Appendix B–I Digital Files: Read Me First

Appendices B–H supplement chapters 2–8. Tables are prepared in Microsoft Word, saved as .rtf files. Figures are saved in a .pdf file for each chapter.

Time series plots comprise the beginning pages of all .pdf files and, in chapters 5 and 7, where the eruptive sequence is divided into stages, time series files are interleaved with map plots whose letter and number designation are given in the figure columns of time series text tables for chapters 4, 5, 6, and 7. The time series plots emphasize earthquake swarms and are also divided into year-by-year tabulations in order to more easily enable study of short time periods or individual events.

The map plots show earthquakes occurring before, during, and after tabulated eruptions, intrusions, and a few large earthquakes with foreshocks and aftershocks, as in the plots included in the text chapters.

Appendix I stands alone with text, tables, and figures that describe the application of Mogi models to tilt and level data.
Appendix B. Supplementary Material to Support Chapter 2

Tables B1a and B1b list earthquakes of magnitudes between 5 and 6 for the same time periods as text tables 2.1 and 2.2, respectively.

Table B2 shows azimuth and distance from Uwēkahuna and Whitney Vaults to points within Kīlauea Caldera shown in text figure 2.4.

Table B3 contains Whitney tilt data to support text figure 2.3.

Figure B1 plots occurrence of earthquakes designated as "south Hawai‘i" on a timeline that also shows (1) Kīlauea eruptions and intrusions, (2) Mauna Loa eruptions, and (3) Kīlauea earthquake swarms.
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1 Location abbreviations: Kilauea caldera (kc); Halemaumau crater (hm); East rift zone (erz); Southwest rift zone (swr); seismic southwest rift zone (sswr); Ko‘a‘e fault zone (koae); South flank (sf)
2 Eruption (E); intrusion (I); Earthquake ≥ M5 (EQ); Earthquake swarm (EQS); Collapse of Kilauea’s summit (C)
3 do. = aftershocks of the 1868 earthquake classified as “South Hawai’i”
### Appendix B Table B1. b. Earthquakes M 5-6, 1895-1925

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<td>(Jaggar, 1947, p. 43-45; Klein and Wright, 2000)</td>
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<td>5/24/1914</td>
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<td>M 5.22 on 6/1/1914</td>
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<td>Earthquake swarm of 560 events (108 at 0-10 km beneath Kilauea caldera; 432 beneath east rift zone) associated with 850-foot lowering of lava lake south flank response (67 events)</td>
<td>(Bevens and others, 1988, v. 3, p. 287-290; Klein and Wright, 2000)</td>
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1 Location abbreviations: Kilauea caldera (kc); Halema’uma’u crater (hm); East rift zone (erz); Southwest rift zone (swr); seismic southwest rift zone (sswr); Koa’e fault zone (koae); South flank (sf)

2 Eruption (E); intrusion (I); Earthquake ≥ M5 (EQ); Earthquake swarm (EQS); Collapse of Kilauea’s summit (C)
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### Appendix B table B2. Azimuth and distance to deformation centers

#### A. Uwēkahuna vault

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#### B. Whitney vault

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1 Numbers denote deformation centers at Kilauea’s summit shown on fig. 5 of Fiske et. al., 1969
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Reference(s):
- BTW2, p. 361-362
- BTW2, p. 465-561
- BTW2, p. 561-728
- BTW2, p. 733-738
- BTW2, p. 844-846
- BTW2, p. 846-885
- BTW2, p. 1055-1186
- BTW2, p. 1077-1078
- BTW2, p. 1074-1186
- BTW2, p. 1074-77
- BTW2, p. 1086

*Table B3. Whitney tilt data associated with Halemaumau draining and collapse (Fig. 2.3)*
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1. Heads 1-7 as follows: Event = type of measurement; Begin and End = beginning and ending times; Dh = increase or decrease in height of lava lake surface difference measured in meters; $E_{Q}$ = number of earthquakes in swarm; $T_{az}$ = Whitney tilt magnitude in seconds; tilt azimuth in degrees.
2. Azimuths from the Whitney vault that fall within the range of centers defined for the inflation preceding the 1967-68 eruption (Fiske and Kinoshita, 1969)—see Chapter 4 appendix table D3—are highlighted in **bold** type.
3. Other inflation/deflation vectors are explained in subsequent footnotes and text.
4. Eruptions and well-documented or suspected intrusions are italicized. Inflation/deflation of Kīlauea’s shallow reservoir are highlighted **bold**. Other inflation/deflation vectors are explained in subsequent footnotes and text.
5. Reference to the weekly and monthly reports of the Hawai’ian Volcano Observatory (Beverns and others, 1988) are abbreviated as follows: Volume 2 = BTW2; volume 3 = BTW 3.
6. Azimuths between 270° and 360° (inflation) or between 90 and 180° (deflation) lie outside of the range of azimuths to inflation centers preceding the 1967-68 eruption (Fiske and Kinoshita, 1969) and are interpreted as a deeper regional inflation. See text for further explanation.
7. Followed by inflation between 2/12 and 2/21. Changes in lava lake level are poorly correlated with tilt change in this period.
8. No tilt measurement between 3/1/1924 and 4/28/1924.
9. During this period an unchanging level of Hālema‘uma‘u lava lake is accompanied by alternating episodes of inflation and deflation. The net tilt change for this period (deflation) is shown.
**Figure B1.** Graphs showing “south Hawai‘i” earthquakes related to Kīlauea (middle panel) or Mauna Loa (lower panel) activity, 1820–1904. Earthquakes identified in the Klein-Wright catalog (Klein and Wright, 2000) as “south Hawai‘i” are compared to times of Kīlauea and Mauna Loa eruptions and intrusions. Closely spaced events near times of eruption or intrusion are probably associated with that volcano. Earthquakes in blue symbols designated “kl sf” for Kīlauea south flank have a bit more evidence regarding their location than merely “south Hawai‘i,” such as better felt reports or association with Kīlauea volcanic events. Most of the events designated “south Hawai‘i” are probably Kīlauea south flank but with insufficient location information. Isolated events of M>4.0 are most likely either south flank or deep magma-supply earthquakes, although the volcano designation is ambiguous.
Appendix Figure B1. "south hawaii" earthquakes related to activity at Mauna Loa and Kilauea

Earthquake magnitude (> 4)

1000

5.0

6.0

Earthquake swarms

Kilauea caldera
East rift zone
Southwest rift zone
South flank
Kilauea caldera > 25 km

Single earthquakes M > 4

"kl sf" in catalog
"klcaldeep" in catalog
South Hawaii" in catalog
Intrusions
Summit-Halemaumau overflows
Southwest rift zone
Summit--Mokuaweoweo
Northeast rift zone
Northeast rift zone
Southwest rift zone
Kilauea caldera

Intervals for which caldera/lava lake dimensions were estimated

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900

1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900
Appendix C. Supplementary Material to Support Chapter 3

Table C1 contains earthquakes of magnitudes between 5 and 6 for the same time periods as text table 3.1.

Table C2 contains Whitney tilt data to support text figure 3.2.

Figures C1 and C2 show time series plots of earthquakes associated with eruptions and intrusions at Kilauea from 1925 to 1953.
### Appendix table C1. Additional earthquakes M 5-6, 1925-1953

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<th>References</th>
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<td>M 4.7  off south coast</td>
<td>(Klein and Wright, 2000)</td>
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<td>11/22/1952</td>
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<td>M 3.95 20.8 km beneath Kilauea’s summit</td>
<td>(Klein and Wright, 2000)</td>
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\(^1\) Location abbreviations: Kilauea caldera (kc); Halema’uma’u crater (hm); East rift zone (erz); Southwest rift zone (swr); seismic southwest rift zone (sswr); Koa’e fault zone (koae); South flank (sf)
\(^2\) Eruption (E); intrusion (I); Earthquake ≥ M5 (EQ); Earthquake swarm (EQS); Collapse of Kilauea’s summit (C)
### Appendix table C2. Whitney tilt and seismic swarms 1925-1953 keyed to figure 3.2

<table>
<thead>
<tr>
<th>Date Beg.</th>
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<td>207.2</td>
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<td>3/15/1937</td>
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<td>Prehistoric inflation</td>
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### Reference

- Finch, 1944, Fiske and others, 1987
- Klein and Wright, 2000
- (Fiske and others, 1987, VL 366-367)
- (Fiske and others, 1987, VL 367)
- (Fiske and others, 1987, VL 415-416)
- (Fiske and others, 1987, VL 443-445)
- (Fiske and others, 1987, VL 445)
- (Fiske and others, 1987, VL 445)
- (Fiske and others, 1987, VL 445)
- (Bevans and others, 1988, v. 3, p. 989-1007)
- (Bevans and others, 1988, v. 3, p. 1173)
- (Bevans and others, 1988, v. 3, p. 1184-1189)
- (Bevans and others, 1988, v. 3, p. 1209-1217)
- (Bevans and others, 1988, v. 3, p. 1209-1217)
- (Fiske and others, 1987, VL 401)
- (Fiske and others, 1987, VL 408)
- (Fiske and others, 1987, VL 415-416)
- (Fiske and others, 1987, VL 443-445)
- (Fiske and others, 1987, VL 445)
- (Fiske and others, 1987, VL 445)
- (Fiske and others, 1987, VL 445)
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$^i$ Seismic swarms are defined as 5 or more events occurring at a rate of greater than 1/hour with no gap more than 2 hours. Locations are assumed to be at 0-5 km depth beneath Kilauea caldera.

$^{ii}$ Tilt magnitudes are in seconds of arc as originally reported. 1 arc-second = 4.848 microradians. Deflation azimuths are between 180 and 270 degrees, normally between 190 and 235 degrees. Inflation azimuths lie between 0 and 90 degrees, normally between 10 and 55 degrees.

$^{iii}$ References to seismicity are to the reprinted Early Serial Publications of the Hawaiian Volcano Observatory (Bevens and others, 1988), the reprinted Volcano Letter (Fiske and others, 1987) and the compilation of Hawaiian earthquakes before 1959 (Klein and Wright, 2000). A continuous record of tilt data obtained at Whitney vault are from an unpublished Hawaiian Volcano Observatory archive (HVO, unpub).
**Figure C1.** 1925–1953. Time-series summary of earthquakes in all regions of Kīlauea during this period plotted against times of eruption and intrusion (top panel) and Whitney tilt magnitudes (2nd panel from top) as in text figure 3.1. The bottom six panels show (from bottom to top) paired rows showing earthquakes per day (eq/day) and magnitudes >4 for earthquakes in the magma supply (bottom), rift and koae (middle) and south flank (upper) regions. Text figures 3.1–3.3 show shorter time periods that emphasize eruptions and intrusions in this period.

**Figure C2.** 1925–1953. Time series plots show heightened seismicity in all regions during this time period plotted against times of eruption and intrusion (top panel) and Whitney tilt magnitudes (2nd panel from top). Heightened seismicity is defined as earthquakes that occur with a frequency of less than six hours. We show three levels; the levels differ depending on the region. Background levels of south flank and deep magma-supply seismicity are higher and symbols are given for sequences of less than 5 events, 5–20 events, and greater than 20 events. For all other regions we plot sequences of less than 3 events, 3–10 events, and greater than 10 events.
Appendix D. Supplementary Material to Support Chapter 4

Table D1 shows additional earthquake swarms and earthquakes of $M_{4–6}$ from 1953 to 1967.

Table D2 summarizes tilt volume, eruption efficiency, and magma supply rate during 1950–1967.

Table D3 summarizes tilt data for deformation centers plotted in text figures 4.2 and 4.3.

Figures D1 and D2 show earthquake swarms using the same data as in text figures 4.1 and 4.9

Figures D3A–N show the same data as text figures 4.1 and 4.9 plotted at 1-year intervals.

Figures D4A–N show earthquake swarm data as in figures D1 and D2 plotted at 1-year intervals, but beginning 3 years earlier at 1 February 1950

Figures D5–9 show time series plots of earthquakes associated with eruptions and traditional intrusions between 1954 and 1965.

Figures D10–17 show map plots of earthquakes associated with eruptions and traditional intrusions between 1954 and 1965.

Figures D18–25 show map plots of deep (20–35 km, ms4) earthquake swarms in and near the magma supply path, organized chronologically.
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<td>Elevated deep magma supply; seismicity; small swarms of 3 events on 5/14, 16, 6/10, 18; average for entire period of 1.79 per week</td>
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1. Bibliographic reference file “wf kil ms.scienceen9.enl”
2. Earthquake classification abbreviations are given according to the classification in Appendix table 4 and locations are shown on Appendix figure 2.
3. Eruption (E); intrusion (I); Earthquake ≥ M5 (EQ); Earthquake swarm (EQS); Collapse of Kilauea’s summit (C)
4. Minimum number of events defining a swarm: 20 for south flank; 10 for all other regions
6. Lag times compare onset of tilt deflection and the beginning of an eruption or earthquake swarm. (+) tilt leads, (-) tilt lags. Instruments in Uwekahuna vault: Press-Ewing seismometer (PE); Ideal-Arrowsmith tiltmeter E-W component (IA).
7. References coded as follows: (1) Klein and Wright, 2000, additional references given), (3) Macdonald and Eaton, 1964), (5) Macdonald and Eaton, 1956), (6) Eaton and Byerly, 1957), (8), (Eaton and Fraser, 1957), (9) Eaton and Fraser, 1957), (11) HVO seismic catalog
8. Seismic network now sufficient to locate larger events—total number of events given with number of located events in comment column
9. Beginning in the third quarter of 1959 earthquake data are taken from the modern catalog for which earthquakes were relocated in 2006. Prior to that time earthquake data is from the catalog compiled by F.W. Klein and T.L. Wright (Klein and Wright, 2000).
Appendix table D2. Tilt volume, E efficiency and magma supply rate 1950-1967

a. Whitney tilt data

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<th>Tvol</th>
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### b. Uwëkahuna tilt data

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1. Abbreviations (also in comment column): avg=average; inf=inflation; def=deflation; trans=transfer; l=intrusion; E=eruption; ks=Kilauea’s summit; erz=East rift zone; uer=upper east rift zone; swr=Southwest rift zone; kfz=Koa’e fault zone
2. Whitney tilt magnitude in microradians
3. The tilt volume in cubic kilometers=Whitney tilt magnitude/0.7 (Uwëkahuna equivalent magnitude)*0.00045 (see text for explanation)
Values are equivalent magma volume obtained by multiplying published volumes by 0.8 to account for vesiculation.

Eruption efficiency calculated for non-sustained rift eruptions as erupted volume/deflation volume associated with the eruption. For consistency eruption efficiencies are only calculated using the Uwëkahuna tilt.

Minimum magma supply rate calculated as described in text. The volume equivalent for pre-eruption inflation is added to the sum of volume equivalents for subsequent deflations and then divided by the elapsed time.

Values used in the calculation are shown in **bold** text. The volume equivalent of pre-eruption *deflation* (italics used for emphasis) is not used as it is already included in the deflation sum.

Ignore deflationary period from 10/31/1951-12/16/1951 (30.4 ur at azimuth 218.3)—central south flank M 4.5 earthquake on 12/6/1951 affected tiltmeter (4.1 second subsidence at azimuth 152.6—toward earthquake source region).


Whitney tilt offset at beginning of eruption. Tilt after 11/14/1959 calculated from the value for 11/15 by comparison with the tilt record at Uwëkahuna.


### Appendix Table D3. Tilt data for deformation centers plotted in figures 4.2 and 4.3

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<td>Center G in figure 4.6: intersection of Whitney and Uwēkahuna azimuths.</td>
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\(^1\) Magnitude in seconds and azimuth of daily tilt measurements from the Bosch-Omori tiltmeter in Whitney vault (1953-1957); water-tube tiltmeter in Uwēkahuna vault (1957-1967). 1 second of arc = 4.848 microradians (ur)

\(^2\) Compare with the intersection of vectors from the long-base tiltmeter array (point J) and leveling done over a time period that includes most, but not all the deflation and that may include some pre-eruption inflation (point K).
## Cross references, chapter 4 tables and appendix D map figures

[Table column heads are row “0;” only rows with information are counted; “do,” same as above; color coding indicates eruptions (red), traditional intrusions without eruption (blue); inflationary intusions (green), and suspected deep intrusions (magenta)]

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**Figure D1.** 1953–1961 earthquake swarms. Plotted data are the same as in text figure 4.1. Short vertical lines correspond to 3–10 events for magma supply, koae and rift regions, >5–20 events for the south flank regions. Long vertical lines correspond to >10 events for magma supply, koae, and rift regions and >20 events for the south flank regions. Swarm data are plotted at exact beginning and ending times. Dates on figure in mm/dd/yyyy format.

**Figure D2.** 1961–1967 earthquake swarms. Plotted data are the same as in text figure 4.9. Short vertical lines correspond to 3–10 events for magma supply, koae, and rift regions, >5–20 events for the south flank regions. Long vertical lines correspond to >10 events for magma supply, koae, and rift regions and >20 events for the south flank regions. Swarm data are plotted at exact beginning and ending times. Dates on figure in mm/dd/yyyy format.

**Figure D3A–N.** 1953–1967. Earthquakes per day and magnitudes above 4 are shown at yearly intervals. Plotted data are the same as in text figure 4.1. Dates on figure in mm/dd/yyyy format.

**Figure D4A–N.** 1953–1967. Earthquake swarms are shown at yearly intervals. Plotted data are the same as in appendix figure D2. Dates on figure in mm/dd/yyyy format.

**Figure D5.** 1 March 1954-1 June 1955. Earthquake swarms showing the long buildup to the 1955 lower east rift eruption. Plotted data are the same as shown in text figure 4.4A. Swarm symbols are expalained on the plot and in appendix figure D1. Dates on figure in mm/dd/yyyy format.

**Figure D6.** Earthquake swarms and tilt changes related to the 1959 and 1960 eruptions. Dates on figure in mm/dd/yyyy format.

**Figure D7.** 1 November 1960–1 November 1962. Earthquake swarms associated with the 1961 eruptions and intrusions. The top panel shows times of eruptions and intrusions with beginning times shown as dotted lines extending to the x axis. The second panel
shows tilt magnitude measured at the Uwēkahuna and Whitney Vaults. The bottom panels show, from bottom to top, magma-supply, rift and koae, and south flank earthquake swarms. The regions are separated by thin horizontal lines. Symbols for 1 or 2 events are given above the top panel of each plot. Earthquake swarm criteria are given next to the double-headed arrows. Dates on figure in mm/dd/yyyy format.

**Figure D8.** 1 November 1962–1 November 1963. Earthquake swarms associated with the 1962 and 1963 eruptions and intrusions. The top panel shows times of eruptions and intrusions with beginning times shown as dotted lines extending to the x axis. The second panel shows tilt magnitude measured at the Uwēkahuna and Whitney Vaults. The bottom panels show, from bottom to top, magma-supply, rift and koae, and south flank earthquake swarms. The regions are separated by thin horizontal lines. Symbols for 1 or 2 events are given above the top panel of each plot. Earthquake swarm criteria are given next to the double-headed arrows. Dates on figure in mm/dd/yyyy format.

**Figure D9.** 1 February 1965-1 February 1966. Earthquake swarms associated with the 1965 eruptions and intrusions. The top panel shows times of eruptions and intrusions with beginning times shown as dotted lines extending to the x axis. The second panel shows tilt magnitude measured at the Uwēkahuna and Whitney Vaults. The bottom panels show, from bottom to top, magma-supply, rift and koae, and south flank earthquake swarms. The regions are separated by thin horizontal lines. Symbols for 1 or 2 events are given above the top panel of each plot. Earthquake swarm criteria are given next to the double-headed arrows. Dates on figure in mm/dd/yyyy format.

**Figure D10.** Map showing locations of earthquakes associated with the summit eruption of 31 May-3 June 1954, including location of a M6.5 south flank earthquake on 30 March 1954. The aftershock zone is shown as a blue rectangle, the size of which is based on analogy with later, better documented south flank earthquakes. Dates on figure in mm/dd/yyyy format.
**Figure D11.** Map showing earthquake swarms 40-60 km deep following the 1960 eruption, which are co-located with earlier swarms shown in figure 4.7, all north of Kīlauea Caldera. All swarms include earthquakes shallower than 35 km located closer to Kīlauea Caldera than the earthquakes at depths >35 km. The earthquakes on 5–6 October are the last swarm of these deep earthquakes to be seen at Kīlauea, although a few more earthquakes at this location and depth occur through the end of 1960. See text for further explanation. Dates on figure in mm/dd/yyyy format.

**Figure D12.** Map showing locations of earthquakes before (blue), during (orange), and after (green) the eruption and intrusion of 22–25 September 1961. Symbol-coded depth ranges are shown on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D13.** Map showing locations of earthquakes before (blue), during (orange), and after (green) the eruption and intrusion of 7–9 December 1962. Symbol coded depth ranges are shown on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D14.** Map showing locations of earthquakes before (blue), during (orange), and after (green) the eruption and intrusion of 21–23 August 1963. Symbol coded depth ranges are shown on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D15.** Map showing locations of earthquakes before (blue), during (orange), and after (green) the eruption and intrusion of 5–6 October 1963. Symbol coded depth ranges are shown on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D16.** Map showing locations of earthquakes before (blue), during (orange), and after (green) the eruption and intrusion of 5–15 March 1965. Symbol coded depth ranges are shown on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D17.** Maps showing locations of earthquakes before (blue), during (orange), and after (green) the eruption of 24 December 1965 and intrusion of 25–30 December 1965. Symbol coded depth ranges are shown on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D18.** Map showing deep (20–35 km) earthquake swarms during 1961 through 1965. Dates are distinguished by color and are labeled on the plot. Dates on figure in mm/dd/yyyy format.

**Figure D19.** Map showing deep (20–35 km) earthquake swarm, 29–30 June 1961. Seismicity is shown from 17 June to 3 July 1961. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.

**Figure D20.** Map showing deep (20–35 km) earthquake swarm, 23–24 July 1961. Seismicity is shown from 23 to 29 July 1961. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.

**Figure D21.** Map showing deep (20–35 km) earthquake swarm, 21–23 November 1961. Seismicity is shown from 20 to 25 November 1961. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.

**Figure D22.** Map showing deep (20–35 km) earthquake swarm, 31 December 1961. Seismicity is shown from 28 December 1961 to 3 January 1962. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.
**Figure D23.** Map showing deep (20–35 km) earthquake swarm, 9–11 May 1962. Seismicity is shown from 9 to 14 May 1962. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.

**Figure D24.** Map showing deep (20–35 km) earthquake swarm, 8 January 1963. Seismicity is shown from 8 to 14 January 1963. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.

**Figure D25.** Map showing deep (20–35 km) earthquake swarm, 2–3 December 1964. Seismicity is shown from 12/2-4/1964. Earthquakes are color coded as to whether they occurred before the swarm date (blue), during the swarm (orange), or after the swarm (green). Dates on figure in mm/dd/yyyy format.
Appendix D Figure D2

Tilt magnitude from arbitrary “0”

South flank earthquake swarms (0-15 km depth)

Koae earthquake swarms (15 km depth)

Rift earthquake swarms (0-15 km depth)

Kilauea caldera earthquake swarms

Deep magma supply path: (20-35; >35 km)

Tilt mag (ur)

Intrusion
Eruption
1/1/1961
1/1/1962
1/1/1963
1/1/1964
1/1/1965
1/1/1966
1/1/1967

Tilt magnitudes are from arbitrary “0”.

Events are plotted as follows:

- <5 events
- 5-20 events
- >20 events

Locations are marked as follows:

- East rift
- Summit
- Western
- Eastern
- Central
- Southwest

Additional notes:
- Whitney vault (daily readings)
- Uwēkahuna vault (daily readings)
- Tilt axis scale change to emphasize smaller deflations

Event counts:
- 1/1/1961: <5 events
- 1/1/1962: >20 events
- 1/1/1963: 5-20 events
- 1/1/1964: >20 events
- 1/1/1965: >20 events
- 1/1/1966: >20 events
- 1/1/1967: >20 events

Eruptions
- Summit
- East rift
- Southwest rift zone

Intrusions
- Summit
- East rift zone
- Southwest rift zone
- Koae

Seismic southwest rift zone (0-15 km)
Far eastern south flank (0-15 km)
Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)

Deep magma supply path (> 35 km)
Kīlauea caldera
- kcal (0-5 km)
- kcal (5-10 km)
- kcal (10-20 km)
- kcal (20-40 km)

Deep earthquakes north of Kīlauea caldera precursory to 1959-1969=0 eruption

Kīlauea caldera
- Deep magma supply path (> 35 km)
- Deep magma supply path (> 20 km)
Appendix figure D3 B


Daily tilt readings
Whitney vault (blue)--left axis
Uwēkahuna (red)--right axis

Eruptions
- Summit
- East rift
- Southwest rift zone

Intrusions
- Koae southwest rift zone

Deep magma supply path (> 20 km)


Kilauea caldera
- kcal (0-5 km)
- kcal (5-10 km)
- kcal (10-20 km)

Deep earthquakes north of Kilauea caldera precursor to 1959-1969=0 eruption

Deep magma supply path (> 35 km)
Appendix figure D3


Daily tilt readings
Whitney vault (blue)--left axis
Uwëkahuna (red)--right axis

Eruptions
- Summit
- East rift
- Southwest rift zone
- Summit (ur)
- Koae

Intrusions
- East rift
- East rift zone
- Southwest rift zone (ur)
- Koae

Tilt mag. (ur)

Far eastern south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Western south flank (0-15 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)

Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Koae fault zone

Deep magma supply path (> 20 km)
Kilauea caldera
- kcal (0-5 km)
- kcal (5-10 km)
- kcal (10-20 km)
- kcal (20-35 km)
- kcal (35-45 km)

Deep earthquakes north of Kilauea caldera
precursory to 1959-1969=0 eruption

- *Eruptions*
  - Summit
  - East rift
  - Southwest rift zone
  - Koae fault zone

- *Intrusions*
  - Summit
  - East rift
  - Southwest rift zone

- *Seismic southwest rift zone (0-15 km)*
  - Lower east rift zone (0-15 km)
  - Middle east rift zone (0-15 km)
  - Upper east rift zone (0-15 km)

- *Far eastern south flank (0-15 km)*
  - Eastern south flank (0-15 km)
  - Central south flank (0-15 km)
  - Western south flank (0-15 km)

- *Kilauea caldera*
  - Deep magma supply path (> 20 km)
  - Deep earthquakes north of Kilauea caldera

- *Daily tilt readings*
  - Whitney vault (blue--left axis)
  - Uwêkahuna (red--right axis)
Appendix figure D3 F

Daily tilt readings
- Whitney vault (blue)--left axis
- Uwēkahuna (red)--right axis

Eruptions
- Summit
- East rift zone
- Southwest rift zone

Intrusions
- Summit
- East rift zone
- Southwest rift zone
- Koae fault zone

Far eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)

Seismic southwest rift zone (0-15 km)
- Koae fault zone

Deep magma supply path (>35 km)
- Deep magma supply path (>20 km)

Kīlauea caldera
- Deep earthquakes north of Kīlauea caldera preceding to 1959-1969 eruption

Kīlauea caldera
- Deep earthquakes north of Kīlauea caldera preceding to 1959-1969 eruption
Deep earthquakes north of Kilauea caldera precursor to 1959-1960 eruption

Daily tilt readings
Whitney vault (blue)—left axis
Uwēkahuna (red)—right axis

Eruptions
- Summit
- Intrusions
  - East rift
  - Southwest rift zone

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Deep earthquakes north of Kilauea caldera precursor to 1959-1960 eruption

Kilauea caldera
- Deep magma supply path (> 20 km)
- kcal (0-5 km)
- kcal (5-10 km)
- kcal (10-20 km)

Eruptions
- Summit
- East rift zone
- Southwest rift zone

Intrusions
- summit
- East rift zone
- southwest rift zone
- Koae fault zone

Daily tilt readings
- Whitney vault (blue)--left axis
- Uwëkahuna (red)--right axis

Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)

Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)

Deep magma supply path (>35 km)
- Deep magma supply path (>20 km)

Deep earthquakes north of Kilauea caldera precursory to 1959-1960 eruption
- Transition from 40-60 km deep earthquake swarms north of Kilauea caldera to 30 km deep earthquake swarms beneath Kilauea caldera
Appendix figure D3 I


Daily tilt readings
- Whitney vault (blue)--left axis
- Uwëkahuna (red)--right axis

Eruptions
- Summit
- East rift
- Southwest rift zone
- Koae fault zone

Intrusions
- summit
- East rift zone
- southwest rift zone

0-15 km: Lower east rift zone
- Central south flank
- Upper east rift zone
- Western south flank

Far eastern south flank
- Eastern south flank
- Central south flank
- Western south flank

Southwest rift zone
- Southeast rift zone
- Koae fault zone

Kilauea caldera
- Deep magma supply path

Kilocalories
- Kcal (0-5 km)
- Kcal (5-10 km)
- Kcal (10-20 km)
Appendix figure D3 J

Daily tilt readings
- Whitney vault (blue) -- left axis
- Uwëkahuna (red) -- right axis
End of Whitney tilt measurement 12/31/1962

- Eruptions
- Intrusions
  - Summit
  - Central south flank (0-15 km)
  - Western south flank (0-15 km)
  - Southeast rift zone
  - Southwest rift zone
  - Koae

- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Koae fault zone

- Deep magma supply path (>20 km)
- Kilauea caldera
  - kcal (0-5 km)
  - kcal (5-10 km)
  - kcal (10-20 km)


Eq/day
End of Whitney tilt measurement 12/31/1962

10 100 1000

WV tilt mag. (sec)

tilt mag. (ur)

Daily tilt readings
- Whitney vault (blue) -- left axis
- Uwëkahuna (red) -- right axis
End of Whitney tilt measurement 12/31/1962

- Eruptions
- Intrusions
  - Summit
  - Central south flank (0-15 km)
  - Western south flank (0-15 km)
  - Southeast rift zone
  - Southwest rift zone
  - Koae

- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Koae fault zone

- Deep magma supply path (>20 km)
- Kilauea caldera
  - kcal (0-5 km)
  - kcal (5-10 km)
  - kcal (10-20 km)


Eq/day

WV tilt mag. (sec)

tilt mag. (ur)

Daily tilt readings from watertube tiltmeter in Uwëkahuna vault
Appendix figure D3 M


Daily tilt readings from watertube tiltmeter in Uwëkahuna vault

Eruptions
- Summit
- East rift
- Southwest rift zone

Intrusions
- summit
- East rift zone
- southwest rift zone
- Koae

Eruptions
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Eruptions
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)

Intrusions
- Deep magma supply path (> 20 km)
- Kilauea caldera (0-5 km)
- Kilauea caldera (5-10 km)
- Kilauea caldera (10-20 km)

Earthquake counts
- 0-5 km s-p
- 0-5 km l-p
- >20 km
Appendix figure D3 N


Daily tilt readings from watertube tiltmeter in Uwëkahuna vault
Appendix figure D4 A

Kilauea caldera
- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

Daily tilt readings
- Whitney vault (blue)--left axis
- Uwēkahuna (red)--right axis

Intrusions
- sumit
- East rift zone
- southwest rift zone
- Koae

Eruptions
- Summit
- East rift
- Southwest rift zone

Earthquake swarms:
- Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
- Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

Earthquake swarms are marked with symbols:
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)
- ms1
- ms2
- ms3
- ms4/5

Tilt mag (ur)


Tilt mag (sec)

Kilauea caldera
- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

Appendix figure D4 C
- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koae fault zone

Daily tilt readings
- Whitney vault (blue)--left axis
- Uwēkahuna (red)--right axis

Intrusions
- summit
- East rift zone
- southwest rift zone
- Koae

Eruptions
- Summit
- East rift
- Southwest rift zone

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)
Appendix figure D4

Daily tilt readings
- Whitney vault (blue) — left axis
- Uwëkahuna (red) — right axis

Intrusions
- Summit
- East rift zone
- Southwest rift zone
- Koae

Eruptions
- Summit
- East rift
- Southwest rift zone

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

Short-base watertube tiltmeter installed in Uwëkahuna vault, July, 1966

Kilauea caldera
- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

Eruptions
- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koae fault zone

Intrusions
- ei1: Seismic southwest rift zone (0-15 km)
- ei2: Southwest rift zone (0-15 km)

Events
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)
Appendix figure D4 F

Tilt mag (ur)

Daily tilt readings
Whitney vault (blue)--left axis
Uwëkahuna (red)--right axis

Kilauea caldera

- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

Eruptions
- Summit
- East rift
- Southwest rift zone

Intrusions
- summit
- East rift zone
- Southwest rift zone

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

sf4swr
sf3kuer
sf2mer
koae
ei5swr
ei4sswr
ei3uer
ei2mer
ms1
ms2
ms3
ms4/5
sf1: Lower east rift zone (0-15 km)
sf2: Middle east rift zone (0-15 km)
sf3: Upper east rift zone (0-15 km)
sf4: Seismic southwest rift zone (0-15 km)
sf5: Southwest rift zone (0-15 km)
koae: Koae fault zone

ms3:
ms2:
ms1:
ms4/5:
ms3:
ms2:
ms1:
ms4/5:
Kilauea caldera

- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

Appendix figure 4.D2

- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koa‘e fault zone

- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)

Daily tilt readings
- Whitney vault (blue)--left axis
- Uwëkahuna (red)--right axis

Intrusions
- summit
- East rift zone
- Southwest rift zone
- Koae

Eruptions
- Summit
- East rift
- Southwest rift zone

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)
Appendix figure D4 J

Kilauea caldera
- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koa’e fault zone

Daily tilt readings
- Whitney vault (blue)--left axis
- Uwēkahuna (red)--right axis

Intrusions
- summit
- East rift zone
- southwest rift zone
- Koa’e

Eruptions
- Summit
- East rift
- Southwest rift zone

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)

Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)
Appendix figure D4 K

Daily tilt readings from watertube tiltmeter in Uwëkahuna vault

Intrusions

- Summit
- East rift zone
- Southwest rift zone
- Koae

Eruptions

- Summit
- East rift zone
- Southwest rift zone

Kilauea caldera

- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

Koa’e fault zone

- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)

- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)
Daily tilt readings from watertube tiltmeter in Uwëkahuna vault

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)
Daily tilt readings from watertube tiltmeter in Uwëkahuna vault

Eruptions
- Kilauea caldera
- Intrusions
- Eruptions

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
- Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)
Daily tilt readings from watertube tiltmeter in Uwëkahuna vault

Appendix figure D4 N

- ms1: 0-5 km
- ms2: 5-10 km
- ms3: 10-20 km
- ms4/5: Deep magma supply path (> 20 km)

**Kilauea caldera**

- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koa’e fault zone
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)

**Intrusions**

- summit
- East rift zone
- southwest rift zone
- koae

**Eruptions**

- Summit
- East rift
- Southwest rift zone

**Earthquake swarm** of 3-10 events (rift, summit) or 5-20 events (south flank)
Appendix D Figure D8

Daily tilt readings
Whitney vault (blue)--left axis
Uwēkahuna (red)--right axis

Tilt offset = reading error? (artifact)

Earthquake swarms
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Intrusions
- ms1
- ms2
- ms3
- ms4/5
- ei1er
- ei2mer
- ei3uer
- ei4sswr
- ei5swr
- sf2mer
- sf3kuer
- sf4swr
- koae

Eruptions
- Summit
- East rift zone
- Southwest rift zone

South flank
- summit
- Seismic southwest rift zone
- Ko'a'e fault zone

Tilt mag (ur)

Longitude, in degrees West

Rift zones/Ko'a'e
- ei1er
- ei2mer
- ei3uer
- ei4sswr
- ei5swr
- sf2mer
- sf3kuer
- sf4swr
- koae
- ms4x5
- ms3
- ms2
- msz

Magmah supply
- ms1
- ms2
- ms3
- ms4/5
- ei1er
- ei2mer
- ei3uer
- ei4sswr
- ei5swr
- sf2mer
- sf3kuer
- sf4swr
- koae

Note: The diagram shows daily tilt readings, intrusion and eruption events, and earthquake swarms from November 1, 1962, to November 1, 1963.
Appendix D Figure D10

5/31-6/3/1954 summit eruption: Data from 1/1/1954 through 7/1/1954

Eruption 5/31-6/3/1954

- Pre-eruption
- Syn-eruption
- Post-eruption
- Eruptive vents

3/30/1954: M 6.5 mainshock with 6.0 foreshock and aftershocks. Aftershock area (blue rectangle) is not given in Macdonald and Eaton (1954, table 3), but we estimate by comparison with the M 6.2 6/25/1989 Kalapana earthquake

Depth (km)
- ● 0-5
- ○ 5-10
- □ 10-15
- ★ > 20
Approximate location of a precursory earthquake swarm of 30 large, shallow events originating near Napau crater beginning at 12:36 pm September 21 and felt by residents of Volcano and the National Park (Richter and others, 1964, p. D19).

Eruption
04:30 9/22/1961
05:00 9/25/1961
Pre-eruption
Syn-eruption
Post-eruption

Eruptive vents

Note: depth discrimination better for later eruptions
Appendix D Figure D13

Kilauea 1962 flank eruption: data from 12/6-19/1962

Eruption
01:10 12/7/1962
15:00 12/9/1962
Pre-eruption
Syn-eruption
Post-eruption

Latitude, in degrees North
Longitude, in degrees West

Pacific Ocean

Kilauea region boundaries
Kilauea August 1963 flank eruption: data from 8/21-23/1963

Eruption
18:15 8/21/1963
08:10 8/23/1963

Pre-eruption
Syn-eruption
Post-eruption

Note: exceptionally low seismicity associated with eruption. No earthquakes located on day of eruption and very few in the week preceding or following.
Appendix D Figure D15

Kilauea 1963 east rift eruption: data from 10/4-19/1963

Eruption
05:25 10/5/1963
10:00 10/6/1963

Pre-eruption
Syn-eruption
Post-eruption

Note: suggestion of slow intrusion(s) in the post-eruption sequence

Eruptive vents
Depth (km)
- ▲ 0-5
- ○ 5-10
- □ 10-15
- ★ > 20

Pacific Ocean

Kilauea region boundaries

Latitude, in degrees North

Longitude, in degrees West
Kilauea March 1965 flank eruption: data from 3/5-14/1965

Appendix D Figure D16

Kilauea region boundaries

Pacific Ocean

Eruption
09:23 3/5/1965
23:00 3/15/1965

Pre-eruption
Syn-eruption
Post-eruption

Eruptive vents

Depth (km)
- 0-5
- 5-10
- 10-15
- > 20

Latitude in degrees North

Longitude, in degrees West
Kilauea December 1965 eruption/intrusion: data from 12/25-30/1965--Bosher data

Aloʻi eruption
21:30 12/24/1965
05:30 12/25/1965
Koaʻe intrusion
13:53 12/25/1965
06:39 12/30/1965

Note: Bosher earthquake locations truncated to the nearest 0.01 degree of latitude and longitude

Eruptive vents:
- Depth (km)
  - ● 0-5
  - ○ 5-10
  - □ 10-15
  - ★ > 20
Kilauea December 1965 eruption/intrusion: data from 12/28/1965-1/2/1966--HVO data only

Appendix D Figure D17 B

HVO data only
Aloi eruption
21:30 12/24/1965
05:30 12/25/1965
Koa intrusion
13:53 12/25/1965
06:39 12/30/1965
Syn-intrusion
Post-intrusion

Pacific Ocean

Depth (km)
- ● 0-5
- ○ 5-10
- □ 10-15
- ★ > 20

Eruptive vents
Appendix D Figure D19


Deep magma supply earthquake swarms
02:48 6/29/1961
02:45 6/30/1961

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Eruptive vents
Depth (km)
0-5
5-10
10-15
> 20
Appendix D Figure D20

Kilauea 1961 deep magma supply earthquake swarms: data from 7/23-29/1961

Deep magma supply earthquake swarms
- deep ms 2
  - 04:19 7/23/1961
  - 07:50 7/24/1961

Pre-earthquake swarm

Syn-earthquake swarm

Post-earthquake swarm

Latitude in degrees North

Longitude in degrees West

Pacific Ocean

Kilauea region boundaries

Eruptive vents

Depth (km)
- ● 0-5
- ○ 5-10
- □ 10-15
- ★ > 20
Appendix D Figure D22


Deep magma supply earthquake swarms
- deep ms 4
  - 08:52 12/31/1961
  - 23:20 12/31/1961

Pre-earthquake swarm

Syn-earthquake swarm

Post-earthquake swarm

Eruptive vents

Depth (km)
- 0-5
- 5-10
- 10-15
- > 20

Pacific Ocean

Kilauea region boundaries

Kilauea region boundaries
Appendix D Figure D23

Kilauea 1962 deep magma supply earthquake swarms: data from 5/9-14/1962

Deep magma supply earthquake swarms
deep ms 5
21:04 5/9/1962
06:37 5/11/1962

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Pacific Ocean

Kilauea region boundaries
Kīlauea 1964 deep magma supply earthquake swarms: data from 12/2-4/1964

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Appendix D Figure D25
Appendix E. Supplementary Material to Support Chapter 5

Table E1 shows the calculation of magma supply and eruption efficiency during this period.

Figure E1A–B presents time series data covering the entire period.

Figure E2A–R presents yearly data from 1967 through 1976 in plots similar to figures 5.1 and E1.

Figures E3–E8 present time series and earthquake locations for events during the pre-Mauna Ulu period listed in table 5.1 and figure 5.1.

Figures E9–E21 present time series and earthquake locations for events during period IA of the Mauna Ulu eruption listed in table 5.3 and figure 5.4.

Figures E22–E36 present time series and earthquake locations for events during period IB of the Mauna Ulu eruption listed in table 5.4 and figure 5.5.

Figures E37–E56 present time series and earthquake locations for events during the Mauna Ulu pause listed in table 5.5 and figure 5.7.

Figures E57–E70 present time series and earthquake locations for events during period II of the Mauna Ulu eruption listed in table 5.6 and figure 5.9.

Figures E71–E87 present time series and earthquake locations for events during the period between the end of Mauna Ulu II and the 1975 earthquake listed in table 5.7 and figure 5.11.
### Appendix table E1. Tilt volume, eruption efficiency and msr 1967-1975

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- Pre-eruption msr
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- Pre-eruption msr
- Net def 1967-MU I msr
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- Episode 2
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- **Net**: Net eruption rate
- **E**: Eruption rate
- **E Jr**: Eruption rate
- **Sum**: Episode summary
- **E Jr**: Eruption rate
- **msr**: Magnitude of seismicity rate

**Comment:**
- Pre-eruption inf: Pre-eruption inf
- Pre-eruption def: Pre-eruption def
- E rate: E rate
- MU I IIA msr: MU I IIA msr
- MU I I B msr: MU I I B msr
- Pre-earthquake inf: Pre-earthquake inf
- Pre-MU I def: Pre-MU I def
- Pre-MU I msr: Pre-MU I msr
- MU I inf: MU I inf
- MU I msr: MU I msr
- MU pause inf: MU pause inf

**Extras:**
- $T_{\text{mag}}$, $T_a$, $T_{\text{vol}}$, $E_{\text{vol}}$, $E_{\text{eff}}$, msr: Various eruption parameters

**Notes:**
- **\mu I msr**: Pre-eruption inf
- **\mu I inf**: Pre-eruption inf
- **Pauahi Mauna Ulu**: Event details for the Mauna Ulu volcano
- **\mu IV**: Event details for the Mauna Ulu volcano
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i inf=inf; def=def; trans=transfer; I=intrusion; E=eruption; ks=Kīlauea’s summit; erz=East rift zone; swr=Southwest rift zone; kfz=Koae fault zone; Hm=Halema’uma’u

ii Tilt magnitude in microradians

iii Tilt volume in cubic kilometers=tilt magnitude*.00045 (see text for explanation)

iv Values are equivalent magma volume obtained by multiplying published volumes by 0.8 to account for vesiculation

v Eruption efficiency calculated for non-sustained rift eruptions as erupted volume/def volume associated with the eruption. A value of 1.0 corresponds to eruption of all of the magma supplied with none left underground. The intrusion fraction = 1.0- eruption efficiency. For consistency eruption efficiencies are only calculated using the Uwekahuna tilt.

vi Minimum msr calculated as described in text. The true msr would include the volume of rift dilation created by spreading during each period. These values are not known because of limitations imposed by the early ground deformation network. The volume equivalent for pre-eruption inf is added to the sum of volume equivalents for subsequent defs and then divided by the elapsed time. Values used in the calculation are shown in bold text. The volume equivalent of pre-eruption def (italics used for emphasis) is not used as it is already included in the def sum.

vii Corrected for offset caused by Honomu earthquake
Cross references, chapter 5 tables and appendix E map figures

[Table column heads are row “0;” only rows with information are counted; “do,” same as above; color coding indicates eruptions (red), traditional intrusions without eruption (blue); inflationary intusions (green), and suspected deep intrusions (magenta)]

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Figure E1. Time series of Kīlauea earthquakes for the entire period 1967-1976. A, Earthquakes/day (eq/day) and earthquakes $M>4$. B, Earthquake swarms for all regions.


Figure E3. Earthquake swarms for the period 1 January 1967 to 1 April 1969 (pre-Mauna Ulu) for all regions. See caption for figure D1.

Figure E4. Map showing earthquake locations for the period 5 November 1967 to 13 July 1968, covering the entire 1967–68 Halemaʻumaʻu eruption, on a background of labeled seismic regions (see fig. A4). Suspected deep intrusions are outlined in black. Data are shown for periods before (blue), during (orange), and after (green) the event, and eruptive vents are plotted as red triangles. Dates on figure in mm/dd/yyyy format.

Figure E5. Map showing activity around eruption of 22–26 August 1968. Exceptionally sparse shallow seismicity extends into the Koae Fault Zone. South flank seismicity is distributed parallel to the rift zone with a preruption concentration suggesting a possible suspected deep intrusion beneath the eastern south flank (sf2mer). Eruption is followed by several earthquakes along the deep magma-supply path. Dates on figure in mm/dd/yyyy format.

Figure E6. Map showing activity around suspected deep intrusion of 16-17 December 1968. A heavy concentration of south flank earthquakes beneath site SDI 2 extends back to the pre-swarm period. Dates on figure in mm/dd/yyyy format.
**Figure E7.** Map showing activity around eruption of 22–28 February 1969. Shallow seismicity beneath Kīlauea’s summit accompanies the eruption. Note the high concentration of precursory south flank earthquakes. Dates on figure in mm/dd/yyyy format.

**Figure E8.** Map showing activity around traditional intrusion of 21 March 1969. Dates on figure in mm/dd/yyyy format.

**Figure E9.** Earthquake swarms for all regions during the period 1 April 1969 to 1 January 1970 (Mauna Ulu period IA). High-fountaining episodes 1–12 are labeled on the top panel. Dates on figure in mm/dd/yyyy format.

**Figure E10.** Map showing activity around summit intrusion of 30 April 1969. The intrusion beneath Kīlauea’s summit, defined by a small swarm of shallow earthquakes and inflationary tilt (table 5.3) was preceded on the same day by south flank earthquakes suggestive of a deep intrusion. Dates on figure in mm/dd/yyyy format.

**Figure E11.** Map showing activity around inflationary intrusion of 4–6 May 1969. Dates on figure in mm/dd/yyyy format.

**Figure E12.** Map showing activity around inflationary intrusion of 21–22 May 1969. Note the abundance of precursory earthquakes beneath the south flank. These continue without interruption beyond the end of episode 1 (24–25 May 1969). Dates on figure in mm/dd/yyyy format.

**Figure E13.** Map showing activity around Mauna Ulu episodes 1 (24–25 May 1969) and 2 (27–29 May 1969). South flank earthquakes continue east of the Mauna Ulu vent with little rift seismicity, suggesting the possibility of deeper aseismic intrusion farther downrift. Dates on figure in mm/dd/yyyy format.

**Figure E14.** Map showing activity around suspected deep intrusion 3–9 June 1969. This is interpreted as an increase in spreading rate associated with increase in magma supply rate. Dates on figure in mm/dd/yyyy format.
**Figure E15.** Map showing activity around traditional intrusion of 3 July 1969. The intrusion is unaccompanied by summit deflation and perhaps was fed from previously intruded magma stored within the rift zone. Dates on figure in mm/dd/yyyy format.

**Figure E16.** Map showing activity around episodes 6 (3–4 August) and 7 (5–6 August) of Mauna Ulu phase IA. Most of the episodes following episode 1 are accompanied by very little if any seismicity beneath the rift zone. These episodes are an exception, but rift seismicity is still sparse. Dates on figure in mm/dd/yyyy format.

**Figure E17.** Maps showing activity around suspected deep intrusions preceding episode 10 (stage I of the Mauna Ulu eruption). Dates on figure in mm/dd/yyyy format. 
*Figure E17 A.* 29 September to 4 October 1969: Four suspected deep intrusions are concentrated south of the Koa'e Fault Zone and upper east rift (site SDI 2 of fig. 5.2). 
*Figure E17 B.* 7–11 October 1970: A suspected deep intrusion is located south of the seismic southwest rift zone (site SDI 1 of fig. 5.2)

**Figure E18.** Map showing activity around traditional intrusion of 2–4 November 1969. Dates on figure in mm/dd/yyyy format.

**Figure E19.** Map showing activity around inflationary intrusion of 11–12 December 1969. This and figures E20 and E21 show the location of earthquakes that heralded the end of high fountaining at Mauna Ulu on 30 December 1969. Rift seismicity is dominantly beneath the seismic southwest rift zone. Dates on figure in mm/dd/yyyy format.

**Figure E20.** Map showing activity around inflationary intrusion of 23 December 1969. This and figures E19 and E21 show the location of earthquakes that heralded the end of high fountaining at Mauna Ulu on 30 December 1969. Rift seismicity is dominantly beneath the seismic southwest rift zone. Dates on figure in mm/dd/yyyy format.
**Figure E21.** Map showing activity around suspected deep intrusion (site SDI 2) of 27–29 December 1969 associated with simultaneous inflationary intrusion beneath the upper east rift zone and upper seismic southwest rift zone. The latter intrusions anticipate the paired inflationary intrusions of Mauna Ulu stage IB. This and figures E19 and E21 show the location of earthquakes that heralded the end of high fountaining at Mauna Ulu on 30 December 1969. Rift seismicity is dominantly beneath the seismic southwest rift zone. Dates on figure in mm/dd/yyyy format.

**Figure E22.** Kilauea activity, 1 January 1970 to 15 June 1971 (Mauna Ulu eruption stage IB). Earthquake swarms are shown for all regions. See also caption for figure E1. Dates on figure in mm/dd/yyyy format.

**Figure E23.** Map showing activity around suspected deep intrusions of 15 January 1970. Two suspected deep intrusions are defined by broken earthquake sequences of 3–7 events. The more westerly sequence occurs before 12 January, overlapping in time with the more easterly sequence. Dates on figure in mm/dd/yyyy format.

**Figure E24.** Map showing activity around summit intrusion of 22 January 1970, which was preceded by a concentration of deep magma supply earthquakes. Dates on figure in mm/dd/yyyy format.

**Figure E25.** Map showing continuation of the inflationary intrusion through 11 February 1970. Deflationary tilt and earthquake locations indicate dominant magma transfer to east rift zone. Dates on figure in mm/dd/yyyy format.

**Figure E26.** Map showing activity around paired inflationary intrusion of 17–23 March 1970. Dates on figure in mm/dd/yyyy format.

**Figure E27.** Map showing activity around paired inflationary intrusion of 4–7 April 1970, preceding a traditional intrusion on 7–8 April 1970. Dates on figure in mm/dd/yyyy format.
Figure E28. Map showing activity around a traditional intrusion beneath the east rift zone, 15–18 May 1970. This is an exceptionally energetic event and appears to be accompanied and followed by suspected deep intrusion at site DSDI 2. The intrusion triggered six deep tectonic earthquakes beneath the eastern south flank. Dates on figure in mm/dd/yyyy format.

Figure E29. Map showing activity around south flank earthquake swarm of 15–16 July 1970. Dates on figure in mm/dd/yyyy format.

Figure E30. Map showing activity around south flank earthquake (M 4.46) at 01:27 on 21 September 1970, which was preceded by two foreshocks and many aftershocks. The main part of the aftershock sequence resembles a suspected deep intrusion. Dates on figure in mm/dd/yyyy format.

Figure E31. Map showing activity around summit intrusion of 26–27 October 1970. Dates on figure in mm/dd/yyyy format.

Figure E32. Map showing activity around summit intrusion of 12–14 December 1970, possibly preceded and accompanied by a suspected deep intrusion. Dates on figure in mm/dd/yyyy format.

Figure E33. Maps showing activity around a series of inflationary intrusions between 22 December 1970 and 5 January 1971. Small suspected deep intrusions occur before, between and after the intrusions, along with a normal south flank response to rift intrusion. Dates on figure in mm/dd/yyyy format. A, 21–23 December 1970. The initial intrusion is beneath Kilauea’s summit. B, 25–26 December 1970. The second and third intrusions extend from the uppermost seismic southwest rift zone westward into the traditional southwest rift zone. C, 28–29 December 1970. The second and third intrusions extend from the uppermost seismic southwest rift zone westward into the traditional southwest rift zone. D, 29 December 1970 to 1 January 1971. The fourth and fifth intrusions are
concentrated beneath the summit and uppermost seismic southwest rift zone. E, 3–6 January 1971. The fourth and fifth intrusions are concentrated beneath the summit and uppermost seismic southwest rift zone.

**Figure E34.** Map showing activity around inflationary intrusion of 1–2 June 1971. Dates on figure in mm/dd/yyyy format.

**Figure E35.** Map showing activity around inflationary intrusion of 8–10 June 1971. Dates on figure in mm/dd/yyyy format.

**Figure E36.** Map showing activity around inflationary intrusion of 11–14 June 1971. Dates on figure in mm/dd/yyyy format.

**Figure E37.** Kílauea activity, 16 June 1971 to 4 February 1972 (Mauna Ulu pause). Earthquake swarms are shown for all regions. Dates on figure in mm/dd/yyyy format. See also caption for figure E1.

**Figure E38.** Map showing activity around inflationary intrusion of 12–14 July 1971 beneath upper seismic southwest rift zone, preceded by suspected deep intrusion on 9 July. Dates on figure in mm/dd/yyyy format.

**Figure E39.** Map showing activity around inflationary intrusion of 18–19 July 1971 beneath upper seismic southwest rift zone. Dates on figure in mm/dd/yyyy format.

**Figure E40.** Map showing activity around inflationary intrusion of 21–24 July 1971 beneath upper east rift zone. Dates on figure in mm/dd/yyyy format.

**Figure E41.** Map showing activity around inflationary intrusion of 27–30 July 1971 beneath both rift zones. Dates on figure in mm/dd/yyyy format.

**Figure E42.** Map showing activity around inflationary intrusion of 5–6 August 1971 beneath both rift zones. Dates on figure in mm/dd/yyyy format.
Figure E43. Maps showing locations of earthquakes associated with the intrusion that heralded the summit eruption of 14 August 1971. Dates on figure in mm/dd/yyyy format. A, Precursory seismicity, 8 August. Earthquakes beneath upper seismic southwest rift zone. B, Precursory seismicity, 9 August. Earthquakes beneath upper seismic southwest rift zone. C, Precursory seismicity, 10 August. Earthquakes beneath upper seismic southwest rift zone. D, Precursory seismicity, 11 August. Earthquakes beneath both rift zones, with increasing seismicity beneath east rift zone. E, Precursory seismicity, 12 August. Earthquakes beneath both rift zones, with increasing seismicity beneath east rift zone F, Precursory seismicity, 13 August.

Figure E44. Map showing activity around summit eruption of 14 August 1971, including precursory seismicity on that date ending at the time of eruption. Dates on figure in mm/dd/yyyy format.

Figure E45. Map showing activity around inflationary intrusions between eruptions—27–29 August 1971. Dates on figure in mm/dd/yyyy format.

Figure E46. Map showing activity around inflationary intrusions between eruptions, 6–8 September 1971. Dates on figure in mm/dd/yyyy format.

Figure E47. Map showing activity around inflationary intrusions between eruptions, 12–14 September 1971. Dates on figure in mm/dd/yyyy format.

Figure E48. Maps showing locations of earthquakes associated with the intrusion that heralded the summit eruption of 19 September. Dates on figure in mm/dd/yyyy format. A, Activity of 17 September. B, Activity of 18 September. C, Activity of 19 September. D, Activity of 20 September. E, Activity of 21 September. F, Activity of 22 September, including deep magma-supply swarm.
Figure E49. Maps showing locations of earthquakes associated with the southwest rift eruption of 24 September 1971. Dates on figure in mm/dd/yyyy format. A, Preeruption seismicity on 23–24 September. B, Posteruption seismicity on 24–25 September. Seismicity masked by tremor and not recorded during this short eruption. C, Posteruption seismicity on 26 September to 1 October.

Figure E50. Map showing activity around suspected deep intrusion of 8–9 October 1971. Dates on figure in mm/dd/yyyy format.

Figure E51. Map showing activity around suspected deep intrusion of 14–16 November 1971 at site SDI 1. Dates on figure in mm/dd/yyyy format.

Figure E52. Map showing activity around inflationary intrusion of 12–13 December 1971. Dates on figure in mm/dd/yyyy format.

Figure E53. Maps showing seismicity associated with the suspected deep intrusions of 22-30 December 1971. Dates on figure in mm/dd/yyyy format. A, 12/22. Earthquake swarm on 22 December beneath central south flank (suspected deep intrusion?) at site SDI 2. B, Activity on 23 December; suspected deep intrusions at sites SDI 1 and SDI 2. C, Activity on 24–25 December; continuation of suspected deep intrusion at site SDI 1. D, Activity on 26-28 December; continuation of suspected deep intrusion at site SDI 1. E, Activity 29–31 December; continuation of suspected deep intrusion followed by intrusion into upper east rift zone and possible new suspected deep intrusion near site SDI 2.

Figure E54. Map showing activity on 1-4 January 1972. Suspected deep intrusion shown by earthquake swarms associated with the return of eruption at Mauna Ulu on 4 February 1972. Dates on figure in mm/dd/yyyy format.
**Figure E55.** Map showing activity on 10-12 January 1972. Traditional intrusion beneath upper east rift zone with south flank response before and after. Earthquake swarms associated with the return of eruption at Mauna Ulu on 4 February 1972. Dates on figure in mm/dd/yyyy format.

**Figure E56.** Maps showing activity around the two last intrusions before the return of lava to Mauna Ulu. Dates on figure in mm/dd/yyyy format.  


B, Activity on 26 January-1 February. Inflationary intrusion beneath uppermost east rift zone on 26–28 January.

**Figure E57.** Kīlauea activity, 4 February 1972–14 June 1974 (Mauna Ulu stage II). Earthquake swarms are shown for all regions. Dates on figure in mm/dd/yyyy format.

**Figure E58.** Map showing seismic activity, 26 January-1 February 1972, precursory to Mauna Ulu stage II. Dates on figure in mm/dd/yyyy format.

**Figure E59.** Map showing activity around traditional intrusion of 18 March 1972, followed by an extended south flank response. Dates on figure in mm/dd/yyyy format.

**Figure E60.** Map showing activity around suspected deep intrusion of 1–2 May 1972 near site SDI 2. Dates on figure in mm/dd/yyyy format.

**Figure E61.** Map showing activity around suspected deep intrusion(?) of 7–8 March 1973. Dates on figure in mm/dd/yyyy format.

**Figure E62.** Map showing south flank earthquake on 15 April 1973. The aftershock pattern mimics that of a slow earthquake. Dates on figure in mm/dd/yyyy format.
**Figure E63.** Map showing activity around traditional intrusion of 8–10 June 1973 into the east rift zone and adjacent Koa'e Fault Zone. Dates on figure in mm/dd/yyyy format.

**Figure E64.** Map showing activity around traditional intrusion of 25 July 1973—a small intrusion followed by a large south flank response. Dates on figure in mm/dd/yyyy format.

**Figure E65.** Map showing activity around 10–11 November 1973 east rift eruption in and near Pauahi Crater. Eruption continues at low level until 9 December 9. Some south flank earthquakes accompanying the extended eruption mimic a slow earthquake pattern, but are not concentrated in time. Dates on figure in mm/dd/yyyy format.

**Figure E66.** Map showing activity around suspected deep intrusion of 25–26 December 1973. Dates on figure in mm/dd/yyyy format.

**Figure E67.** Map showing activity around inflationary intrusion of 23 February to 4 March 1973. The intrusion continues for an unusually long time. Dates on figure in mm/dd/yyyy format.

**Figure E68.** Map showing activity around inflationary intrusion of 10–19 March 1973. Dates on figure in mm/dd/yyyy format.

**Figure E69.** Map showing locations of earthquakes associated with a traditional intrusion on 24 March 1974. Intrusion is followed by a suspected deep intrusion near site SDI 2 and by a cluster of deep magma-supply earthquakes. Dates on figure in mm/dd/yyyy format.

**Figure E70.** Maps showing increased seismicity associated with the end of eruption at Mauna Ulu in June 1974. Dates on figure in mm/dd/yyyy format. *A,* Summit intrusion of 22 May 1974. Preintrusion seismicity includes a possible suspected deep intrusion near
site SDI 2 and a cluster of three deep magma-supply earthquakes. B, Suspected deep intrusion on 24–25 May near sites SDI 1 and 2. C, East rift intrusion of 28–30 May.

**Figure E71.** Kilauea activity, 15 June 1974–29 November 1975 (Post Mauna Ulu). Earthquake swarms are shown for all regions.

**Figure E72.** Map showing activity around suspected deep intrusion of 21–22 June 1974. Dates on figure in mm/dd/yyyy format.

**Figure E73.** Map showing activity around summit intrusion of 27 June 1974. Dates on figure in mm/dd/yyyy format.

**Figure E74.** Map showing activity around eruption of 19 September 1974. The eruption is apparently aseismic, preceded by intrusion into upper seismic southwest rift zone and followed by south flank seismicity. Dates on figure in mm/dd/yyyy format.

**Figure E75.** Map showing activity around inflationary intrusion of 6–15 October 1974, a composite of small swarms of earthquakes beneath the east rift zone and south flank. Dates on figure in mm/dd/yyyy format.

**Figure E76.** Map showing activity around inflationary intrusions of 31 October-2 November and 5–6 November 1974. The first intrusion is confined to the upper seismic southwest rift zone, whereas the second is a paired seismic southwest rift and east rift intrusion. Dates on figure in mm/dd/yyyy format.

**Figure E77.** Map showing activity around inflationary intrusions of 21–25 November and 1–5 December 1974. Both intrusions are focused beneath the upper seismic southwest rift zone, with the second intrusion showing additional activity beneath Kilauea's summit. Dates on figure in mm/dd/yyyy format.

**Figure E78.** Map showing activity around inflationary intrusion of 6–14 December 1974. Locus of this intrusion shifts to the upper east rift zone, and it is followed by a cluster of deep magma-supply earthquakes. Dates on figure in mm/dd/yyyy format.
**Figure E79.** Map showing activity around inflationary intrusion of 17–21 December 1974. A paired intrusion beneath the upper parts of both rift zones. Dates on figure in mm/dd/yyyy format.

**Figure E80.** Following the 31 December 1974 southwest rift eruption, intense intrusion continued beneath the lower seismic southwest rift zone, and south flank seismicity resumes beneath the upper east rift zone and Koa'e. Dates on figures in mm/dd/yyyy format. A, Activity on 1 January 1975. B, Activity on 2 January 1975. C, Activity on 3 January 1975. D, Activity on 4 January 1975. E, Activity on 5 January 1975. Seismicity begins to diminish beneath the lower southwest rift zone and western south flank. F, Activity on 6–8 January 1975.

**Figure E81.** Map showing activity around suspected deep intrusions of 15–16 and 18–20 March 1975. Clusters of south flank earthquakes at sites SDI 1, 2, and in between 1 and 2 are followed by a cluster of deep magma-supply earthquakes. Dates on figure in mm/dd/yyyy format.

**Figure E82.** Map showing activity around suspected deep intrusion of 24–26 March 1975. A continuation of seismic patterns shown in the preceding figure. Dates on figure in mm/dd/yyyy format.

**Figure E83.** Map showing activity around suspected deep intrusions of 2–3 and 5 April 1975. An intensification of the activity shown in March. Dates on figure in mm/dd/yyyy format.

**Figure E84.** Map showing activity around suspected deep intrusion of 16–18 April 1975 at site SDI 2. Dates on figure in mm/dd/yyyy format.
**Figure E85.** Map showing activity around suspected deep intrusion of 5 August 1975 at site SDI 1. Dates on figure in mm/dd/yyyy format.

**Figure E86.** Map showing activity around suspected deep intrusion of 23 October 23 at site SDI 2. Dates on figure in mm/dd/yyyy format.

**Figure E87.** Map showing activity around inflationary intrusion of 12-14 November 1975. Dates on figure in mm/dd/yyyy format.
Figure E1 a. 1/1/1967-12/1/1975 short-period located earthquakes, single eq (M ≥ 4.0) and tilt

Earthquake swarms (open symbols)  SI = slow intrusions
Single earthquakes M ≥ 4.0 (closed symbols)  II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions
- Mauna Ulu eruption stages
- East rift
  - IA
  - IB

Intrusions
- Intrusions
- Summit
- East rift
- Southwest rift
- Koae fault zone

Number of events/day


Located s-p earthquakes
- Kilauea caldera
  - 0-5 km
  - 5-10 km
  - 10-20 km

Deep magma supply path (> 20 km)
Figure E1b

Mauna Ulu: 1967-68 eruption through 1975 earthquake

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

- **Eruptions**
  - Summit
  - East rift
  - Southwest rift zone

- **Intrusions**
  - summit
  - East rift zone
  - southwest rift zone
  - Koae

**Legend**

- (1) 1967-68 Halemaumau eruption
- (2) August 1968 eruption
- (3) October 1968 eruption
- (4) February 1969 eruption
- (IA) (IB) pause (IIA) (IIB): Mauna Ulu eruption

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

- sf4swr
- sf3kuer
- sf2mer
- koae
- ei5swr
- ei4sswr
- ei3uer
- ei2mer
- ms1
- ms2
- ms3
- ms4/5
Appendix Figure E2 b. 2/1/1968-2/1/1969 eq counts, single eq ($M \geq 4.0$) and tilt

- Earthquake swarms (open symbols)
- SI = slow intrusions
- Single earthquakes $M \geq 4.0$ (closed symbols)
- II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

1967-68 Halemaumau eruption

- Eruptions
- Summit
- East rift
- Southwest rift zone
- Kilauea caldera (5-10 km)
- Kilauea caldera (0-5 km)
- Kilauea caldera (10-20 km)
- East rift zone (0-15 km)
- East rift zone (0-5 km)
- East rift zone (5-10 km)

- Intrusions
- $M \geq 4.0$ (closed symbols)
- Koae fault zone

Earthquake counts

- Kilauea caldera (0-5 km)
- Kilauea caldera (5-10 km)
- Kilauea caldera (10-20 km)
- Deep magma supply path (> 20 km)

Appendix Figure E2 b. 2/1/1968-2/1/1969 eq counts, single eq ($M \geq 4.0$) and tilt
Appendix Figure E2 c. 2/1/1969-2/1/1970 eq counts, single eq (M ≥ 4.0) and tilt

Earthquake swarms (open symbols)  SI = slow intrusions
Single earthquakes M ≥ 4.0 (closed symbols)  II = inflationary intrusions

Eruptions
Summit
Southwest rift
Intrusions
Mauna Ulu IA
Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Koae fault zone

Kilauea caldera (0-5 km)
Kilauea caldera (5-10 km)
Deep magma supply path (> 20 km)

Earthquake counts
0-5 km s-p  0-5 km l-p  >20 km

Tilt mag (ur)

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"
Appendix Figure E2 d. 2/1/1970-2/1/1971 eq counts, single eq (M ≥ 4.0) and tilt

Earthquake swarms (open symbols)  SI = slow intrusions
Single earthquakes M ≥ 4.0 (closed symbols) II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Mauna Ulu IB

Far eastern south flank (0-15 km)  Central south flank (0-15 km)
Eastern south flank (0-15 km)  Western south flank (0-15 km)

Lower east rift zone (0-15 km)  Seismic southwest rift zone (0-15 km)
Middle east rift zone (0-15 km)  Southwest rift zone (0-15 km)
Upper east rift zone (0-15 km)  Koae fault zone

Kilauea caldera (0-5 km)  Deep magma supply path (> 20 km)
Kilauea caldera (5-10 km)  Kilauea caldera (10-20 km)

0-5 km s-p  0-5 km l-p  >20 km
Appendix Figure E2 e. 2/1/1971-2/1/1972 eq counts, single eq (M $\geq$ 4.0) and tilt

Earthquake swarms (open symbols)  SI = slow intrusions
Single earthquakes M $\geq$ 4.0 (closed symbols)  II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Mauna Ulu IB

Mauna Ulu pause

Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)

Kilauea caldera (0-5 km)
Deep magma supply path (> 20 km)

Kilauea caldera (5-10 km)
Kilauea caldera (10-20 km)

Koae fault zone

Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Appendix Figure E2 f. 2/1/1972-2/1/1973 eq counts, single eq (M ≥ 4.0) and tilt
Earthquake swarms (open symbols)  SI = slow intrusions
Single earthquakes M ≥ 4.0 (closed symbols)  II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Mauna Ulu IIA

Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)

Kilauea caldera (0-5 km)
Kilauea caldera (5-10 km)
Kilauea caldera (10-20 km)
Deep magma supply path (> 20 km)

Earthquake counts
0-5 km s-p
0-5 km l-p
>20 km

Number eq/day
Appendix Figure E2 g. 2/1/1973-2/1/1974 eq counts, single eq (M ≥ 4.0) and tilt

Earthquake swarms (open symbols)  SI = slow intrusions
Single earthquakes M ≥ 4.0 (closed symbols)  II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions
- Summit
- East rift

Intrusions
- summit
- southwest rift
- Koae

Mauna Ulu IIA
- Mauna Ulu IIB

Eruptions
- Kilauea caldera (5-10 km)
- Kilauea caldera (10-20 km)
- Deep magma supply path (> 20 km)

Earthquake counts
- 0-5 km s-p
- 0-5 km t-p
- >20 km

Number eq/day
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Western south flank (0-15 km)

Number eq/day
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Southwest rift zone (0-15 km)

Number eq/day
- Kilauea caldera (0-5 km)
- Kilauea caldera (5-10 km)

Number eq/day
- Earthquake counts
Appendix Figure E2 h. 2/1/1974-2/1/1975 eq counts, single eq (M ≥ 4.0) and tilt

Earthquake swarms (open symbols)
Single earthquakes M ≥ 4.0 (closed symbols)
SI = slow intrusions
II = inflationary intrusions

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions
- Summit
- East rift
- Southwest rift

Intrusions
- summit
- southwest rift
- Koae

Mauna Ulu IIB

Number eq/day

Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)

Lower east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Middle east rift zone (0-15 km)
Southwest rift zone (0-15 km)

Upper east rift zone (0-15 km)
Koae fault zone

Kilauea caldera (0-5 km)
Kilauea caldera (10-20 km)
Kilauea caldera (5-10 km)
Deep magma supply path (> 20 km)

Earthquake counts
0-5 km s-p
0-5 km l-p
>20 km

Number eq/day
Appendix Figure E2 i. 2/1/1975-2/1/1976 eq counts, single eq (M ≥ 4.0) and tilt

Earthquake swarms (open symbols)
Single earthquakes M ≥ 4.0 (closed symbols)
II = inflationary intrusions
SI = slow intrusions
II = inflationary intrusions

Number eq/day

Eruptions
Summit
East rift
Southwest rift

Intrusions
summit
southwest rift
East rift
Koae

Upper east rift zone (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Far eastern south flank (0-15 km)
Lower east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)

Kilauea caldera (5-10 km)
Kilauea caldera (0-5 km)

Earthquake counts
0-5 km s-p
0-5 km l-p
>20 km

Deep magma supply path (> 20 km)
Kilauea caldera (5-10 km)
Kilauea caldera (10-20 km)
Kilauea caldera (0-5 km)

Tilt magnitude (seconds)
Mauna Ulu: 1967-68 eruption through 1975 earthquake

Appendix figure E2 j

Kilauea caldera
- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koae fault zone

Tail mag (ur)
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Earquakes:
- Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
- Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

Magma supply path:
- (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (> 20 km)

Intrusions:
- Summit
- East rift
- Southwest rift zone

Eruptions:
- Summit
- East rift
- Southwest rift zone

Koae faults:
- koae: Koae fault zone
- ei1: Lower rift zone (0-15 km)
- ei2: Middle rift zone (0-15 km)
- ei3: Upper rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koae fault zone

Tilt mag (ur)
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)
Mauna Ulu: 1967-68 eruption through 1975 earthquake

Appendix figure E2 m

Kīlauea caldera
- ○: Lower east rift zone (0-15 km)
- □: Middle east rift zone (0-15 km)
- △: Upper east rift zone (0-15 km)
- ◊: Seismic southwest rift zone (0-15 km)
- ◇: Southwest rift zone (0-15 km)

- ●: Deep magma supply path (> 20 km)
- ●: Koae fault zone

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Intrusions
- ○: summit
- □: East rift zone
- ◊: southwest rift zone
- ●: Koae

Eruptions
- ●: Summit
- □: East rift
- ◊: Southwest rift zone

Mauna Ulu IB

- Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
- Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)
Mauna Ulu: 1967-68 eruption through 1975 earthquake

- Kilauea caldera
  - e1: Lower east rift zone (0-15 km)
  - e2: Middle east rift zone (0-15 km)
  - e3: Upper east rift zone (0-15 km)
  - e4: Seismic southwest rift zone (0-15 km)
  - e5: Southwest rift zone (0-15 km)
  - koae: Koae fault zone
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)
Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Mauna Ulu IB
Mauna Ulu pause

<table>
<thead>
<tr>
<th>Intrusions</th>
<th>Eruptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>summit</td>
<td>Summit</td>
</tr>
<tr>
<td>East rift zone</td>
<td>East rift</td>
</tr>
<tr>
<td>southwest rift zone</td>
<td>Southwest rift zone</td>
</tr>
<tr>
<td>koae</td>
<td></td>
</tr>
</tbody>
</table>

sf4swr
sf3kuer
sf2mer
koae
ei5swr
ei4surr
ei3uer
ei2mer
ms1
ms2
ms3
ms4/5
Mauna Ulu: 1967-68 eruption through 1975 earthquake

Kilauea caldera
- O (0-5 km)
- □ (5-10 km)
- △ (10-20 km)
- ★ Deep magma supply path (> 20 km)

Eruptions
- ● Summit
- ● East rift
- ● Southwest rift zone
- ★ Koae fault zone

Intrusions
- ○ summit
- □ East rift zone
- ● southwest rift zone
- ★ Koae fault zone

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Mauna Ulu IIA

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)

Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

sf4swr sf3kuer sf2mer koae ei5swr ei4sswr ei3uer ei2mer

ms1 ms2 ms3 ms4/5


Tilt mag (ur)
- 650
- 660
- 670
- 680
- 690
- 700


2/1/1973
Mauna Ulu: 1967-68 eruption through 1975 earthquake

Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

Deep magma supply path (> 20 km)

Kilauea caldera
- (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (> 20 km)
- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- koae: Koae fault zone

sf1: Far eastern south flank (0-15 km)
sf2: Eastern south flank (0-15 km)
sf3: Central south flank (0-15 km)
sf4: Western south flank (0-15 km)

Mauna Ulu IIB

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"
Mauna Ulu: 1967-68 eruption through 1975 earthquake

Kilauea caldera

- (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (> 20 km)

- ei1: Lower east rift zone (0-15 km)
- ei2: Middle east rift zone (0-15 km)
- ei3: Upper east rift zone (0-15 km)
- ei4: Seismic southwest rift zone (0-15 km)
- ei5: Southwest rift zone (0-15 km)
- sf1: Far eastern south flank (0-15 km)
- sf2: Eastern south flank (0-15 km)
- sf3: Central south flank (0-15 km)
- sf4: Western south flank (0-15 km)

Eruptions

- Summit
- East rift
- Southwest rift zone

Intrusions

- summit
- East rift zone
- southwest rift zone
- Koae

Earthquake swarm of over 10 events (rift, summit and koae) or over 20 events (south flank)

Earthquake swarm of 3-10 events (rift, summit and koae) or 5-20 events (south flank)

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

M 7.2 south flank earthquake
Figure E3. 1967-68 summit eruption through 1968-1969 east rift eruptions: earthquake counts and tilt
Figure E4

- Pre-eruption
- Syn-eruption
- Post-eruption
- Halemaumau vent

Kilauea region boundaries

Depth ranges:
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Mauna Ulu December 1968 suspected deep intrusion: data from 12/13-18/1968

Appendix Figure E6

Mauna Ulu vent

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Kilauea region boundaries

Pacific Ocean

Latitude, in degrees North

Longitude, in degrees West

19.05 19.15 19.25 19.35 19.45 19.55
154.7 154.8 154.9 155.0 155.1 155.2 155.3 155.4 155.5

16:28 12/16/1968
08:42 12/17/1968

Pre-intrusion
Syn-intrusion
Post-intrusion

suspected deep intrusion

12/13-18/1968
Appendix Figure E8


Intrusion
02:34  3/21/1969
03:26  3/21/1969

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean

Kilauea region boundaries
Figure E9. Mauna Ulu IA: earthquake swarms and tilt

Kilauea caldera
○ (0-5 km)
□ (5-10 km)
△ (10-20 km)
★ Deep magma supply path (> 20 km)

- Lower east rift zone (0-15 km)
- Mid east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Koae fault zone
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Tilt magnitude: Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions
- Summit
- East rift
- Southwest rift

Intrusions
- summit
- East rift
- southwest rift
- Koae

High-fountaining episodes

SI - slow intrusion
II - inflationary intrusion

Kilauea caldera

East rift zone

Seismic southwest rift zone

Southwest rift zone

Koae fault zone

Far eastern south flank

Eastern south flank

Central south flank

Western south flank

Lower east rift zone

Mid east rift zone

Upper east rift zone

Seismic southwest rift zone

Southwest rift zone

Koae fault zone

Far eastern south flank

Eastern south flank

Central south flank

Western south flank

Deep magma supply path

0-5 km
5-10 km
10-20 km
> 20 km

Note: suspected deep intrusion precedes summit intrusion

Mauna Ulu vent (from 5/24/1969)

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean

Kilauea region boundaries
Appendix Figure E11

- Inflationary intrusion?
- 09:16 5/4/1969
- 00:34 5/6/1969
- Pre-intrusion
- Syn-intrusion
- Post-intrusion

Mauna Ulu vent (from 5/24/1969)

Kilauea region boundaries


Depth ranges:
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Latitude, in degrees North
Longitude, in degrees West

Pacific Ocean
Figure E12


Note: south flank activity continuous from 5/21 through episode 1

inflationary intrusion?
17:53 5/21/1969
03:49 5/22/1969
pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent (from 5/24/1969)

Latitude, in degrees North
Longitude, in degrees West

Pacific Ocean

Kīlauea region boundaries

Depth ranges
● 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km
Figure E13

Mauna Ulu IA Episode 1 and 2 data from 5/23-30/1969

- Eruption 5/24-25/1969
  - 04:45 5/24/1969
  - 15:00 5/25/1969
- Pre-eruption
- Syn-eruption
- Between eruptions
- Syn-eruption
- Post-eruption

\[ \text{Mauna Ulu vent (from 5/24/1969)} \]

\[ \text{Note: south flank activity continuous from 5/21; eastern suspected deep intrusion accompanies episode 1?} \]

\[ \text{Depth ranges} \]
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ⧫ > 20 km

\[ \text{Pacific Ocean} \]

\[ \text{Kīlauea region boundaries} \]

Appendix Figure E14

Slow intrusion
12:09 6/9/1969

pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Kilauea region boundaries

Pacific Ocean

Intrusion
06:36 7/3/1969
22:15 7/3/1969

Pre-intrusion
Syn-intrusion
Post-intrusion

Note: no summit deflation--magma supplied from previous east rift intrusions

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- 15-20 km
- > 20 km

Kīlauea region boundaries

Pacific Ocean
Mauna Ulu IA episodes 6-7: data from 8/1-7/1969

Appendix Figure E16

Episode 6
17:15 8/3/1969
00:10 8/4/1969

Episode 7
21:00 8/5/1969
05:45 8/6/1969

Note: Most eruptive episodes are accompanied by little seismicity. When it occurs it is dominantly beneath the south flank.

Depth ranges:
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pre-eruptions
between eruptions*
Post-eruptions
*includes 3 syn-eruption earthquakes

Appendix Figure E17a

Longitude, in degrees West
Latitude, in degrees North

Suspected deep intrusions
pre-intrusions
1. 23:51 9/29/1969
   18:11 9/30/1969
2.  02:46 10/1/1969
   21:20 10/1/1969
3.  03:34 10/2/1969
   02:15 10/3/1969
4.  09:47 10/3/1969
   18:37 10/4/1969

post-intrusions
between intrusions

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Mauna Ulu vent
Mauna Ulu IA Suspected deep intrusion/pre-episode 10 by date: data from 10/6-10/1969

Appendix Figure E17b

Suspected deep intrusions
10:26 10/7/1969
12:44 10/11/1969
episode 10
09:00 10/10/1969
11:00 10/13/1969

Note: double suspected deep intrusion--the intrusion is split between the eastern and western parts of the central south flank; closer to the time of eruption the western branch of the intrusion moves slightly east.
Seismic precursors to end of Mauna Ulu IA: data from 12/10-13/1969

Note: anticipates inflationary intrusions of next period

Intrusion
01:58 12/11/1969
13:28 12/12/1969

Pre-intrusion
Syn-intrusion
Post-intrusion
Seismic precursors to end of Mauna Ulu IA. Suspected deep intrusion: data from 12/26-29/1969

Appendix Figure E21

Suspected deep Intrusion
16:59  12/27/1969
08:21  12/29/1969

Pre-intrusion
Syn-intrusion
Post-intrusion

Mauna Ulu vent
Figure E22. Mauna Ulu IB earthquake swarms and tilt

Kilauea caldera

- ○ Lower east rift zone (0-15 km)
- □ Middle east rift zone (0-15 km)
- △ Upper east rift zone (0-15 km)
- ⭐ Deep magma supply path (> 20 km)
- ○ Summits
- green squares: East rift
- pink/purple diamonds: Southwest rift
- blue triangles: Seismic southwest rift zone (0-15 km)
- orange squares: Southwest rift zone (0-15 km)
- red plus symbols: Koae fault zone
- green circles: Far eastern south flank (0-15 km)
- blue squares: Eastern south flank (0-15 km)
- red triangles: Central south flank (0-15 km)
- purple diamonds: Western south flank (0-15 km)

Tilt magnitude: daily readings from arbitrary "0"

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Intrusions

- continuous eruption

Eruptions

- slow intrusion (SI)
- inflationary intrusion (II)

Kilauea caldera

- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Summits
- East rift
- Southwest rift
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Koae fault zone
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)
Mauna Ulu IB 1/1970 suspected deep intrusion: data from 1/7-15/1970

Note: two slow intrusions defined by broken swarm sequences of 3-7 events. Events before 1/12 define the more westerly intrusion, although there is some time overlap between the east and west N-S sequences.

- **Intrusion**
  - 00:29  1/22/1970
  - 03:41  1/22/1970

- **Mauna Ulu vent**
  - Uwekahuna tilt azimuth 308.3

- **Depth ranges**
  - ● 0-5 km
  - ○ 5-10 km
  - □ 10-15 km
  - ★ > 20 km

- **Kilauea region boundaries**
Appendix Figure E25

Note: Continuation of 2/4-9 intrusion. Deflationary tilt indicates end of summit intrusion and continued magma transfer to rift zones.
Appendix Figure E26

- Inflationary intrusion
- Pre-intrusion (15:45 3/17/1970)
- Post-intrusion

Mauna Ulu

Depth ranges:
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean

Kilauea region boundaries
Appendix Figure E27

Inflationary intrusion

pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu

Latitude, in degrees North
Longitude, in degrees West

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean
Kilauea region boundaries

Koae
ms1-3
ms4-5
sf3kuer
ei3uer
ei2mer
ei1ler
sf1ler
sf2mer
sf3mer
ei4sswr
ei5swr

Figure E28


- Intrusion 5/15-18/1970
  - 04:40 5/15/1970
- Pre-intrusion
- Syn-intrusion
- Post-intrusion

△ Mauna Ulu vent (from 5/24/1969)

Note: suspected deep intrusion appears to accompany this major rift earthquake swarm. pre-intrusion seismicity consists of 7 events obscured beneath the later seismicity

Depth ranges
- ▲ 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Mauna Ulu IB suspected deep intrusion?: data from 7/8-15/1970

Pre-intrusion
Syn-intrusion
Post-intrusion

suspected deep intrusion?
11:05 7/15/1970
02:02 7/16/1970

Kilauea region boundaries

Mauna Ulu vent

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean

Kilauea region boundaries

Appendix Figure E29

Latitude, in degrees North

Longitude, in degrees West
Appendix Figure E30
Mauna Ulu IB South flank earthquake: data from 9/20-22/1970

Earthquake M 4.46
11:05 7/15/1970
02:02 7/16/1970

foreshock
mainshock
aftershock

Depth ranges
• 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km

Kīlauea region boundaries
Pacific Ocean
Appendix Figure E31

Intrusion
13:30 10/26/1970
14:57 10/27/1970
Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean
Kīlauea region boundaries

Longitude, in degrees West
Latitude, in degrees North

Kīlauea region boundaries

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Appendix Figure E32


Note: suggestion of a suspected deep intrusion during and following summit intrusion

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean
Kīlauea region boundaries

Note: Initial intrusion is beneath Kilauea's summit. The second and third intrusions extend down the southwest rift zone. Subsequent intrusions occur within the boundaries of intrusions 2 and 3.
Note: Initial intrusion is beneath Kilauea's summit. The second and third intrusions extend down the southwest rift zone. Subsequent intrusions occur within the boundaries of intrusions 2 and 3.
Note: Initial intrusion is beneath Kilauea's summit. The second and third intrusions extend down the southwest rift zone. Subsequent intrusions occur within the boundaries of intrusions 2 and 3.
Appendix Figure E33d


Note: Initial intrusion is beneath Kilauea's summit. The second and third intrusions extend down the southwest rift zone. Subsequent intrusions occur within the boundaries of intrusions 2 and 3.
Note: Initial intrusion is beneath Kilauea's summit. The second and third intrusions extend down the southwest rift zone. Subsequent intrusions occur within the boundaries of intrusions 2 and 3.
Appendix Figure E34

Inflationary intrusion
08:52  6/1 1971
11:40  6/2 1971
pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Pacific Ocean

Kilauea region boundaries

Depth ranges
- ▪ 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Appendix Figure E35

Mauna Ulu IB 6/1971 inflationary intrusion: data from 6/6-10/1971

Inflationary intrusion
08:01  6/8/1971
14:54  6/10/1971

pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Kilauea region boundaries

Pacific Ocean

Depth ranges

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Appendix Figure E36

Inflationary intrusion
07:01  6/11/1971
08:02  6/14/1971

pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Kīlauea region boundaries

Kīlauea region boundaries

Depth ranges
- Black: 0-5 km
- Orange: 5-10 km
- Green: 10-15 km
- Yellow: >20 km

Pacific Ocean

Latitude, in degrees North

Longitude, in degrees West

Appendix Figure E36
Figure E37. Mauna Ulu pause: earthquake swarms and tilt

Kilauea caldera
- Lower east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Far eastern south flank (0-15 km)
- (0-5 km)
- Middle east rift zone (0-15 km)
- Eastern south flank (0-15 km)
- (5-10 km)
- Southwest rift zone (0-15 km)
- Central south flank (0-15 km)
- (10-20 km)
- Upper east rift zone (0-15 km)
- Western south flank (0-15 km)
- Koae fault zone
- Deep magma supply path (> 20 km)


Tilt mag (ur)

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Intrusions
- Eruptions
- Summit
- East rift
- Southwest rift

Eruptions

Lava visible in Mauna Ulu until 10/15/1971

SI - slow intrusion  II - inflationary intrusion

sf4swr  sf3kuer  sf2mer

koae  ei5swr  ei4swwr  ei3ueer  ei2mer

ms1  ms2  ms3  ms4/5

Mauna Ulu pause inflationary intrusions: data from 7/7-15/1971

Note: First of four inflationary intrusions; preceded by suspected deep intrusion, mainly on 7/9/1971, in same location as the one on 7/5-6/1971.
Appendix Figure E39
Mauna Ulu pause inflationary intrusions: data from 7/16-20/1971

Note: Second of four inflationary intrusions; repeat of intrusion 1.
Appendix Figure E40
Mauna Ulu pause inflationary intrusions: data from 7/20-25/1971

Note: Third of four inflationary intrusions; shift to east rift zone

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Mauna Ulu vent
Appendix Figure E41
Mauna Ulu pause inflationary intrusions: data from 7/26-8/1/1971

inflationary intrusion
18:32 7/27/1971
21:41 7/30/1971
Pre-intrusion
Syn-intrusion
Post-intrusion

Note: Last of four inflationary intrusions; paired intrusions beneath east and seismic southwest rift zones

Mauna Ulu vent
Pacific Ocean
Kīlauea region boundaries

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Appendix Figure E42
Mauna Ulu pause 8/14/1971 eruption precursory intrusion: data from 8/2-8/1971

Summit eruption 8/14/1971 09:00-19:00
precursory intrusion
23:20 8/5/1971
15:36 8/6/1971
Pre-intrusion
Syn-intrusion
Post-intrusion

Eruptive vents
Δ Kïlauea region boundaries

Depth ranges
● 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km

Pacific Ocean

Latitude, in degrees North
Longitude, in degrees West

Kilauea region boundaries
Appendix Figure E43a

Mauna Ulu pause 8/14/1971 eruption precursory seismicity by date: data for 8/8/1971

- Summit eruption 8/14/1971 09:00-19:00
- Precursory intrusion 01:04 8/8/1971
- 08:55 8/14/1971
- Pre-intrusion (8/2-7)
- Syn-intrusion (8/8)

- Eruptive vents

- Depth ranges:
  - ● 0-5 km
  - ○ 5-10 km
  - □ 10-15 km
  - ★ > 20 km

- Pacific Ocean

- Kilauea region boundaries
Summit eruption 8/14/1971 09:00-19:00
precursory intrusion
01:04 8/8/1971
08:55 8/14/1971
Syn-intrusion(8/9)

Eruptive vents

Appendix Figure E43b
Mauna Ulu pause 8/14/1971 eruption precursory seismicity by date: data for 8/9/1971

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean
Kīlauea region boundaries

Latitude, in degrees North
Longitude, in degrees West
Mauna Ulu pause 8/14/1971 eruption precursory seismicity by date: data for 8/10/1971

- Summit eruption 8/14/1971 09:00-19:00
- precursory intrusion 01:04 8/8/1971
- 08:55 8/14/1971
- Syn-intrusion (8/10)

- Depth ranges:
  - 0-5 km •
  - 5-10 km ○
  - 10-15 km □
  - > 20 km ★

- Eruptive vents:
  - ei3uer
  - ei2mer
  - ei1ler
  - ms1-3
  - ms4-5
  - sf1ler
  - sf2mer
  - sf3kuer
  - sf4swr
  - ei4sswr
  - ei5swr

- Kiluea region boundaries

- Pacific Ocean
Appendix Figure E43d
Mauna Ulu pause 8/14/1971 eruption precursory seismicity by date: data for 8/11/1971

Summit eruption 8/14/1971 09:00-19:00
precursory intrusion
01:04  8/8/1971
08:55  8/14/1971
Syn-intrusion (8/11)

Eruptive vents

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean
Kīlauea region boundaries
Appendix Figure E43f

Mauna Ulu pause 8/14/1971 eruption precursory seismicity by date: data for 8/13/1971

- Summit eruption 8/14/1971 09:00-19:00
- Precursory intrusion 01:04 8/8/1971
- 08:55 8/14/1971
- Syn-intrusion (8/13)

- Eruptive vents

Depth ranges:
- • 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean

Kilauea region boundaries
Mauna Ulu pause 8/14/1971 eruption precursory seismicity by date: data for 8/14/1971

Appendix Figure E44

Note: continued intrusion. Seismicity during eruption obscured by tremor

Eruptive vents

Latitude, in degrees North

Longitude, in degrees West

Kilauea region boundaries

Pacific Ocean

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Mauna Ulu pause seismicity between eruptions: data from 8/25-9/1/1971
Appendix Figure E46
Mauna Ulu pause inflationary intrusions: data from 9/4-10/1971

Inflationary intrusions between summit eruptions
15:29  9/6/1971
17:42  9/8/1971
pre-intrusions
syn-intrusions
post-intrusions

Note: east rift earthquake swarm follows seismic southwest rift swarm. Elevated activity on both rift zones precedes (hidden beneath the syn- and post-swarm symbols) and follows the swarms.

Pacific Ocean
Kīlauea region boundaries

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Appendix Figure E48b
Mauna Ulu pause 9/24/1971 eruption--pre-eruption seismicity by date: data from 9/18/1971

Summit eruption 9/24/1971 19:20-20:00
precursory intrusions
14:29 9/17/1971
10:01 9/21/1971
Syn-intrusion (9/18)

Eruptive vents

Kilauea region boundaries

Pacific Ocean

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Appendix Figure E48c
Mauna Ulu pause 9/24/1971 eruption--pre-eruption seismicity by date: data from 9/19/1971

Summit eruption 9/24/1971 19:20-20:00
precursory intrusions
14:29 9/17/1971
10:01 9/21/1971
Syn-intrusion (9/19)

Eruptive vents

Latitude, in degrees North
Longitude, in degrees West

Depth ranges
● 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km

Pacific Ocean
Kīlauea region boundaries
Appendix Figure E48d
Mauna Ulu pause 9/24/1971 eruption--pre-eruption seismicity by date: data from 9/20/1971

- Summit eruption 9/24/1971 19:20-20:00
- Precursory intrusions
  - 14:29 9/17/1971
  - 10:01 9/21/1971
- Syn-intrusion (9/20)

- Eruptive vents
- Depth ranges:
  - ● 0-5 km
  - ○ 5-10 km
  - □ 10-15 km
  - ★ > 20 km

Latitude, in degrees North
Longitude, in degrees West
Appendix Figure E48e
Mauna Ulu pause 9/24/1971 eruption--pre-eruption seismicity by date: data from 9/21/1971

Summit eruption 9/24/1971 19:20-20:00
precursory intrusions
14:29  9/17/1971
10:01  9/21/1971
Syn-intrusion (9/21)

Eruptive vents

Kilauea region boundaries

Pacific Ocean

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Mauna Ulu pause 9/24/1971 eruption--pre-eruption seismicity--deep magma supply event 9/22/1971

Deep magma supply swarm
04:12  9/22/1971
06:01  9/22/1971

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Eruptive vents

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

- Eruption
  - 19:20 9/24/1971
  - 20:00 9/24/1971
- Summit and rift earthquake swarms
  - 02:27 9/26/1971
- South flank earthquake swarms
  - 23:53 9/24/1971
  - 02:41 10/1/1971

**Note:** No located earthquakes during short eruption

---

**Depth ranges**
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

**Kilauea region boundaries**

**Pacific Ocean**
Figure E49b

Mauna Ulu pause 9/24/1971 eruption: post-eruption seismicity by date 9/24-25/1971

- Eruptive vents
- Depth ranges:
  - ● 0-5 km
  - ○ 5-10 km
  - □ 10-15 km
  - ★ > 20 km

Pacific Ocean
Mauna Ulu pause 9/24/1971 eruption: post-eruption seismicity by date 9/26-10/1/1971

- Eruptive vents
- Summit and rift earthquake swarms
- South flank earthquake swarms

Depth ranges:
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean
Kīlauea region boundaries
Mauna Ulu pause Suspected deep intrusion?: data from 10/2-13/1971

Pre-intrusion
Syn-intrusion
Post-intrusion

Suspected deep intrusion?
19:20 10/8-07:43 10/9/1971

Not compelling as a typical suspected deep intrusion, but an extended south flank swarm without accompanying rift seismicity suggests deep magma pressure applied to a broad band beneath the rift zones.

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Mauna Ulu vent (from 5/24/1969)

suspected deep intrusion
19:33 11/15/1971
17:27 11/16/1971
pre-intrusion
syn-intrusion
post-intrusion

Appendix Figure E51
Mauna Ulu pause inflationary intrusion: data from 12/9-16/1971

- **inflationary intrusion**: 20:49 12/12/1971
- **Pre-intrusion**
- **Syn-intrusion**
- **Post-intrusion**

- **Mauna Ulu vent**

- **Mainshock 02:15 12/9/1971 M 4.3**
- **aftershocks**

- Depth ranges:
  - **0-5 km**
  - **5-10 km**
  - **10-15 km**
  - **> 20 km**
Appendix Figure E53a

Mauna Ulu pause 12/1971-1/1972 suspected deep intrusion by date: data from 12/22/1971

suspected deep intrusion
18:36 12/22/1971
08:08 12/29/1971

pre-intrusion
syn-intrusion 12/22

△ Mauna Ulu vent
Mauna Ulu pause 12/1971-1/1972 suspected deep intrusion by date: data from 12/23/1971

Appendix Figure E53b

suspected deep intrusion
18:36 12/22/1971
08:08 12/29/1971

syn-intrusion 12/23

Mauna Ulu vent

Latitude, in degrees North
Longitude, in degrees West

Depth ranges
- • 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Kīlauea region boundaries
Pacific Ocean

- suspected deep intrusion
  - 18:36 12/22/1971
  - 08:08 12/29/1971
- east rift intrusion
  - 07:08 12/24/1971
  - 23:04 12/24/1971

- pre-intrusion
- syn-intrusion
- post-intrusion

Note: earthquake swarm associated with suspected deep intrusion continues through the time of the east rift intrusion
Mauna Ulu pause 12/1971-1/1972 suspected deep intrusion by date: data from 12/26-281971

suspected deep intrusion
18:36 12/22/1971
08:08 12/29/1971

syn-intrusion 12/26-28

Note: continuation of suspected deep intrusion related to seismic southwest rift zone first seen with N-S orientation on 12/24

Depth ranges:
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Appendix Figure E53e


- Suspected deep intrusion: 18:36 12/22/1971
- Syn-intrusion: 08:08 12/29/1971
- Post-intrusion syn-intrusion 12/29
- Post-intrusion

- Continuation of western suspected deep intrusion with lower numbers of events after 12/29/1972

- Depth ranges:
  - ● 0-5 km
  - ○ 5-10 km
  - □ 10-15 km
  - ★ > 20 km

Mauna Ulu vent

Kilauea region boundaries

Kiluaea

Pacific Ocean
Appendix Figure E54

Mauna Ulu pause  Post-intrusion by date: data from 1/1-4/1972

Longitude, in degrees West

19.05  19.15  19.25  19.35  19.45  19.55

155.5  155.4  155.3  155.2  155.1  155.0  154.9  154.8  154.7

Latitude, in degrees North

Mauna Ulu vent

Pacific Ocean

Kilauea region boundaries

suspected deep intrusion

1/1/1972
1/2/1972
1/3/1972
1/4/1972

Three days of non-swarm seismicity suggestive of suspected deep intrusion

Depths:
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

19.05  19.15  19.25  19.35  19.45  19.55

Appendix Figure E54

Appendix Figure E56 a

Note: deep magma supply swarm follows intrusion
Appendix Figure E56 b


Mauna Ulu vent

Latitude, in degrees North

Longitude, in degrees West

Pre-intrusion
Syn-intrusion
Post-intrusion

Note: deep magma supply swarm follows intrusion

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kīlauea region boundaries

Pacific Ocean
Figure E58


Return of eruption to Mauna Ulu
16:28 2/4/1972

pre-eruption
syn-eruption
△ Mauna Ulu

Note; deep magma supply earthquake swarm directly precedes return to eruption at Mauna Ulu

Depth ranges
- ▲ 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Kilauea region boundaries
Pacific Ocean
Appendix figure E59


East rift intrusion
18:44 3/18/1972
20:07 3/18/1972

pre-intrusion
syn-intrusion
post-intrusion

Note; intrusion directly beneath Mauna Ulu vent; extended south flank response

Latitude, in degrees North
Longitude, in degrees West

Kīlauea region boundaries
Pacific Ocean

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Mauna Ulu vent
Koae

Appendix figure E60

Longitude, in degrees West

Latitude, in degrees North

suspected deep intrusion
09:52  5/1/1972
09:31  5/2/1972

pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Depth ranges

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean

Kilauea region boundaries

Koaeh
Mauna Ulu IIA--March 1973 suspected deep intrusion?: data from 3/7-8/1973

Appendix figure E61

suspected deep intrusion?
04:36  3/7/1973
02:09  3/8/1973
pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Kilauea region boundaries

Pacific Ocean

Latitude, in degrees North

Longitude, in degrees West

Depth ranges

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Appendix figure E62

Mainshock M 4.46 01:08 4/15/1973
aftershocks

Mauna Ulu vent

Note: south flank mainshock-aftershock sequences resemble suspected deep intrusions, i.e., earthquakes are aligned normal to the rift zone

Depth ranges:
- • 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Mauna Ulu IIB June 1973 intrusion: data from 5/30-6/12/1973

Appendix figure E63

Mauna Ulu IIB June 1973 intrusion: data from 5/30-6/12/1973

Mauna Ulu vent

Kilauea region boundaries

East rift/koae intrusion
23:57 6/8/1973
00:25 6/10/1973

pre-intrusion
syn-intrusion
post-intrusion

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean

Appendix figure E64


Latitude, in degrees North

Longitude, in degrees West

East rift intrusion
02:26 7/25/1973
23:44 7/25/1973

Pre-intrusion
Syn-intrusion
Post-intrusion

Mauna Ulu vent

Kilauea region boundaries

Pacific Ocean

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Appendix figure E65

Latitude, in degrees North

Longitude, in degrees West

East rift (Pauahi) Eruption: 11/10-12/9/1973
Intrusion
17:22 11/10/1973
08:08 11/11/1973

Mauna Ulu vent
November 1973 vents

Pre-intrusion
Syn-intrusion
Post-intrusion (continuing eruption)

Note: suggestion of slow earthquake concentrations in post-intrusion period, but data are scattered in time.

Depth ranges:
- **0-5 km**
- **5-10 km**
- **10-15 km**
- **> 20 km**

Pacific Ocean

Kilauea region boundaries
Mauna Ulu IIB--December 1973 suspected deep intrusion?: data from 12/22-27/1973

Appendix figure E66

Mauna Ulu--December 1973 suspected deep intrusion?: data from 12/22-27/1973

suspected deep intrusion?
08:04  12/25/1973
06:00  12/26/1973

pre-intrusion
syn-intrusion
post-intrusion

△ Mauna Ulu vent

Depth ranges
● 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km

Latitude, in degrees North
Longitude, in degrees West

Kīlauea region boundaries

Pacific Ocean

Inflationary intrusion
17:49 2/23/1974
07:00 3/4/1974

pre-intrusion
syn-intrusion
post-intrusion

Note: no rift earthquake swarm, but typical of periods of rift activity and south flank response, both above above background levels

Kilauea region boundaries
Pacific Ocean

Appendix figure E68


Inflationary intrusion
00:46  3/11/1974
12:59  3/17/1974

pre-intrusion
syn-intrusion
post-intrusion

Mauna Ulu vent

Kilauea region boundaries

Pacific Ocean

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Latitude, in degrees North

Longitude, in degrees West

Note: an unusual case of a suspected deep intrusion occurring as a south flank response to a rift intrusion. The non-swarm pre- and post-south flank seismicity also plot within the zone defined by the suspected deep intrusion.
Mauna Ulu IIB Precursors to end of Mauna Ulu eruption: data from 5/12-23/1974

Mauna Ulu vent

Latitude, in degrees North

Longitude, in degrees West

summit intrusion?
03:09  5/22/1974
11:37  5/22/1974

pre-intrusion
syn-intrusion
post-intrusion

Depth ranges

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kīlauea region boundaries

Pacific Ocean
Mauna Ulu IIB  Precursors to end of Mauna Ulu eruption: data from 5/24-26/1974

suspected deep intrusion
17:49 5/24/1974
14:07 5/25/1974
pre-intrusion
syn-intrusion
post-intrusion
△ Mauna Ulu

Depth ranges
- ▲ 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Pacific Ocean
Kīlauea region boundaries

Longitude, in degrees West
Figure E70c

East rift intrusion
04:24 5/28/1974
03:06 5/30/1974
pre-intrusion
syn-intrusion
post-intrusion
△ Mauna Ulu

Pacific Ocean
Kīlauea region boundaries

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Figure E71. Post-Mauna Ulu: earthquake swarms and tilt

- Kilauea caldera
  - (0-5 km)
  - (5-10 km)
  - (10-20 km)
  - Deep magma supply path (> 20 km)
- Lower east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Koae fault zone
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Tilt mag (ur)

Uwekahuna water-tube tilt magnitude: daily readings from arbitrary '0'

M 7.2 Kalapana earthquake

Eruptions: Summit, East rift, Southwest rift
Intrusions: Summit, East rift, Southwest rift, Koae

SI - slow intrusion  II - inflationary intrusion

Kilauea caldera

Deep magma supply path (> 20 km)

(0-5 km)  (5-10 km)  (10-20 km)

**Appendix figure E72**

Mauna Ulu vent

1. suspected deep intrusion?
2. pre-intrusion
3. syn-intrusion
4. post-intrusion

Latitude, in degrees North
Longitude, in degrees West

*Pacific Ocean*

Kilauea region boundaries

Depth ranges:
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Mauna Ulu post summit intrusion?: data from 6/26-30/1974

- Summit intrusion?
- Pre-intrusion
- Syn-intrusion
- Post-intrusion

Appendix figure E73

- Mauna Ulu vent
- Depth ranges:
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Kilauea region boundaries

Pacific Ocean
Appendix figure E74


intrusion
06:02 9/16/1974
19:48 9/17/1974
eruption
01:21 9/19/1974
15:00 9/19/1974

Note: intrusion beneath seismic southwest rift zone precedes eruption
Appendix figure E75

Post-Mauna Ulu inflationary intrusions: data from 10/4-16/1974

Inflationary intrusion (composite)
14:09 10/6/1974
07:50 10/15/1974

pre-intrusion
syn-intrusion
post-intrusion

Post-Mauna Ulu inflationary intrusions: data from 10/4-16/1974

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Note:

Kilauea region boundaries

Pacific Ocean
Appendix figure E76

intrusion 1
19:05 10/31/1974
16:20 11/2/1974
intrusion 2
19:37 11/5/1974
03:52 11/6/1974


Pacific Ocean
Kīlauea region boundaries

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Post-Mauna Ulu inflationary intrusions: data from 11/19-12/5/1974

Note: II 4 is similar to 3 with additional activity beneath Kilauea's summit; 5 shifts to upper east rift zone; 6 reinforces 4 and 5

Depth ranges:
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries
Appendix figure E78  

Post-Mauna Ulu inflationary intrusions: data from 12/6-15/1974

Inflationary intrusions (composite)
02:04  12/6/1974
13:49  12/14/1974

pre-intrusion
syn-intrusion
post-intrusion

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean

Kīlauea region boundaries
Post-Mauna Ulu inflationary intrusions: data from 12/16-23/1974

Latitude, in degrees North
Longitude, in degrees West

Appendix figure E79

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Kilauea region boundaries
Pacific Ocean
Appendix figure E80a

Post-Mauna Ulu major earthquake swarm/eruption by date: data from 1/1/1975

intrusion 2 ei4
21:43 12/27/1974
05:42 1/8/1975

syn-intrusion

Kilauea region boundaries

Pacific Ocean

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Koae
Appendix figure E80b

Post-Mauna Ulu major earthquake swarm/eruption by date: data from 1/2/1975

Latitude, in degrees North
Longitude, in degrees West

Kilauea region boundaries
Pacific Ocean

Depth ranges
- • 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

- syn-intrusion
- intrusion 2 e14
  21:43 12/27/1974
  05:42 1/8/1975
Appendix figure E80c

Post-Mauna Ulu major earthquake swarm/eruption by date: data from 1/3/1975

- Syn-intrusion
  - 21:43 12/27/1974
  - 05:42 1/8/1975

- Depth ranges
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

- Kilauea region boundaries
- Pacific Ocean
Appendix figure E80e

Post-Mauna Ulu major earthquake swarm/eruption by date: data from 1/5/1975

Latitude, in degrees North
Longitude, in degrees West

Depth ranges:
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

Kilauea region boundaries

Pacific Ocean
Appendix figure E80f

Post-Mauna Ulu major earthquake swarm/eruption by date: data from 1/6-8/1975

intrusion 2 ei4
21:43 12/27/1974
05:42 1/8/1975

syn-intrusion
post-intrusion

Kilauea region boundaries

Pacific Ocean

Depth ranges
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Appendix figure E81

suspected deep intrusion 1?
11:11 3/15/1975
08:17 3/16/1975
suspected deep intrusion 2?
22:54 3/18/1975
09:14 3/20/1975

Note: a small swarm of long-period earthquakes at depths of 5-20 km beneath Kilauea's summit follows the intrusions.

Kilauea region boundaries
Pacific Ocean

Depth ranges

<table>
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<th>Short-period</th>
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<td>5-10 km</td>
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<td>&gt; 20 km</td>
</tr>
</tbody>
</table>

Appendix figure E82

suspected deep intrusion? 1
02:00  4/2/1975
10:14  4/3/1975

suspected deep intrusion? 2
04:14  4/5/1975
18:34  4/5/1975

pre-intrusion
syn-intrusion 1
between intrusions
syn-intrusion 2
post-intrusion

Kilauea region boundaries

Pacific Ocean

Depth ranges:
- • 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Post-Mauna Ulu April 1975 suspected deep intrusions: data from 4/15-20/1975

Appendix figure E84

Latitude, in degrees North

Longitude, in degrees West

Kīlauea region boundaries

Pacific Ocean

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km

suspected deep intrusion
14:47 4/16/1975
15:01 4/18/1975

pre-intrusion
syn-intrusion
post-intrusion
Appendix figure E85
Post-Mauna Ulu suspected deep intrusion: data from 8/4-7/1975

suspected deep intrusion
07:36 8/5/1975
19:22 8/5/1975

Koae
ms1-3
ms4-5
sf1-ler
sf2mer
sf3mer
sf4mer
sf4swr
ei1ler
ei2mer
ei3uer
ei4sswr
ei5swr

Pacific Ocean
Kilauea region boundaries

Depth ranges
● 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km
Post-Mauna Ulu suspected deep intrusion: data from 10/22-25/1975

Appendix figure E86

suspected deep intrusion?
00:32 10/23/1975
18:42 10/23/1975

pre-intrusion
syn-intrusion
post-intrusion

Post-Mauna Ulu suspected deep intrusion: data from 10/22-25/1975

Kīlauea region boundaries
Pacific Ocean

Depth ranges
- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ★ > 20 km
Appendix figure E87

Post-Mauna Ulu inflationary intrusion: data from 11/11-18/1975

inflationary intrusion
17:04  11/12/1975
03:58  11/14/1975

pre-intrusion
syn-intrusion
post-intrusion

Post-Mauna Ulu inflationary intrusion: data from 11/11-18/1975

 Depth ranges

- ● 0-5 km
- ○ 5-10 km
- □ 10-15 km
- ▲ > 20 km

Kīlauea region boundaries

Pacific Ocean

Latitude, in degrees North

Longitude, in degrees West
Appendix F. Supplementary Material to Support Chapter 6

Table F1 presents tilt volume, eruption efficiency, and magma supply rate for the period 1975–1983.

Figure F1 shows short- and long-period earthquake swarms for all regions.

Figures F2A–H show short-period earthquake counts and earthquakes of $M > 4$ at 1-year intervals from 1 February 1975 to 1 February 1983.

Figure F2I–P show long-period earthquake counts and earthquakes of $M > 4$ at 1-year intervals from 1 February 1975-1 February 1983.

Figure F3 shows time series plots at 1-year intervals for 1975–1983.

Figure F4 presents the $M7.2$ south flank earthquake of 29 November 1975. Aftershocks are shown through 5 December 1975.

Figures F5–F38 show locations of earthquakes for eruptions and intrusions between June 1976 and December 1982.
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Table F1. Tilt volume, eruption efficiency and magma supply rate 1975-1983

1inf=inflation; def=deflation; trans=transfer; I=intrusion; E=eruption; ks=Kilauea’s summit; erz=East rift zone; swr=Southwest rift zone; kfz=Koaʻe fault zone
2Uwekahuna tilt magnitude in microradians
3Tilt volume in cubic kilometers=Uwekahuna tilt magnitude*.00045 (see text for explanation)
4Values are equivalent magma volume obtained by multiplying published volumes by 0.8 to account for vesiculation
5Eruption efficiency calculated for non-sustained rift eruptions as erupted volume/deflation volume associated with the eruption. For consistency eruption efficiencies are only calculated using the Uwekahuna tilt.
6Minimum magma supply rate calculated as described in text. The volume equivalent for pre-eruption inflation is added to the sum of volume equivalents for subsequent deflations and then divided by the elapsed time. Values used in the calculation are shown in bold text. The volume equivalent of pre-eruption deflation (italics used for emphasis) is not used as it is already included in the deflation sum. The true magma supply rate includes the volume of rift dilation during the 1975 earthquake. These values are not known because of limitations imposed by the early ground deformation network.
Cross references, chapter 6 tables and appendix F map figures

[Table column heads are row “0;” only rows with information are counted; “do,” same as above; color coding indicates eruptions (red), traditional intrusions without eruption (blue); inflationary intusions (green), and suspected deep intrusions (magenta)]

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**Figure F1.** Graphs showing Kīlauea short- and long-period earthquake swarms for all regions of the volcano from 1 November 1975 to 1 February 1983 (through episode 1 of the Pu'u 'Ō'o-Kupaianaha eruption). Dates on figure in mm/dd/yyyy format.

**Figure F2.** Graphs showing Kīlauea activity from 1 February 1975 to 1 February 1983. Dates on figure in mm/dd/yyyy format. A–H, Short-period earthquake counts and earthquakes of M>4 at 1-year intervals. J–P, Long-period earthquake counts and earthquakes of M>4 at 1-year intervals.

**Figure F3.** 1975–1983. A–H, Time series plots at 1-year intervals for 1975–1983. Shown are Uwēkahuna tilt, times of eruption and intrusion, occurrence of earthquakes by region.

**Figure F4.** Map showing Kīlauea activity around the M7.2 south flank earthquake on 29 November 1975. Aftershocks are shown through 5 December 1975. Black polygons show zones of earthquakes defining slow intrusions defined in chapter 5 (fig. 5.2). These are parallel or coincident with preferred concentrations of aftershocks, indicating a similarity in south flank stress regime for slow intrusions and large earthquakes. Dates on figure in mm/dd/yyyy format.

**Figure F5.** Maps showing Kīlauea activity around the June 1976 and July 1976 traditional east rift intrusions. Dates on figure in mm/dd/yyyy format. A, Data from 17–26 June. B, Data from 9–19 July.

**Figure F6.** Map showing Kīlauea activity around the January 1977 traditional east rift intrusion. South flank seismicity extends to south of the vents for the September 1977 eruption. Dates on figure in mm/dd/yyyy format.

**Figure F7.** Map showing Kīlauea activity around the February 1977 traditional east rift intrusion. South flank seismicity extends to south of the vents for the September 1977 eruption. Dates on figure in mm/dd/yyyy format.

**Figure F8.** Map showing activity around September 1977 east rift eruption. Data from 13 September to 4 October 1977. Dates on figure in mm/dd/yyyy format.
**Figure F9.** Map showing activity around May 1979 traditional east rift intrusion that extends to the east of the vents for the later November 1979 eruption and even east of the seismicity associated with that eruption. Data from 28 May to 1 June. Dates on figure in mm/dd/yyyy format.

**Figure F10.** Map showing activity around August 1979 traditional upper east rift intrusion with almost no south flank accompaniment. Data from 7–16 August. Dates on figure in mm/dd/yyyy format.

**Figure F11.** Map showing activity during 21–24 September 1979. An intense south flank earthquake swarm is accompanied by a long-period earthquake swarm. Dates on figure in mm/dd/yyyy format.

**Figure F12.** Map showing activity during 1–14 October 1979, including paired upper east rift/upper seismic southwest rift intrusion. Intense south flank activity both precedes and follows the intrusion. Dates on figure in mm/dd/yyyy format.

**Figure F13.** Map showing activity around November 1979 eruption. Data from 14–19 November. Overlapping intrusions precede, accompany, and follow the eruption at short distances uprift and downrift from the erupting vents. No long-period seismicity accompanied this eruption. Dates on figure in mm/dd/yyyy format.

**Figure F14.** Map showing activity around January 1980 traditional east rift intrusion. Data from 13–24 January. Symbols are covered by continued posteruption seismicity. Dates on figure in mm/dd/yyyy format.

**Figure F15.** Map showing activity around February 1980 traditional east rift intrusion. Data from 31 January to 5 February. Symbols are covered by continued post eruption seismicity. Dates on figure in mm/dd/yyyy format.

**Figure F16.** Map showing activity around March 1980 traditional east rift intrusion. Data from 1–4 March. Dates on figure in mm/dd/yyyy format.
Figure F17. Map showing activity around March 1980 eruption. A small eruption is accompanied by a large intrusion. Data from 8–14 March. Dates on figure in mm/dd/yyyy format.

Figure F18. Map showing activity around July 1980 traditional east rift intrusion. South flank seismicity occurs before and after the intrusion. Data from 28 July to 7 August. Dates on figure in mm/dd/yyyy format.

Figure F19. Map showing activity around August 1980 traditional east rift intrusion. Data from 26–30 August. Dates on figure in mm/dd/yyyy format.

Figure F20. Map showing activity around October 1980 traditional east rift intrusion. The earthquake swarm extends from upper to lower east rift zone. Data from 20–28 October. Dates on figure in mm/dd/yyyy format.

Figure F21. Map showing activity around November 1980 traditional east rift intrusion. Data from 30 October to 6 November. Dates on figure in mm/dd/yyyy format.

Figure F22. Maps showing activity around January 1981 seismic southwest rift zone intrusion. Dates on figure in mm/dd/yyyy format. A. Data from 17–22 January. Intrusive activity shifts to the west. B. Data from 23–31 January. Two intrusions during 24–28 January. South flank response remains south of the east rift.

Figure F23. Map showing activity around January-February 1981 seismic southwest rift zone intrusions. Data from 17 January to 18 February. Central and eastern south flank seismicity precedes, accompanies, and follows three closely spaced intrusions within nearly continuous intrusive activity. Intrusion is at the southwest end of the seismic southwest rift zone, overlapped by both pre- and postintrusion seismicity. February intrusion has progressed farther downriff from the location of the January intrusions. Dates on figure in mm/dd/yyyy format.
**Figure F24.** Map showing activity around April 1981 seismic southwest rift zone suspected slow intrusion. Data from 24–28 April. Dates on figure in mm/dd/yyyy format.

**Figure F25.** Map showing activity around June 1981 summit intrusion. Data from 23–28 June. Ideal-Arrowsmith tiltmeter shows a sharp inflationary tilt step between 14:00 and 16:00 on 25 June and a more gradual inflation between 17:00 and 24:00 on 26 June. These times do not correspond to specific concentrations of summit earthquakes. Dates on figure in mm/dd/yyyy format.

**Figure F26.** Map showing activity around July 1981 seismic southwest rift zone intrusion. Data from 17–24 July. Symbols are partly covered by continued post eruption seismicity. Dates on figure in mm/dd/yyyy format.

**Figure F27.** Map showing activity around the beginning of a migrating sequence of seismic southwest rift zone intrusions during 1–7 August 1981. Data from 31 July to 7 August. South flank seismicity is sparse and located beneath the east rift. Dates on figure in mm/dd/yyyy format.

**Figure F28.** Map showing activity around 9–15 August 1981 seismic southwest rift zone intrusion. Dates on figure in mm/dd/yyyy format. A, Earthquakes from 8–23 August are colored by date and indicate a complex pattern of migration within the seismic southwest rift zone. South flank seismicity occurs adjacent to the rift seismicity. B, Earthquakes subdivided by day from 9–15 August. A major intrusion beneath the seismic southwest rift zone that resembles the intrusion following the eruption of 31 December 1974.

**Figure F29.** Map showing activity around January 1982 seismic southwest rift zone intrusion. Data from 14–17 January. This the first of five intrusions within nearly continuous intrusive activity preceding the April 1982 summit eruption. Dates on figure in mm/dd/yyyy format.
Figure F30. Map showing activity around February 1982 seismic southwest rift zone intrusion. Data from 24 February to 1 March. Dates on figure in mm/dd/yyyy format.

Figure F31. Map showing activity around 3 March 1982 seismic southwest rift zone intrusion. Data from 2–5 March. Dates on figure in mm/dd/yyyy format.

Figure F32. Map showing activity around 9 March 1982 seismic southweast rift zone intrusion. Data from 6–12 March. Dates on figure in mm/dd/yyyy format.

Figure F33. Map showing activity around the 23 March 1982 seismic southwest rift zone intrusion. Data from 21–27 March. This intrusion was the last on the seismic southwest rift zone preceding the April 1982 eruption. Dates on figure in mm/dd/yyyy format.

Figure F34. Map showing activity around April 1982 summit eruption/intrusion. Data from 25 April to 11 May. Following the eruption a small paired intrusion propagates south and southeast. Dates on figure in mm/dd/yyyy format.

Figure F35. Map showing activity around 8–9 June 1982 seismic southwest rift zone intrusion. Data from 4–14 June. This the first of two large intrusions within nearly continuous intrusive activity between the two 1982 summit eruptions. Pre-, syn- and postintrusion data overlap with the postintrusion earthquakes extending farther downrift. Dates on figure in mm/dd/yyyy format.

Figure F36. Map showing activity around 22–24 June 1982 seismic southwest rift zone intrusion. Data from 18–28 June. This is the second of two large intrusions within nearly continuous intrusive activity between the two 1982 summit eruptions. This and the preceding intrusion resemble the seismic sequence of August 1981. Dates on figure in mm/dd/yyyy format.

Figure F37. Map showing activity around September 1982 summit eruption/intrusion. Data from 23 September to 8 October. Intrusion precedes eruption and continues beyond the period of eruption. A second small intrusion (30 September–1 October) extends
to the south and southeast within the posteruption period. Seismicity beneath the western south flank may indicate a continuation of the June intrusion. Dates on figure in mm/dd/yyyy format.

**Figure F38.** Map showing activity around October 1982 east rift zone intrusions. Data from 1–15 October. Four intrusions, mostly beneath the uppermost east rift zone. Seismicity beneath the western south flank may indicate a continuation of the June intrusion. Dates on figure in mm/dd/yyyy format.
2/1/1975-2/1/1976 Short-period seismicity: earthquakes per day and single earthquakes M ≥ 4.0

Located earthquakes (open symbols) | Single earthquakes M ≥ 4.0 (closed symbols) | Earthquake counts (vertical lines)

A

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Intrusions: ○ summit ■ east rift zone ○ southwest rift zone □ Koae
Eruptions: ● summit ● east rift zone ● southwest rift zone

Far eastern south flank (0-15 km) △ Central south flank (0-15 km)
Eastern south flank (0-15 km) ○ Western south flank (0-15 km)

Lower east rift zone (0-15 km) ■ Middle east rift zone (0-15 km) ○ Seismic southwest rift zone (0-15 km)
Koae fault zone (0-15 km) △ Upper east rift zone (0-15 km) ● Southwest rift zone (0-15 km)

Kīlauea caldera ○ (0-5 km) ■ (5-10 km) △ (10-20 km) ○ Deep magma supply path (20-35 km)

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**Note:**
- Eq/day: Earthquakes per day
- M: Magnitude

**Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"**

**Intrusions:**
- Summit
- East rift zone
- Southwest rift zone
- Koa'ee

**Eruptions:**
- Summit
- East rift zone
- Southwest rift zone

**Kilauea caldera**
- (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (20-35 km)
2/1/1977-2/1/1978 Short-period seismicity: earthquakes per day and single earthquakes M ≥ 4.0

Locaed earthquakes (open symbols)  Single earthquakes M ≥ 4.0 (closed symbols)  Earthquake counts (vertical lines)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Intrusions: ○ summit  □ east rift zone  ◇ southwest rift zone  ● Koae
Eruptions: ● summit  □ east rift zone  ◇ southwest rift zone

Earthquake counts (vertical lines)

Locaed earthquakes (open symbols)

Intrusions:
- Summit
- East rift zone
- Southwest rift zone
- Koae

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Earthquake counts (vertical lines)

Locaed earthquakes (open symbols)

Intrusions:
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Koae fault zone (0-15 km)
- Upper east rift zone (0-15 km)
- Southwest rift zone (0-15 km)

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Earthquake counts (vertical lines)

Locaed earthquakes (open symbols)

Intrusions:
- Kilauea caldera (0-5 km)
- Kilauea caldera (5-10 km)
- Kilauea caldera (10-20 km)
- Deep magma supply path (20-35 km)

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Earthquake counts (vertical lines)
2/1/1978-2/1/1979 Brittle failure seismicity: earthquakes per day and single earthquakes M ≥ 4.0

- **Locaed earthquakes** (open symbols)
- **Single earthquakes M ≥ 4.0** (closed symbols)
- **Earthquake counts** (vertical lines)

Uwëkahuna water-tube tilt magnitude: daily readings from arbitrary “0”

Intrusions: ○ summit  □ east rift zone  ◇ southwest rift zone  ◆ Koae

Eruptions: ● summit  ● east rift zone  ● southwest rift zone

- **Far eastern south flank (0-15 km)**  ○
- **Central south flank (0-15 km)**  △
- **Eastern south flank (0-15 km)**  □
- **Western south flank (0-15 km)**  ◆

- **Lower east rift zone (0-15 km)**  ○
- **Middle east rift zone (0-15 km)**  □
- **Seismic southwest rift zone (0-15 km)**  ◆
- **Koae fault zone (0-15 km)**  ◆
- **Upper east rift zone (0-15 km)**  △
- **Southwest rift zone (0-15 km)**  ◆

- **Kilauea caldera**  ○
- **(0-5 km)**
- **(5-10 km)**  □
- **(10-20 km)**  △
- **Deep magma supply path (20-35 km)**  ◆
2/1/1980-2/1/1981 Brittle failure seismicity: earthquakes per day and single earthquakes M ≥ 4.0

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Ubékahuna water-tube tilt magnitude: daily readings from arbitrary "0".
2/1/1982-2/1/1983 Brittle failure seismicity: earthquakes per day and single earthquakes $M \geq 4.0$

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"°

Puʻu ʻOʻo eruption episode 1:

- Intrusions: ○ summit
- Eruptions: ○ summit
- east rift zone
- southwest rift zone
- Koae fault zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Koae fault zone (0-15 km)
- Upper east rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Kīlauea caldera
- Deep magma supply path (20-35 km)
Uwekahuna water-tube tilt magnitude: daily readings

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Intrusions:
- Summit
- East rift zone
- Southwest rift zone
- Koae

Harmonic tremor (minutes)
- Shallow (0-5 km)
- Intermediate (5-15 km)
- Deep (>20 km)

Located earthquakes
- Kilauea caldera (0-5 km)
- Daily earthquake counts (lpc-a)
- Ipc-a (3-5 Hz)
- Located earthquakes

Deep magma supply path (>20 km)

Daily earthquake counts (not recorded)

Kilauea caldera (5-15 km)

Daily earthquake counts (lpc-c)
Figure F2 j


- **Tilt mag (ur)**
- **Earthquakes/day**
- **Minutes of tremor/day**
- **Located earthquakes**
- **Daily earthquake counts**
- **Eruptions:**
  - summit
  - east rift zone
  - southwest rift zone
- **Intrusions:**
  - summit
  - east rift zone
  - southwest rift zone
  - Koae

- **Harmonic tremor (minutes)**
  - Shallow (0-5 km)
  - Intermediate (5-15 km)
  - deep (>20 km)

- **Kilauea caldera (0-5 km)**
- **Kilauea caldera (5-15 km)**
- **Deep magma supply path (>20 km)**

Graphs showing data from 2/1/1976 to 2/1/1977 with various markers for different types of events and observations.
Figure F2 k

- Uwekahuna water-tube tilt magnitude: daily readings
- Eruptions: sumit, east rift zone, southwest rift zone
- Intrusions: summit, east rift zone, southwest rift zone, Koae
- Harmonic tremor (minutes)
  - Shallow (0-5 km)
  - Intermediate (5-15 km)
  - Deep (>20 km)
- Kilauea caldera (0-5 km) Daily earthquake counts
- Ipc-a (3-5 Hz)
  - Located earthquakes
- Daily earthquake counts
  - Kilauea caldera (5-15 km)
  - Deep magma supply path (>20 km)
- Daily earthquake counts (not recorded)
  - Located earthquakes
Uwekahuna water-tube tilt magnitude: daily readings

Eruptions:
- summit
- east rift zone
- southwest rift zone

Intrusions:
- summit
- east rift zone
- southwest rift zone

Located earthquakes

Minutes of tremor/day
- Harmonic tremor (minutes)
- Shallow (0-5 km)
- Intermediate (5-15 km)
- Deep (> 20 km)

Daily earthquake counts
- Kilauea caldera (0-5 km)
- Located earthquakes

Deep magma supply path (>20 km)

Located earthquakes

Daily earthquake counts (not recorded)
Figure F2 m

2/1/1979-2/1/1980 Long-period seismicity

Uwekahuna water-tube tilt magnitude: daily readings

Eruptions: 
- summit
- east rift zone
- southwest rift zone

Intrusions: 
- summit
- east rift zone
- southwest rift zone
- Koae

Harmonic tremor (minutes)
- Shallow (0-5 km)
- Intermediate (5-15 km)
- Deep (>20 km)

Kilauea caldera (0-5 km) Daily earthquake counts
- Ipc-a (3-5 Hz)
- Located earthquakes

Kilauea caldera (5-15 km)
- Daily earthquake counts (ipc-c)

Deep magma supply path (>20 km)
- Located earthquakes
- Daily earthquake counts (not recorded)
Figure F2 n 2/1/1980-2/1/1981 Long-period seismicity

Uwekahuna water-tube tilt magnitude: daily readings

Eruptions: • summit  ■ east rift zone  © southwest rift zone
Intrusions: • summit  □ east rift zone  © southwest rift zone  ● Koa‘e

Harmonic tremor (minutes) • Shallow (0-5 km)  ● Intermediate (5-15 km)  ★ deep (>20 km)

Kilauea caldera (0-5 km) Daily earthquake counts  ○ lpc-a (3-5 Hz)
Located earthquakes  ○

Earthquakes/day

Located earthquakes  ▲
Kilauea caldera (5-15km)  △

Daily earthquake counts (lp-c)  ▲
Located earthquakes  ○

Deep magma supply path (>20 km)

Located earthquakes  ●

Daily earthquake counts (not recorded)  ○
Appendix figure F3 b

Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km

Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)

Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Koae fault zone

Far eastern south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Western south flank (0-15 km)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Earthquake swarms:
- 3-10 events (magma supply, rift zones)
- 5-20 events (south flank)
- >10 events (magma supply, rift zones)
- >20 events (south flank)

Intrusions:
- Summit
- East rift zone
- Southwest rift zone

Tilt mag (ur)

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Tilt mag (ur)
Appendix figure F3 d

Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Koae fault zone
Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)

Tilt mag (ur)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Intrusions:
- Summit
- East rift zone
- Southwest rift zone
- Koae

Earthquake swarms
- 3-10 events (magma supply, rift zones); 5-20 events (south flank)
- >10 events (magma supply, rift zones); >20 events (south flank)

sf4swr
sf3kuer
sf2mer
koae
ei5swr
ei4sswr
ei3uer
ei2mer

ms1
ms2
ms3
ms4/5


Appendix figure F3 e

Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)

Lower south rift zone (0-15 km)
Southwest rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)

Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)

Deep magma supply path (> 20 km)

Tilt mag (ur)

Uwékahuna water-tube tilt magnitude: daily readings from arbitrary "0*"

Eruptions:
- Summit
- East rift zone
- Southwest rift zone
- Intrusions:
  - Summit
  - East rift zone
  - Southwest rift zone
  - Koae fault zone

Earthquake swarms
- 3-10 events (magma supply, rift zones)
- >10 events (magma supply, rift zones)
- >20 events (south flank)

Inflationary intrusion

Appendix figure F3 e
Appendix figure F3 f

Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Koa fault zone
Far eastern south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Western south flank (0-15 km)

Uwëkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Tilt mag (ur)

Eruptions:
- Summit
- East rift zone
- Southwest rift zone
- Intrusions:
  - Summit
  - East rift zone
  - Southwest rift zone
  - Koa fault zone

Earthquake swarms
- 3-10 events (magma supply, rift zones)
- 10-20 events (south flank)
- 20-30 events (south flank)

Inflationary intrusion

Western south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Far eastern south flank (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Koa fault zone
East rift zone
Summit


Il Inflationary intrusion

Ms
- I-p
- S-p

3-10 events (magma supply, rift zones)
10-20 events (south flank)
20-30 events (south flank)
Appendix figure F3 g

Kilauea caldera
- ○ 0-5 km
- □ 5-10 km
- ▲ 10-20 km
- ★ Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)  
Middle east rift zone (0-15 km)  
Upper east rift zone (0-15 km)  
Seismic southwest rift zone (0-15 km)  
Southwest rift zone (0-15 km)  
Far eastern south flank (0-15 km)  
Eastern south flank (0-15 km)  
Central south flank (0-15 km)  
Koae fault zone  
Western south flank (0-15 km)


Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary 0°

Eruptions:  
- ■ Summit  
- ● East rift zone  
- □ Southwest rift zone

Intrusions:  
- ○ summit  
- □ East rift zone  
- ◇ southwest rift zone  
- ★ Koae

Earthquake swarms  
- | 3-10 events (magma supply, rift zones); 5-20 events (south flank)  
- | >10 events (magma supply, rift zones); >20 events (south flank)

II Inflationary intrusion

sf4swr  
sf3kuer  
sf2mer  
koae  
ei5swr  
ei4swr  
ei3uer  
ei2mer

ms1  l-p  s-p  
ms2  l-p  s-p  
ms3  l-p  s-p  
ms4/5  l-p  s-p

Figure F4  11/29/1975 south flank earthquake and aftershocks; data from 11/26-12/5/1975

- South flank earthquake
- x foreshock
- x mainshock
- Pre-earthquake
- Syn-earthquake 11/29
- Post-earthquake 11/30
- Post-earthquake 12/1-5
- ▲ Eruption 11/29/1975

Note the displacement in space but similarity in orientation to some of the concentrations of 1975 aftershocks.

Pre-intrusion
Syn-intrusion
Post-intrusion

Latitude, in degrees North
Longitude, in degrees West

Depth ranges
Short-period
Long-period

- 0-5 km
- 0-5 km
- 5-10 km
- 5-10 km
- 10-15 km
- 10-15 km

Pacific Ocean
Kilauea region boundaries
July 1976 east rift zone intrusion: data from 7/9-19/1976

Latitude, in degrees North
Longitude, in degrees West

Depth ranges
- Short-period:
  - 0-5 km
  - 5-10 km
  - 10-15 km
- Long-period:
  - 0-5 km
  - 5-10 km
  - 10-15 km

Kilauea region boundaries

Pacific Ocean
Appendix figure F6

January 1977 east rift zone intrusion data from 1/17-27/1977

Kilauea region boundaries

Depth ranges
- Short-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
- Long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km

Latitude, in degrees North

Longitude, in degrees West

05:28  1/22/1977
02:39  1/23/1977
Pre-intrusion
Syn-intrusion
Post-intrusion
February 1977 east rift intrusion: data from 2/3-13/1977

- **Intrusion**
  - 20:28 2/7/1977
  - 00:44 2/9/1977
- **Pre-intrusion**
- **Syn-intrusion**
- **Post-intrusion**

**Depth ranges**
- **Short-period**
  - 0-5 km
  - 5-10 km
  - 10-15 km
- **Long-period**
  - 0-5 km
  - 5-10 km
  - 10-15 km

**Kilauea region boundaries**

**Pacific Ocean**
Note: This is the first eruption in Kilauea’s modern history to be accompanied by swarms of long-period earthquakes, nearly all less than 5 km deep and confined to Kilauea’s summit. The two early swarms show a broader distribution. The four later swarms overlap with a N-S orientation. Long-period earthquakes continue at lower rates through 10/9.
May 1979 East rift zone intrusion: data from 5/28-6/1/1979

Note: this intrusion extends to the east of the vents for the November 1979 eruption and even east of the seismicity associated with the eruption.
Appendix figure F10

August 1979 East rift zone intrusion: data from 8/7-16/1979

- **Pre-intrusion**
- **Syn-intrusion**
- **Post-intrusion**

**1979 vents**

**Kilauea region boundaries**

**Latitude, in degrees North**

**Longitude, in degrees West**

**Depth ranges**

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**Pacific Ocean**
September 1979 south flank swarm/lp swarm: data from 9/21-24/1979

- Summit lp earthquake swarm 9/22 13:23-16:01/1979
- syn-earthquake swarm
- South flank earthquake M 5.7 21:59 9/21/1979
- mainshock
- foreshocks?
- aftershocks

- 1979 vents

Depth ranges
- Short-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
- Long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
Appendix figure F12

October 1979 East rift zone intrusion: data from 10/1-14/1979

Note: pre-, syn- and post-intrusion rift seismicity overlap, i.e., repeated intrusion into the upper east rift and upper seismic southwest rift zones. South flank seismicity extends well east of the 1979 vents.
November 1979 east rift eruption: data from 11/14-19/1979

Eruption
08:18  11/16/1979
07:30  11/17/1979
intrusion 1
00:06  11/15/1979
05:32  11/15/1979
intrusion 2
20:27  11/15/1979
01:38  11/17/1979
intrusion 3
23:30  11/19/1979
14:06  11/21/1979

Note: Three intrusions precede, accompany and follow the eruption. Intrusion 1 occurs in the same location as the longer intrusion 2 and is obscured by the symbols for the latter. South flank seismicity precedes but offers sparse accompaniment to the intrusions. No long-period seismicity accompanied this eruption.

Kilauea region boundaries
Appendix figure F14


Note: inflationary east rift intrusion covered by continued post-intrusion seismicity

Depth ranges
Short period   Long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries
February 1980 East rift zone intrusion: data from 1/31-2/51980

Note: East rift intrusion covered by continued post-intrusion seismicity

- Pre-intrusion
- Syn-intrusion
- Post-intrusion

Depth ranges:
- Short period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Kilauea region boundaries

Pacific Ocean

Note: vent discovered in March 1982. Fume smelled at 23:30 3/10/1980. Eruption seismicity is covered by seismicity from ongoing intrusion. Intrusion seismicity lies mostly uprift of vent. Post-intrusion seismicity is widely distributed, even as earthquakes are closely spaced in time.

Depth ranges
- Short period: 0-5 km, 5-10 km, 10-15 km, > 20 km
- Long-period: ○, ●, □, ★, #

- **Intrusion**: 07:24 7/30/1980, 08:44 7/30/1980
- **Pre-intrusion**
- **Syn-intrusion**
- **Post-intrusion**

**Depth ranges**
- Short period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
- Long-period

**Kilauea region boundaries**

**Pacific Ocean**
August 1980 East rift zone intrusion: data from 8/26-30/1980

Depth ranges
- Short period
- Long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries

Pacific Ocean
Figure F20


Latitude, in degrees North

Longitude, in degrees West

Kilauea region boundaries

Pacific Ocean

Depth ranges
- Short-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
- Long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Intrusion
Pre-intrusion
Syn-intrusion
Post-intrusion

Kilauea region boundaries

19.05
19.15
19.25
19.35
19.45
19.55
154.7
154.8
154.9
155.0
155.1
155.2
155.3
155.4
155.5
19.55
19.45
19.35
19.25
19.15
19.05
154.7
154.8
154.9
155.0
155.1
155.2
155.3
155.4
155.5
19.55
19.45
19.35
19.25
19.15
19.05
154.7
154.8
154.9
155.0
155.1
155.2
155.3
155.4
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155.5
19.55
19.45
19.35
19.25
19.15
19.05
154.7
154.8
154.9
155.0
155.1
155.2
155.3
155.4
155.5
Appendix figure F21


intrusion
14:11 11/2/1980

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
Short period | Long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kīlauea region boundaries

Pacific Ocean
January 1981 seismic southwest rift zone rift zone intrusion data from 1/17-22/1981

Note: The first of several intrusions within nearly continuous intrusive activity.
January 1981 seismic southwest rift zone rift zone intrusion data from 1/23-31/1981

Note: The second of several intrusions within nearly continuous intrusive activity. Two intrusions are separated by about 8 hours--the second intrusion has progressed downrift.
Kilauea region boundaries

Figure F23

Note: Intrusions progress down the seismic southwest rift zone. The western south flank responds on February 10, anticipating the movement downrift before intrusion 3. The central and eastern south flank is active throughout.

Depth ranges
- Short-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
- Long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Pacific Ocean
Appendix figure F24  

April 1981 slow intrusion?: data from 4/24-28/1981

- Pre-intrusion
- Syn-intrusion
- Post-intrusion

Depth ranges:
- Short period
- Long-period

- 0-5 km
- 5-10 km
- 10-15 km
- >20 km

Kilauea region boundaries

Pacific Ocean
Appendix figure F25


interrupted summit intrusion
15:17 6/25/1981
02:55 6/27/1981
Pre-intrusion
Syn-intrusion
Post-intrusion

Note: Ideal-Arrowsmith tiltmeter shows a sharp inflationary tilt step between 14:00 and 16:00 6/25/1981 and a more gradual inflation between 17:00 and 24:00 on 6/26/1981. These times do not correspond to specific concentrations of summit earthquakes.
July 1981 seismic southwest rift zone rift zone intrusion data from 7/17-24/1981

Note: The first of a second set of intrusions within nearly continuous intrusive activity. Intrusion is north of the bend in the seismic southwest rift zone, overlapped by post-intrusion seismicity.

Depth ranges

- Short period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

- Long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
August 1981 seismic southwest rift zone rift zone intrusion data from 7/31-8/7/1981

Intrusion 1
16:33 8/1/1981
05:26 8/4/1981
Intrusion 2
03:01 8/7/1981

Pre-intrusions
Syn-intrusion 1
Syn-intrusion 2
Post-intrusion

Note: The second of a second set of intrusions within nearly continuous intrusive activity. Intrusion 1 is north of the bend in the seismic southwest rift zone, overlapping pre-intrusion seismicity; intrusion 2 is south of the bend. Both intrusions are overlapped by post-intrusion seismicity.
August 1981 seismic southwest rift zone rift zone intrusion data from 8/8-23/1981

Note: This seismic sequence resembles the seismic southwest rift zone intrusion.

Note: The third and largest of the second set of intrusions within nearly continuous intrusive activity. Pre-intrusion seismicity co-located with the earlier August intrusion 2. Seismicity propagated from north to southwest multiple times along the entire length of the seismic southwest rift zone.
August 1981 seismic southwest rift zone intrusion: Subdivided by day 8/9-15/1981

Note: Complex migration pattern of the culminating August seismic southwest rift zone intrusion. By 8/12 intrusion has extended to the southwest end of the rift zone, then retreats uprift on 8/13. 8/14-15 show a reoccupation of the entire earlier intrusion area.
January 1982 seismic southwest rift zone rift zone intrusion: data from 1/14-17/1982

Note: This the first of several intrusions within nearly continuous intrusive activity preceding the first 1982 summit eruption.
February 1982 seismic southwest rift zone rift zone intrusion data from 2/24-3/1/1982

Note: This the second of several intrusions within nearly continuous intrusive activity preceding the first 1982 summit eruption. Pre- and syn-intrusion data overlap.

Depth ranges
- Short period
- Long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
March 1982 seismic southwest rift zone rift zone intrusion data from 3/2-5/1982

Note: This the third of several intrusions within nearly continuous intrusive activity preceding the first 1982 summit eruption. Pre- and syn-intrusion data overlap.
March 1982 seismic southwest rift zone rift zone intrusion data from 3/6-12/1982

Note: This is the fourth of several intrusions within nearly continuous intrusive activity preceding the first 1982 summit eruption. Pre- and syn-intrusion data overlap.

Depth ranges
- Short period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Long-period

Kilauea region boundaries
Note: This is the fifth and last of several intrusions within nearly continuous intrusive activity preceding the first 1982 summit eruption. South flank activity shifted westward.

Note: summit intrusion marked by small inflationary tilt step overlaps eruption in both time and location of seismicity. Following the eruption a small intrusion propagates south and southeast.

Depth ranges
Short period  Long-period
● 0-5 km  ×
○ 5-10 km  ●
□ 10-15 km  ●
★ > 20 km  ●

Kilauea region boundaries
Pacific Ocean

Eruption
11:37  4/30/1982
06:30  5/1/1982
Intrusion
08:55  4/30/1982
11:41  4/30/1982
Pre-all
Syn-intrusion
Syn-eruption
Post-all

Vent
ms1-3
ms4-5
sf4swr
sf3kuer
ei3uer
Koae
ei5swr
ei1ler
sf1ler
ei2mer
sf2mer

Appendix figure F35  june 1982 seismic southwest rift zone rift zone intrusion data from 6/4-14/1982

Latituden, in degrees North

Longitude, in degrees West

Intrusion
15:30 6/8/1982
07:45 6/9/1982

Pre-intrusion
Syn-intrusion
Post-intrusion

Note: This is the first of two large intrusions within nearly continuous intrusive activity between the two 1982 summit eruptions. Pre-, syn- and post-intrusion data overlap with the post-intrusion extending farther downrift.
Note: This is the second of two large intrusions within nearly continuous intrusive activity between the two 1982 summit eruptions. This and the preceding intrusion resemble the seismic sequence of August 1981, but earthquakes are deeper then 5 km.
September 1982 summit eruption and intrusion: data from 9/23-10/8/1982

Note: intrusion precedes eruption and continues beyond the period of eruption. A second small intrusion (9/30-10/1) extends to the south and southeast within the post-all period. Seismicity beneath the western south flank may indicate a continuation of the June intrusion.
October 1982 east rift zone intrusions: data from 10/1-15/1982

- Intrusion 1: 11:46:00 AM 10/1/1982
- Intrusion 2: 08:34:00 AM 10/3/1982
- Intrusion 3: 01:50:00 AM 10/5/1982
- Intrusion 4: 01:12:00 PM 10/6/1982
- Intrusion 5: 08:15:00 PM 10/7/1982
- Intrusion 6: 09:27:00 PM 10/8/1982
- Intrusion 7: 10:54:00 AM 10/10/1982
- Intrusion 8: 10:36:00 AM 10/11/1982

Note: intrusions overlap in space, mostly beneath upper east rift zone. Similar seismicity both before and after defined intrusions.

Depth ranges:
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pre-all
Syn-intrusion 1
Syn-intrusion 2
Syn-intrusion 3
Syn-intrusion 4
Between intrusions
Post-all

Pacific Ocean
Kilauea region boundaries
Appendix G. Supplementary Material to Support Chapter 7

Table G1 presents tilt volume, eruption efficiency, and magma supply rate from 1983 to 2008.

Figures G1–G3 present 1-year time series plots between 1 February 1982 and 1 February 2008 showing details of numbers of both short- and long-period earthquakes shown in text figures.

Figures G4–G7 present time series plot of earthquake swarms and plots of earthquake locations for the events of Stage IA.

Figures G8–G15 present time series plots of earthquake swarms and plots of earthquake locations for the events of Stage IB.

Figures G16–G24 present time series plot of earthquake swarms and plots of earthquake locations for the events of Stage IIA.

Figures G25–G49 present time series plot of earthquake swarms and plots of earthquake locations for the events of Stage IIB.

Figures G50–G82 present time series plot of earthquake swarms and plots of earthquake locations for the events of Stage III.
## Appendix table G1. Tilt volume, eruption efficiency and magma supply rate 1983-2008

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¹ Abbreviations: inf=inf; def=def; vol=volume; dil=dilation; cw=clockwise; trans=transfer; l=intrusion; E=E; ks=Kilauea’s summit; erz=East rift zone; swr=Southwest rift zone; kfz=Koa‘e fault zone
² Uwêkahuna tilt magnitude in microradians
³ Tilt volume in cubic kilometers=Uwêkahuna tilt magnitude*.00045 (see text for explanation)
⁴ Values are equivalent magma volume obtained by multiplying published volumes by 0.8 to account for vesiculation
⁵ Eruption efficiency calculated for non-sustained rift eruptions as erupted volume/deflation volume associated with the eruption. For consistency eruption efficiencies are only calculated using the Uwêkahuna tilt.
⁶ Minimum magma supply rate calculated as described in text. The volume equivalent for pre-E inf is added to the sum of volume equivalents for subsequent defs and then divided by the elapsed time. Values used in the calculation are shown in bold text. The volume equivalent of pre-eruption deflation (italics used for emphasis) is not used as it is already included in the deflation sum.
⁷ $mr^2$ = HVO monthly report
⁸ xt = Christinal Heliker volume estimate (see Heliker and Mattox, 2003, table 1)

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1. Abbreviations: inf=inf; def=def; vol=volume; dil=dilation; cw=clockwise; trans=transfer; l=intrusion; E=E; ks=Kilauea’s summit; erz=East rift zone; swr=Southwest rift zone; kfz=Koa‘e fault zone
2. Uwêkahuna tilt magnitude in microradians
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7. $mr^2$ = HVO monthly report
8. xt = Christinal Heliker volume estimate (see Heliker and Mattox, 2003, table 1)
## Cross references, chapter 7 tables and appendix G map figures

[Table column heads are row “0;” only rows with information are counted; “do,” same as above; color coding indicates eruptions (red), traditional intrusions without eruption (blue); inflationary intusions (green), and suspected deep intrusions (magenta)]

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Figure G1. Graphs showing Kīlauea short-period earthquakes per day and those of magnitude >4, 1982 to February 2008. A–Z, Data at 1-year intervals. Dates on figures in mm/dd/yyyy format.

Figure G2. Graphs showing Kīlauea long-period earthquakes per day and those of magnitude >4, 1982 to February 2008. A–Z, Data at 1-year intervals. Dates on figures in mm/dd/yyyy format.
**Figure G3.** Graphs showing Kīlauea earthquake swarms (long- and short-period), from 1982 to February 2007. A–Z, Data at 1-year intervals. Dates on figures in mm/dd/yyyy format.

**Figure G4.** Graphs showing Kīlauea activity from 1 January 1983–20 July 1986 (Pu‘u ‘Ō‘o-Kupaianaha eruption Stage IA). Time series shows short- and long-period earthquake swarms for all regions as short vertical lines. Dates on figure in mm/dd/yyyy format. See text figure 7.1 and table 7.1 for event details.

**Figure G5.** Map showing activity around suspected deep intrusion on 23 December 1984. Data from 22–24 December. Dates on figure in mm/dd/yyyy format.

**Figure G6.** Map showing activity around suspected deep intrusion on 5–6 October 1985 beneath site SDI 2 (chap. 5, fig. 5.2). Data from 4–8 October. Dates on figure in mm/dd/yyyy format.

**Figure G7.** Map showing activity around episode 48 fissure eruption on 18–19 July 1986 associated with migration of eruption from Pu‘u ‘Ō‘o to Kupaianaha. Data from 14–24 July. Dates on figure in mm/dd/yyyy format.

**Figure G8.** Graphs showing Kīlauea activity during Puʻu ‘Ō‘o-Kupaianaha eruption Stage IB from 20 July 1986 to 8 November 1991. Time series shows short- and long-period earthquake swarms for all regions. See text figure 7.5 and table 7.2 for event details. Dates on figure in mm/dd/yyyy format.
**Figure G9.** Map showing activity around Nāmakanipaio earthquake swarm of 13 September 1986. Data from 13–14 September. This sequence not associated with an east rift intrusion. Dates on figure in mm/dd/yyyy format.

**Figure G10.** Map showing activity around Nāmakanipaio earthquake swarm of 11–12 July 1988. This sequence not associated with an east rift intrusion. Dates on figure in mm/dd/yyyy format.

**Figure G11.** Map showing activity around upper east rift intrusion on 17 September 1988. Data from 12–21 September. Dates on figure in mm/dd/yyyy format.

**Figure G12.** Map showing M6.2 south flank earthquake on 25 June 1989, mainshock and aftershocks to 30 June. Dates on figure in mm/dd/yyyy format.

**Figure G13.** Map showing activity around summit intrusion on 4 December 1990. Data from 11 November to 6 December. Intrusion indicated by inflationary tilt begins near the shallow magma chamber (small open cross) imaged in 1996 by long-period seismic array. Intrusion then extends downrift to south and southeast. The intrusion was accompanied by a few long-period earthquakes. It is possible that this intrusion marks the advent of a second summit magma reservoir at ~1 km depth. This is the first of several intrusions to be preceded within a month or so by a Nāmakanipaio sequence (Okubo and Nakata, 2003). Dates on figure in mm/dd/yyyy format.
Figure G14. Map showing activity around upper east rift intrusion on 26 March 1991. Data from 25–30 March, with a precursory Nāmakanipaio sequence on 13 March. Dates on figure in mm/dd/yyyy format.

Figure G15. Map showing activity around upper east rift intrusion on 21 August 1991. Data from 17–25 August, with a precursory Nāmakanipaio sequence on 10 August. Dates on figure in mm/dd/yyyy format.

Figure G16. Graphs showing Kīlauea activity from 8 November 1991 to 1 January 1997 (Puʻu ʻŌʻo-Kupaianaha eruption Stage IIA). Time series shows short- and long-period earthquake swarms for all regions as vertical lines connected across the time of intrusion. See text figure 7.7 and table 7.3 for event details. Dates on figure in mm/dd/yyyy format.

Figure G17. Map showing activity around eruption of 8–26 November 1991 (episode 49 to 26 November. Eruption returns to Puʻu ʻŌʻo accompanied by very few earthquakes. Dates on figure in mm/dd/yyyy format.

Figure G18. Map showing activity around upper east rift intrusion on 28–29 January 1992. Data from 25–31 January. Dates on figure in mm/dd/yyyy format.

Figure G19. Map showing activity around eruption of 17 February-3 March 1992 (episode 50 to 3 March). Data from 9–19 February. Eruption is preceded by a Nāmakanipaio sequence on 4 February 1992 and an east rift intrusion on 11–13 February. Dates on figure in mm/dd/yyyy format.
**Figure G20.** Map showing activity around upper east rift intrusion on 3–4 March 1992. Data from 1–5 March. Intrusion precedes episode 51 on 7 March. Dates on figure in mm/dd/yyyy format.

**Figure G21.** Map showing activity around suspected deep intrusion on 11–12 September 1993 beneath site SDI 2 (chap. 5, fig. 5.2). Data from 9–14 September. Dates on figure in mm/dd/yyyy format.

**Figure G22.** Map showing activity around deep magma-supply earthquake 1 February 1994. Data from 26 January to 4 February. M5.2 mainshock is located just offshore in the central south flank. Aftershocks trace a major part of the deep magma supply path (Wright and Klein, 2006). Possible foreshocks are located a considerable distance to the west and north. Dates on figure in mm/dd/yyyy format.

**Figure G23.** Maps showing: A, Activity around a suspected deep intrusion on 25–26 October 1994. Data from 23 to 27 October. B–C, Activity around a paired inflationary intrusion on 1–2 February 1996, within which an eruption “surge” occurs about 3 hours after the beginning of intrusion—(B) short-period seismicity and (C) long-period seismicity. Data from 27 January to 11 February. Dates on figure in mm/dd/yyyy format.

**Figure G24.** Map showing activity around a suspected deep intrusion on 25–26 October 1996 beneath site SDI 2 (see chap. 5, fig. 5.2). Data from 23–30 October. Dates on figure in mm/dd/yyyy format.
Figure G25. Graphs showing Kīlauea activity from 1 January 1997–1 December 2003 (Pu‘u ‘Ō‘o-Kupaianaha eruption Stage IIB). Time series shows short- and long-period earthquake swarms for all regions as vertical lines. See text figure 7.10 and table 7.4 for event details. Dates on figure in mm/dd/yyyy format.

Figure G26. Map showing earthquake locations for a Nāmakanipaio sequence on 2–3 June 1997 not associated with an east rift intrusion. Data from 30 May to 10 June. Dates on figure in mm/dd/yyyy format.

Figure G27. Map showing activity around a small summit and upper east rift intrusion accompanied by a "surge" on 14 January 1988. Dates on figure in mm/dd/yyyy format. A, Short-period seismicity. B, Long-period seismicity.

Figure G28. Map showing activity around a Nāmakanipaio sequence on 27–28 January 1998 not associated with an east rift intrusion. Data from 26–28 January. Dates on figure in mm/dd/yyyy format.

Figure G29. Map showing activity around a silent earthquake (Montgomery-Brown and others, 2009) on 19 September 1998. Data from 18–20 September. The earthquake pattern resembles that of suspected deep intrusions beneath zone SDI 2. Dates on figure in mm/dd/yyyy format.

Figure G30. Map showing Kīlauea activity on 27–28 September 1998. Data from 27–30 September. Two mainshocks: M4.6 (27 September) located northeast of Kīlauea Caldera, and M4.8 (28 September) located in the eastern south flank, the latter with aftershocks. Dates on figure in mm/dd/yyyy format.
**Figure G31.** Map showing activity around *M*5.2 Hilea (Mauna Loa) earthquake on 16 April 1999 and aftershocks. Data from 16–23 April. Seismicity beneath the Kīlauea lower southwest rift zone was triggered beginning 1 hour after the mainshock and continuing for nearly 15 hours. Dates on figure in mm/dd/yyyy format.

**Figure G32** Map showing activity around 26 May 1999 Nāmakanipaio mainshock *M*4.3 with aftershocks. Data from 25–30 May. Dates on figure in mm/dd/yyyy format.

**Figure G33.** Map showing activity around upper east rift intrusion on 12 September 1999. Data from 10–16 September. Dates on figure in mm/dd/yyyy format.

**Figure G34.** Map showing activity around upper east rift intrusion on 23–24 February 2000, preceded by a swarm of deep magma-supply earthquakes. Data from 17–29 February. *A*, Short-period seismicity. *B*, Long-period seismicity.

**Figure G35.** Map showing activity around an eruptive surge on 24 September 2000. Data from 20–28 September. Dates on figure in mm/dd/yyyy format.

**Figure G36.** Map showing activity around a silent earthquake (Montgomery-Brown and others, 2009) on 8–9 November 2000 preceding a broader south flank earthquake swarm. Data from 8–18 November. Dates on figure in mm/dd/yyyy format.
Figure G37. Map showing activity around an eruptive surge on 20 May 2001. Data from 16–24 May. Dates on figure in mm/dd/yyyy format.

Figure G38. Map showing activity around suspected deep intrusion on 23–24 June 2001 beneath site SDI 2 (chap. 5, fig. 5.2). Data from 22–30 June. Dates on figure in mm/dd/yyyy format.

Figure G39. Map showing activity around a silent earthquake (Montgomery-Brown and others, 2009) on 19 September 2001. Data from 17–22 September. Dates on figure in mm/dd/yyyy format.

Figure G40. Map showing activity around an eruptive surge on 9 December 2001 preceding a small summit intrusion. Data from 8–15 December. Dates on figure in mm/dd/yyyy format.

Figure G41. Map showing activity around a small upper east rift intrusion on 19 December 2001. Data from 17–23 December. Dates on figure in mm/dd/yyyy format.

Figure G42. Map showing activity around suspected deep intrusion on 12 February 2002 beneath site SDI 2 (chap. 5, fig. 5.2). Data from 10–16 February. Dates on figure in mm/dd/yyyy format.

Figure G43. Map showing activity around an eruptive surge on 5 April 2002. Data from 2–8 April. No earthquakes occurred during the surge. Dates on figure in mm/dd/yyyy format.
**Figure G44.** Map showing activity around two suspected deep intrusions on 21 August and 28–29 August 2002 beneath site SDI 2 (chap. 5, fig. 5.2). Data from 20–31 August. Dates on figure in mm/dd/yyyy format.

**Figure G45.** Map showing activity around a silent earthquake (Montgomery-Brown and others, 2009) on 17 December 2002. Data from 11–18 December. Dates on figure in mm/dd/yyyy format.

**Figure G46.** Map showing activity around an eruptive surge on 21 January 2003. Data from 8–28 January. No earthquakes during the surge. Dates on figure in mm/dd/yyyy format.

**Figure G47.** Map showing activity around a Nāmakanipaio sequence on 6–7 April 2003, preceded and followed by deep magma supply earthquakes. Data from 31 March-14 April. Dates on figure in mm/dd/yyyy format.

**Figure G48.** Map showing activity around a silent earthquake (Montgomery-Brown and others, 2009) on 3 July 2003 preceded by a suspected deep intrusion near site SDI 3 (chap. 5, fig. 5.2) on 1–2 July. Data from 28 June-5 July. Dates on figure in mm/dd/yyyy format.

**Figure G49.** Map showing activity around an eruptive surge on 8 August 2003, with both short-period and long-period summit seismicity before and after. Data from 6–10 August. Dates on figure in mm/dd/yyyy format.
Figure G50. Graphs showing Kīlauea activity from 1 December 2003 to 19 March 2008 (Pu‘u ‘Ō‘o-Kupaianaha eruption Stage III). Time series shows short- and long-period earthquake swarms for all regions as vertical lines connected across the times of intrusion. Dates on figure in mm/dd/yyyy format. See text fig. 7.13 and tables 7.5 and 7.6 for event details.

Figure G51. Map showing activity around a suspected deep intrusion on 22 December 2003 beneath site SDI 2 (see chap. 5, fig. 5.2). Data from 18–26 December 2003. Dates on figure in mm/dd/yyyy format.

Figure G52. Map showing activity around an upper east rift intrusion on 4 March 2004 accompanying a surge. Data from 2–8 March 2004. Dates on figure in mm/dd/yyyy format.

Figure G53. Map showing seismic activity preceding and following an eruptive surge on 20 March 2004. Data from 18–26 March 2004. Dates on figure in mm/dd/yyyy format.

Figure G54. Map showing activity around an uppermost east rift intrusion on 12–13 May 2004, preceding an eruptive surge on 15 May. Data from 8–18 May. Dates on figure in mm/dd/yyyy format.

Figure G55. Map showing activity around a small upper east rift intrusion 4 June 2004. Data from 3–9 June. Dates on figure in mm/dd/yyyy format.
**Figure G56.** Map showing activity around a double east rift intrusion on 9–10 July 2004 showing downrift migration of epicenters. Data from 1–14 July. Pre- and posteruption south flank earthquakes extend well east of the rift intrusion site. Dates on figure in mm/dd/yyyy format.

**Figure G57.** Map showing activity around an upper east rift intrusion on 27 July 2004 accompanying a surge. Data from 25 July-2 August. Earthquakes after the surge occur near the upper middle east rift boundary. Dates on figure in mm/dd/yyyy format.

**Figure G58.** Map showing activity around a Nāmakanipaio sequence on 2 November 2004. Data from 29 October-9 November. Dates on figure in mm/dd/yyyy format.

**Figure G59.** Map showing activity around an upper east rift intrusion on 22–23 December 2004. Data from 19–29 December. Dates on figure in mm/dd/yyyy format.

**Figure G60.** Map showing activity around a silent earthquake (Montgomery-Brown and others, 2009) on 25–27 January 2005, preceded on 24-25 January by an upper east rift intrusion and followed on 27-29 January by a Nāmakanipaio sequence. Dates on figure in mm/dd/yyyy format.

**Figure G61.** Map showing activity around an upper-middle east rift intrusion on 29–30 December 2005, preceded by deep magma-supply earthquakes. Data from 25 December 2005 to 2 January 2006. Dates on figure in mm/dd/yyyy format.
Figure G62. Map showing activity around the beginning of paired intrusions on the uppermost seismic southwest rift zone and the uppermost east rift zone on 15–16 January 2006. Data from 14–19 January. The first intrusion is on the upper east rift. Dates on figure in mm/dd/yyyy format.

Figure G63. Map showing activity around a Nāmakanipaio sequence on 22–23 January 2006. Data from 20–23 January. Dates on figure in mm/dd/yyyy format.

Figure G64. Maps showing activity around a series of nearly continuous paired intrusions into the upper east rift zone and the uppermost seismic southwest rift zone in January-February 2006. Dates on figure in mm/dd/yyyy format. 


B, 29–31 January 2006: Two intrusions beneath the upper east rift zone separated by about 10 hours. The preintrusion east rift seismicity is colocated with the syneruption seismicity. Data from 29–31 January. 

C, 1–8 February 2006: A large paired intrusion into the upper east rift zone and upper seismic southwest rift zone accompanied by several deep magma-supply earthquakes. Data from 1–9 February. 

D, 9–18 February 2006: A continuation of nearly continuous intrusions into the upper east rift zone and the uppermost seismic southwest rift zone, consisting of successive swarms of 40, 38, 10, 12, and 48 rift events. Data from 9–20 February.

Figure G65. Map showing activity around two intrusions overlapping in time on 22–24 February 2006, which are the last of a 1-month sequence of paired intrusions on the uppermost east rift zone and uppermost seismic southwest rift zone. Data from 21–25
February. The intrusions were preceded by a Nāmakanipaio sequence that began on 22 February. Dates on figure in mm/dd/yyyy format.

**Figure G66.** Map showing activity during waning of nearly continuous intrusion into the upper east rift zone and the uppermost seismic southwest rift zone on 27 February to 1 March 2006. Data from 26 February to 2 March. Dates on figure in mm/dd/yyyy format.

**Figure G67.** Map showing activity around Nāmakanipaio sequence on 1–4 March 2006, directly preceding a small upper seismic southwest rift intrusion. Data from 1–5 March. Dates on figure in mm/dd/yyyy format.

**Figure G68.** Map showing activity around Nāmakanipaio sequence on 6 March 2006, overlapping with a small upper seismic southwest rift intrusion on 6–7 March. Data from 5–7 March. Dates on figure in mm/dd/yyyy format.

**Figure G69.** Map showing activity around Nāmakanipaio sequence on 11 March 2006 accompanying a small intrusion into the uppermost seismic southwest rift zone. Data from 10–12 March. Dates on figure in mm/dd/yyyy format.

**Figure G70.** Map showing activity around a suspected deep intrusion on 16 March 2006 beneath site SDI 2 (chap. 5, fig. 5.2). Data from 15–17 March. Dates on figure in mm/dd/yyyy format.
**Figure G71.** Map showing activity around a small upper east rift intrusion on 22–23 March 2006, followed by paired (nonswarm) activity beneath the upper east rift zone and upper seismic southwest rift zone. Data from 19–29 March. Dates on figure in mm/dd/yyyy format.

**Figure G72.** Map showing activity around a small upper-middle east rift intrusion on 9–10 May 2006, preceded by paired (nonswarm) activity beneath the upper east rift zone and upper seismic southwest rift zone and a possible suspected deep intrusion beneath the central south flank. Data from 4–12 May. Dates on figure in mm/dd/yyyy format.

**Figure G73.** Map showing activity around an intrusion on 29–30 July 2006 beneath the upper seismic southwest rift zone. Data from 28–31 July. Dates on figure in mm/dd/yyyy format.

**Figure G74.** Map showing activity around an upper east rift intrusion on 3–4 August 2006, followed by paired (nonswarm) activity beneath the upper east rift zone and upper seismic southwest rift zone. Data from 1–8 August. Dates on figure in mm/dd/yyyy format.

**Figure G75.** Map showing activity around a suspected deep intrusion on 3–5 April 2007 beneath the central south flank. Continuous GPS measurement did not record a spreading step. Data from 1–10 April. Dates on figure in mm/dd/yyyy format.

**Figure G76.** Map showing activity around a silent earthquake (Montgomery-Brown and others, 2010) on 16 April 2007 associated with very low seismicity. Data from 15–18 April. Dates on figure in mm/dd/yyyy format.
Figure G77. Map showing activity around two intrusions on 24–27 May 2007 beneath the upper east rift zone separated by about 9 hours. Data from 22–29 May. Dates on figure in mm/dd/yyyy format.

Figure G78. Map showing activity around intrusion on 31 May-1 June 2007 beneath the uppermost seismic southwest rift zone. Data from 30 May-2 June. Dates on figure in mm/dd/yyyy format.

Figure G79. Map showing activity around silent earthquake (Montgomery-Brown and others, 2009) on 17–18 June 2007 that overlaps in time with the intrusion accompanying the Father’s Day eruption (see text fig. 7.14). Data from 17–18 June. Dates on figure in mm/dd/yyyy format.

Figure G80. Map showing activity around a small upper east rift intrusion on 3–4 July 2007. Data from 2–4 July. Dates on figure in mm/dd/yyyy format.

Figure G81. Map showing activity around a small middle east rift intrusion on 5–6 July 2007, anticipating the east rift eruption of 21 July (vents shown). Data from 5–11 July. Dates on figure in mm/dd/yyyy format.

Figure G82. Map showing activity around an upper east rift intrusion on 16–17 July 2007, precursory to the eruption on 21 July (vents shown). Data from 12–21 July. South flank seismicity occurs only before and after the intrusion and extends to a region south of the eruption vents. Dates on figure in mm/dd/yyyy format.
Appendix figure G1 a

Current eruption brittle-failure seismicity 2/1/1982-2/1/1983: earthquake swarms and single earthquakes M ≥ 4.0

Located earthquakes (open symbols)

Single earthquakes M ≥ 4.0 (closed symbols)

Earthquake counts (vertical lines)

Intrusions: • summit

Eruptions: • summit

Uwekahuna water-tube tilt magnitude: daily readings

Irruption pauses

Surges (*deflation-inflation-deflation events)

Located earthquakes (open symbols)

Single earthquakes M ≥ 4.0 (closed symbols)

Earthquake counts (vertical lines)

Intrusions: • summit

Eruptions: • summit

Uwekahuna water-tube tilt magnitude: daily readings

Irruption pauses

Surges (*deflation-inflation-deflation events)
Current eruption brittle-failure seismicity 2/1/1983-2/1/1984: earthquakes per day and single earthquakes $M \geq 4.0$

Located earthquakes (open symbols)

Single earthquakes $M \geq 4.0$ (closed symbols)

Earthquake counts (vertical lines)

Intrusions: ○ summit

Eruptions: ● summit

High-fountaining eruptive episodes

"Silent" eq (spreading steps)

M 6.6 Kaoiki earthquake (Mauna Loa)

Tilt mag (ur)

Appendix figure G1 b
<table>
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<th>Date</th>
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- **Far eastern south flank (0-15 km)**
- **Central south flank (0-15 km)**
- **Western south flank (0-15 km)**
- **Lower east rift zone (0-15 km)**
- **Middle east rift zone (0-15 km)**
- **Upper east rift zone (0-15 km)**
- **Seismic southwest rift zone (0-15 km)**
- **Koae fault zone (0-15 km)**
- **Kilauea caldera (0-5 km)**
- **Kilauea caldera (10-20 km)**
- **Kilauea caldera (5-10 km)**
- **Deep magma supply path (> 20 km)**

**Legend:**
- **C**: Current eruption brittle-failure seismicity
- **M**: Tilt magnitude (ur)
- **EJ**: Earthquake counts (vertical lines)
- **Silent'eq (spreading steps)**
- **Significant eq M ≥ 5.0**

**Appendix figure G1 c**

Current eruption brittle-failure seismicity 2/1/1984-2/1/1985: earthquakes per day and single earthquakes M ≥ 4.0

Uwekahuna water-tube tilt magnitude: daily readings

High-fountaining eruptive episodes
Current eruption brittle-failure seismicity 2/1/1985-2/1/1986: earthquakes per day and single earthquakes $M \geq 4.0$

- Located earthquakes (open symbols)
- Single earthquakes $M \geq 4.0$ (closed symbols)
- Earthquake counts (vertical lines)

Uwekahuna water-tube tilt magnitude: daily readings

High-fountaining eruptive episodes

- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Western south flank (0-15 km)
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Koae fault zone (0-15 km)
- Upper east rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Kilauea caldera (0-5 km)
- Kilauea caldera (5-10 km)
- Kilauea caldera (10-20 km)
- Deep magma supply path (> 20 km)

Intrusions: 
- summit
- east rift zone
- southwest rift zone

Eruptions: 
- summit
- east rift zone
- southwest rift zone

Koae: 
- eruption pauses
- surges ("deflation-inflation-deflation events"
- Significant eq $M \geq 5.0$
- "Silent"eq (spreading steps)
Current eruption brittle-failure seismicity 2/1/1986-2/1/1987: earthquakes per day and single earthquakes M ≥ 4.0

- Far eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Eastern south flank (0-15 km)
- Western south flank (0-15 km)
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Koae fault zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Kilauea caldera (0-5 km)
- Kilauea caldera (5-10 km)
- Kilauea caldera (10-20 km)
- Deep magma supply path (> 20 km)

- Shift of vent from Pu'u 'O'o to Kupaianaha, beginning of continuous eruption

- Significant eq M ≥ 5.0
- "Silent"eq (spreading steps)
Current eruption brittle-failure seismicity 2/1/1988-2/1/1989: earthquakes per day and single earthquakes $M \geq 4.0$

Intrusions: ○ summit □ east rift zone ◇ southwest rift zone ▪ Koae ▲ eruption pauses
Eruptions: ■ summit □ east rift zone ◇ southwest rift zone ▪ surges (*deflation-inflation-deflation events)

Appendix figure G1  g

Significant eq $M \geq 5.0$
"Silent"eq (spreading steps)
Current eruption brittle-failure seismicity 2/1/1989-2/1/1990: earthquakes per day and single earthquakes M ≥ 4.0

- Intrusions:
  - Summit
  - East rift zone
  - Southwest rift zone
  - Koa Fault
  - Eruptions:
  - Summit
  - East rift zone
  - Southwest rift zone
  - Eruption pauses
  - Surges ("deflation-inflation-deflation events"

Uwekahuna water-tube tilt magnitude: daily readings

Significant eq M ≥ 5.0
"Silent"eq (spreading steps)
Appendix figure G1

Current eruption brittle-failure seismicity 2/1/1990-2/1/1991: earthquakes per day and single earthquakes M ≥ 4.0

Located earthquakes (open symbols)
Single earthquakes M ≥ 4.0 (closed symbols)
Earthquake counts (vertical lines)

Intrusions: ○ summit □ east rift zone ◊ southwest rift zone ○ Koae
Eruptions: ● summit ■ east rift zone ◊ southwest rift zone

Significant eq M ≥ 5.0
“Silent”eq (spreading steps)
Episode 48 continuing

Earthquake counts (vertical lines)

Far eastern south flank (0-15 km)
Central south flank (0-15 km)
Eastern south flank (0-15 km)
Western south flank (0-15 km)
Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Koae fault zone (0-15 km)
Upper east rift zone (0-15 km)
Southwest rift zone (0-15 km)
Kilauea caldera (0-5 km)
Kilauea caldera (10-20 km)
Kilauea caldera (5-10 km)
Deep magma supply path (>20 km)

Uwekahuna water-tube tilt magnitude: daily readings

2/1/1990
3/1/1990
4/1/1990
5/1/1990
6/1/1990
7/1/1990
8/1/1990
9/1/1990
10/1/1990
11/1/1990
12/1/1990
1/1/1991
2/1/1991
Appendix figure G1

Current eruption brittle-failure seismicity 2/1/1991-2/1/1992: earthquakes per day and single earthquakes M ≥ 4.0

Tilt mag (ur)

Located earthquakes (open symbols)

Single earthquakes M ≥ 4.0 (closed symbols)

Earthquake counts (vertical lines)

2/1/1991

10

M

5

100

1000

Eq/day

10

100

1000

370

380

390

400

410

Eruptions:

Kilauea caldera

Located earthquakes (open symbols)

Koae fault zone (0-15 km)

Lower east rift zone (0-15 km)

Far eastern south flank (0-15 km)

Central south flank (0-15 km)

Eastern south flank (0-15 km)

Western south flank (0-15 km)

Sierra fault zone (10-20 km)

Seismic southwest rift zone (0-15 km)

Koae fault zone (0-15 km)

Upper east rift zone (0-15 km)

Baring fault zone (0-15 km)

Southwest rift zone (0-15 km)

8/1/1991

10

5

1

10

100

1000

Kilauea caldera

Table

(0-5 km)

(5-10 km)

(10-20 km)

Deep magma supply path (20-35 km)
Appendix figure G1  k

Current eruption brittle-failure seismicity 2/1/1992-2/1/1993: earthquakes per day and single earthquakes $M \geq 4.0$

Located earthquakes (open symbols)

Single earthquakes $M \geq 4.0$ (closed symbols)

Earthquake counts (vertical lines)

Tilt mag (ur)

2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
2/1/1993

Uwekahuna water-tube tilt magnitude: daily readings

Intrusions: C summit I east rift zone I southwest rift zone I Koae + eruption pauses

Eruptions: D summit I east rift zone I southwest rift zone

Located earthquakes (open symbols)

3/1/1992
50
51
52
6/1/1992
1000

Far eastern south flank (0-15 km)

Central south flank (0-15 km)

Eastern south flank (0-15 km)

Western south flank (0-15 km)

Lower east rift zone (0-15 km)

Middle east rift zone (0-15 km)

Koae fault zone (0-15 km)

Seismic southwest rift zone (0-15 km)

Upper east rift zone (0-15 km)

Southwest rift zone (0-15 km)

Kilauea caldera

(0-5 km)

(5-10 km)

(10-20 km)

Deep magma supply path (20-35 km)
Current eruption brittle-failure seismicity 2/1/1993-2/1/1994: earthquakes per day and single earthquakes $M \geq 4.0$

Appendix figure G1

Located earthquakes (open symbols) | Single earthquakes $M \geq 4.0$ (closed symbols) | Earthquake counts (vertical lines)

Uwékahuna water-tube tilt magnitude: daily readings

Intrusions:  ○ summit  □ east rift zone  ◇ southwest rift zone  ○ Koae  ▲ eruption pauses  ▼ surges (deflation-inflation-deflation events)

Eruptions:  ▼ summit  □ east rift zone  ◇ southwest rift zone

Significant eq $M \geq 5.0$

"Silent" eq (spreading steps)

Equations per day

Kīlauea caldera  ○ (0-5 km)  □ (5-10 km)  ▲ (10-20 km)  ○ Deep magma supply path (20-35 km)
Appendix figure G1 m

Current eruption brittle-failure seismicity 2/1/1994-2/1/1995: earthquakes per day and single earthquakes $M \geq 4.0$

- Located earthquakes (open symbols)
- Single earthquakes $M \geq 4.0$ (closed symbols)
- Earthquake counts (vertical lines)

Tilt mag (ur)

- Intrusions: □ summit
- Eruptions: ● summit
- east rift zone
- southwest rift zone
- Koae
- eruption pauses
- surges (dieflation-inflation-deflation events)
- Significant eq $M \geq 5.0$
- "Silent"eq (spreading steps)

Episode 53 continuing

- Far eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Eastern south flank (0-15 km)
- Western south flank (0-15 km)

- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Koae fault zone (0-15 km)
- Upper east rift zone (0-15 km)
- Southwest rift zone (0-15 km)

- Kilauea caldera
- (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (20-35 km)
Current eruption brittle-failure seismicity 2/1/1995-2/1/1996 earthquakes per day and single earthquakes $M \geq 4.0$

- Located earthquakes (open symbols)
- Single earthquakes $M \geq 4.0$ (closed symbols)
- Earthquake counts (vertical lines)

- Uwēkahuna water-tube tilt magnitude: daily readings

- Intrusions: summit, east rift zone, southwest rift zone, Koae
- Eruptions: summit, east rift zone, southwest rift zone

- Episode 53 continuing

- Significant eq $M \geq 5.0$
- "Silent"eq (spreading steps)

- Fār eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Eastern south flank (0-15 km)
- Western south flank (0-15 km)

- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Koae fault zone (0-15 km)
- Upper east rift zone (0-15 km)
- Southwest rift zone (0-15 km)

- Kīlauea caldera (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (20-35 km)
Current eruption brittle-failure seismicity 2/1/1996-2/1/1997: earthquakes per day and single earthquakes \( M \geq 4.0 \)

Located earthquakes (open symbols)  
Single earthquakes \( M \geq 4.0 \) (closed symbols)  
Earthquake counts (vertical lines)

- **Tilt mag (ur)**
- **Ep/day**
- **Eq/day**
- **M**
- **Eq/day**

Intrusions:  
- Summit
- East rift zone
- Southwest rift zone
- Koae

Eruptions:  
- Summit
- East rift zone
- Southwest rift zone

- **Episode 55**
- **Silent**eq (spreading steps)
- **Surges** (*dieflation-inflation-deflation events*)
- **Eruption pauses**
- **Significant eq M ≥ 5.0**

Activity at:  
- Kilauea caldera
- Summit
- East rift zone
- Southwest rift zone
- Seismic southwest rift zone
- Koae fault zone
- Upper east rift zone
- Lower east rift zone

Kilauea caldera
- (0-5 km)
- (5-10 km)
- (10-20 km)
- Deep magma supply path (20-35 km)
Appendix figure G1  q

Current eruption brittle-failure seismicity 2/1/1998-2/1/1999: earthquakes per day and single earthquakes M ≥ 4.0

Located earthquakes (open symbols)  Single earthquakes M ≥ 4.0 (closed symbols)  Earthquake counts (vertical lines)

Uwékahuna water-tube tilt magnitude: daily readings

Intrusions: ○ summit □ east rift zone ◇ southwest rift zone □ Koa'e □ eruption pauses
Eruptions: ● summit ■ east rift zone ◆ southwest rift zone□ "dieflation-inflation-deflation events"
          ▲ Significant eq M ≥ 5.0
          □ "Silent"eq (spreading steps)

Episode 55 continuing

Earthquake counts (vertical lines)

Kilauea caldera ○ (0-5 km) □ (5-10 km) ▲ (10-20 km) ◆ Deep magma supply path (20-35 km)
Current eruption brittle-failure seismicity 2/1/1993-2/1/1994: earthquakes per day and single earthquakes $M \geq 4.0$

- **Tilt mag (ur)**
  - 2/1/1989: 100
  - 3/1/1989: 10
  - 3/1/1999: 4
  - 3/1/2000: 1

- **Intrusions:**
  - Far eastern south flank (0-15 km)
  - Eastern south flank (0-15 km)
  - Western south flank (0-15 km)

- **Eruptions:**
  - Summit
  - East rift zone
  - Southwest rift zone
  - Koae fault zone
  - Seismic southwest rift zone

- **Kilauea caldera**
  - (0-5 km)
  - (5-10 km)
  - (10-20 km)
  - Deep magma supply path (20-35 km)

- **Hilea earthquake M 5.6**
  - Significant $M \geq 5.0$
  - "Silent" eq (spreading steps)
  - Episode 55 continuing

- **Koae fault zone (0-15 km)**

- **Lower east rift zone (0-15 km)**
Appendix figure G1

Current eruption brittle-failure seismicity 2/1/2000-2/1/2001 earthquakes per day and single earthquakes $M \geq 4.0$

- **Tilt mag (ur)**
- **Eq/day**
- **Earthquake counts (vertical lines)**

**Intrusions:**
- **summit**
- **east rift zone**
- **southwest rift zone**
- **Kbae**

**Eruptions:**
- **summit**
- **east rift zone**
- **southwest rift zone**
- **surges ("deflation-inflation-deflation events")**

- **Significant eq $M \geq 5.0$**
- **"Silent"eq (spreading steps)**

- **Episode 55 continuing**

**Locations:**
- **Far eastern south flank (0-15 km)**
- **Central south flank (0-15 km)**
- **Eastern south flank (0-15 km)**
- **Western south flank (0-15 km)**

- **Lower east rift zone (0-15 km)**
- **Middle east rift zone (0-15 km)**
- **Seismic southwest rift zone (0-15 km)**
- **Koae fault zone (0-15 km)**
- **Upper east rift zone (0-15 km)**
- **Southwest rift zone (0-15 km)**

- **Kilauea caldera**
  - (0-5 km)
  - (5-10 km)
  - (10-20 km)
  - Deep magma supply path (20-35 km)
Appendix figure G1  t

Current eruption brittle-failure seismicity 2/1/2006-2/1/2007: earthquakes per day and single earthquakes M ≥ 4.0

Located earthquakes (open symbols)  Single earthquakes M ≥ 4.0 (closed symbols)  Earthquake counts (vertical lines)

Eq/day


Tilt mag (ur)

Eq/day

M

Eq/day

M

Eq/day

M
Current eruption brittle-failure seismicity 2/1/2002-2/1/2003: earthquakes per day and single earthquakes M ≥ 4.0

Located earthquakes (open symbols)

Single earthquakes M ≥ 4.0 (closed symbols)

Earthquake counts (vertical lines)

Intrusions: ◆ summit

Eruptions: o summit

Uwëkahuna water-tube tilt magnitude: daily readings

Koae

Episode 55 continuing

Far eastern south flank (0-15 km)

Central south flank (0-15 km)

Western south flank (0-15 km)

Lower east rift zone (0-15 km)

Middle east rift zone (0-15 km)

Seismic southwest rift zone (0-15 km)

Koae fault zone (0-15 km)

Upper east rift zone (0-15 km)

Southwest rift zone (0-15 km)

Kilauea caldera

(0-5 km)

(5-10 km)

(10-20 km)

Deep magma supply path (20-35 km)

Appendix figure G1 u

Earthquake counts (vertical lines)
Current eruption brittle-failure seismicity 2/1/2003-2/1/2004: earthquakes per day and single earthquakes M ≥ 4.0

- **Uwēkahuna water-tube tilt magnitude: daily readings**
- **Intrusions:**
  - Summit
  - East rift zone
  - Southwest rift zone
  - Koae
- **Eruptions:**
  - Summit
  - East rift zone
  - Southwest rift zone
- **Earthquake counts (vertical lines):**
  - Far eastern south flank (0-15 km)
  - Eastern south flank (0-15 km)
  - Western south flank (0-15 km)
  - Lower east rift zone (0-15 km)
  - Middle east rift zone (0-15 km)
  - Seismic southwest rift zone (0-15 km)
  - Koae fault zone (0-15 km)
  - Upper east rift zone (0-15 km)
  - Southwest rift zone (0-15 km)
- **Kīlauea caldera:**
  - (0-5 km)
  - (5-10 km)
  - (10-20 km)
  - Deep magma supply path (20-35 km)

**Located earthquakes (open symbols):**
- *Significant eq M ≥ 5.0*
- *"Silent"eq (spreading steps)*
- *Surges ("deflation-inflation-deflation events")*
- *Eruption pauses*

**Episode 55 continuing**

The graph shows the seismic activity from 2/1/2003 to 2/1/2004, with daily readings of tilt magnitude and earthquake counts by location and magnitude.
Current eruption brittle-failure seismicity 2/1/2004-2/1/2005: earthquakes per day and single earthquakes M ≥ 4.0

Appendix figure G1

Located earthquakes (open symbols)  Single earthquakes M ≥ 4.0 (closed symbols)  Earthquake counts (vertical lines)

Uwēkahuna water-tube tilt magnitude: daily readings

Intrusions: summit  east rift zone  southwest rift zone  Koae  eruption pauses  surges ("dieflation-inflation-deflation events")

Eruptions: summit  east rift zone  southwest rift zone  Kilauea caldera  Lower east rift zone (0-15 km)  Central south flank (0-15 km)  Eastern south flank (0-15 km)  Western south flank (0-15 km)

Kilauea caldera  (0 km)  (5-10 km)  (10-20 km)  Deep magma supply path (20-35 km)
Current eruption brittle-failure seismicity 2/1/2005-2/1/2006: earthquakes per day and single earthquakes M ≥ 4.0

- **Located earthquakes** (open symbols)
- **Single earthquakes M ≥ 4.0** (closed symbols)
- **Earthquake counts** (vertical lines)

**Intrusions:**
- Summit
- East rift zone
- Southwest rift zone
- Koae

**Eruptions:**
- Summit
- East rift zone
- Southwest rift zone

- **
- Surge ("dieflation-inflation-deflation events")
- Significant eq M ≥ 5.0
- "Silent" eq (spreading steps)

**Episode 55 continuing**

- **Uwëkahuna water-tube tilt magnitude:**
  - Daily readings

- **Eq/day**
  - Far eastern south flank (0-15 km)
  - Central south flank (0-15 km)
  - Eastern south flank (0-15 km)
  - Western south flank (0-15 km)

- **Eq/day**
  - Lower east rift zone (0-15 km)
  - Middle east rift zone (0-15 km)
  - Seismic southwest rift zone (0-15 km)
  - Koae fault zone (0-15 km)
  - Upper east rift zone (0-15 km)
  - Southwest rift zone (0-15 km)

- **Kilaeua caldera**
  - (0-5 km)
  - (5-10 km)
  - (10-20 km)
  - Deep magma supply path (20-35 km)
Appendix figure G1  
y
Current eruption brittle-failure seismicity 2/1/2006-2/1/2007: earthquakes per day and single earthquakes M ≥ 4.0

Located earthquakes (open symbols)  Single earthquakes M ≥ 4.0 (closed symbols)  Earthquake counts (vertical lines)

Uwakahuna water-tube tilt magnitude: daily readings

Intrusions: ○ summit  □ east rift zone  ◇ southwest rift zone  ○ Koae  ▲ eruption pauses
Eruptions: ● summit  ● east rift zone  ● southwest rift zone

Episode 55 continuing

Kiholo Bay earthquake

Earthquake counts (vertical lines)

Far eastern south flank (0-15 km)  △ Central south flank (0-15 km)
Eastern south flank (0-15 km)  ○ Western south flank (0-15 km)

Lower east rift zone (0-15 km)  □ Middle east rift zone (0-15 km)  ○ Seismic southwest rift zone (0-15 km)
Koae fault zone (0-15 km)  △ Upper east rift zone (0-15 km)  ○ Southwest rift zone (0-15 km)

Kilauea caldera  ● (0-5 km)  ● (5-10 km)  △ (10-20 km)  ○ Deep magma supply path (20-35 km)
Current eruption brittle-failure seismicity 2/1/2007-2/1/2008: earthquakes per day and single earthquakes M ≥ 4.0

Uwēkahuna water-tube tilt magnitude: daily readings

Intrusions: ○ summit □ east rift zone △ southwest rift zone + Koaʻe

Eruptions: ● summit ● east rift zone ● southwest rift zone

Episode 55 end 6/17 0900 Father’s Day eruption 7/19/2007 0050-0300?

Episode 58

Significant eq M ≥ 5.0

"Silent" eq (spreading steps)

Appendix figure G2 a


Appendix figure G2 a


Appendix figure G2 a

Appendix figure G2b

Earthquakes/day

Tilt mag (ur)

Eruptions: ▲ summit  ▪ east rift zone  ▪ southwest rift zone
Intrusions: ○ summit  □ east rift zone  ▪ southwest rift zone  ▄ Koa

High-fountaining eruptive episodes

Kilauea caldera (0-5 km) Daily earthquake counts

Daily earthquake counts (lpc-c)

Located earthquakes

Located earthquakes

Deep magma supply path (>20 km)  ▲ Daily earthquake counts (not recorded)  ▪ Located earthquakes

Appendix figure G2 c

- Eruptions: ● summit
- Significant eq M ≥ 5.0
- "Silent eq (spreading steps)

High-fountaining eruptive episodes

- Harmonic tremor (minutes)
- Shallow (0-5 km)
- Intermediate (5-15 km)
- Deep (> 20 km)

Daily earthquake counts

- Kilauea caldera (0-5 km)
- Lpc-a (3-5 Hz)
- Lpc-b (1-3 Hz)
- Located earthquakes

Located earthquakes

Deep magma supply path (>20 km)

Daily earthquake counts (not recorded)

Located earthquakes

Earthquakes/day

Minutes of tremor/day

Eq/day
Appendix figure G2 e


Eruptions: • summit • east rift zone • southwest rift zone
Intrusions: ○ summit ○ east rift zone ○ southwest rift zone • Koae
Significant eq M ≥ 5.0
"Silent" eq (spreading steps)
"Surge " (deflation-inflation-deflation events)
Eruption pauses

High-fountaining eruptive episodes

Located earthquakes

Daily earthquake counts

Daily earthquake counts (lpc-c)

Daily earthquake counts (not recorded)

Located earthquakes

Kilauea caldera (0-5 km) Daily earthquake counts

Kilauea caldera (5-15 km) Daily earthquake counts (lpc-c)

Deep magma supply path (>20 km)

Tilt mag (ur)
Appendix figure G2 j


Daily earthquake counts (not recorded) ≥ "Silent"eq (spreading steps)

Episodes:
- Episode 48 continuing
- Other episodes

Intrusions:
- Significant eq M ≥ 5.0
- "Silent"eq (spreading steps)

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Located earthquakes

Earthquakes/day

Kilauea caldera (0-5 km) Daily earthquake counts

Kilauea caldera (5-15 km) Daily earthquake counts

Deep magma supply path (>20 km) Daily earthquake counts

Tilt mag (ur)

Uwekahuna water-tube tilt magnitude: daily readings
Appendix figure G2 n

Uwekahuna water-tube tilt magnitude: daily readings in microradians

Eruptions: ● summit ■ east rift zone ▲ southwest rift zone
Intrusions: ○ summit □ east rift zone ◇ southwest rift zone ♦ Koae

Minutes of tremor/day

Eq/day

Earthquakes/day

Kilauea caldera (0-5 km) Daily earthquake counts ○ lpc-a (3-5 Hz) ▲ lpc-b (1-3 Hz) ▲ Located earthquakes

Kilauea caldera (5-15 km) △ Daily earthquake counts (lpc-c) ▲ Located earthquakes

Deep magma supply path (>20 km) ◇ Daily earthquake counts (not recorded) ▲ Located earthquakes

Appendix figure G2 r


Appendix figure G2 s

Uwekahuna water-tube tilt magnitude: daily readings

Eruptions:  ● summit  ■ east rift zone  ▲ southwest rift zone
Intrusions:  ○ summit  ● east rift zone  ◆ southwest rift zone  ▲ Koae

• Significant eq M ≥ 5.0
• “Silent" eq (spreading steps)

Episode 55

Harmonic tremor (minutes)  ◆ Shallow (0-5 km)  ▲ Intermediate (5-15 km)  ▲ deep (> 20 km)

Located earthquakes

Kilauea caldera (0-5 km)

Kilauea caldera (5-15 km)

Deep magma supply path (>20 km)
Appendix figure G2 t


The figure shows daily readings of the Uwekahuna water-tube tilt magnitude. The data includes episodes of significant earthquakes (M ≥ 5.0), "silent" earthquakes (spreading steps), eruption pauses, and surges (dieflation-inflation-deflation events).

The chart also displays the number of earthquakes per day in different depth ranges: shallow (0-5 km), intermediate (5-15 km), and deep (> 20 km). Additionally, it shows the number of minutes of tremor per day, with separate plots for each depth range, including the Kilauea caldera (0-5 km) and (5-15 km).
Appendix figure G2 u

Uwekahuna water-tube tilt magnitude: daily readings

Eruptions: • summit  ■ east rift zone  ○ southwest rift zone
Intrusions: ○ summit  ■ east rift zone  ○ southwest rift zone  ○ Koae

* Significant eq M ≥ 5.0
* "Silent"eq (spreading steps)

Episode 55

Harmonic tremor (minutes)  ★ Shallow (0-5 km)  ★ Intermediate (5-15 km)  ★ deep (> 20 km)

Kilauea caldera (0-5 km)  ● Located earthquakes

Kilauea caldera (5-15 km)  ▲ Located earthquakes

Deep magma supply path (>20 km)  ● Located earthquakes

Uwekahuna water-tube tilt magnitude: daily readings

Harmonic tremor (minutes)
- Shallow (0-5 km)
- Intermediate (5-15 km)
- Deep (> 20 km)

Kilauea caldera (0-5 km)
- Located earthquakes

Kilauea caldera (5-15 km)
- Located earthquakes

Deep magma supply path (>20 km)
- Located earthquakes

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Intrusions:
- Summit
- East rift zone
- Southwest rift zone
- Koae

- Significant eq M ≥ 5.0
- "Silent" eq (spreading steps)
- Eruption pauses
- Surges ("dieflation-inflation-deflation events")

Episode 55
Appendix figure G2 w

- Uwekahuna water-tube tilt magnitude: daily readings
- Eruptions: summit, east rift zone, southwest rift zone
- Intrusions: summit, east rift zone, southwest rift zone, Koae
- Significant eq M ≥ 5.0
- "Silent" eq (spreading steps)
- Episode 55
- Eruption pauses
- Surges ("dieflation-inflation-deflation events")
- Harmonic tremor (minutes)
  - Shallow (0-5 km)
  - Intermediate (5-15 km)
  - Deep (> 20 km)
- Kilauea caldera (0-5 km)
- Located earthquakes (blue dots)
- Kilauea caldera (5-15 km)
- Located earthquakes (green triangles)
- Deep magma supply path (>20 km)
- Located earthquakes (red asterisks)

Graph showing daily readings, seismic activity, and related events over a period from 2/1/2004 to 2/1/2005.
Appendix figure G2 x


Uwekahuna water-tube tilt magnitude: daily readings

Eruptions: summit • east rift zone • southwest rift zone
Intrusions: summit • east rift zone • southwest rift zone • Koaʻe

Significant eq M ≥ 5.0
*Silent* eq (spreading steps)

Episode 55

Harmonic tremor (minutes) • Shallow (0-5 km) • Intermediate (5-15 km) • deep (> 20 km)

Kilauea caldera (0-5 km) • Located earthquakes

Kilauea caldera (5-15 km) • Located earthquakes

Deep magma supply path (>20 km) • Located earthquakes

Earthquakes/day

Minutes of tremor/day

Eq/day

Tilt mag (ur)
Appendix figure G2 z


- Uwekahuna water-tube tilt magnitude: daily readings
- Eruptions: • summit, ■ east rift zone, ◇ southwest rift zone
- Intrusions: ○ summit, □ east rift zone, ◇ southwest rift zone, ♦ Koae
- Significant eq M ≥ 5.0
- "Silent"eq (spreading steps)
- Eruption pauses
- Surges (*dieflation-inflation-deflation events)
- Episode 55 end
- Father’s Day eruption
- Episode 58

- Harmonic tremor (minutes)
- Shallow (0-5 km)
- Intermediate (5-15 km)
- Deep (> 20 km)

- Kilauea caldera (0-5 km)
- Located earthquakes

- Kilauea caldera (5-15km)
- Located earthquakes

- Deep magma supply path (>20 km)
- Located earthquakes

- Earthquakes/day
- Minutes of tremor/day
Appendix figure G3 b


Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)


Tilt mag (ur)

470
460
450
440
430
420

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions: Summit  East rift zone  Southwest rift zone  Intrusions: summit  East rift zone  southwest rift zone  Koae
- eruption pauses  ‡ surges (Deflation-Inflation-Deflation events)  ♦ "Silent" eq  × Significant eq M ≥ 5.0

High-fountaining eruptive episodes

Earthquake swarms: brittle-failure
- 3-10 events (magma supply, rift zones)
- >10 events (magma supply, rift zones)

Long-period
- 1-3 events (lpms4.5)
- 3-10 events (lpms4.5)
- >10 events (lpms4.5)


Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Earthquake swarms: brittle-failure
- 3-10 events (magma supply, rift zones); 5-20 events (south flank)
- >10 events (magma supply, rift zones); >20 events (south flank)

Intrusions: 
- "Silent" eq
- Significant eq M ≥ 5.0
- eruption pauses
- surges (Deflation-Inflation-Deflation events)

High-fountaining eruptive episodes
- 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- >10 events (lpms4.5); >100 events (lpms1-3)

Kīlauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Far eastern south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Western south flank (0-15 km)
Appendix figure G3 e


Kilauea caldera
- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Deep magma supply path (> 20 km)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions:
- Summit
- East rift zone
- Southwest rift zone
- Intrusions:
  - Summit
  - East rift zone
  - Southwest rift zone
- Koae

High-fountaining eruptive episodes
- Shift of vent from Pu‘u ‘Ō’o to Kuapianaha—beginning of continuous eruption

Earthquake swarms:
- Brittle-failure
  - 3-10 events (magma supply, rift zones)
  - >10 events (magma supply, rift zones)
- Long-period
  - 1-3 events (lpms4.5)
  - 1-10 events (lpms1-3)
  - 3-10 events (lpms4.5)
  - >10 events (lpms4.5)


Tilt (mm)
- 2/1/1986
- 3/1/1986
- 4/1/1986
- 5/1/1986
- 6/1/1986
- 7/1/1986
- 8/1/1986
- 9/1/1986
- 10/1/1986
- 11/1/1986
- 12/1/1986
- 1/1/1987
- 2/1/1987


Ki‘alaeau caldera

- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions: red circle - Summit
Green square - East rift zone
Purple diamond - Southwest rift zone
Intrusions: orange circle - summit
Green square - East rift zone
Purple diamond - southwest rift zone
Green plus - Koae

- eruption pauses
- surges (Deflation-Inflation-Deflation events)
- "Silent" eq
- Significant eq M ≥ 5.0

Episode 48 continuing

Earthquake swarms:
- brittle-failure
- 3-10 events (magma supply, rift zones); 5-20 events (south flank)
- >10 events (magma supply, rift zones); >20 events (south flank)

Long-period
- + 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- + 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- + >10 events (lpms4.5); >100 events (lpms1-3)

Western south flank (0-15 km)

Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)

Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

Uwëkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions:
- Summit
- East rift zone
- Southwest rift zone
- Intrusions:
  - summit
- East rift zone
- southwest rift zone

- Koae

episode 48 continuing

Earthquake swarms:
- brittle-failure
  - 3-10 events (magma supply, rift zones); 5-20 events (south flank)
  - >10 events (magma supply, rift zones); >20 events (south flank)

long-period
- 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- >10 events (lpms4.5); >100 events (lpms1-3)

Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Eruptions:  Summit  East rift zone  Southwest rift zone
Intrusions:  summit  East rift zone  southwest rift zone  Koae
- eruption pauses  ↓ surges (Deflation-Inflation-Deflation events)  "Silent" eq  Significant eq M ≥ 5.0

Episode 48 continuing  ep 49  Episode 48 continuing

Earthquake swarms:  brittle-failure
| 3-10 events (magma supply, rift zones); 5-20 events (south flank)
| >10 events (magma supply, rift zones); >20 events (south flank)
| 1-3 events (lpms4.5); 1-10 events (lpms1-3)
| 3-10 events (lpms4.5); 10-100 events (lpms1-3)
| >10 events (lpms4.5); >100 events (lpms1-3)

Deep magma supply path (> 20 km)
0-5 km
5-10 km
10-20 km

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"


Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions: Summit, East rift zone, Southwest rift zone
Intrusions: East rift zone, southwest rift zone, Koae

Earthquake swarms: brittle-failure
3-10 events (magma supply, rift zones); 5-20 events (south flank)
>10 events (magma supply, rift zones); >20 events (south flank)

Long-period
1-3 events (lpms4.5); 1-10 events (lpms1-3)
3-10 events (lpms4.5); 10-100 events (lpms1-3)
>10 events (lpms4.5); >100 events (lpms1-3)
Earthquake swarms: brittle-failure
3-10 events (magma supply, rift zones); 5-20 events (south flank)
>10 events (magma supply, rift zones); >20 events (south flank)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Episode 53 continuing


Kīlauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)
Far eastern south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Western south flank (0-15 km)

Kīlauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
Middle east rift zone (0-15 km)
Upper east rift zone (0-15 km)
Seismic southwest rift zone (0-15 km)
Southwest rift zone (0-15 km)

Far eastern south flank (0-15 km)
Eastern south flank (0-15 km)
Central south flank (0-15 km)
Western south flank (0-15 km)

Seismic southwest rift zone (0-15 km)
Lower east rift zone (0-15 km)

Eruptions: Summit  East rift zone  Southwest rift zone
Intrusions: summit  East rift zone  southwest rift zone  Koae

- eruption pauses  ^ surges (Deflation-Inflation-Deflation events)  "Silent" eq  × Significant eq M ≥ 5.0

Earthquake swarms: \textit{shock-failure} \hspace{1cm} \textit{long-period}  
\begin{itemize}
\item 3-10 events (magma supply, rift zones); 5-20 events (south flank)
\item >10 events (magma supply, rift zones); >20 events (south flank)
\item 1-3 events (lpms4.5); 1-10 events (lpms1-3)
\item 3-10 events (lpms4.5); 10-100 events (lpms1-3)
\item >10 events (lpms4.5); >100 events (lpms1-3)
\end{itemize}

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

episode 55

3-10 events (magma supply, rift zones); 5-20 events (south flank)
>10 events (magma supply, rift zones); >20 events (south flank)
1-3 events (lpms4.5); 1-10 events (lpms1-3)
3-10 events (lpms4.5); 10-100 events (lpms1-3)
>10 events (lpms4.5); >100 events (lpms1-3)
Deep magma supply path (> 20 km)


Kilauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

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Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Intrusions:
- Summit
- East rift zone
- Southwest rift zone

Earthquake swarms:
- "brittle-failure"
- 3-10 events (magma supply, rift zones); 5-20 events (south flank)
- >10 events (magma supply, rift zones); >20 events (south flank)

Long-period
- 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- >10 events (lpms4.5); >100 events (lpms1-3)

Significant eq M ≥ 5.0

Earthquake swarms: brittle-failure
- 3-10 events (magma supply, rift zones); 5-20 events (south flank)
- >10 events (magma supply, rift zones); >20 events (south flank)

Long-period
- 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- >10 events (lpms4.5); >100 events (lpms1-3)

Eruptions: Summit, East rift zone, Southwest rift zone
Intrusions: summit, East rift zone, southwest rift zone, Koae
- eruption pauses
- surges (Deflation-Inflation-Deflation events)
- "Silent" eq
- Significant eq M ≥ 5.0

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"
Appendix figure G3 s


Kiʻauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

2/1/2000
3/1/2000
4/1/2000
5/1/2000
6/1/2000
7/1/2000
8/1/2000
9/1/2000
10/1/2000
11/1/2000
12/1/2000
1/1/2001
2/1/2001

Tilt mag (ur)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions:  Summit  East rift zone  Southwest rift zone  Intrusions:  summit  East rift zone  southwest rift zone  Koa
- eruption pauses
- surges (Deflation-Inflation-Deflation events)
- "Silent" eq
- Significant eq M ≥ 5.0

Earthquake swarms:  brittle-failure

Long-period
- 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- >10 events (lpms4.5); >100 events (lpms1-3)

sf4swr
sf3kuer
sf2mer
koae
ei5swr
ei4sswr
ei3uer
ei2mer

ms1
ms2
ms3
ms4-5

2/1/2000
3/1/2000
4/1/2000
5/1/2000
6/1/2000
7/1/2000
8/1/2000
9/1/2000
10/1/2000
11/1/2000
12/1/2000
1/1/2001
2/1/2001

episode 55 continuing

Appendix figure G3 w

Kilauea caldera
○ 0-5 km
□ 5-10 km
△ 10-20 km
★ Deep magma supply path (>20 km)

- Lower east rift zone (0-15 km)
- Middle east rift zone (0-15 km)
- Upper east rift zone (0-15 km)
- Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Far eastern south flank (0-15 km)
- Eastern south flank (0-15 km)
- Central south flank (0-15 km)
- Western south flank (0-15 km)

W

Tilt mag (ur)
430
420
410
400
390

Eruptions: ★ Summit ★ East rift zone ★ Southwest rift zone Intrusions: ○ summit ■ East rift zone ■ Southwest rift zone ★ Koae

Earthquake swarms: Brittle-failure
| 3-10 events (magma supply, rift zones); 5-20 events (south flank) |
| >10 events (magma supply, rift zones); >20 events (south flank) |

Long-period
| 1-3 events (lpms4.5); 1-10 events (lpms1-3) |
| 3-10 events (lpms4.5); 10-100 events (lpms1-3) |
| >10 events (lpms4.5); >100 events (lpms1-3) |

sf4swr sf3kuersf2merkoae
ei5swr ei4swreisuer ei2mer

ms1 l-p s-p
ms2 l-p s-p
ms3 l-p s-p
ms4-5 l-p s-p

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary “0”

Episod 55 continuing
Appendix figure G3 x


Kīlauea caldera
- ○ 0-5 km
- □ 5-10 km
- ▲ 10-20 km
- ★ Deep magma supply path (> 20 km)

Earthquake swarms:
- Brittle-failure:
  - 3-10 events (magma supply, rift zones)
  - >10 events (magma supply, rift zones)
  - >20 events (south flank)
- Long-period:
  - 1-3 events (lpms4.5)
  - 1-10 events (lpms1-3)
  - 10-100 events (lpms1-3)
  - >10 events (lpms4.5)

Seismic southwest rift zone (0-15 km)
- Southwest rift zone (0-15 km)
- Uwëkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions:
- Summit
- East rift zone
- Southwest rift zone

Intrusions:
- Summit
- East rift zone
- Southwest rift zone
- Koae

Episode 55 continuing

Tilt mag (ur)

X


Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary “0”

Earthquake swarms:
- Brittle-failure:
  - 3-10 events (magma supply, rift zones);
  - 5-20 events (south flank);
  - >20 events (south flank)

- Long-period:
  - 1-3 events (lpms 4.5);
  - 10-100 events (lpms 1-3)
Figure G4

Pu’u ‘Ō’o-Kupaianaha eruption: Stage IA, episodes 1-47

Kīlauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)


Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"*

Eruptions: ● summit ■ east rift zone ♦ southwest rift zone Intrusions: ○ summit ■ east rift zone ♦ southwest rift zone ▲ Koae

Episodes

Earthquake swarms: "brittle-failure"

- 3-10 events (magma supply, rift zones); 5-20 events (south flank)

- >10 events (magma supply, rift zones); >20 events (south flank)

Significant eq M 5.0

‘Silent’eq (spreading steps)

S

Eruption pauses

Surges (‘dieflation-inflation-deflation events’)

Tilt magnitude (arc-seconds)
12/23/1984 suspected deep intrusion data from 12/22-24/1984

Intrusion
south flank eqs beg: 12/23/1984 06:14
south flank eqs end: 12/23/1984 13:37

Pre-intrusion
syn-intrusion
Post-intrusion
Appendix figure G7  Episode 48 fissure eruption leading to continuous eruption: data from 7/14-24/1986

Episode 48  Pu'u 'O'o-Kupaianaha vents
Fissure eruption  7/18/1986 12:05-7/19/1986 09:30
Continuous eruption  7/20/1986 08:30-2/7/1992

Magma transfer from Pu'u 'O'o to Kupaianaha

Depth ranges
- brittle-failure  - long-period
- 0-5 km  - 0-5 km
- 5-10 km  - 5-10 km
- 10-15 km  - 10-15 km
- > 20 km  - > 20 km
Earthquake swarm
eqs beg: 9/13/1986 12:15
eqs end: 9/13/1986 19:58
Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Latitude, in degrees North
Longitude, in Degrees West

Kilauea region boundaries

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Appendix figure G10


Earthquake swarm
eqs beg: 7/11/1988 17:43
eqs end: 7/12/1988 01:19

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm
Appendix figure G11


Pre-intrusion
Syn-intrusion
Post-intrusion

Kinase region boundaries

Depth ranges
brittle-failure
long-period

0-5 km
5-10 km
10-15 km
> 20 km
Appendix figure G13


- Very-Long-Period earthquake location 1.095 km depth
- Very-Long-Period earthquake location 6.7 km depth
- Pre-intrusion
- Syn-intrusion
- Post-intrusion
- Namakani Paio precursor 11/11-14/1990

Depth ranges:
- Brittle-failure
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
- Long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Kilauea region boundaries

Pacific Ocean
Appendix figure G14


Intrusion
eqs beg: 3/26/1991 0532
eqs end: 3/26/1991 1527
Pre-intrusion
Syn-intrusion
Post-intrusion

Latitude, in degrees North
Longitude, in Degrees West

Depth ranges
brittle-failure long-period
● 0-5 km ★ 0-5 km
○ 5-10 km × 5-10 km
□ 10-15 km ★★ 10-15 km
★ > 20 km ★★ > 20 km

Namakani Paio precursor 3/13/1991

Appendix figure G15


- Pre-intrusion
- Syn-intrusion
- Post-intrusion

Depth ranges:
- brittle-failure
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
- long-period
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

Kilauea region boundaries

Pacific Ocean

Namakani Paio precursor 8/10-11/1991
Appendix figure G17

Episode 49 Return to Pu'u 'O'o: data from 11/5-13/1991

Pre-eruption
Syn-eruption

Pu'u 'O'o vent

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- > 10 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries
Pacific Ocean

Latitude, in degrees North
Longitude, in Degrees West

Appendix figure G17 Episode 49 Return to Pu'u 'O'o: data from 11/5-13/1991

Pre-eruption
Syn-eruption

Pu'u 'O'o vent

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- > 10 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries
Pacific Ocean

Latitude, in degrees North
Longitude, in Degrees West
Appendix figure G18


Intrusion 13 events
eqs beg: 1/28/1992 07:18
eqs end: 1/29/1992 03:15

Pre-intrusion
Syn-intrusion
Post-intrusion

Kilauea region boundaries

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
>20 km
Episode 50: data from 2/9-19/1992

Pre-intrusion
Syn-intrusion
Post-intrusion/pre-eruption
Syn-eruption

Namakani Paio precursor 2/4/1992

Vent

Depth ranges
brittle-failure  long-period
- 0-5 km     - 0-5 km
- 5-10 km    - 5-10 km
- 10-15 km   - 10-15 km
- >20 km     - >20 km

Latitude, in degrees North
Longitude, in Degrees West
Appendix figure G20


Intrusion--east rift
eqs beg: 3/3/1992 0045
eqs end: 3/4/1992 2220

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
>20 km

long-period
0-5 km
5-10 km
10-15 km
>20 km

Kilauea region boundaries

Pacific Ocean
Earthquake swarm
eqs beg: 9/11/1993 12:27
eqs end: 9/12/1993 12:13
Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Appendix figure G21

9/11-12/1993 suspected deep intrusion?: Data from 9/9-14/1993

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Latitude, in degrees North
Longitude, in Degrees West
Earthquake swarm
eqs beg: 10/25/1994 23:20
eqs end: 10/26/1994 14:22
Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Appendix figure G23 a

Intrusion
ms 1 eqs beg: 2/1/1996 08:53
ms1 eqs end: 2/2/1996 05:41
"surge" 2/1/1996 08:09-12:10

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km
Intrusion
ms 1 eqs beg: 2/1/1996 08:53
ms1 eqs end: 2/2/1996 05:41
"surge" 2/1/1996 08:09-12:10

Pre-intrusion
Syn-intrusion
Post-intrusion


Appendix figure G23c

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
Appendix figure G24


Intrusion
ms 1 eqs beg: 10/25/1996 21:41
ms1 eqs end:10/26/1996 12:46

Pre-intrusion
syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Latitude, in degrees North
Longitude, in Degrees West
Pacific Ocean
Kilauea region boundaries

Figure G25
Pu’u ‘Ō‘o-Kupaianaha eruption: Stage IIB

Kīlauea caldera
- 0-5 km
- 5-10 km
- 10-20 km
- Deep magma supply path (> 20 km)

Uwēkahuna water-tube tilt magnitude: daily readings from arbitrary "0"

Eruptions: • summit □ east rift zone ▲ southwest rift zone

Intrusions: ○ summit □ east rift zone ▲ southwest rift zone ● Koae

Significant eq M 5.0

Silent eq (spreading steps)

54 (Napau eruption)

55

Earthquake swarms: bridle-failure
- 3-10 events (magma supply, rift zones); 5-20 events (south flank)
- >10 events (magma supply, rift zones); >20 events (south flank)

long-period
- 1-3 events (lpms4.5); 1-10 events (lpms1-3)
- 3-10 events (lpms4.5); 10-100 events (lpms1-3)
- >10 events (lpms4.5); >100 events (lpms1-3)

Appendix figure G26

Namakani Paio sequence: data from 5/30/-6/10/1997

ms 1.2 eqs beg: 6/2/1997 03:35
ms 1.2 eqs end: 6/3/1997 19:45

Pre-earthquake swarm
syn-earthquake swarm
Post-earthquake swarm

Latitude, in degrees North
Longitude, in Degrees West

Kilauea region boundaries
Pacific Ocean

Depth ranges
brittle-failure
long-period

0-5 km
5-10 km
10-15 km
> 20 km

0-5 km
5-10 km
10-15 km
> 20 km

Appendix figure G26 Namakani Paio sequence: data from 5/30/-6/10/1997

ms 1.2 eqs beg: 6/2/1997 03:35
ms 1.2 eqs end: 6/3/1997 19:45

Pre-earthquake swarm
syn-earthquake swarm
Post-earthquake swarm

Latitude, in degrees North
Longitude, in Degrees West

Kilauea region boundaries
Pacific Ocean

Depth ranges
brittle-failure
long-period

0-5 km
5-10 km
10-15 km
> 20 km

0-5 km
5-10 km
10-15 km
> 20 km
Appendix figure G27a  1/14/1998 intrusion and "surge (D-I-D)"; data from 1/12-25/1998

"surge" 1/14/1988 18:20-20:35
inclusion 1/14/1988 18:57-23:00

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure  long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries
Pacific Ocean

Latitude, in degrees North
Longitude, in Degrees West
Appendix figure G27b  1/14/1998 "surge (D-I-D)"; data from 1/12-25/1998

"surge" 1/14/1988 18:20-20:35

invasion 1/14/1998 18:57-23:00

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries

Pacific Ocean

Latitude, in degrees North

Longitude, in Degrees West
Appendix figure G28


Pre-earthquake swarm
syn-earthquake swarm
Post-earthquake swarm

eqs end: 1/28/1998 08:33

Depth ranges
brittle-failure  long-period
• 0-5 km  • 0-5 km
○ 5-10 km  ● 5-10 km
□ 10-15 km  ● 10-15 km
★ > 20 km  ⊕ > 20 km
pre-earthquake swarm: 9/18/98 17:30 to 9/19/98 6:08
syn-earthquake swarm 9/19/98 8:09 to 9/20/98 03:12

Appendix figure G29
Appendix figure G30

Glenwood (M 4.6) and south flank (M 4.8) earthquakes data from 9/27-30/1998

Glenwood mainshock: 9/27 21:56
South flank mainshock 9/28 20:39
syn glenwood
pre-south flank
syn south flank
post-south flank

Latitude, in degrees North
Longitude, in Degrees West

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean
Appendix figure G31


Hilea mainshock 4/16/1999 14:56
triggered eqs beg: 4/16/1999 15:48
triggered eqs end: 4/17/1999 05:23

Pre-mainshock
syn-triggered eqs
Post-triggered eqs

Mainshock M5.6

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean

Hilea mainshock 4/16/1999 14:56
triggered eqs beg: 4/16/1999 15:48
triggered eqs end: 4/17/1999 05:23

Pre-mainshock
syn-triggered eqs
Post-triggered eqs

Mainshock M5.6

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean

Hilea mainshock 4/16/1999 14:56
triggered eqs beg: 4/16/1999 15:48
triggered eqs end: 4/17/1999 05:23

Pre-mainshock
syn-triggered eqs
Post-triggered eqs

Mainshock M5.6

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean

Hilea mainshock 4/16/1999 14:56
triggered eqs beg: 4/16/1999 15:48
triggered eqs end: 4/17/1999 05:23

Pre-mainshock
syn-triggered eqs
Post-triggered eqs

Mainshock M5.6

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean
Mainshock 5/26/1999 06:01
aftershock eqs beg: 5/26/1999 06:04
aftershock eqs end: 5/27/1999 01:27

Appendix figure G32
Namakani Paio mainshock-aftershock sequence: data from 5/25-30/1999

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean

Pre
aftershock
Post

mainshock M 4.3

Mainshock 5/26/1999 06:01
aftershock eqs beg: 5/26/1999 06:04
aftershock eqs end: 5/27/1999 01:27
Appendix figure G33

9/12/1999 intrusion: data from 9/10-16/1999

Intrusion
eqs beg: 9/12/1999 0136
eqs end: 9/12/1999 1547
Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
long-period
● 0-5 km ★ 0-5 km
○ 5-10 km ┨ 5-10 km
□ 10-15 km ■ 10-15 km
★ > 20 km + > 20 km

Latitude, in degrees North
Longitude, in Degrees West
Pacific Ocean
Intrusion—east rift

Pre-intrusion

Syn-intrusion

Post-intrusion

Note: high number of deep (> 20 km) magma supply earthquakes preceding this intrusion

Depth ranges
brittle-failure  long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

South flank earthquake swarm
Pre-earquake swarm
syn-earquake swarm
Post-earthquake swarm

Mainshock
Pre-earquake swarm
syn-earquake swarm
Post-earthquake swarm
Appendix figure G38


suspected deep intrusion
eqs end: 6/24/2001 06:10

Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- > 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- > 10-15 km
- > 20 km

suspected deep intrusion

pre-earthquake swarm

syn-earthquake swarm

post-earthquake swarm

Silent earthquake: 9/19/2001 11:40
Pre event: 9/17-18
During event: 9/19
Post event: 9/20-22

Appendix figure G39
12/9/2001 "surge (D-I-D)"; data from 12/8-15/2001

- Pre-intrusion
- Syn-intrusion
- Post-intrusion

Appendix figure G40

Depth ranges:
- Brittle-failure
  - 0-5 km
  - 5-10 km
  - > 10 km

- Long-period
  - 0-5 km
  - 5-10 km
  - > 10 km

Pre-intrusion

- Intrusion 12/9/2001 20:54-12/10/2001 1:03

Post-intrusion

Pacific Ocean

Kilauea region boundaries

Appendix figure G41

Intrusion
ei3 eqs beg: 12/19/2001 08:49
ei3 eqs end: 12/19/2001 11:24
Pre-intrusion
Syn-intrusion
Post-intrusion

Pacific Ocean

Kilauea region boundaries

Depth ranges
brittle-failure
● 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km
long-period
＋ 0-5 km
＊ 5-10 km
＊＊ 10-15 km
＋＋ > 20 km
2/12/2002 suspected deep intrusion: data from 2/10-16/2002

Appendix figure G42

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km
- brittle-failure
- long-period

Pre-earthquake swarm
syn-earthquake swarm
Post-earthquake swarm

suspected deep intrusion
south flank eqs beg: 2/12/2002 06:47
south flank eqs end: 2/12/2002 20:41

Depth ranges

Kilauea region boundaries

Pacific Ocean

Appendix figure G43

Depth ranges
- brittle-failure: 0-5 km
- long-period: > 20 km
- 5-10 km
- 10-15 km
- > 20 km

Pre-surge
syn-surge
Post-surge
suspected deep intrusion
eqs beg: 8/21/2002 15:55
eqs end: 8/21/2002 20:00
suspected deep intrusion
eqs beg: 8/28/2002 12:02
eqs end: 8/29/2002 03:21


Kilauea region boundaries

Longitude, in Degrees West

Latitude, in degrees North

Depth ranges
brittle-failure
long-period

0-5 km
5-10 km
10-15 km
> 20 km

Pacific Ocean
Silent earthquake: 12/17/2002 11:47
south flank earthquake swarm: 12/15 18:54-12/16 15:19/2002

pre-earthquake swarm
syn-earthquake swarm
post-earthquake swarm
Appendix figure G47

Namakani Paio sequence: data from 3/31-4/14/2003

ms1 eqs beg: 4/6/2003 21:27
ms1 eqs end: 4/7/2007 3:23
Pre-eqs
Syn-eqs
Post-eqs

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries
Pacific Ocean

Latitude, in degrees North
Longitude, in Degrees West

Appendix figure G48

**Depth ranges**

- **brittle-failure**
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km

- **long-period**
  - 0-5 km
  - 5-10 km
  - 10-15 km
  - > 20 km
Pu'u 'O'o-Kupaianaha eruption 8/8/2003 "surge (D-I-D)"; data from 8/6-10/2003


Pre-surge
syn-surge
Post-surge

Kilauea region boundaries

Latitude, in degrees North
Longitude, in Degrees West

Depth ranges
brittle-failure long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Appendix figure G49
Appendix figure G51

12/22/2003 suspected deep intrusion?: data from 12/18-26/2003

suspected deep intrusion
sf3kuer eqs beg: 12/22/2003 11:16
sf3kuer eqs end: 12/22/2003 16:09
Pre-earthquake swarm
Syn-earthquake swarm
Post-earthquake swarm

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries
Pacific Ocean
Intrusion
eqs beg: 3/4/2004 0339
eqs end: 3/4/2004 0708
surge begin 3/4/2004 03:00
surge end 3/4/2004 04:00

Pre-intrusion/surge
Syn-intrusion/surge
Post-surge/syn intrusion
Post-intrusion/surge

Depth ranges
brittle-failure long-period
● 0-5 km ✧ 0-5 km
○ 5-10 km ✻ 5-10 km
□ 10-15 km ★ 10-15 km
★ > 20 km + > 20 km

Appendix figure G52
Appendix figure G54


Intrusion
eqs beg: 5/12/2004 0805
eqs end: 5/13/2004 0128
surge 5/15/2004 16:00-17:10

Pre-all
syn-surge
Post-intrusion/pre-surge
syn-intrusion
Post-all

Depth ranges
brittle-failure
long-period
• 0-5 km    ♦ 0-5 km
〇 5-10 km   ◯ 5-10 km
□ 10-15 km  ■ 10-15 km
★ > 20 km   + > 20 km

Intrusion
5/12-13/2004
surge 5/15/2004 16:00-17:10

Pre-all
syn-surge
Post-intrusion/pre-surge
syn-intrusion
Post-all

Depth ranges
brittle-failure
long-period
• 0-5 km    ♦ 0-5 km
〇 5-10 km   ◯ 5-10 km
□ 10-15 km  ■ 10-15 km
★ > 20 km   + > 20 km

Kilauea region boundaries
Pacific Ocean
Appendix figure G55


Pre-intrusion
syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km
Appendix figure G56

7/9-10/2004 intrusion: data from 7/1-14/2004

Intrusion
eqs beg: 7/9/2004  03:13
eqs end: 7/9/2004 18:24
eqs beg: 7/10/2004  04:00
eqs end: 7/10/2004 15:12

Pre-intrusion
Syn-intrusion 1
between intrusions
Syn-intrusion 2
Post-intrusion

Kilauea region boundaries

Depth ranges
brittle-failure
long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Pacific Ocean

Appendix figure G56 7/9-10/2004 intrusion: data from 7/1-14/2004
Appendix figure G57


Intrusion
eqs beg: 7/27/2004 0417
eqs end: 7/27/2004 1727
surge 7/27/2004 08:00-09:00

Pre-all
syn-intrusion/surge
syn-intrusion/post-surge
syn-intrusion
Post-all

Depth ranges
brittle-failure
0-5 km
0-5 km
5-10 km
5-10 km
10-15 km
10-15 km
> 20 km
> 20 km

Latitude, in degrees North
Longitude, in Degrees West
Appendix figure G58


ms 1 eqs beg: 11/2/2004 13:02
ms 1 eqs end: 11/2/2004 16:56

Pre-intrusion
syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
0-5 km
5-10 km
5-10 km
10-15 km
10-15 km
> 20 km
> 20 km

Kilauea region boundaries
Pacific Ocean

Latitude, in degrees North
Longitude, in Degrees West
Intrusion
eqs beg: 12/22/2004 0707
eqs end: 12/23/2004 2059
Pre-intrusion
Syn-intrusion
Post-intrusion

Appendix figure G59


Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Pacific Ocean
Kilauea region boundaries

1/26/2005 silent earthquake: data from 1/24-1/29/2005

Intrusion
eqs beg: 1/24/2005 22:42
eqs end: 1/25/2005 04:00
Silent earthquake
eqs beg: 1/25/2005 17:54
Namakani Paio
eqs beg: 1/27/2005 10:23
eqs end: 1/29/2005 16:35

Pre-silent earthquake
Syn-silent earthquake
Post-silent earthquake

Intrusion
eqs beg: 1/24/2005 22:42
eqs end: 1/25/2005 04:00
Silent earthquake
eqs beg: 1/25/2005 17:54
Namakani Paio
eqs beg: 1/27/2005 10:23
eqs end: 1/29/2005 16:35

Pre-silent earthquake
Syn-silent earthquake
Post-silent earthquake

1/26/2005 silent earthquake: data from 1/24-1/29/2005

Appendix figure G60

Depth ranges
brittle-failure  long-period
• 0-5 km  + 0-5 km
○ 5-10 km  × 5-10 km
□ 10-15 km  ♦ 10-15 km
★ > 20 km  + > 20 km

Pre-intrusion
Syn-intrusion
Post-intrusion

Intrusion
eqs beg: 1/15/2006 05:39
eqs end: 1/16/2006 01:50

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km
long-period
0-5 km
5-10 km
10-15 km
> 20 km

Kilauea region boundaries

Appendix figure G62
Appendix figure G63


Namakani Paio sequence
eqs beg: 1/22/2006 23:07
eqs end: 1/23/2006 11:40

Pre-intrusion
Syn-intrusion
Post-intrusion

Kilauea region boundaries

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km


Intrusion
eqs beg: 1/25/2006 06:23
eqs end: 1/26/2006 22:36

Pre-intrusion
Syn-intrusion
Post-intrusion

Kilauea region boundaries

Depth ranges
brittle-failure
long-period

brittle-failure
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Appendix figure G64 a
Intrusion 1 Namakani Paio
Intrusion 2 Paired East rift/seismic southwest rift

Note: Namakani Paio seismicity mostly precedes a paired inflationary intrusion beneath the seismic southwest rift zone and the upper east rift zone; rift seismicity (non-swarm) begins coincident with the Namakani Paio swarm.

Pre-rift intrusions
Syn-rift intrusions
Post-rift intrusions

Depth ranges
brittle-failure
long-period
● 0-5 km
❖ 0-5 km
○ 5-10 km
☒ 5-10 km
□ 10-15 km
مستشار 10-15 km
★ > 20 km
+ > 20 km

Appendix figure G65

East rift intrusion
eqs beg: 2/27/2006 2242
eqs end: 3/1/2006 1703

Pre-intrusion
syn-intrusion
Post-intrusion

Latitude, in degrees North

Longitude, in Degrees West

Depth ranges
brittle-failure
long-period
• 0-5 km
○ 5-10 km
□ 10-15 km
★ > 20 km
+ > 20 km

Pacific Ocean

Kilauea region boundaries
Appendix figure G67


- Intrusion
  - ms1.2 eqs beg: 3/1/2006 01:55
  - ms1.2 eqs end: 3/4/2006 20:25

- Pre-intrusion
- syn-intrusion
- Post-intrusion

Depth ranges

- brittle-failure
- long-period

- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries

Latitude, in degrees North

Longitude, in Degrees West

Pacific Ocean
suspected deep intrusion
sf3kuer eqs beg: 3/16/2006 02:02
sf3kuer eqs end: 3/16/2006 22:51
Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Appendix figure G70
Appendix figure G71


Intrusion 15 events

eqs beg: 3/22/2006 1237
eqs end: 3/23/2006 0228

Pre-intrusion
Syn-intrusion
Post-intrusion

Kilauea region boundaries

Intrusion 15 events

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
long-period

0-5 km
5-10 km
10-15 km
> 20 km

0-5 km
5-10 km
10-15 km
> 20 km
Appendix figure G73


Intrusion 13 events
eqs beg: 7/29/2006 1530
eqs end: 7/30/2006 1123

Pre-intrusion
Syn-intrusion
Post-intrusion

Latitude, in degrees North
Longitude, in Degrees West

Kilauea region boundaries
Pacific Ocean

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km
Appendix figure G74


Kilauea region boundaries

Intrusion 13 events

eqs beg: 8/3/2006 08:07
eqs end: 8/4/2006 02:30

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges

brittle-failure
long-period

- 0-5 km
- > 20 km
- 5-10 km
- 0-5 km
- 10-15 km
- > 20 km
- 10-15 km
Appendix figure G75


Longitude, in Degrees West

Latitude, in degrees North

Intrusion
south flank eqs end: 4/5/2007 07:20

Pre-intrusion
syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
long-period

Kilauea region boundaries

Pacific Ocean

0-5 km
5-10 km
10-15 km
> 20 km

Appendix figure G76

Note: sparse seismic accompaniment for this event--slight south flank offset on 4/16/2007

Latitude, in degrees North
Longitude, in Degrees West

Kilauea region boundaries

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km
Appendix figure G77


Pre-intrusion
syn-intrusion 1
syn-intrusion 2
Post-intrusion

Depth ranges
- brittle-failure
- long-period

Kilauea region boundaries
Appendix figure G78


Intrusion
eqs beg: 5/31/2007 21:29
eqs end: 6/1/2007 04:08

Pre-intrusion
syn-intrusion
Post-intrusion

Latitude, in degrees North
Longitude, in Degrees West

Kilauea region boundaries

Depth ranges
brittle-failure long-period
0-5 km
5-10 km
10-15 km
> 20 km

Pacific Ocean

post-earthquake swarms

Note: earthquake swarm coincident with silent earthquake is preceded and followed by east rift and near-east rift seismicity

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- 5-10 km
- 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 5-10 km
- 10-15 km
- > 15 km
Appendix figure G81 7/5-6/2007 intrusion: data from 7/5-11/2007

Note: upper and middle east rift swarm seismicity obscured by continuing non-swarm seismicity beneath the same locations

Intrusion 12 events
eqs beg: 7/5/2007 0611
eqs end: 7/6/2007 0138

Pre-intrusion
Syn-intrusion
Post-intrusion

7/21 vents

Kilauea region boundaries

Depth ranges
brittle-failure
0-5 km
5-10 km
10-15 km
> 20 km

long-period
0-5 km
5-10 km
10-15 km
> 20 km

Pacific Ocean
Appendix figure G82

7/16-17/2007 intrusion: data from 7/12-21/2007

Intrusion 17 events
eqs beg: 7/16/2007 2107
eqs end: 7/17/2007 1323

Pre-intrusion
Syn-intrusion
Post-intrusion

Depth ranges
brittle-failure
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

long-period
- 0-5 km
- 5-10 km
- 10-15 km
- > 20 km

Kilauea region boundaries

Pacific Ocean

Koae
sf3kuer
er1ler
sf2mer
er5swr
ms4-5
ms1-3
er4sswr
er5swr
sf4swr
sf1ler
sf3mer
er2mer
ms1-3
Appendix H. Supplementary Material to Support Chapter 8

Tables H1–H3 contain accumulated earthquake counts and moment for all regions plotted in figures 8.11 and 8.12.

Table H4a gives volumes of the three magma batches erupted at Halema‘uma‘u in 1952, 1961, and 1967-68 that are identified in eruptions between 1952 and the beginning of the Mauna Ulu eruption in May 1969. Table H4b gives additional volumes inferred for intrusions over the same period of time. See text for interpretations using these quantities.

Figure H1 shows the location of edm and Global Positioning System (GPS) stations used in constructing figures 8.8 and 8.9.
<table>
<thead>
<tr>
<th>Stage</th>
<th>Region(^1)</th>
<th>Cum cts</th>
<th>Cts/yr</th>
<th>Cum mom</th>
<th>Mom/yr</th>
<th>Acc adj mom(^1)</th>
<th>Comment</th>
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<td>pre-1952</td>
<td>ms1</td>
<td>53</td>
<td>21.30</td>
<td>1.489</td>
<td>0.599</td>
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<td>Period of inflation from March 5 1950 to the beginning of the 1952 Halema‘uma‘u eruption on June 27, 1952</td>
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<tr>
<td>1/1/1950</td>
<td>ms2,3</td>
<td>7</td>
<td>2.82</td>
<td>0.274</td>
<td>0.056</td>
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<td>40-60 km deep earthquakes north of Kīlauea caldera; precursors to the 1959 eruption in Kīlauea Iki 11/14/-12/20/1959</td>
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<tr>
<td>6/27/1952</td>
<td>ms4.5</td>
<td>21</td>
<td>8.45</td>
<td>4.131</td>
<td>0.738</td>
<td></td>
<td>Koa‘e crisis of December 8-12/1950; deep magma supply earthquakes and shallow events associated with cracking across the Koa‘e fault zone</td>
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<tr>
<td>908 days</td>
<td>ms5gln</td>
<td>1</td>
<td>0.4</td>
<td>0.028</td>
<td>0.0113</td>
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<td>Offshore south flank crisis affecting all regions with many earthquakes recorded on Oahu</td>
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<td>2.486 years</td>
<td>er1</td>
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<td>Buildup to eruption in Kīlauea Iki on November 14, 1959</td>
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<td>er2,3</td>
<td>36</td>
<td>14.5</td>
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<td>5.500</td>
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<td>Buildup to eruption on lower east rift zone on February 28, 1955</td>
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<td>8</td>
<td>3.22</td>
<td>2.333</td>
<td>0.938</td>
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<td>M 6.2, 6.6 earthquakes on March 30, 1954</td>
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<td>27</td>
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<td>4.1892</td>
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<td>1952-1961</td>
<td>ms1</td>
<td>743</td>
<td>85.8</td>
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<td>Period from the beginning of the 1952 Halema‘uma‘u eruption to the beginning of the 1961 Halema‘uma‘u eruptions</td>
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<td>6/27/1952</td>
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<td>Buildup to eruption on lower east rift zone on February 28, 1955</td>
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<td>1961-1967</td>
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<td>8.81</td>
<td>3.074</td>
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<td>Period from the beginning of the 1961 Halema‘uma‘u eruptions to the beginning of the 1967-68 Halema‘uma‘u eruption</td>
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<td>2/24/1961</td>
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<td>7.62</td>
<td>3.673</td>
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<td>Beginning in 1960 20-35 km deep earthquake swarms beneath Kīlauea caldera supplant the 40-60 km deep earthquakes north of the caldera</td>
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<td>11/5/1967</td>
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<td>6.694 years</td>
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Appendix table 8.1 cont. Accumulated counts and moment release from 1/1/1950 to 11/29/1975

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<th>cum mom</th>
<th>mom/yr</th>
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<td>193</td>
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<td>1967-68 Halema‘uma‘u eruption and the buildup to the east rift Mauna Ulu eruption</td>
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1 Regions shown in chapter 1, figure 1.3

a Moment of earthquakes of M≥6.0 is counted as “0” and shown on plots with a symbol (†) accompanied by date, magnitude and true moment.
Appendix table H2. Accumulated counts and moment release from 1/1/1976 to 1/1/1982

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^1 Counts and moment in all regions include continuing aftershocks associated with the M 7.2 earthquake of 11/29/1975
^2 Regions shown in appendix figure
^3 Moment of earthquakes of M ≥ 6.0 is counted as “0” and shown on plots with a symbol (†) accompanied by date, magnitude and true moment
## Appendix table H3a. Accumulated short-period counts and moment release for the Pu‘u ‘Ō‘o-Kupaianaha eruption

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**Comment:**
- High count from earthquakes triggered by the 11/16/1983 Kaʻōiki earthquake
- High count from earthquakes triggered by the 11/16/1983 Kaʻōiki earthquake
- Probably continuing effects of Kaʻōiki earthquake
- Probably continuing effects of Kaʻōiki earthquake
- Dominated by M 6.2 earthquake on June 25, 1989
## Appendix table 8.3a cont.

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<td>0.5365</td>
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<td>0.0193</td>
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<td>0.0198</td>
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</tr>
<tr>
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<td>8.93</td>
<td>1.5474</td>
<td>0.3005</td>
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<td>0.0986</td>
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<td>420.98</td>
<td>36.509</td>
<td>7.0893</td>
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<tr>
<td></td>
<td>sf4</td>
<td>32</td>
<td>6.21</td>
<td>0.963</td>
<td>0.0187</td>
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</tr>
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| Stage IIB | ms1 | 804 | 116.30 | 16.4008 | 2.3724 |
| 1/1/1997 | ms2.3 | 219 | 31.68 | 1.1227 | 0.1624 |
| 12/1/2003 | ms4.5 | 812 | 117.46 | 18.1447 | 2.6258 |
| 2525 days | msnp | 389 | 56.27 | 14.7828 | 2.1384 |
| 6.913 years | er1 | 114 | 16.49 | 2.2650 | 0.3276 |
| | er2.3 | 489 | 70.74 | 4.1389 | 0.5987 |
| | er4 | 16 | 2.31 | 0.0710 | 0.0103 |
| | er5 | 78 | 11.28 | 0.3074 | 0.0465 |
| | er4.5 | 94 | 13.60 | 0.3785 | 0.0548 |
| | koae | 125 | 18.08 | 0.5333 | 0.0771 |
| | sf1 | 71 | 10.27 | 1.0831 | 0.1567 |
| | sf2.3 | 3796 | 549.10 | 86.0533 | 12.5926 |
| | sf4 | 32 | 6.21 | 0.963 | 0.0187 |

| Stage IIIA | ms1 | 302 | 87.27 | 1.1262 | 0.3254 |
| 12/1/2003 | ms2.3 | 87 | 25.14 | 0.4026 | 0.1163 |
| 5/18/2007 | ms4.5 | 668 | 193.03 | 7.5018 | 2.1677 |
| 1264 days | msnp | 508 | 146.79 | 2.1303 | 0.6156 |
| 3.461 years | er1 | 65 | 18.78 | 0.5059 | 0.1462 |
| | er2.3 | 1382 | 399.35 | 9.5478 | 1.7187 |
| | er4 | 696 | 201.12 | 2.3368 | 0.6753 |
| | er5 | 34 | 9.82 | 0.0599 | 0.0173 |
| | er4.5 | 730 | 210.92 | 2.3968 | 0.6925 |
| | koae | 19 | 5.49 | 0.0254 | 0.0073 |
| | sf1 | 92 | 26.58 | 0.5784 | 0.1671 |
| | sf2.3 | 2986 | 862.85 | 24.1275 | 6.9720 |
| | sf4 | 157 | 45.37 | 0.3303 | 0.0954 |

Dominated by M 5.2 earthquake on February 1, 1994
Appendix table 8.3a cont.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Region</th>
<th>cum cts</th>
<th>cts/yr</th>
<th>cum mom</th>
<th>mom/yr</th>
<th>Comment</th>
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<td>136.07</td>
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<td>5/18/2007</td>
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<td>0.1108</td>
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<td>3/19/2008</td>
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<td>150</td>
<td>179.04</td>
<td>1.9009</td>
<td>2.2690</td>
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<td>306 days</td>
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<td>54.89</td>
<td>0.1203</td>
<td>0.1436</td>
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<td>0.838 years</td>
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<td>0.0609</td>
<td>0.0727</td>
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<td>606.36</td>
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<td>14.7732</td>
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<td>70</td>
<td>83.55</td>
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<td></td>
<td>er5</td>
<td>8</td>
<td>9.55</td>
<td>0.0098</td>
<td>0.0116</td>
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<td></td>
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<td>0.4445</td>
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<td>0.0690</td>
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<td>0.0527</td>
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<td></td>
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<td></td>
<td>sf4</td>
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<td>19.09</td>
<td>0.0778</td>
<td>0.0929</td>
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### Appendix table 8.3b. Accumulated long-period counts and moment release for Pu‘u ʻŌ‘o-Kupaianaha eruption

<table>
<thead>
<tr>
<th>Stage</th>
<th>Region¹</th>
<th>cum cts</th>
<th>Cts/yr</th>
<th>Cum mom</th>
<th>Mom/yr</th>
<th>Comment</th>
</tr>
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<td>pre-1983</td>
<td>lpms1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>1/1/1982</td>
<td>lpms2</td>
<td>5</td>
<td>4.61</td>
<td>0.0287</td>
<td>0.0265</td>
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<tr>
<td>2/1/1983</td>
<td>lpms3</td>
<td>1</td>
<td>0.92</td>
<td>0.0065</td>
<td>0.0060</td>
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<tr>
<td>396 days</td>
<td>lpms2.3</td>
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<td>5.53</td>
<td>0.0352</td>
<td>0.0325</td>
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<tr>
<td>1.084 years</td>
<td>lpms4.5</td>
<td>7</td>
<td>6.46</td>
<td>0.0170</td>
<td>0.0425</td>
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<td>Stage IA</td>
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<td>10.12</td>
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<td>0.0334</td>
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<td>0.1099</td>
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<tr>
<td>7/18/1986</td>
<td>lpms3</td>
<td>66</td>
<td>19.09</td>
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<tr>
<td>1263 days</td>
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<td>167</td>
<td>48.29</td>
<td>0.6747</td>
<td>0.1951</td>
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<td>10.12</td>
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<td>Stage IB</td>
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<td>422</td>
<td>79.49</td>
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<td>0.4421</td>
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<tr>
<td>7/18/1986</td>
<td>lpms2</td>
<td>1900</td>
<td>357.90</td>
<td>15.4470</td>
<td>2.9098</td>
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</tr>
<tr>
<td>1939 days</td>
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<td>790.40</td>
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<tr>
<td>5.309 years</td>
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<td>250</td>
<td>48.54</td>
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<tr>
<td>11/8/1991</td>
<td>lpms2</td>
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<td>66.41</td>
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<tr>
<td>1/1/1997</td>
<td>lpms3</td>
<td>1446</td>
<td>280.78</td>
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<tr>
<td>1881 days</td>
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<td>347.19</td>
<td>6.1555</td>
<td>1.1953</td>
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<tr>
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<td>0.0837</td>
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<tr>
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<td>201.94</td>
<td>15.0146</td>
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<tr>
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<td>1193</td>
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<td>0.8311</td>
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<td>128.88</td>
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<td>3.461 years</td>
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<td>8.09</td>
<td>0.2228</td>
<td>0.0644</td>
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<td>Stage IIIIB</td>
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<td>97.88</td>
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<td>5/18/2007</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3/19/2008</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>0.838 years</td>
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<td>11</td>
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<td>0.1105</td>
<td>0.1319</td>
<td>Need explanation for dramatic decrease in long-period counts</td>
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¹ Regions shown in figure 1.3
Appendix table H4. Volumes of magma batches entering Kīlauea plumbing

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<th>Magma name</th>
<th>date begin</th>
<th>date end</th>
<th>V (km$^3$)</th>
<th>Comment</th>
<th>Reference</th>
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<tbody>
<tr>
<td>1952</td>
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<td>11/9/1952</td>
<td>.0870</td>
<td>Halema'uma'u eruption</td>
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<tr>
<td>3/20/1955</td>
<td>5/26/1965</td>
<td>.0333</td>
<td>Latter part of 1955 eruption; mixing percentage 41.9</td>
<td>9, 1</td>
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</tr>
<tr>
<td>1/26/1960</td>
<td>1/29/1960</td>
<td>.0035</td>
<td>Middle part of 1960 eruption; mixing percentage 35.7</td>
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<tr>
<td>Total</td>
<td>6/3/1954</td>
<td>11/20/1959</td>
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</tr>
<tr>
<td>11/14/1959</td>
<td>11/21/1959</td>
<td>.0042</td>
<td>1959 eruption episode 1: mixing percentage 45.5</td>
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<td>11/22/1959</td>
<td>12/20/1959</td>
<td>.0027</td>
<td>1959 eruption episodes 2-17: mixing percentage 13.2</td>
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<tr>
<td>Total</td>
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<td>2/4/1960</td>
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<td>2/24/1961</td>
<td>7/17/1961</td>
<td>.0103</td>
<td>Halema'uma'u eruptions (3)</td>
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<tr>
<td>Total</td>
<td>2/18/1960</td>
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<tr>
<td>11/5/1967</td>
<td>7/14/1968</td>
<td>.0744</td>
<td>Halema'uma'u eruption</td>
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<td>Total</td>
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<td></td>
<td>.5130</td>
<td>Grand total: Total amount of unfractionated magma identified; add .01 km$^3$/year for rift dilation during spreading; lifetime of magma batches ~ 10 years</td>
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### b. Additional magma transfer to east rift zone: Deflation volumes not associated with eruption$^i$

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<th>Comment</th>
</tr>
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<td>Assumed to be magma batch of 1952 chemistry</td>
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<td>Minimum volume1952 magma intruded into the rift zone.</td>
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<td>3/24/1954</td>
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<tr>
<td>12/13/1954</td>
<td>1/17/1955</td>
<td>.0114</td>
<td>do</td>
</tr>
<tr>
<td>2/19/1955</td>
<td>12/29/1955</td>
<td>.1494</td>
<td>do</td>
</tr>
<tr>
<td>8/31/1959</td>
<td>11/14/1959</td>
<td>.0011</td>
<td>do</td>
</tr>
<tr>
<td>Subtotal</td>
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<td>.2024</td>
<td>Volume of 1961 magma intruded into the east rift zone</td>
</tr>
<tr>
<td>11/15/1959</td>
<td>11/23/1959</td>
<td>.0213</td>
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<td>12/23/1959</td>
<td>1/17/1960</td>
<td>.0103</td>
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<td>12/6/1962</td>
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<td>do</td>
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<td>6/28/1963</td>
<td>7/2/1963</td>
<td>.0085</td>
<td>do</td>
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<td>8/22/1963</td>
<td>.0036</td>
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<td>10/1/1966</td>
<td>10/7/1966</td>
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<td>Subtotal</td>
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<tr>
<td>Total</td>
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</tr>
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$^i$ Volumes calculated from deflation

$^ii$ Latest time that magma can enter east rift zone for mixing with the latter part of the 1960 eruption
Figure H1. Maps showing locations of stations shown in text figures 8.9 and 8.10. A, Stations in the Hawaiian Volcano Observatory edm network. Stations used in the plots in this report are circled in red. B, Stations in the Hawaiian Volcano Observatory Global Positioning System (GPS) network. Stations used in the plots in this report are circled in red.
Appendix figure H1 b. Kilauea south flank GPS network
Appendix I. Summit tilt calculations and Mogi inflation centers

Modeling of tilt changes

The simplest and most useful way to model the buried inflation and deflation source at Kīlauea is the point Mogi pressure source in an elastic half-space (Mogi, 1958). We state here the theoretical elevation, tilt and total volume relations historically used to model contour maps of elevation changes from leveling surveys, and maps of tilt vectors from tiltmeter arrays. Here \( d \) is the horizontal distance from the source center, \( f \) is the depth of the source, \( a \) is the radius of the source sphere, \( P \) is the pressure inside the buried sphere and \( \mu \) is the rigidity measured in the same units as the pressure. The elevation change when pressure is applied is (Eaton, 1962; Mogi, 1958):

\[
\Delta h = \frac{3a^3P}{4\mu} \left[ \frac{f}{(f^2 + d^2)^{3/2}} \right]
\]

We abbreviate the expression \( 3a^3P/4\mu \) with the letter \( K \) (expressed in units of \( \text{km}^3 \)), which is (1) constant for a given episode, (2) determined empirically by the data, and (3) a measure of the strength of the source. The change at the center of inflation (\( d = 0 \)) is \( \Delta h_0 = K/f^2 \). The integrated volume of the uplift or collapse is \( \Delta V = \Delta h_0 2\pi f^2 \) (Eaton, 1962). Thus:

\[
\Delta V = 2\pi K
\]

and depends only on the strength of the source and not directly on its depth \( f \). This \( \Delta V \) is the volume of the elastic source but must allow for magma compression before equating to magma volume. The radial tilt change \( \tau \) around the Mogi source is also a function of distance \( d \) and depth \( f \) (Eaton, 1962; Jackson and others, 1975):

\[
\tau = \frac{K 3d/f}{f^3(1 + d^2/f^2)^{5/2}}
\]

The maximum tilt \( \tau_m \) occurs at \( d = f/2 \) and is \( \tau_m = 0.86K/f^3 \). A useful relation is:

\[
\frac{\tau}{\tau_m} = 3.5 \frac{d/f}{(1 + d^2/f^2)^{5/2}}
\]

The volume change is \( \Delta V = 2.32\pi f^3 \tau_m \) (Dzurisin et al, 1984). Thus \( \Delta V = 2\pi K \), the same relation as derived from elevation. \( K \) (and thus \( \Delta V \)) can be determined from elevation changes, tilt, or both. It is useful to estimate volume change from a single tiltmeter like Uwēkahuna or Whitney when it is the only record of a single deflation event. Combining equations 2 and 3 yields:
\[
\Delta V = \frac{\tau 2\pi \left(1 + d^2 / f^2\right)^{3/2}}{3d / f} = D\tau 
\]

(5)

The volume factor \(D\) can be calculated for each tiltmeter’s response to a single source, and may not change much during several inflation/deflation episodes.

The elevation change \(\Delta h\) and tilt \(\tau\) have different dependencies on the source depth \(f\). The maximum height \(\Delta h_0\) scales with \(\sim f^2\): moving a source deeper rapidly reduces the height of the bulge, but broadens it so that the volume depends only on the strength of the Mogi source. For distances \(d\) large compared to the source depth \(f\), \(\Delta h \sim Kf/d^3\), for \(d >> f\). The height has a weak dependence on source depth but very rapidly falls off with distance. The maximum tilt \(\tau_m\) scales with \(\sim f^3\), thus tilt diminishes rapidly with increasing source depth, and has a stronger dependence on source depth than the elevation function \(\Delta h\). For distances \(d\) large compared to the source depth \(f\), \(\tau \sim 3Kf/d^4\), for \(d >> f\). The tilt on the flanks of the bulge also has a weak dependence on source depth, but falls off very strongly with distance.

At Kīlauea, we estimate the volume change \(\Delta V\) (essentially the factor \(K\)) from a single tilt change \(\tau\). The tilt scales linearly with \(K\), once the distance and source depth are known. The tilt has a weak dependence on source depth \(f\), and varies essentially as \(f\) to the first power. Tilt has a strong dependence on distance \(d\), however, starting at 0 at \(d = 0\), reaching a sharp maximum, and falling off as \(d\) to the fourth power. For the \(d >> f\) case, \(\tau \sim 3Kf/d^4\). A source depth change from 2.5 to 3.5 km produces only a 30% change in tilt, but changing \(d\) by 20% changes tilt by 100%. The volume change \(\Delta V\) does not depend only on the source depth: the source depth (even an approximate one) is needed to calculate the shape of the elevation or tilt curve, but the volume scales with the amplitude of the curve, not its width. It is therefore very important to determine the inflation source location fairly well before scaling \(\Delta V\) from \(\tau\), and to calibrate the \(\Delta V\) to \(\tau\) relation for a time period with well-determined source location but not necessarily well-determined source depth. In other words, for a Mogi source of a given strength, changing the lateral position of the source by 1 km can have a much bigger effect on tilt than changing the depth by 1 km.

The location and depth of the Mogi source, or more complicated source approximated with concentric contours, can be determined from a map of level contours or a map of tilt vectors. The level contours are concentric on the source location and their average radii yield a set of distance versus \(\Delta h\) points. A spreadsheet programmed with equation (1) can calculate the elevation profile, and the source depth and intensity \(K\) can be determined interactively.

For any two stations, 1 and 2, the depth \(f\) of the deformation source can be determined from measuring the tilt magnitude \(\tau\) and the known distance from each station to the source location and then calculating depth directly from the tilts \(\tau_1\) and \(\tau_2\), and their source distances \(d_1\) and \(d_2\). Taking the ratio of the tilt equations and solving for \(f\) yields

\[
f^2 = (Cd_1^2 - d_2^2)/(1 - C) \quad \text{where} \quad C = (\tau_1 d_2 / \tau_2 d_1)^{2/5}
\]

(6)
A graphic solution may be found for the source location from the average intersection of tilt vectors. The source depth and the constant K (or volume) may then be determined iteratively by fitting tilts (or elevations) and distances with a spreadsheet. Errors of the source determination may be empirically estimated from the fitting or mismatch of elevation contours and the circularity of contours. Alternatively, a least-squares solution for the source depth and location can be obtained for measurements from a network of stations using a computer program. This can yield average values for different time periods, but the progression of inflation or deflation centers is best estimated from changes of tilt azimuth over short periods of time.

**Examples of fitting a Mogi source**

We next examine an example elevation and tilt profile for the 1966–1967 summit inflation (figure I1). This example covers a time when both the leveling and tilt measurements span approximately the same period, and there are adequate measurements to determine the Mogi source. The example also illustrates some problems with using only tilt data. The inflation height contour radii were measured from the October 1967 leveling survey differenced from the January 1966 survey (Fiske and Kinoshita 1969, their figure 4A). The deformation location is near 155º 16.8’ west, 19º 23.7’ north. The iteratively determined source depth from both elevation and tilt is at 3.3 km. The wet tilt measurements fit the Mogi profile fairly well, except for measurements like Ke‘amoku, which typically shows tilt magnitudes much larger than the model fit to other stations, and may have some amplification due to local ground effects. Because there are only 5 independent and un-corrupted tilt stations, and because the tilt curve fit is poorer than the level curve, water tube tilt by itself does not yield a good Mogi solution. The Uwēkahuna long-base tiltmeter is a few hundred meters from the vault housing the short-base tiltmeter, but the two measurements agree fairly well. The calculated volume change from tilt and leveling is 0.056 km$^3$. The volume factor D estimated for Uwēkahuna from this 1966–1967 episode is about 0.00050 km$^3$/microradian.

We next plot elevation and tilt profiles for the 1959 inflation and 1960 summit deflation (figure I2). This is not as clean a time period as the 1967 example because the episode includes both inflation and deflation with possible migration of the deformation center, and because the elevation and tilt surveys include overlapping but not identical time periods. The tilt history at Uwēkahuna and Whitney is plotted vs. time in figure A1, showing the amount and timing of pre-eruption inflation and the big January 1960 collapse. The deflation height contour radii (figure I2a) were measured from the May 1960 leveling survey differenced from the January 1958 survey (figure I3; Eaton, unpublished). The deformation location is the same as 1966-67 and is near 155º 16.8’ west, 19º 23.7’ north. The iteratively determined source depth from elevation contours is at 2.53 +/- 0.05 km, the volume change is 0.070 km$^3$ (K=0.011 km$^3$), and the Mogi fit is good over all radii. We estimate a minimum error of 0.05 km based on multiple fit attempts and the scatter of data points within model curves. The lateral error is larger, about 0.2 km based on visual examination of contours and the original leveling points. The Mogi model curves are fit to an average radius of the level contours, and lack of circularity or concentricity of the contours is another source of error. A rigorous statistical inversion of level data and errors is beyond the scope of this paper and is unnecessary for the volcanic conclusions we draw. The tilt solution (addendum figure 3b) uses the water tube tilt changes between January 12, 1959 and July 7, 1960 (HVO tilt file, Asta Miklius, personal communication, 2009). This interval is as close as possible to
the leveling interval, but includes the pre-eruption inflation in 1958–59, the November 1959 eruption, and most of the 1960 deflation. The tilt values (figure 12b), even when the Keʻamoku site is excluded, do not define a smooth Mogi curve. The Mogi source at the depth of 2.53 km (determined from the 1/58-5/60 leveling survey) can’t be determined from the noisy and sparse 1/59–7/60 tilt data, and a tilt-based source at 3.0 km depth is equally likely. The volume changes are 0.107 and 0.125 km$^3$, respectively. Even though the two 1959-60 volumes derived from tilt are very uncertain, they agree within 20–30% of each other, and are larger than the 0.07 km$^3$ volume determined from leveling because they exclude a year of prior inflation and include two additional months of deflation.

The 1/20/60 – 4/1/60 tilt survey (figure 14), started just after the great deflation had begun, is a large event and is fit as well by a Mogi solution as any Kīlauea an water tube tilt survey can be. We show alternative Mogi solutions at 2.5, 3.0, and 3.5 source depths. We exclude the errant Keʻamoku station. The best fit is between the 3.0 km and 3.5 km source depths, where only the first two stations discriminate between those depths. The 2.5 km source depth, found for the 1/58–5/60 leveling survey, which includes the 1/60–4/60 tilt survey and two years of prior inflation, is a poorer fit to the water tube data. This suggests the pre-1960 inflation was centered shallower than 2.5 km, and the 1960 deflation was between 3.0 and 3.5 km.

The tilt results suggest that a well-placed tilt station (like Uwēkahuna or Whitney on the flank of a tilt bulge) can estimate the magnitude of an inflation or deflation to about 20%, once the location and depth of the center is known. The comparisons also suggest that level surveys are much better than tilt surveys to locate inflation centers: even a tilt survey made over the optimum 1/60-4/60 period where the changes are very large can only resolve depths to about a kilometer, but level surveys can resolve Mogi depths to about 0.2 km or better with smaller changes. Water tube tilt was measured more easily by a survey crew over a shorter time period than a level survey, and tilt provides a crude approximation to a level survey. We only use level surveys to estimate inflation/deflation centers (table I1).

The leveling and tilt data suggest the inflation in 1958–1959 was at a shallower 2–2.5 km Mogi center depth than the subsequent 1960 collapse, which was deeper, perhaps between 3.0 and 3.5 km, but this is not well-determined. Figure 12a demonstrates 2.53 km is a good average depth for the 150 microradian inflation and 350 microradian deflation (net 200 microradian deflation) of the whole 1958–60 episode. The 3.0 to 3.5 km source depth of the 1/20/60 – 4/1/60 tilt collapse (figure I4) suggests that the deflation occurred at a depth greater than the average. Thus the inflation (about half of the later deflation) must have been shallower than 2.53 km. We interpret this result to mean that the top of the magma reservoir expands in response to inflation and magma addition, but that deflations, particularly large ones, are centered deeper in the reservoir.
Both source depths and volumes are subject to errors in determination. Note that the source depth $f$ can be fairly well determined by fitting the elevation profile (figure I2a). Estimating the source depth from a tilt profile as equal to twice the distance at which the maximum tilt occurs (figures I1b, I2b) can be more difficult, however: tilt varies widely near its maximum radius and near the source because tilt is very sensitive to non-Mogi irregularities of the source near the surface. Also there is more depth error if only sparse tilt data are available. Both the elevation and tilt curves scale linearly with the volume change $\Delta V$. Thus the volume determination is generally well determined from a profile of height or tilt measurements, and is less sensitive to irregularities in the tilt curve. Choosing a short time period spanning a single but large inflation or deflation episode may yield a better fit from a simple Mogi source. The tilt data and multiple Mogi curves of figure I2b show that even if source depth and location are well known, volume estimates made from a single tilt measurement can easily be in error by about 20–40%, and more if the location is poorly known.

**Multiple inflation and deflation centers and reservoir volume relations**

We determined a Mogi inflation/deflation source for a large set of published level surveys, and can infer some characteristics of the magma reservoir source. We determined the deformation center locations, depth and volumes from contoured level survey maps using the same methods as in the sample cases above. The Mogi center locations and depths are in appendix figures A2 and I5 along with those of Fiske and Kinoshita (1969). The level profiles with model fits are in figures I6 and I7, and the events and parameters are listed in the table I1.

Most of the Mogi centers strongly cluster in the south caldera, with another smaller cluster in the central caldera. Two centers lie outside the main cluster (10/76–3/77 and 3/77–8/77), one to the south and one to the SW (appendix figure A2). The level surveys for these two centers involve a rift zone contribution and are not a bulls-eye pattern. Both the centers determined in this paper and the Fiske and Kinoshita (1969) centers define the two south and central caldera areas active during this period. The Fiske and Kinoshita centers may scatter a bit more in the east-west direction, but the apparent east-west lineation is not visible in the larger data set and two irregular clusters without an east-west lineation is a better representation of the active area.

We interpret the scatter of different deformation centers as both a shifting locus of magma accumulation and depletion, and the expression of a source that is irregular in shape and definitely not a point source as represented in the Mogi model. The 2 km extent of the sources is larger than the error associated with any one source, and individual error does not contribute much to the extent of sources. Detailed inversions of source shapes are possible using tilt, level and displacement data (eg. Dieterich and Decker, 1975), but we will only generalize that the deforming part of the caldera is an irregular shape about 2 km in diameter in the south caldera.
**1924 subsidence**

We determined three alternative Mogi models to the 1921–1927 survey which includes the large 1924 eruption and caldera collapse (Wilson, 1935). This was the largest eruption observed geodetically and the maximum deflation was more than twice that in the large January 1960 eruption. The models are for 1, 2 and 3 Mogi sources all centered below Halema‘uma‘u. The first 1-source model with a deflation center at 1.65 km depth does not fit the level data very well (figure I6a). Adding a shallow deflation source 800 m below Halema‘uma‘u to a source at a typical 3.8 km depth greatly improves the fit to level contours out to 6 km from the center (figure I6b). Subsidence did not stop at the caldera boundary 6 km from Halema‘uma‘u, however, and the level line continued through Keaau (39 km from Halema‘uma‘u) to Hilo. The line to Keaau is almost radial to caldera, but we do not model the dog-leg extension from Keaau to Hilo. A third deflation source at about 30 km depth is required to subside the flank of Kīlauea out to 40 km. We kept the shallow 800m source and moved the 3.8 km source to a depth of 3.5 km to get the best fit (figure I6c). The exact depth and volume of the 30 km source is definitely not well determined because it comes only from fitting the four points along the Volcano highway to Keaau. This is only one radial line and not a concentric set of confirming level curves as would be desired.

There is no geodetic record elsewhere in the past 200 years for a deforming magma source below the base of the crust. And yet Wilson’s leveling suggests a source on the order of 30 km distant from the documented sources within the crust beneath Halema‘uma‘u. We suggest in the text for chapter 3 that the anomalous source is not a deep Mogi source beneath Halema‘uma‘u, but rather as an eccentric and unlocated source that we postulate as representing the loss of a deep magma system beneath the east rift zone, a loss that extended beyond the documented intrusion near the end of the onshore east rift zone.

**Filling and draining of magma reservoirs**

The depths of the Mogi inflation/deflation centers illuminate the portions of the magma reservoir that fill between eruptions and drain during different size deflations. Refer to figure I8 showing the distribution of Mogi depths for centers listed in table I1 by the volume change of the event. Most inflation and deflation centers are between 3 and 4 km deep, and this is the most active part of the reservoir. All but one of the centers between 2.0 and 2.9 km are small inflation centers. This means the top of the active reservoir is just above 2 km depth. The exception to the small inflation in the upper reservoir rule is the 1/58–5/60 period, which includes two years of inflation followed by a larger deflation, with a net average depth of 2.5 km. Of course the upper reservoir can participate in other events, which also include volume changes in other parts of the reservoir and have deeper average Mogi centers. We exclude the 10/76–3/77 event as a special case: it is south of the caldera and is separated from the other centers laterally and is much deeper at 6.0 km. This center occurred during the recovery after the M7.2 Kalapana earthquake in which the south flank moved laterally south up to 6 m, and probably represents filling of the deeper voids in the Koae fault zone created by the earthquake as well as filling the shallow magma reservoir.
The largest volume reservoir events (>0.06 km³) are different in distribution from the smaller events (figure I8). On average, the smaller events (<0.06 km³) tend to inflate at a shallow center between 2.0 and 3.6 km, but small rapid deflation events are between 3.0 and 3.8 km. The four largest deflationary points include collapses from the 1924 eruption, the Nov. 1975 earthquake, and the Jan–Feb 1960 eruption (which is included in two survey periods). These four deflationary points have a linear trend where the larger the volume change, the deeper the deflation center. This means the draining must tap deeper parts of the reservoir to gain more magma volume change, and the deflation center moves downward as more of the deeper reservoir is tapped. The depths of different sized inflation and deflation sources means the reservoir tends to add magma at its top (like filling a pail) and to subtract magma lower down (like opening a valve on the side of a pail).

The linear relation of volume change of the largest deflations to the Mogi depth, and the observation that all volume changes lie below this line (figure I8), suggest that there is a geometric relation between the change of liquid magma and the total reservoir volume. The line defined by the four large deflations is $\Delta V = 0.089(f-1.75)$ where $\Delta V$ is the magma volume change in km³, and $f$ is the depth of the Mogi center. The intercept of this linear relation (1.75 km) and the shallowest observed Mogi depth (2.0 km) suggest that we assume the top of the reservoir is at 1.75 km. Let us also assume for modeling purposes that the active reservoir is a sphere centered at depth $f$. The deepening of this active reservoir with magma volume change also means the size of the active reservoir increases with depth. If we model the top of the reservoir at a depth of 1.75 km, its radius is $f-1.75$ and its volume $V$ is $4\pi/3 (f-1.75)^3$.

The volume fraction of inflating/deflating magma is $\Delta V/V$, which in our model depends on $f$. For Mogi depths of 2.5, 3.0 and 3.5, the liquid to total volume fractions are 3.7%, 1.3% and 0.68%. Wright and Klein (AGU 2010) noted that erupted/intruded magma batches in mid-20th century Kīlauea eruptions had volumes of about 0.2 km³, which for a reservoir diameter of 3 km, yields a liquid fraction of 1.4%, the same as our middle value. The hypothesized relation between liquid fraction and depth means that larger, deeper deflations have smaller liquid magma fractions by volume, and small shallow events have more liquid. Note that the observed volume changes in figure I8 are all below this maximum line because many volume changes occur within a spherical volume that does not reach the top of the reservoir at 1.75 km. Thus the top of the reservoir is mostly liquid and the bottom is mostly solid, which agrees with the lower density of magma compared to rock. Of course this reasoning is based on a simplified point model and is qualitative in nature.

**Whitney tilt volume calculations**

In an effort to determine magma center volume changes from a single tiltmeter, we examine the simpler period of January 20 to April 1, 1960, during which Kīlauea summit underwent a massive deflation associated with the East rift eruption of 1/13–2/19/1960. Unfortunately there is no level survey for this interval, but the deflation is included in a longer interval from 1/58 to 5/60 for which a level survey exists (table I1, event 1). We can use this 1960 deflation as an example of estimating source depth from two tiltmeters and volume change from a single tiltmeter. The tilts are 275 and 199 microradians and the source distances are 3.2 and 3.8 km for the short-base water tubes at Uwēkahuna and Whitney, respectively. Equation (6) thus yields a source depth of 3.0 km. Comparison of measured portable water-tube tilts and a calculated Mogi source at 3.0 km depth (figure I4) confirm the 3.0 km depth and a volume of
0.107 km$^3$ as a good fit to the tilt data, excluding Ke‘amoku as an amplified site. Note that (figure 15) the location of the two tiltmeters on the flank of the tilt bulge does not give a good resolution of the source depth but does measure the height of the tilt curve. The tradeoff between volume and source depth of the three curves of figure 14 means that for variation of +/- 0.5 km from its average source depth of 3.0 km, the magma volumes vary by +/- 20%. The volume error will be more than these interdependence variances. These tiltmeters give similar volume estimates. From appendix table A2, the ratio of Whitney to Uwēkahuna tilt for a depth of 3 km is 1.38. We apply this ratio to the Dvorak factor for Uwēkahuna of 0.00045 km$^3$/micro-radian to yield 0.00062 km$^3$/micro-radian for the conversion of Whitney tilt magnitude to volume. We use this factor for the volume calculations during periods before 1960 when the only measurements were tilt made at the Whitney vault.

Given the good fit of a Mogi source to the water-tube tilts of the 1960 deflation, what volume changes do the continuous tiltmeters at Uwēkahuna and Whitney imply? We can both calculate theoretical volume factors from the 3.0 km source using equation (5), and determine empirical factors from the 0.107 km$^3$ source volume determined from all 7 tiltmeters. Equation (5) applied to Uwēkahuna yields a theoretical volume factor of D$_{UT}$=0.00035 km$^3$/microradian. The empirical volume factor using 275 microradians of deflation and a 0.107 km$^3$ source determined by the Mogi curve fit imply that D$_{UE}$=0.00039 km$^3$/microradian for Uwēkahuna. The empirical value is probably a better one to use because it uses volumes calculated by an array of tiltmeters and includes a tiltmeter site correction. The 0.107 km$^3$ source volume was determined by fitting a curve to an array of 7 tiltmeters, not just the tiltmeter whose volume factor we are determining. Increasing the theoretical volume factors calculated from equation (5) by 10% should empirically correct other sources measured at Uwēkahuna. Note that the Uwēkahuna short-base tilt in the 1966–67 inflation (figure 11b) similarly requires a positive 20% correction to match the Mogi source determined by the tiltmeter array. The empirical volume factor is similar to the summit volume factor value of 0.00045 km$^3$/microradian used by Dvorak and Okamura (1985) and Dvorak and Dzurisin (1993). Each tiltmeter will have its own volume factor D because it depends on the distance and depth to the source.

The theoretical volume factor for the Whitney tiltmeter and the 1960 deflation source is D$_{WT}$=0.00049 km$^3$/microradian, which is somewhat larger than the Uwēkahuna factor because Whitney is farther from the source. The empirical factor for Whitney is D$_{WE}$=0.00054 km$^3$/microradian. The theoretical volume factors for Whitney also require a 10% correction. Using equation (5) and typical deformation centers (table I1), we can calculate a table of tiltmeter volume factors for various Mogi locations and depths, and apply the 10% empirical correction (see table I2). The Dvorak factor for Uwēkahuna that we use (0.00045 km$^3$/micro-radian) corresponds to a source depth of ~ 3.8 km in appendix table A1. The tilt factor applied to the Pu‘u ‘Ō‘o -Kupaianaha (PK) eruption gave an eruption efficiency of 1.01 for deflation azimuths near Fiske-Kinoshita center 1. The dike volume estimated for the dike associated with episode 1 of the PK eruption is higher by a factor of 1.5 than the volume estimated by the tilt deflation (Hall Wallace and Delaney, 1995). If this volume is used in the summation of text table 7.8, the eruption efficiency is close to or slightly less than 1.
References


Mogi, K., 1958, Relations between the eruptions of various volcanoes and the deformations of the ground surfaces around them: Bulletin of the Earthquake Research Institute, v. 36, p. 111–123.

## Appendix table I1: Inflation/deflation centers derived from leveling contour maps.

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<td>Swanson et al 1976 fig 20</td>
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<td>Shallow deflation source 2 km NE of inflation center; elongate source.</td>
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<td>Kidney shaped contours; average of E and W transects; possible deep ~30 km source may improve curve fit.</td>
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<td>Intrusion made an inflation signal, not deflation. Elongated contours follow SW rift; volume thus underestimated; NW transect from uprift end of source.</td>
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<td>Subset of previous period, primarily with inflation and no deflation.</td>
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<td>Jul</td>
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<td>Average of NW and SE transects.</td>
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<td>East rift has a non-Mogi dike intrusion deformation, but caldera has Mogi src.</td>
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<td>Complex pattern in S &amp; E caldera; inner contour not fit by model and may require a very shallow source; SW transect</td>
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<td>SSE transect, contours elongate to NE.</td>
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<td>East transect; contours elongate to NE.</td>
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<td>Average of NW &amp; NE transects; inner contour poorly fit.</td>
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<td>Elongate dike-like bulge along SWR and diminished central bulge relative to Mogi model. Mogi volume is thus overestimated for summit, but total volume including SW extension may be underestimated by Mogi model.</td>
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<td>Lipman et al 1985 fig 17</td>
<td>Lipman et al 1985 fig 17c</td>
<td>M7.2 earthquake</td>
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<td>Lipman et al 1985 fig 17d</td>
<td>Lipman et al 1985 fig 17e</td>
<td>Post earthquake deflation; ERZ deflation from intrusions.</td>
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<td>Lipman et al 1985 fig 17f</td>
<td>Lipman et al 1985 fig 17g</td>
<td>Southerly, deep deflation center; one ERZ intrusion.</td>
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<td>0.0043</td>
<td>Lipman et al 1985 fig 17h</td>
<td>Lipman et al 1985 fig 17i</td>
<td>Mogi fit to west end of elongate depression across south caldera with small bump in middle. Actual source is maybe 2x larger and more irregular than Mogi.</td>
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<td>Lipman et al 1985 fig 17j</td>
<td>Lipman et al 1985 fig 17k</td>
<td>West transect. Excellent Mogi fit.</td>
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<td>Delaney et al 1993 fig 5</td>
<td>Cervelli and Miklius 2003 fig 5</td>
<td>Steady deflation sustained Puu Oo eruption. Total from 8 yr average.</td>
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<td>Steady deflation sustained Puu Oo eruption. Total from 6 yr average.</td>
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(*) Irregular source shape, Mogi elevation contours not a good fit, but source depth may be OK.
Contours roughly circular unless noted otherwise. Mogi a good fit unless noted with *. Transect through contours taken to give "average" radii to the NW or N unless noted otherwise. Zero contour assumed to be arbitrary and chosen at an outer benchmark within deformation zone, thus the offset factor adjusts the data to a baseline to fit the Mogi curve.
## Appendix table I2. Long-base water-tube tilt vectors 1960-1965

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References

1(Koyanagi and others, 1963; Krivoy and others, 1963; Krivoy and others, 1964); 2(Krivoy and others, 1964); 3(Koyanagi and others, 1964); 4(Krivoy and others, 1965); 5(Koyanagi and others, 1964); 6(Koyanagi and others, 1964); 7(Koyanagi and others, 1964); 8(Okamura and others, 1964?); 9(Kinoshita and others, 1965?; Koyanagi and others, 1965; Koyanagi and others, 1965; Okamura and others, 1965; Okamura and others, 1966); 10(Okamura and others, 1966); 11(Koyanagi and others, 1966; Powers and others, 1966); 12(Koyanagi and others, 1969); 13(Okamura and others, 1963); 14(Okamura and others, 1964)

¹Long-base water-tube tilt stations in use: Tree Molds; Uwekahuna; Keauuhua; Sand Spit; Ahua (figure 18). One additional station (Kalihipaa) lies to the south of the network on the map. Magnitudes are small and azimuths from this station are not used.

²The Keauuhua station vector is consistently ~10 degrees more southerly than the intersection of the other vectors.

³Sand Spit lies very close to the centers of inflation/deflation and its azimuth determines the direction to the center.

⁴The Ahua station vector is consistently ~10 degrees more westerly than the intersection of the other vectors.

⁵Results from the daily readings in Uwekahuna vault measured over the same time interval as the long-base network.

⁶Results from the daily readings in Uwekahuna vault measured over the entire period of inflation or deflation.

⁷Inconsistent tilt intersection. Ahua (southernmost station) shows deflation toward Koae fault zone—other stations mixed.

⁸Ahua shows inflation toward Koae—still recording recovery from Koae intrusions.

⁹Ahua shows deflation toward the Koae—still showing effects of Koae intrusions.

¹⁰Anomalous deflation toward east rift zone associated with Koae deformation and intrusion.

¹¹Ahua shows deflation toward Koae; Uwekahuna, Tree Molds and Sand Spit show deflation toward east rift zone.
Figure 11. Comparison of leveling contour radii (A) and water-tube tilt surveys (B) around Kīlauea Caldera for the nearly identical time periods of the two survey types (March 1966–November 1967 for tilt, January 1966–October 1967 for leveling). Leveling data from Fiske and Kinoshita (1969); water-tube tilt data from the files of the Hawaiian Volcano Observatory. The same Mogi model is compared to both data sets—source depth of 3.3 km; source volume of 0.056 km$^3$. The Mogi fit was to the level data, which is much better at determining the location and depth of the Mogi center. The tilt data confirms that a Mogi source fit can only approximate the tilt data. Tilt data, particularly from a short-base tiltmeters in a vault, has the advantage of frequency of measurement. The tilt at the Uwēkahuna Vault closely matches the Mogi model and thus is a good measure of source volume, assuming the source is about 3 km distant. For locations of the long-base water-tube tiltmeters, see figure I5.

Figure 12. Comparison of leveling contour radii (A) and water-tube tilt surveys (B) around Kīlauea Caldera for the overlapping but nonidentical time period including the major 1960 collapse. The source depth of 2.53 km is well determined for the January 1958–May 1960 leveling interval. A depth error of about +/-0.05 km is a minimum error because it only considers misfit of the average radii data points to the Mogi model and not other error sources (see text). The same source depth (with an adjustment for a slightly larger volume change) adequately fits the tilt data for the shorter January 1959–July 1960 period. A deeper Mogi source at 3.0 km (blue curve in B) improves the tilt fit for the shorter time interval, however. For locations of the long-base water-tube tiltmeters, see figure I5.

Figure 13. Elevation changes in the Kīlauea summit region, from 1958 to July 1960. Contour interval in feet. The primary zone of subsidence is centered on Halemaʻumaʻu Crater. A secondary zone of subsidence is defined near Makaopuhi Crater on Kīlauea's east rift zone. This is an area of secondary magma storage and intrusion that has also been active during subsequent eruption cycles (Jackson and others, 1975, figure 32; Moore and Krivoy, 1964, figure 4; Swanson and others, 1976b, figure 4). Finally, the changes along the Hilina Pali road, traversing the Koaʻye Fault Zone between the east rift and south flank, show seaward tilting in the Koaʻye,
and relative uplift of the south flank across the Kalanaokuaiki Pali. This uplift is consistent with movement of magma from the upper parts of Kīlauea’s east rift zone combined with seaward movement of Kīlauea’s south flank. This is also in agreement with the south-southeast azimuths of Whitney tilt vectors shown in text figure 4.3 during this period. (Contour map produced by the Topographic Division of the U.S. Geological Survey at the request of Jerry Eaton. Based on unpublished data of Jerry Eaton).

**Figure 14.** Tilt values from the water-tube tilt array for the major caldera collapse from 20 January to 1 April 1960. Also plotted are Mogi model curves for three different source depths. The large size of the tilt values relative to background noise mean this is the best data in the Kīlauea water-tube tilt record to constrain a Mogi source, yet there is still uncertainty with regard to the source depth. A depth of 3.0–3.5 km fits better than the shallow 2.53-km depth for the longer period that includes both inflation and deflation (figure I2). Fortunately, the Uwēkahuna Vault is well placed to record the the source amplitude (for volume calculations) and is relatively insensitive to source depth because the model curves intersect near the 3-km distance of Uwēkahuna for this source location. For locations of the long-base water-tube tiltmeters, see figure I5.

**Figure 15.** Location of inflation-deflation centers. Using Mogi models: Tiltmeter locations are shown as green triangles, and locations of inflation and deflation centers as red circles. The green stars are centers from the mid 1960s identified by Fiske and Kinoshita (1969). The blue symbols are locations of the long-base water-tube tilt network. Red x’s are geographic features. The blue symbols (keyed to depth) in appendix A figure A2 (not shown here) are inflation and deflation centers determined in this study and listed in appendix table I1. Using long-base water-tube network: Tilt vectors are tabulated and plotted in Hawaiian Volcano Observatory seismic summaries. As the tilt vectors do not intersect in a point, the location is estimated by eye from the various plots. The Sand Spit and Outlet stations lie very close to the centers of inflation/deflation located south-southeast of Halema‘uma‘u. The locations plotted use The Sand Spit tilt vector to place the deformation epicenter, even though intersections from other pairs of stations, for example Tree Molds and Uwēkahuna, may lie on the opposite side of Sand Spit from that indicated by the vector at Sand Spit. The
centers of inflation and deflation all lie within the Fiske-Kinoshita array within an area of 1 km$^2$ marked by black oval and are approximately equidistant from Uwēkahuna. Time periods covered by inflation (+) and deflation (-) centers are labeled as follows:

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**Figure I6.** Elevation profiles vs. radius from the Mogi inflation/deflation center, determined for the 1924 subsidence measured between 1921 and 1927, assuming a single source ($A$), two sources ($B$) or three surces ($C$). See table I1 for the Mogi sources.

**Figure I7.** Elevation profiles vs. radius from the Mogi inflation/deflation center, determined for the set of 32 survey time periods after 1924 that are listed in table I1. The elevation vs. distance data are for the average radius from all published elevation contour maps the authors could locate in the literature. The iteratively determined Mogi fits are also plotted. The sub-figure numbers (01 to 32) are keyed to survey numbers in table I1.

**Figure I8.** Mogi volume changes vs. Mogi source depths for the set of time periods listed in table I1. The inflation center depths (squares), which are almost exclusively in the range from 2.0 to 3.5 km, average less than the deflation depths (diamonds), which are concentrated in the range of 3.0 to 3.8 km. This means the reservoir tends to expand near its top, but deflate from lower down near 3–4 km. The four largest volume deflations nearly form a line which is an empirical limit to the size of the maximum deflation, with
larger deflations limited to Mogi centers lower in the reservoir. This linear relation of volume to depth, when combined with the assumption that the top of the reservoir is at about 1.75 km depth, predicts that the percentage of the active fraction of magma increases with shallower depths. Thus the top of the reservoir is mostly liquid and the bottom is mostly solid.
Appendix fig I1. Leveling data 1/66-10/67 (Fiske and Kinoshita 1969)
Water tube tilt data 3/16/66 - 11/7/67 (HVO files)
Mogi model for both: 3.3 km source depth, 0.056 km³ source volume

A

Leveling

Mogi model

elev change

B

Water tube tilt

Sand spit

Kamokukolau

long base
short base

Uwekahuna

Keamoku

Tree molds

Mehana

Uwekahuna Short base

~0.00050 km³/microradian
Appendix fig I2.

A. Leveling

- Mogi model
- Elev change

a. 1/58-5/60 inflation & collapse. 2.53 km deep source, deflation volume 0.07 km^3.

B. Water tube tilt

- Mogi 3.0 km model
- Water tube tilt
- Mogi 2.53 km model

b. 1/12/59-7/7/60 inflation & collapse. 3.0 km deep source, deflation volume 0.125 km^3. Alternative 2.53 km deep source, deflation volume 0.107 km^3.
Figure I3. Elevation changes, 1958-July 1960 [Run by the Topographic Division of the U.S. Geological Survey at the request of Jerry Eaton; unpublished data courtesy of Jerry Eaton]
Appendix fig I4. 1/20/60 - 4/1/60 collapse, water tube tilt

source depth 3.5 km, volume 0.132 km^3,
source depth 3.0 km, volume 0.107 km^3,
source depth 2.5 km, volume 0.085 km^3

- Mogi model 3 km
- water tube tilt
- Mogi model 2.5 km
- Mogi model 3.5 km

Legend:
- Whitney vault
- Uwekahuna
- Ahua
- Tree molds
- Keamoku
- Sand spit
- Mehana
- long water tube
- short water tube
Appendix I. Figure I5 Inflation/deflation centers determine from the long-base water tube network

Inflation centers (i)       -    deflation centers (d)

Fiske-Kinoshita inflation centers 1-10

Long-base water-tube tilt sites

Latitude

Longitude
Appendix fig. 16. Mogi model fits to contoured levelling data. See addendum table I1 for Mogi source data.
Appendix fig. I7.01-04. Mogi model fits to contoured levelling data. See table I1 for Mogi source data.
Appendix fig. I7.05-08. Mogi model fits to contoured levelling data. See table I1 for Mogi source data.
Appendix fig. I.09-12. Mogi model fits to contoured levelling data. See table I.1 for Mogi source data.
Appendix fig. I.7.13-16. Mogi model fits to contoured levelling data. See table I.1 for Mogi source data.
Appendix fig. I.7.17-20. Mogi model fits to contoured levelling data. See table I.1 for Mogi source data.
Appendix fig. I7.21-24. Mogi model fits to contoured levelling data. See table I1 for Mogi source data.
Appendix fig. I7.25-28. Mogi model fits to contoured levelling data. See table I1 for Mogi source data.
Appendix fig. 17.29-32. Mogi model fits to contoured levelling data. See table I1 for Mogi source data.
Appendix figure I8. Mogi volume changes vs. Mogi center depths for a set of level surveys.