Jump to Navigation

Quaternary Fault and Fold Database of the United States

As of January 12, 2017, the USGS maintains a limited number of metadata fields that characterize the Quaternary faults and folds of the United States. For the most up-to-date information, please refer to the interactive fault map.

Garlock fault zone, Eastern Garlock section (Class A) No. 69c

Last Review Date: 2000-06-29

citation for this record: **Bryant, W.A., compiler, 2000, Fault number 69c, Garlock fault zone, Eastern Garlock section, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, https://earthquakes.usgs.gov/hazards/qfaults, accessed 12/14/2020 02:02 PM.**

Synopsis	**General:** Major Holocene active, east to northeast-striking sinistral strike-slip fault that forms the boundary between the Tehachapi Mountains, Sierra Nevada, and Basin and Range province on the north and the Mojave Desert province to the south. Aseismic fault creep has been reported along the westernmost 60 km of the Garlock fault zone (Rodgers, 1979 #6071; Snay and Cline, 1980 #6070; Louie and others, 1985 #5731). However, U.S. Geological Survey quadrilateral sites spaced at 15 km intervals along this part of the fault zone have not detected evidence of fault creep (M. Clark, personal communication in McGill, 1992). There are seven paleoseismic study sites involving trenching along the western and central Garlock fault sections described in this compilation, with additional slip rate sites involving geomorphic analysis (Burke, 1979 #2985; Carter, 1980 #6043; LaViolette, 1981 #6051;

Roquemore and others, 1982 #2993; McGill and Sieh, 1991 #6062; McGill, 1992 #6053; McGill and Sieh, 1993 #6063; McGill, 1994 #6056; McGill and Rockwell, 1998 #6064; McGill, 1999 #6060; McGill, in preparation #6061). A Holocene slip rate for the western Garlock fault section of 1.6–3.3 mm/yr was reported by LaViolette (1981 #6051) for the Oak Creek Canyon site. McGill and others (in preparation #6061) reported a preferred minimum Holocene slip rate of at least 6.8±1.5 mm/yr at the Lone Tree Canyon site. Clark and others (1984 #2876), based on data reported by Carter (1980 #6043), calculated a preferred long-term sinistral slip rate of 11 mm/yr near Mesquite Canyon. Near Koehn Lake a sinistrally offset 11- to 15-ka lake bar indicates a slip rate of 5–8 mm/yr (radiocarbon years) (Clark and others, 1984 #2876). McGill and Sieh (1991 #6062), using the calibration of Bard and others (1990 #6042), re-calculated the slip rate reported by Clark and others (1984 #2876) at Koehn Lake to be 4–7 mm/yr. McGill and Sieh (1993 #6063) reported a slip rate of 5–11 mm/14Cyr or 4–9 mm/yr after calibration of the radiocarbon dates. Their preferred slip rate was 6–8 mm/14Cyr (or 5–7 mm/yr in calibrated years) calculated from the southern Searles Valley site. McGill and Sieh (1991 #6062) and McGill (1992 #6053) concluded that some sinistral slip is transferred to the Owl Lake fault [70]. The slip rate of the Garlock fault east of its intersection with the Owl Lake fault [70] is not known with any certainty. Recurrence intervals for the Garlock fault zone are 800–2,700 yr for the western Garlock fault section (McGill, 1994 #6056); 190–3,405 yr for the central Garlock fault section (McGill and Rockwell, 1998 #6064); and 200–3,000 yr for the eastern Garlock fault section (McGill and Sieh, 1991 #6062). McGill and Rockwell (1998 #6064) noted that recurrence intervals are irregular at the El Paso Peaks site and reported preferred average recurrence intervals of 1,230 yr assuming 5 events or 700 yr assuming 8 events. In a deeper re-excavation at the El Paso Peaks site, Dawson (2000 #6047) confirmed the irregular nature of recurrence, but eliminated one of McGill and Rockwell's events, and added an older event that was not exposed in the original trench.

Sections: This fault has 3 sections. Garlock fault zone is divided based on McGill (1992 #6053). The western Garlock fault section extends from the complex intersection with the San Andreas fault [1g] near Frazier Park east-northeast to a 3-km-wide left-releasing step-over in the vicinity of Koehn Lake. The central Garlock section extends from the left-releasing step-over near Koehn Lake

	eastward to the Quail Mountains where the Owl Lake fault [70] intersects the Garlock fault zone. The eastern Garlock fault section extends from the Owl Lake fault [70] eastward to the complex intersection with the southern extent of the Southern Death Valley fault zone [143b].
Name comments	**General:** **Section:** Name and section boundaries proposed by McGill (1992 #6053). In this compilation the Eastern Garlock section extends from the intersection with the Owl Lake fault [70] at the southern end of the Quail Mountains eastward to the complex intersection with the southern extent of the Southern Death Valley fault zone [143]. Faults delineating this section include the Garlock fault west of the Owl Lake fault [70]. East of the Owl Lake fault [70] the Garlock fault zone is delineated by two principal faults, the Mule Springs fault (sinistral-oblique slip to southwest-dipping thrust fault) and the sinistral strike-slip Leach Lake fault (Brady, 1986 #1450). McGill (1992 #6053) reported that traces of the Leach Lake fault as mapped by Clark (1973 #483) delineate the principal Holocene active branch of the Eastern Garlock section. Thrust fault scarps in Quaternary alluvium are also present near the eastern termination of the Garlock fault on the northeastern flank of the Avawatz Mountains (Troxel and Butler, 1979 #6074). **Fault ID:** Includes 270 (Garlock fault zone), 272 (ground breaks in Fremont Valley), 274 (triggered slip associated with 1952 Arvin-Tehachapi earthquake), and 310 (South Branch Garlock fault) of Jennings (1994 #2878).
County(s) and State(s)	SAN BERNARDINO COUNTY, CALIFORNIA
Physiographic province(s)	BASIN AND RANGE
Reliability of location	Good Compiled at 1:48,000 scale. *Comments:* Locations based on digital revisions to Jennings (1994 #2878) using original mapping by Muehlberger (1954 #6065) at 1:48,000; original mapping by Clark (1973 #483), Brady (1986 #1450), and Spencer (1990 #6329) at 1:24,000.
Geologic setting	The Garlock fault zone, one of the principal Holocene active faults of California, is an east-northeast striking sinistral strike-

	slip fault that separates the Tehachapi-Sierra Nevada and Basin and Range provinces on the north against the Mojave Desert province on the south. The Garlock fault extends from its complex intersection with the San Andreas fault zone [1g] at its western end northeastward, curves to a more easterly strike east of the Koehn Lake area and extends to the Avawatz Mountains near the south end of Death Valley. Maximum cumulative sinistral strike-slip displacement of 48 km to 64 km has been documented (Smith, 1962 #6066; Smith and Ketner, 1970 #6069; Davis and Burchfiel, 1973 #1492; Carr and others, 1993 #6452). Hill and Dibblee (1953 #923) suggested that the sinistral Garlock and Big Pine [86] faults and the dextral San Andreas fault [1] are conjugate shears resulting from a north-south oriented regional contractional strain pattern. Later workers (Hamilton and Myers, 1966 #1531; Troxel and others, 1972 #6075; Davis and Burchfiel, 1973 #1492) considered the Garlock fault to be an intracontinental transform fault accommodating extension in the Basin and Range province to the north relative to the more stable Mojave block to the south. However, McGill (1992 #6053) stated that a simple transform model is inadequate to explain this relationship because the extension direction of the portion of the Basin and Range province north of the Garlock fault is not parallel to the fault (Stewart, 1983 #1653; Burchfiel and others, 1987 #1454; Minster and Jordan, 1987 #3288; Jones, 1987 #6050; Wernicke and others, 1988 #1686). It is possible that the extension component parallel to the Garlock fault is driving sinistral slip on the fault and the component normal to the fault has rotated the central and eastern Garlock fault clockwise (Carter and others, 1987 #6045; Jones, 1987 #6050; Dokka and Travis, 1990 #3188). (Smith and others, 1968 #6456) (Clark and Lajoie, 1974 #6046)
Length (km)	This section is 60 km of a total fault length of 257 km.
Average strike	N88°W (for section) versus N68°E (for whole fault)
Sense of movement	Left lateral *Comments:* Sense of movement is variable. The Leach Lake fault of the Eastern Garlock section predominantly is a sinistral strike-slip fault (Clark, 1973 #483; McGill, 1992 #6053). Western strands of the Mule Spring fault are principally sinistral-strike slip, but the eastern traces are predominantly west-dipping reverse and thrust faults (Brady, 1986 #1450). South to west-dipping thrust fault scarps in Quaternary alluvium are also present near

	the eastern termination of the Garlock fault on the northeastern and eastern flank of the Avawatz Mountains, outboard of the Mule Spring fault (Troxel and Butler, 1979 #6074; Brady, 1986 #1450).
Dip Direction	V *Comments:* Fault dips are locally variable, but generally near vertical. The Leach Lake strand of the Eastern Garlock section predominantly is a vertical to near vertically dipping sinistral strike-slip fault (Clark, 1973 #483; McGill, 1992 #6053; McGill, 1993 #6054; 1994 #6057; 1994 #6058). Dip direction varies from vertical to westerly for eastern traces of the Mule Springs fault (Brady, 1986 #1450).
Paleoseismology studies	69-9 by McGill (1994 #6057; 1994 #6058) studied terrace risers offset by the Leach Lake fault on the east side of Cave Spring Wash. Both the correlation of geomorphic features offset by the fault, and the age constraints are uncertain (McGill, personal communication, 2000). 69-10 by Stroud and McGill (1994 #6072; 1994 #6073) studied the youngest looking fault scarp along the unnamed thrust fault at the northeastern corner of the Avawatz Mountains. They measured a scarp height of about 2 m, and estimated its age based on comparison of the degree of desert varnish formation with dated surfaces elsewhere.
Geomorphic expression	The Eastern Garlock fault zone (Leach Lake fault) is delineated by geomorphic features indicative of latest Pleistocene and Holocene sinistral strike-slip faulting. Geomorphic features include sinistrally offset ridges and steam channels, linear scarps and vegetation contrasts in latest Pleistocene and Holocene alluvium, aligned benches and notches, linear trenches and linear valleys (Clark, 1973 #483; McGill, 1993 #6054; 1994 #6057; 1994 #6058). Fault scarps are also present on Quaternary alluvial fan surfaces along an unnamed thrust fault on the northeastern and eastern flank of the Avawatz Mountains (Troxel and Butler, 1979 #6074; Brady, 1986 #1450).
Age of faulted surficial	A terrace offset along the Leach Lake fault is at least 1656±88 14C yr BP, based on radiocarbon dating of organic matter beneath

deposits	rock varnish on cobbles exposed on the terrace surface (McGill, 1994 #6057). Along the unnamed thrust fault at the northeastern corner of the Avawatz Mountains, the youngest looking fault scarp offsets an alluvial fan surface with a degree of varnish development that appears similar to or slightly older than a 9.5–11.8 ka fan surface on the east side of the Soda Mountains (Stroud and McGill, 1994 #6072; 1994 #6073) that had previously been dated (Wells and others, 1987 #6076).
Historic earthquake	
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* McGill (1993 #6054) reported that the most recent paleoevent along the Eastern Garlock fault (Leach Lake fault) section occurred between 1,583±90 yr BP and 1,656±88 yr BP. On the unnamed thrust fault at the northeastern end of the Avawatz Mountains, at least one earthquake has occurred within about the past 104 yr (Stroud and McGill, 1994 #6072; 1994 #6073).
Recurrence interval	200 yr to 3,000 yr (Holocene) *Comments:* McGill and Sieh (1991 #6062) inferred Holocene recurrence interval of 200 yr to 3,000 yr for a 2 - to 3-m slip/event. This interval is based on the assumption that up to 2 mm/yr slip rate is transferred to faults north of Garlock, including Panamint Valley fault zone [67] and Owl Lake fault [70], yielding preliminary slip rate of 1 mm/yr to 9 mm/yr for the Leach Lake and Avawatz Mountains area. McGill (1994 #6057) assumed a slip rate of 2.5 mm/yr and a 2- to 3-m slip/event to derive a recurrence interval of 800 yr to 1,200 yr.
Slip-rate category	Between 1.0 and 5.0 mm/yr *Comments:* McGill (1994 #6057) reported a preliminary Holocene sinistral slip rate of 3–6 mm/yr for the Eastern Garlock fault (Leach Lake fault) near Cave Spring Wash. Here a terrace riser was originally interpreted as being sinistrally offset 35–60 m. Cation-ratio ages from three rock varnished cobbles indicate a 10- to 12-ka age for the offset terrace riser. Subsequent work by McGill (1994 #6058) proposed a different cross-fault correlation in which the same surface is offset only 5–15 m, yielding a slip rate of only 0.4 mm/yr to 1.5 mm/yr. Still more recent work involving radiocarbon dating of desert varnish by Alan Watchman

	has yielded inconsistent results. Consequently the slip rate for the Eastern Garlock fault (Leach Lake fault) is not known with certainty (McGill, personal communication, 2000). Stroud and McGill (1994 #6072; 1994 #6073) report an uplift rate of a few tenths of a millimeter per year for the unnamed thrust fault on the northeastern flank of the Avawatz Mountains. Slip rate assigned to this part of the Garlock fault by Petersen and others (1996 #4860) for probabilistic seismic hazard assessment for the State of California was 7.0 mm/yr (with minimum and maximum assigned slip rates of 5.0 mm/yr and 9.0 mm/yr, respectively. Petersen and others (1996 #4860) did not model a separate Eastern Garlock section. Slip rate determined for Central Garlock section [69b].
Date and Compiler(s)	2000 William A. Bryant, California Geological Survey
References	#6042 Bard, E., Hamelin, B., Fairbanks, R.G., and Zindler, A., 1990, Calibration of the C-14 timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals: Nature, v. 345, p. 405-410. #1450 Brady, R.H., III, 1986, Cenozoic geology of the northern Avawatz Mountains in relation to the intersection of the Garlock and Death Valley fault zones, San Bernardino County, California: Davis, University of California, unpublished Ph.D. dissertation, 292 p., 2 pls., scale 1:24,000. #1454 Burchfiel, B.C., Hodges, K.V., and Royden, L.H., 1987, Geology of Panamint Valley-Saline Valley pull-apart system, California—Palinspastic evidence for low-angle geometry of a Neogene range-bounding fault: Journal of Geophysical Research, v. 92, no. B10, p. 10,422-10,426. #2985 Burke, D.B., 1979, Log of a trench in the Garlock fault zone, Fremont Valley, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1028, 1 sheet, scale 1:125,000. #6452 Carr, M.D., Harris, A.G., Poole, F.G., and Fleck, R.J., 1993, Stratigraphy and structure of Paleozoic outer continental margin rocks in Pilot Knob Valley, north central Mojave Desert, California: U.S. Geological Survey Bulletin 2015, 33 p. #6043 Carter, B.A., 1980, Quaternary displacement on the

Garlock fault, California, *in* Fife, D.L., and Brown, A.R., eds., Geology and mineral wealth of the California desert: South Coast Geological Society, Santa Ana, California, p. 457-466.

#6045 Carter, J.N., Luyendyk, B.P., and Terres, R.R., 1987, Neogene clockwise tectonic rotation of the eastern Transverse Ranges, California, suggested by paleomagnetic vectors: Geological Society of America Bulletin, v. 98, p. 199-206.

#483 Clark, M.M., 1973, Map showing recently active breaks along the Garlock and associated faults, California: U.S. Geological Survey Miscellaneous Geologic Investigations I-741, 3 sheets, scale 1:24,000.

#6046 Clark, M.M., and Lajoie, K.R., 1974, Holocene behavior of the Garlock fault: Geological Society of America, Abstracts with Programs, v. 6, p. 156-157.

#2876 Clark, M.M., Harms, K.H., Lienkaemper, J.J., Harwood, D.S., Lajoie, K.R., Matti, J.C., Perkins, J.A., Rymer, M.J., Sarna-Wojcicki, A.M., Sharp, R.V., Sims, J.D., Tinsley, J.C., III, and Ziony, J.I., 1984, Preliminary slip rate table and map of late Quaternary faults of California: U.S. Geological Survey Open-File Report 84-106, 12 p., 5 plates, scale 1:1,000,000.

#1492 Davis, G.A., and Burchfiel, B.C., 1973, Garlock fault—An intracontinental transform structure, southern California: Geological Society of America Bulletin, v. 84, p. 1407-1422.

#6047 Dawson, T.E., 2000, A 7000 year record of paleoearthquakes on the central Garlock fault, near El Paso Peaks, California: San Diego State University, unpublished M.S. thesis, 90 p.

#3188 Dokka, R.K., and Travis, C.J., 1990, Late Cenozoic strike-slip faulting in the Mojave Desert, California: Tectonics, v. 9, p. 311-340.

#1531 Hamilton, W.B., and Myers, W.B., 1966, Cenozoic tectonics of the western United States: Reviews of Geophysics, v. 4, p. 509-549.

#923 Hill, M.L., and Dibblee, T.W., Jr., 1953, San Andreas, Garlock, and Big Pine faults, California: Geological Society of

America Bulletin, v. 64, p. 443–458.

#2878 Jennings, C.W., 1994, Fault activity map of California and adjacent areas, with locations of recent volcanic eruptions: California Division of Mines and Geology Geologic Data Map 6, 92 p., 2 pls., scale 1:750,000.

#6050 Jones, C.J., 1987, Is extension in Death Valley accommodated by thinning of the mantle lithosphere beneath the Sierra Nevada, California?: Tectonics, v. 6, p. 449-473.

#6051 LaViolette, J.W., 1981, Holocene and late Pleistocene displacement history of the western Garlock fault: Long Beach, California State University, unpublished M.S. thesis, 72 p.

#5731 Louie, J.N., Allen, C.R., Johnson, P.C., Haase, P.C., and Cohn, S.N., 1985, Fault slip in southern California: Bulletin of the Seismological Society of America, v. 75, no. 3, p. 811-833.

#6054 McGill, S.F., 1993, Late Quaternary slip rate of the Owl Lake fault and maximum age of the latest event on the easternmost Garlock fault, S. California: Geological Society of America Abstracts with Programs, v. 25, no. 5, p. 118.

#6056 McGill, S.F., 1994, Preliminary slip rate and recurrence interval for the western Garlock fault system near Lone Tree Canyon, California: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 72.

#6057 McGill, S.F., 1994, Holocene slip rate of the easternmost Garlock, fault, Avawatz Mountains, California, *in* Reynolds, J., ed., Abstracts from proceedings—The 1994 Desert research symposium: Quarterly of San Bernardino County Museum Association, v. 41, no. 3, p. 24.

#6058 McGill, S.F., 1994, Neotectonics of the easternmost Garlock fault in the Avawatz Mountains, *in* Reynolds, R., ed., Off limits in the Mojave Desert: San Bernardino County Museum Association Special Publication 94-1, p. 96-100.

#6060 McGill, S.F., 1999, Slip-rate studies of the Garlock and Owl Lake faults: U.S. Geological Survey National Earthquake Hazards Reduction Program, Annual Summaries v. 40, Contract no. 1434-92-G-2210, 6 p., (electronic version on line at http://erp-

web.er.usgs.gov/).

#6061 McGill, S.F., and others, in preparation, Slip rate of the western Garlock fault, rate of soil development, and paleoclimatic implications at a site near Lone Tree Canyon, Mojave Desert, California: Unpublished manuscript in preparation, 18 p.

#6064 McGill, S.F., and Rockwell, T.R., 1998, Ages of late Holocene earthquakes on the central Garlock fault near El Paso Peaks, California: Journal of Geophysical Research, v. 103, no. B4, p. 7265-7279.

#6062 McGill, S.F., and Sieh, K., 1991, Surficial offsets on the central and eastern Garlock Fault associated with prehistoric earthquakes: Journal of Geophysical Research, v. 96, p. 21,587-21,621.

#6063 McGill, S.F., and Sieh, K., 1993, Holocene slip rate of the central Garlock fault in southeastern Searles Valley, California: Journal of Geophysical Research, v. 98, p. 14,217-14,231.

#6053 McGill, S.H.F., 1992, Paleoseismology and neotectonics of the central and eastern Garlock fault, California: Pasadena, California Institute of Technology, unpublished Ph.D. dissertation, 235 p.

#3288 Minster, J.B., and Jordan, T.H., 1987, Vector constraints on western U.S. deformation from space geodesy, neotectonics, and pl. motion: Journal of Geophysical Research, v. 92, p. 4798.

#6065 Muehlberger, W.R., 1954, Geology of the Quail Mountains, San Bernardino County: California Division of Mines Bulletin 170, Geology of Southern California Map Sheet 16, scale 1:48,000.

#4860 Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A., and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08 (also U.S. Geological Open-File Report 96-706), 33 p.

#6071 Rodgers, D.A., 1979, Vertical deformation, stress accumulation and secondary faulting in the vicinity of the

Transverse Ranges of southern California: California Division of Mines and Geology Bulletin 203, p. 74.

#2993 Roquemore, G.R., Smith, P.E., and Banks, E.W., 1982, Holocene earthquake activity of the eastern Garlock Fault in Christmas Canyon, San Bernardino County, California: Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 228.

#6066 Smith, G.I., 1962, Large lateral displacement on the Garlock fault, California, as measured from offset dike swarm: American Association of Petroleum Geologists Bulletin, v. 46, p. 85-104.

#6069 Smith, G.I., and Ketner, K.B., 1970, Lateral displacement on the Garlock fault, southeastern California, suggested by offset sections of similar metasedimentary rocks: U.S. Geological Survey Professional Paper 700-D, p. 1-9.

#6456 Smith, G.I., Troxel, B.W., Gray, C.H., Jr., and von Huene, R., 1968, Geologic reconnaissance of the Slate Range, San Bernardino and Inyo Counties, California: [California] Division of Mines and Geology Special Report 96, 1 sheet, scale 1:62,500.

#6070 Snay, R.A., and Cline, M.W., 1980, Crustal movement investigations at Tejon Ranch, California: National Oceanic and Atmospheric Administration Technical Report 87.

#6329 Spencer, J.E., 1990, Geologic map of southern Avawatz Mountains, northeastern Mojave Desert region, San Bernardino County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2117, 1 sheet, scale 1:24,000.

#1653 Stewart, J.H., 1983, Extensional tectonics in the Death Valley area, California—Transport of the Panamint Range structural block 80 km northwestward: Geology, v. 11, no. 3, p. 153-157.

#6072 Stroud, J.R., and McGill, S.F., 1994, Neotectonic activity on a thrust fault in the northeastern Avawatz Mountains, California: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 97.

#6073 Stroud, J.R., and McGill, S.F., 1994, Late Quaternary

activity on a thrust fault in the northeastern Avawatz Mountains, Mojave Desert, California: San Bernardino County Museum Association Quarterly, v. 41, no. 3, p. 30-31.

#6074 Troxel, B.W., and Butler, P.R., 1979, Tertiary and Quaternary fault history of the intersection of the Garlock and Death Valley fault zone, southern Death Valley, California: Unpublished report submitted to U.S. Geological Survey, Menlo Park, California, 29 p.

#6075 Troxel, B.W., Wright, L.A., and Jahns, R.H., 1972, Evidence for differential displacement along the Garlock fault zone, California: Geological Society of America Abstracts with Programs, v. 5, p. 250.

#6076 Wells, S.G., McFadden, L.D., and Dohrenwend, J.C., 1987, Influence of late Quaternary climatic changes on geomorphic and pedogenic processes on a desert piedmont, eastern Mojave Desert, California: Quaternary Research, v. 27, p. 130-146.

#1686 Wernicke, B., Axen, G.J., and Snow, J.K., 1988, Basin and Range extensional tectonics at the latitude of Las Vegas, Nevada: Geological Society of America Bulletin, v. 100, p. 1738-1757.