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Quaternary Fault and Fold Database of the United States

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Embudo fault (Class A) No. 2007

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Compiled in cooperation with the New Mexico Bureau of Geology & Mineral Resources

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Synopsis	The Embudo fault bounds the northern and western sides of the Picuris Mountains, where it strikes east and northeast, respectively. The fault is primarily a left-lateral strike-slip fault, with a component of west-down throw where it strikes northeast. This major structure of the Rio Grande rift acts as a transfer zone that accommodates differential movement between the east-tilted San Luis Basin to the north and the west-tilted Española Basin to the south. The fault forms the southeastern boundary of the San Luis Basin and continues southwestward into the Velarde graben (sensu Koning and others, 2004 #7546) in the northern Española Basin. At a location 2–3 km northeast of the town of Dixon, the Embudo fault splits into two splays: the La Mesita fault on the

	west and the Velarde-Dixon faults on the east (Koning and others, 2004 #7546; Manley, 1976 #1114, 1979 #1117). The Velarde-Dixon fault bounds the eastern side of the Velarde graben and slickenside lineations indicate left-normal oblique slip (Koning and others, 2004 #7546). Detailed mapping is present along parts of the fault; however, large landslides obscure most of the fault in the south. Enough exposures exist to constrain the location of the Velarde-Dixon fault, and late Quaternary deposits do not appear to be offset. Quaternary deposits along the northeastern section of the Embudo fault show evidence of probable repeated late Quaternary ruptures. Prior subdivision into sections: Early workers interpreted the Embudo fault as a scissors-style fault with two sections. Kelley (1978 #1107) and Personius and Machette (1984 #1124) identified a reversal of throw along the Embudo fault on La Mesita near Embudo. Later interpretations, combining field mapping with seismic reflection and gravity data, discounted a scissors fault interpretation (Koning and others, 2004 #7546) and extend the western strand of the southern Embudo fault (i.e., the La Mesita fault) to the town of Alcalde. Between Alcalde and the southern tip of Black Mesa, there is a 3 km step-over between the northern end of the Santa Clara fault and the southern end of the La Mesita fault. Between these two faults, northwest-trending folds have been mapped on the basalt-capped Black Mesa, as well as the west-trending Chamita syncline west of Alcalde (Koning and Manley, 2003 #7545 Koning, 2004 #7543 Koning and others, 2013 #7265, plate 1). What has been previously referred to as the Hernandez section of the Embudo fault has been renamed as the Santa Clara fault (Koning and others, 2004 7546) following nomenclature suggested by Harrington and Aldrich (1984 #1102).
Name comments	The Embudo fault extends from the southern Sangre de Cristo fault [2017], near the Talpa, southwest to the northern terminus of the Santa Clara fault about 12 km north of Española. This fault zone was mapped by Miller and others (1963 #1121), Kelley (1978 #1107), Muehlberger (1979 #1123), Steinpress (1980 #1392), Leininger (1982 #1759), Dungan and others (1984 #1181), Aldrich and Dethier (1990 #1085), and Kelson and others (1997 #1374). Kelley (1978 #1107), Aldrich and Dethier (1990 #1085), and Kelson and others (1997 #1374) extend the Embudo fault southwestward to the north end of the Pajarito fault near Clara Peak. The section of the fault east of Española was named the Santa Clara fault zone by Harrington and Aldrich (1984 #1102), a name advocated and used by Koning and others (2004 #7546, 2013 #7265). To the north, parts of the fault were called

	the Velarde fault by Manley (1979 #1117) and the frontal fault zone by Muehlberger (1978 #1391). Earlier versions of this compilation designated the Pilar section for that part of the Embudo fault extending from the southern Sangre de Cristo fault [2017] near Talpa to the town of Embudo (Machette and Personius, 1984 #1113). At Embudo, there was inferred to be a reversal of throw (west-down to the northeast of Embudo, southeast-down to the southwest of this town) by several previous workers (Kelley, 1978 #1107; Personius and Machette, 1984 #1124; Muehlberger, 1979 #1123). Later investigations, combining 1:24,000-scale field mapping (Koning and Aby, 2003 #7544; Koning and Manley, 2003 #7545; Koning, 2004 #7543 with geophysical data (Ferguson, 1995 #1158; Koning and others, 2004 #7546), did not find evidence of scissor-type motion. Consequently, the southern end of the Embudo fault is now interpreted to correspond to faults associated with the central and eastern parts of the Velarde graben (Koning and others, 2004 #7546). These faults include the La Mesita fault (to the west) and the Velarde-Dixon faults (to the east), which converge northwards into the Embudo fault 2–3 km northeast of the town of Dixon. Southeast-down, northeast-striking faults associated with the northwestern margin of the Santa Clara graben are now considered part of the Santa Clara fault zone.
County(s) and State(s)	RIO ARRIBA COUNTY, NEW MEXICO TAOS COUNTY, NEW MEXICO
Physiographic province(s)	SOUTHERN ROCKY MOUNTAINS
Reliability of location	Good Compiled at 1:250,000 scale. *Comments:* The location is based on analysis of aerial photography and field mapping at a scale of 1:12,000 by Kelson and others (1997 #1374), on analysis of aerial photography and field reconnaissance compiled at scales of 1:250,000 (Machette and Personius, 1984 #1113; Wong and others, 1995 #1155) and about 1:46,000 (Muehlberger, 1979 #1123), and on field mapping at scales of 1:125,000 (Smith and others, 1970 #1125) and 1:16,000 (Leininger, 1982 #1759).
Geologic setting	The Embudo fault is described as an accommodation zone between the west-tilted Española basin and the east-tilted San Luis basin of the Rio Grande rift, with probable high-angle fault

	displacement with different senses of vertical separation along strike (Kelley, 1978 #1107; Muehlberger, 1978 #1391; 1979 #1123; Leininger, 1982 #1759; Machette and Personius, 1984 #1113; Wong and others, 1995 #1155; Kelson and others, 1996 #1191; 1997 #1374).
Length (km)	40 km.
Average strike	N60°E
Sense of movement	Left lateral, Normal *Comments:* Roadcut exposures of the Embudo fault near Arroyo Hondo show that the main fault strand has had predominantly left-lateral slip (Kelson and others, 2004 #7249). Near-surface kinematic indicators on the primary fault include sigmoidal "s" shears in the fault zone and moderately plunging slickensides (15° toward S. 65°W. with a rake of less than 10°). Left-lateral slip is suggested elsewhere by field relations (Muehlberger, 1978 #1391; 1979 #1123; Steinpress, 1980 #1392; 1981 #1393; Leininger, 1982 #1759; Hillman, 1986 #1758; Hall, 1988 #1757; Bradford, 1992 #1174; Wong and others, 1995 #1155; Kelson and others, 1997 #1374) including small-scale kinematic indicators, contraction associated with a right-stepover, changes in sense and amounts of vertical displacement along strike, and possible fault-related stream deflections. Down-to-the-northwest separation of bedded volcanic and alluvial rift-fill deposits is apparent along the northern part of fault.
Dip Direction	V *Comments:* Seismic reflection surveys clearly show a northwest dip for the Velarde fault (Koning and others, 2004 #7546), but subsurface data is lacking to the north and available geophysical data (Ferguson and others, 1995 #1158; Koning and others, 2004 #7546) do not constrain the dip of the La Mesita fault. Muehlberger (1978 #1391; 1979 #1123) and Leininger (1982 #1759) identify the fault exposed in Arroyo Hondo roadcuts as a west-vergent thrust fault, although Kelson and others (1996 #1191; 1997 #1374) interpret the strand noted by these previous workers as a secondary thrust fault that merges down-dip with the primary, near-vertical fault.
Paleoseismology	There have been limited detailed paleoseismic studies of the

studies	Embudo fault. Kelson and others (1997 #1374, 2004 #7249) provide a detailed map of Quaternary surficial deposits and potentially fault-related features between Talpa and Pilar. Machette and Personius (1984 #1113) and Kelson and others (1997 #1374) collected data for several scarp profiles along the Pilar section of the fault.
Geomorphic expression	The Embudo fault is characterized by discontinuous scarps and lineaments. The height of fault scarps along the northeastern part of the fault appear to correlate more with local strikes of fault strands than with age of the displaced deposit (Kelson and others, 2004 #7249). Prominent northwest-facing topographic scarps are present along the fault trace at Arroyo Hondo, northeast of Pilar (Machette and Personius, 1984 #1113; Personius and Machette, 1984 #1124). Kelson and others (1997 #1374) show a complex pattern of Quaternary deformation, with the heights of fault scarps in similar-aged deposits varying substantially along strike. Overall, there is a decrease in scarp height to the southwest from Talpa to Pilar. The pattern of other potentially fault-related features (e.g., lineaments, stream deflections) also suggest a distributed pattern of surface deformation. Southwest of Pilar, the fault is obscured by large landslides along the Rio Grande gorge. Numerous strands mapped along the northeastern 18 km of the section is the surface expression of a positive flower structure (Kelson and others, 2004 #7249), and overall geomorphology is consistent with different ratios of lateral to normal faulting along strike. Bauer and Kelson (2004 # 7250) further suggest that the Embudo and Southern Sangre de Cristo [2017] faults are kinematically linked and lack a distinct boundary.
Age of faulted surficial deposits	Pleistocene alluvium is displaced by a thrust fault splay in road cut at Arroyo Hondo at northern end of fault (Personius and Machette, 1984 #1124). The youngest map unit displaced by the Embudo fault is the latest Pleistocene to Holocene (<30 ka) alluvial-fan deposit (unit Qfy, Bauer and others, 1999 #7248; Baurer and Kelson, 2004 #7250), although faulting of this deposit is identified only within the Arroyo Hondo area (Kelson and others, 2004 #7249). The Velarde-Dixon fault is mapped as crossing several late Quaternary deposits, which do not appear to be offset (Koning and Aby, 2003 #7544).
Historic earthquake	
Most recent	late Quaternary (<130 ka)

prehistoric deformation	*Comments:* The timing of the most-recent event is constrained only on the basis of the estimated age of displaced alluvium at Arroyo Hondo. Machette and Personius (1984 #1113) and Personius and Machette (1984 #1124) suggest a Pleistocene age of faulted alluvium, but note that a probable single-event fault scarp has morphology of late Pleistocene normal faults in similar climates. Kelson and others (1996 #1191; 1997 #1374; 2004 #7249) and Bauer and Kelson (2004 #7250) suggest possible latest Pleistocene movement on the Pilar fault section, although deposit ages are poorly constrained. The structural connection with the southern Sangre de Cristo fault [2017] to the northeast also suggests a probable latest Pleistocene age for this section of the Embudo fault.
Recurrence interval	
Slip-rate category	Less than 0.2 mm/yr *Comments:* Kelson and others (1997 #1374) estimated a poorly constrained vertical-displacement rate of <0.1 mm/yr for the Embudo fault. The reported height of scarps on Quaternary deposits does not constrain deformation rate because movement on the fault is primarily lateral; based on a number of assumptions including rift-extension direction, ratios of lateral to vertical displacement of 1.7–1.8:1 and 10:1 are reported by Kelson and others (2004 #7249) along the northeastern 18 km of the section. Bauer and Kelson (2004 #7250) use an offset Pliocene basalt southwest of Pilar to interpret the following averaged values of post-3 Ma slip-rates: 35 m/m.y. (vertical), 96 m/m.y. (horizontal), and 102 m/m.y. (net slip).
Date and Compiler(s)	2015 Keith I. Kelson, William Lettis & Associates, Inc. Kathleen M. Haller, U.S. Geological Survey Daniel J. Koning, New Mexico Bureau of Geology & Mineral Resources
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Questions or comments?