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North Frontal thrust system, Eastern section (Class A) No. 109b

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Synopsis	**General:** The North Frontal thrust system is a major, generally east-west trending fault zone that marks the boundary between the Transverse Ranges and Mojave Desert geomorphic provinces. This fault zone is characterized by a broad, complex zone of discontinuous, generally south-dipping thrust, reverse, and, locally, strike-slip faults with latest Pleistocene to Holocene offset. Geologic and geomorphic mapping includes Vaughn (1922 #5801), Woodford and Harriss (1928 #6726), Gillou (1953 #6730), Richmond (1960 #6728), Hollenbaugh (1968 #6634), Dibblee (1964 #1343; 1967 #6614; 1974 #6605), Sadler (1982 #6619), Meisling (1984 #6606), and Miller (1987 #6617), Bryant (1986 #6611; 1986 #6612), and Spotila (2001 #6622). In this compilation the fault zone is divided into the Western [109a] and the Eastern [109b] sections. The Western section includes the Ord Mountains fault zone, Ocotillo Ridge fold, Sky High Ranch fault,

and White Mountains Thrust. The Eastern section extends eastward from the Helendale fault [110b] and includes the Blackhawk fault zone and other unnamed thrust and reverse faults. There are two detailed study sites along the Western section [109a]. Site 109-1 involved a trench by Meisling (1984 #6606) across the Ocotillo Ridge fold. This trench exposed a monoclinal warp expressed as a 55° north-dipping section of coarse fluvial sand and gravel overlying massive debris-flow deposits. Site 109-2 by Spotila (2001 #6622) exposed Holocene thrust displacement (maximum age of offset 9,710±50 yr BP) along a 23° south-dipping fault. In addition, Spotila measured 16 fault scarp profiles across traces of the Western [109a] and Eastern [109b] sections. There are no detailed studies for the Eastern section [109b]. Slip rates for the North Frontal thrust system are poorly constrained, especially with respect to age of displacement. Clark and others (1984 #2876) reported a long term vertical slip-rate of 0.07–0.14 mm/yr for the Ord Mountains fault zone. Bryant (1986 #6612) estimated the vertical slip rate of reverse and thrust faults along the Western section to be about 0.15–0.3 mm/yr, based on reported 40 m vertical offsets of Qf2 alluvial fan surfaces (Meisling, 1984 #6606). Meisling (1984 #6606) estimated a preferred vertical slip rate of 0.1–0.14 mm/yr for the Ord Mountains fault zone, based on offset late Quaternary alluvial fans and deposits. His maximum vertical slip rate along the Ord Mountains fault zone was 0.7–1.2 mm/yr. Wesnousky (1986 #5305) and Petersen and Wesnousky (1994 #6024) assign similar values based on Meisling (1984 #6606). Meisling (1984 #6606) estimated a preferred dextral slip rate of 1.25 mm/yr (0.34–15 mm/yr) for the Sky High Ranch fault, based on 250–750 m dextral offset Qf2 fanglomerate deposits estimated to be 50–730 ka. No slip rates have been reported for the Eastern section. The geomorphic expression and lower frequency of mapped Holocene displacement suggest that the slip rate for the Eastern section is probably less than slip rates estimated for the Western section. No recurrence interval studies exist for the Western and Eastern sections.

Sections: This fault has 2 sections. There is insufficient data to delineate seismogenic segments. Spotila (2001 #6622) divided the North Frontal thrust system into 3 segments. The Western segment extended north-south along the western flank of the Ord Mountains, then east along the northern front of the San Bernardino Mountains its intersection with the Helendale fault [110b]. Spotila's Central segment extended east from the

	Helendale fault [110b] to its intersection with the Old Woman Springs fault [117]. The Eastern segment extended east to a location about 4 km west of Highway 247. In this compilation the North Frontal thrust system is divided into 2 sections, the Western section west of the Helendale fault, and the Eastern section, which extends eastward to about 4 km west of Highway 247. Spotila (2001 #6622) observed that young-looking traces of the North Frontal thrust system are much more common west of the Helendale fault [110b] than east of the Helendale fault.
Name comments	**General:** The North Frontal thrust system is a complex zone of thrust, reverse, and dextral strike-slip faults that have a complicated mapping and naming history. Mendenhall (1905 #6616) was the first to recognize the steep north-facing escarpment along the northern San Bernardino Mountains. Vaughn (1922 #5801), Woodford and Harriss (1928 #6726), Gillou (1953 #6730), Richmond (1960 #6728), and Hollenbaugh (1968 #6634) all reported evidence of late Cenozoic deformation and faulting of various locations along the northern front of the San Bernardino Mountains. Woodford and Harriss (1928 #6726) mapped the geology in the vicinity of Blackhawk Mountain and named south-dipping thrust faults in bedrock (Santa Fe, Voorhies, and Grapevine thrusts). Shreve (1968 #6620) used these names and collectively termed these bedrock thrusts the Santa Fe thrust zone. Dibblee (1964 #1343; 1967 #6614; 1974 #6605) mapped along the entire range front and presented evidence for late Quaternary uplift in the San Bernardino Mountains (Dibblee, 1974 #6605; 1975 #6678). Dibblee, however, did not name faults along the northern range front. Meisling (1984 #6606) and Meisling and Weldon (1989 #6607) named faults along the northern front of the San Bernardino Mountains the North Frontal fault system, but this system included the Cleghorn [108], Grass Valley [108], Tunnel Ridge [327], Bowen Ranch [326], and Arrastre Canyon Narrows [325] faults. These faults will be considered in separate compilations. Meisling (1984 #6606) further named the individual fault zones within this system, from west to east: Ord Mountains fault zone (includes the Deep Creek fault on the south and Apple Valley Highlands fault on the north); Ocotillo Ridge fold, Sky High Ranch fault, and White Mountains Thrust system. Meisling and Weldon (1989 #6607) termed faults along the northern front of the San Bernardino Mountains, from west to east, the Deep Creek fault zone (along the western flank of the Ord Mountains), the Sky High Ranch fault (a northwest-striking dextral strike-slip fault), and the North Frontal thrusts. Ziony and Yerkes (1985 #5931) called the fault zone the North

	Frontal Fault Zone of San Bernardino Mountains. Bortugno and Spittler (1986 #6602) and Bryant (1986 #6611; 1986 #6612) used the name North Frontal Fault zone for the recently active thrust faults along the north face of the San Bernardino Mountains. Miller (1987 #6617) informally referred to the range-bounding reverse faults as the frontal fault system. He did not name the system. Spotila and Sieh (2000 #6623) termed the range-bounding faults as the North Frontal thrust system. This system included the Ord Mountains fault zone, Ocotillo Ridge fold, Sky High Ranch fault, White Mountain thrust (system), Blackhawk fault, and unnamed thrust and reverse faults east of Blackhawk Mountain. Wesnousky (1986 #5305) may have been the first to name thrust faults east of the Helendale fault [110b] the Black Hawk Spring fault. The name North Frontal thrust system will be used in this compilation. Individual fault names within this fault zone, from west to east, include: Ord Mountains fault zone, Ocotillo Ridge fold, White Mountains Thrust, and Blackhawk fault zone. **Section:** Eastern section extends from its complex intersection with the Helendale fault [110b] easterly to about 5.5 km east of Ruby Canyon and 4 km west of Highway 247. Spotila (2001 #6622) considered this section of the North Frontal thrust system to consist of two segments, his Central segment extending east from the Helendale fault [110b], and Eastern segment that extends east from the intersection with the Old Woman Springs fault [117]. Most strands of the Eastern section are unnamed. Wesnousky (1986 #5305) assigned the name Black Hawk Spring fault to a group of northwest-striking south-dipping reverse faults east of the Helendale fault [110b]. Spotila and Sieh (2000 #6623) refer to this fault as the Blackhawk fault, but mapped it as a northwest-trending structure with a large dextral strike-slip component. **Fault ID:** Includes numbers 405 (Ord Mountains fault) 407 (North Frontal Fault zone), 408 (Sky High Ranch fault) of Jennings (1994 #2878), and number 93 (North Frontal fault zone of San Bernardino Mountains) of Ziony and Yerkes (1985 #5931).
County(s) and State(s)	SAN BERNARDINO COUNTY, CALIFORNIA
Physiographic province(s)	BASIN AND RANGE
Reliability of	Good

location	Compiled at 1:62,500 scale. *Comments:* Locations based on digital revisions to Jennings (1994 #2878) using original mapping by Sadler (1982 #6619) and Bryant (1986 #6612) at 1:24,000; mapping by Miller (1987 #6617) is at 1:48,000; mapping by Dibblee (1964 #1343; 1967 #6614) is at 1:62,500.
Geologic setting	The North Frontal thrust system is a major range front fault system, located between the Transverse Ranges to the south and Mojave Desert to the north, along which uplift of the northern San Bernardino Mountains has occurred. The 80-km-long fault system consists of a complex zone of generally east-, north-, and northwest-trending thrust, reverse, and strike-slip faults that is locally 2 km wide. Meisling and Weldon (1989 #6607) and Spotila and Sieh (2000 #6623) reported that uplift of a broad plateau consisting of a relict, low-relief granitic erosion surface initiated on the North Frontal thrust system between 1.5–3 Ma. Maximum vertical displacement along the North Frontal thrust system is about 2.9 km near the center of the fault system (Spotila and Sieh, 2000 #6623). Displacement is not equally distributed along the system. Vertical offset drops to zero on the eastern end of the system, but is about 610 m at the western end of the system (Spotila and Sieh, 2000 #6623). Complex intersections with dextral strike-slip faults of the Mojave Desert characterize the eastern extent of the Western section [109a] and Eastern section [109b]. The intersection of the Helendale-South Lockhart fault zone [110] and North Frontal thrust system near Cushenbury Canyon is complex and there are differing interpretations as to whether the Helendale fault [110b] is a through-going dextral strike slip fault or if north-vergent reverse displacement along the North Frontal thrust system is dominant (Dibblee, 1964 #1343; Hollenbaugh, 1968 #6634; Sadler, 1982 #6619; Bryant, 1986 #6611; Miller, 1987 #6617; Meisling and Weldon, 1989 #6607). Miller (1987 #6617) and Bryant (1986 #6611) mapped strands of the North Frontal thrust system as continuous across the strike of the Helendale fault [110b]. Miller (1987 #6617) reported that both the Helendale [110b] and Old Woman Springs [117] faults do not appear to extend into the rocks south of the frontal fault system. Miller stated that offset along the Helendale fault [110b] may continue to the south beneath the San Bernardino Mountains, but displacement is confined to the block beneath the north-vergent thrust faults. Spotila (1999 #6621) suggested that, because no clear crosscutting relationship between the dextral strike-slip

	faults north of the North Frontal thrust system have been mapped, it is likely that both fault systems are active.
Length (km)	This section is 31 km of a total fault length of 67 km.
Average strike	N70°W
Sense of movement	Thrust *Comments:* Dibblee (1964 #1343; 1967 #6614); Miller (1987 #6617).
Dip	10° to 50° S *Comments:* Dips measured at the surface range from 10? to greater than 50?, based on mapping by Dibblee (1967 #6614) and Miller (1987 #6617). The subsurface dip of the Eastern section is not well constrained. Spotila and Sieh (2000 #6623) constructed a north-south cross section a few kilometers west of the intersection with the Old Woman Springs fault [117] and depicted a 25? south-dipping fault plane that steepens to about 52? below about 7 km depth (figure 9, cross section A-A' of Spotila and Sieh, 2000 #6623).
Paleoseismology studies	
Geomorphic expression	Strands of the Eastern section are delineated by scarps in late Pleistocene alluvium and locally are delineated by up to 4-m-high scarps on Holocene alluvium, incised drainages, and vegetation contrasts in alluvium (Bryant, 1986 #6611).
Age of faulted surficial deposits	Age of faulted deposits in not well constrained. Strands of the Eastern section offset pre-Cambrian (?) and Mesozoic crystalline basement rocks over late Cenozoic sedimentary rocks, offset late Quaternary alluvium and, locally, Holocene alluvium (Dibblee, 1964 #1343; 1967 #6614; Shreve, 1968 #6620; Bryant, 1986 #6611; Miller, 1987 #6617). Offset late Pleistocene alluvium characterized by soil-profile development indicating age of about 130 ka (G. Borchardt in Bryant, 1986 #6611).
Historic earthquake	
Most recent prehistoric	latest Quaternary (<15 ka)

deformation	*Comments:* Timing of the most recent paleoevent is poorly constrained. Fault offsets late Pleistocene alluvial surfaces estimated by Borchardt (in Bryant, 1986 #6611) to be about 130 ka. Bryant (1986 #6611) identified strands of the Eastern section that offset Holocene alluvial fans just east of the intersection with the Old Woman Springs fault [117] and just west of the Silver Reef fault [340]. Spotila (2001 #6622) reported that youthful geomorphic expression of the North Frontal thrust system is much more prominent west of the intersection with the Helendale fault [110b] and rare along the Eastern section.
Recurrence interval	*Comments:* Bull (1978 #6613) identified possible multiple offsets along strands of the Eastern section just east of the Silver Reef fault [340] where an approximately 60-m-high fault scarp is associated with inset stream terraces. Bull estimated that these benches and terraces indicate as many as five episodes of uplift. Bryant (1986 #6611) reported a compound fault-scarp profile just west of the canyon identified by Bull (1978 #6613). Bryant inferred possibly 3 events here, based on scarp profile, stream knickpoints, and terraces. Age of offset alluvial fan surface estimated by G. Borchardt (in Bryant, 1986 #6611) is about 130 ka.
Slip-rate category	Between 0.2 and 1.0 mm/yr *Comments:* No slip rates have been reported for the Eastern section. Fault scarp height in late Pleistocene alluvial surfaces is less than along the Western section [109a] and evidence of Holocene displacement is less, suggesting that the slip rate may be significantly less than the Western section. Slip rate assigned by Petersen and others (1996 #4860) for probabilistic seismic hazard assessment for the State of California was 0.5 mm/yr (with minimum and maximum assigned slip rates of 0.25 mm/yr and .75 mm/yr, respectively).
Date and Compiler(s)	2003 William A. Bryant, California Geological Survey
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