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Hilina fault system, 'Apua Pali section (Class A) No. 2610m

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Synopsis	**General:** The first person to map the faults on the south flank of Kilauea Volcano remains unknown, but Wood (1914 #6979) noted that subsidence occurred on the oceanward side of these structures related to the 1868 Great Ka'u earthquake, an estimated M8 earthquake (Wyss, 1988 #6980). Tilling and others (fig. 16, 1976 #6974) summarize faulting on the Hilina fault system associated with the November 29, 1975, M7.2 Kalapana earthquake. Lipman and others (1985 #6952) provide a comprehensive report of the 1975 Kalapana earthquake. Refer to the description of the November 29, 1975, Kalapana earthquake in this compilation for more details. Kellogg and Chadwick (1987 #6948) record 1975 Kalapana earthquake fault offsets preserved in the Mauna Ulu pahoehoe lava flows (1969-1974) for the central Hilina fault system. Riley and others (1999 #6972) estimate the depth of the Hilina fault system and recurrence interval for the

1975 Kalapana earthquake using paleomagnetic measurements of south flank lava flows. Expanding on the work of Kellogg and Chadwick (1987 #6948), Cannon and Burgmann (2001 #6934) and Cannon and others (2001 #6935) present detailed fracture maps of central Hilina faults, estimate prehistoric fault offset rates and recurrence intervals for large (M>6) prehistoric south flank earthquakes, and provide evidence for a shallow rather than a deep-seated interpretation for some of the Hilina faults. Faulting along the Hilina fault system is related to large (M>6) earthquakes on the southern flank of Kilauea Volcano. Delaney and others (1998 #6939) conclude that the small strains observed across the southern flank in the past several decades suggest that the Hilina faults remained inactive except for during the 1975 Kalapana earthquake. The landslide and tsunami potential of the Hilina fault system remains a great concern. Ma and others (1999 #6984) estimate that the tsunami created by the 1975 Kalapana earthquake displaced approximately 2.5 cubic kilometers of water. Along the coast and offshore of Kilauea's south flank to the southeast, the Hilina fault system may represent the landslide headscarps to the submarine Hilina slump and Papa'u sand-rubble flow. Slumps and seafloor structures offshore of the Hilina fault system are interpreted as landslide blocks and debris (see Moore and others, 1989 #6961, 1995 #6958; Moore and Chadwick, 1995 #6959; Morgan and others, 2000 #6964, 2003 #6965). Significant coastal and submarine mass movements may have occurred within the past 100 ka. Geologic evidence demonstrates the existence of Quaternary deformation, but the fault system is associated with volcanic features that might not extend deeply enough to be a potential source of significant earthquakes.

Sections: This fault has 15 sections. The Hilina fault system is an approximately 50-km-long, 5-km-wide zone of primarily normal faults that extend east across the southeastern flank of Kilauea Volcano. For this long fault system, we identify 15 fault sections based on fault-scarp morphology reflected on 7.5-minute topographic maps, continuity of expression, and evidence of apparent recent movement from cross-cutting relations of faults, fractures, and lava flows. The large number of sections for this fault system in particular is largely the result of young movement, high rates of movement, associations with large historic earthquakes, and focused study by researchers. The 15 sections are Pu'u Mo'o [2610a], Kukalau'ula Pali [2610b], Hilina Pali [2610c], Keana Bihopa [2610d], Pu'u Ka'one [2610e], Pu'u Kapukapu [2610f], Makahanu Pali [2610g], Pu'u'eo Pali [2610h],

	Kipukapapalinamoku 2610i], Poliokeawe Pali [2610j], 'Ainahou [2610k], Holei Pali [2610l], 'Apua Pali [2610m], Paliuli [2610n], and Pulama pali [2610o].
Name comments	**General:** The Hilina fault system consists of a set of roughly east-trending normal fault structures with moderate dips to the south and southeast. The term pali, used in several of the section names, is the Hawaiian work for "cliff" or "scarp." For example, the name Hilina Pali represents the geomorphic scarp of the Hilina fault. Another term used, pu'u is the Hawaiian work for "hill." **Section:** The 'Apua Pali section is in the central to eastern region of the Hilina fault system.
County(s) and State(s)	HAWAII COUNTY, HAWAII
Physiographic province(s)	HAWAIIAN-EMPEROR ISLAND-SEAMOUNT CHAIN
Reliability of location	Good Compiled at 1:100,000 scale. *Comments:* The fault trace is shown on the 1:100,000-scale geologic map as concealed (Wolfe and Morris, 1996 #6977), and the geomorphic fault scarp is recognizable on the 1:24,000-scale Makaopuhi Crater and Kalapana topographic maps. Cannon and Burgmann (2001 #6934) present detailed fracture maps of the 1975 Kalapana earthquake based on fracture mapping in Mauna Ulu pahoehoe lava flows (1969-1974) that flowed across 'Apua Pali.
Geologic setting	The Hilina fault system is a normal fault system in the southern flank of Kilauea Volcano, Hawai'i. The present southern flank is being displaced to the southeast along a basal detachment by high-level rift zone intrusions and deep-seated gravitational spreading of the island. Between 1990 and 1996, south flank horizontal velocity rates determined from global positioning system (GPS) surveys indicate as much as 10 cm/yr of lateral motion (Owen and others, 1995 #6968, 2000 #6969). This slightly northwest-dipping basal detachment at approximately 8-10 km depth represents the boundary between ocean lithosphere and the volcanic edifice. Pelagic sediment deposited on the seafloor prior to the formation of the volcanic edifice could be lubricating the basal detachment and promoting southeastward motion of the

	south flank. A comprehensive analysis of geodetic data for the 1975 Kalapana earthquake (Owen and Burgmann, 2006 #6985) indicates that measured ground deformation on the south flank is best explained by a combination of faulting of the basal detachment, opening of the east rift zone [2608b] and southwest rift zone [2608c], a summit eruption and collapse of the summit magma chamber, and faulting on the Hilina fault system. Sections of the Hilina fault system may vary in depth from shallow, arcuate normal faults to steeply dipping normal fault splays off the deep, basal detachment. Cannon and others (2001 #6935) conclude that Holei Pali [2610l] and 'Apua Pali [2610m] have fault dips of about 20? at the surface and may flatten downward, reaching a 1-2 km depth at the coast and possibly intersecting the base of a 2- to 3-km-thick hyaloclastic layer offshore (Morgan and others, 2000 #6964). Riley and others (1999 #6972) interpret Hilina Pali [2610c] to be a cylindrical (curved) fault that extends to a depth of 5 km. The Hilina fault system may also be a network of steeply-dipping normal fault splays off the 8- to 10-km-deep basal detachment (Lipman and others, 1985 #6952), with microseismicity possibly being localized at the intersection (Okubo and others, 1997 #6982).
Length (km)	This section is 7 km of a total fault length of 50 km.
Average strike	N. 65° E. (for section) versus N. 69° E. (for whole fault)
Sense of movement	Normal *Comments:* From Wolfe and Morris (1996 #6977).
Dip Direction	S *Comments:* Based on 186 piercing-point measurements along 'Apua Pali in Mauna Ulu lava flows (19691974) that were fractured by the 1975 Kalapana earthquake. The average piercing-point azimuth is S. 25? E. with average deviation (two-sigma) of 4? (Cannon and others, 2001). Additional information on dip directions is available from Wolfe and Morris (1996) and Cannon and Burgmann (2001). In addition, piercing-point measurements indicates the average plunge of the slip vector is 13? with a mean angular deviation (one-sigma) of 15? (Cannon and Burgmann, 2001 #6934).

Paleoseismology studies	
Geomorphic expression	The largest scarp is approximately 55 m high with a scarp slope of about 20?.
Age of faulted surficial deposits	Faults cut surface lava flows that range in age from historic to 1,500-3,000 yr B.P. (Wolfe and Morris, 1996 #6977). The Mauna Ulu lava flows (1969-1974) cover 'Apua Pali to the west and are cut by the fault. See Holcomb (1987 #6944) for details of ages of individual lava flows.
Historic earthquake	Kalapana earthquake M7.2 1975 Ka'u earthquake 1868 Kaimu earthquake 1823
Most recent prehistoric deformation	latest Quaternary (<15 ka) *Comments:* The maximum horizontal and vertical fault offsets across 'Apua Pali from the 1975 Kalapana earthquake are 0.82?0.02 m and -0.43?0.04 m, respectively (one-sigma instrument measurement uncertainty; Cannon and others, 2001 #6935). A negative vertical fault offset indicates hanging wall-down motion. Cannon and Burgmann (2001 #6934) present an 'Apua Pali fault rupture map for the 1975 Kalapana earthquake for 'Apua Pali regions covered by Mauna Ulu lava flows (1969-1974).
Recurrence interval	20-40 yr *Comments:* Based on a field site on 'Apua Pali where both 400-750 yr B.P. lava flows and Mauna Ulu lava flows (1969-1974) were faulted by the 1975 Kalapana earthquake along the same fracture (Cannon and Burgmann, 2001 #6934). The fracture in the older lava flow has a total offset of 89 cm while the Mauna Ulu flow only has 5 cm of total offset. This recurrence interval range, which is based on the assumption that 17-18 events similar size events have ruptured this part of the fault system, yields short recurrence times, but this rate of earthquakes is not supported by the number of historic earthquakes that have produced fault rupture on the south flank of Kilauea. Non-tectonic movement of the fracture may have occurred.
Slip-rate category	Between 1.0 and 5.0 mm/yr *Comments:* Kellogg and Chadwick (1987 #6948) first determined fault offsets in prehistoric and Mauna Ulu (1969-1974) lava flows

	along 'Apua Pali. Building on their work, Cannon and Burgmann (2001 #6934) calculated fault slip rates based on fault offsets in 400-750 yr B.P. lava flows for 'Apua Pali. The calculated slip rates are approximately 0.4 mm/yr horizontal and 0.1 mm/yr vertical (a negative vertical rate indicates hanging wall-down motion), which yield a net slip rate of about 0.4 mm/yr. However, fracture preservation may be poor, as indicated by the frequent estimated recurrence interval of 20-40 years. Poliokeawe Pali [2610j] and Holei Pali [2610l] have scarp heights approximately four times larger than the 'Apua Pali's scarp, with total offset that indicate rates of approximately 5-6 mm/yr. These lines of evidence suggests that the estimated slip rate falls in the 1-5 mm/yr category, but the actual rate is probably close to 1-2 mm/yr based on field observations and on comparison of scaled slip rates with Poliokeawe Pali [2610j] and Holei Pali [2610l].
Date and Compiler(s)	2006 Eric C. Cannon, none Roland Burgmann, University of California at Berkeley
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Questions or comments?