms whose investigations and monitoring began immediately after the earthquake.*

Table 1. Summary of field activities at the field site

Activity	July 1-8, 1992	September 26-27, 1992	June 2-4, 1993	May 19-21, 1994	May 4-5, 1995	May 20-21, 1997	December 18-19, 1998	March 11-12, 2000	May 1, 2008	September 15, 2009	August 26, 2012	June 7, 2016	October 17-28, 2022
Observations and general photography	F[1]	F	F	F	F	F	F	F	D[2]	D	D	D	D
Mapping of surface ruptures	OTS+PTA[3]												
Establishment of permanent benchmarks		B1, BM2, BM3 Rebar in Concrete											RTKGPS[4]
Ground stereo photography		F	F	F	F	F	F	F		D	D	D, SfM[6]	D, SfM
Scarp and Gully Profiles		OTS[5]	OTS	OTS	OTS	OTS	OTS	OTS	TLS[7]		SfM	SfM	SfM
Knickpoint Contour Maps		OTS	OTS	OTS	OTS	OTS	OTS	OTS	TLS		SfM	SfM	SfM
Basin Topography						OTS			TLS		SfM	SfM	SfM
Trenching Parallel Perpendicular													60 m 20 m
Total points surveyed	375	625	858	1,130	1,221	597	1,643	987	9,540,000	NA	>46M	>100M	3.2B

Figure 2. Scarp 1 changes over 30 years. See figure 1 for location.

Figure 3. Gully 3 changes over 30 years. See figure 1 for location. Note grey rock for reference.

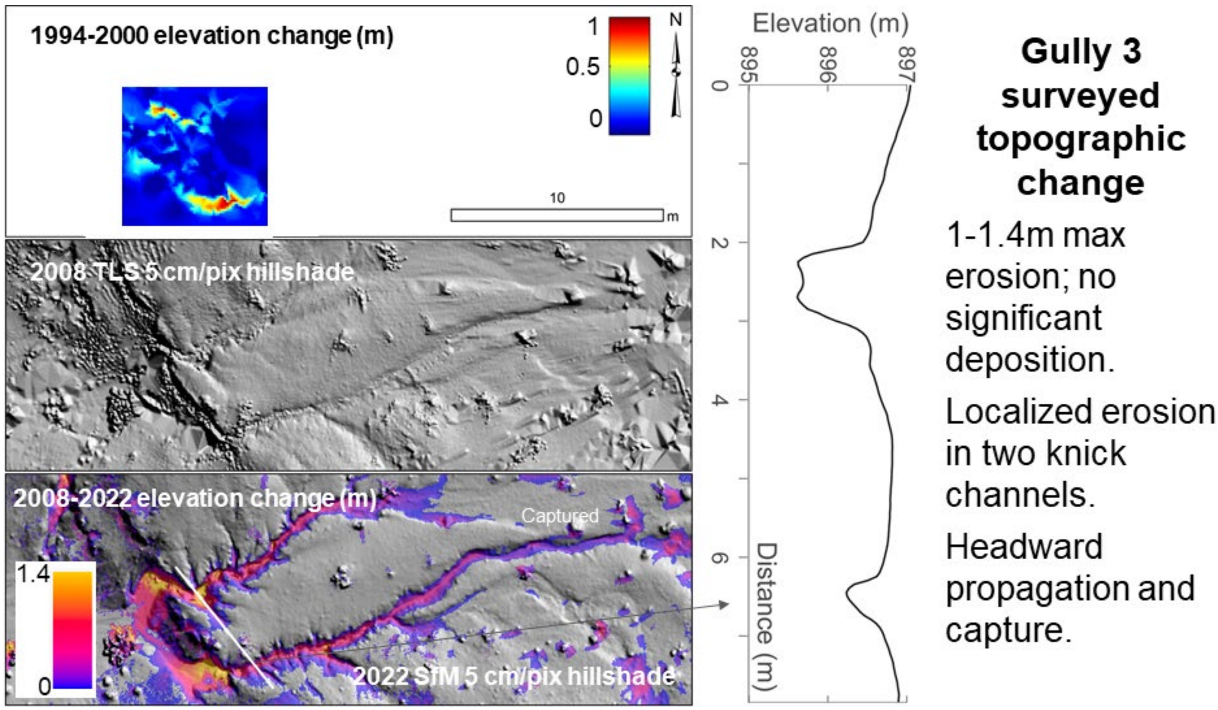

Figure 4. Gully 3 surveyed topographic change. The three maps (left column) have the same extent. The upper panel shows the 1994-2000 elevation change. The lower panel shows the change from 2008 to 2022 and illustrates the headward growth of the erosion signal. 1-1.4 m of maximum erosion is observed with no significant deposition.