DOE/OR/22089-3

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

ANNOTATED BIBLIOGRAPHY

VOLCANOLOGY AND VOLCANIC ACTIVITY WITH A PRIMARY FOCUS ON POTENTIAL HAZARD IMPACTS FOR THE HAWAI'I GEOTHERMAL PROJECT

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U.S. Geological Survey

OPEN-FILE REPORT 93-512A

Prepared in cooperation with the U.S. Department of Energy

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INTRODUCTION

This annotated bibliography is intended to provide a convenient review of published references about potential volcanic hazards on the Island of Hawai'i that are pertinent to drilling and operating geothermal wells. The bibliography was prepared at the request of the U.S. Department of Energy (DOE), as part of the U.S. Geological Survey's contribution to the Kilauea Environmental Impact Statement being written by DOE.

The first two sections of this annotated bibliography list the most important publications that describe eruptions of Kilauea volcano, with special emphasis on activity in and near the designated geothermal subzones (A report on geothermal resource subzones for designation by the Board of Land and Natural Resources, State of Hawaii, Department of Land and Natural Resources, August 1984, 101 p.). In addition, we assume that power lines transporting electricity will be constructed either across the Humu'ula Saddle, between Mauna Loa and Mauna Kea, or along the Hamakua (northeastern) coast. Therefore, we also describe references about historic eruptions from Mauna Loa's northeast rift zone, as well as the most recent activity on the southern flank of dormant Mauna Kea, adjacent to the Humu'ula Saddle. The most recent eruptions of Mauna Kea on its northeastern and northern flanks (Hamakua coast) occurred about 5,000 years ago (Laupahoehoe Point) and 7,100 years ago (Pu'u Kole).

The last section of this annotated bibliography lists the most important publications that describe and analyze deformations of the surface of Kilauea and Mauna Loa volcanoes. No deformation studies of Mauna Kea have been published.

I. VOLCANIC ACTIVITY ON THE ISLAND OF HAWAI'I

A. KILAUEA

Decker, R.W., and Christiansen, R.L., 1984, Explosive eruptions of Kilauea Volcano, Hawaii: in Explosive Volcanism: Inception, evolution, and hazards. Washington, D.C., National Academy Press, p. 122-132.

This paper summarizes studies of deposits produced by phreatomagmatic and phreatic explosions at Kilauea's summit, concentrating on the 1924 and 1790 eruptions, the Uwekahuna and Pahala Ashes, and pyroclastic deposits in the Hilina Basalt. The authors conclude that, in all cases, lowering of the magma column below a shallow water table triggered phreatomagmatic and phreatic explosions.

Holcomb, R.T., 1987, Eruptive history and long-term behavior of Kilauea volcano: U.S. Geological Survey Professional Paper 1350, Chapter 12, p. 261-350.

This important paper describes the geology of all of Kilauea. It focuses on the age of the volcano's modern surface, as determined mainly by paleomagnetic secular-variation studies and interpretation of relative ages from air photographs. Holcomb determined that 90% of Kilauea's surface is less than 1,100 years old, and 70% is less than 500 years old.

Macdonald, G.A., Abbott, A.T., and Peterson, F.L., 1983, Volcanoes in the sea--The geology of Hawaii (second edition): University of Hawaii Press, Honolulu, 517 p.

This excellent book, revised from the first edition published in 1970, summarizes the geology of the entire State of Hawai'i. Chapters of particular usefulness for the Environmental Impact Statement describe volcanic activity, historic eruptions, hazards associated with eruptions, and the regional geology of the Island of Hawai'i.

McPhie, J., Walker, G.P.L., and Christiansen, R.L., 1990, Phreatomagmatic and phreatic fall and surge deposits from explosions at Kilauea volcano, Hawaii, 1790 A.D.; Keanakakoi Ash Member: Bulletin of Volcanology, v. 52, p. 334-354.

The authors recognized three phases of the A.D. 1790 hydromagmatic eruption: (1) an early phreatomagmatic episode that deposited well-bedded ash rich in juvenile material and older lithic fragments; (2) Strombolian activity that produced a scoria-fall deposit, followed by phreatomagmatic activity that deposited ash similar to that of the first phase; and (3) a phreatic episode that deposited lapilli and lithic blocks interbedded with pyroclastic-surge layers. The magma column is thought to have been at a high level beneath Halema'uma'u Crater during the phreatomagmatic and Strombolian phases, but withdrawal of the magma column to feed eruptions on Kilauea's lower east rift zone is postulated as the cause of the phreatic eruptions.

Moore, R.B., 1983, Distribution of differentiated tholeiitic basalts on the lower east rift zone of Kilauea Volcano, Hawaii; A possible guide to geothermal exploration: Geology, v. 11, p. 136-140.

This paper summarizes the geology of Kilauea's lower east rift zone and presents data on the distribution of vents that erupted olivine-controlled and differentiated tholeiitic basalt. Several small, shallow magma reservoirs that might be targets for geothermal exploration are identified on the basis of the chemical data.

Moore, R.B., 1992, Volcanic geology and eruption frequency, lower east rift zone of Kilauea volcano, Hawaii: Bulletin of Volcanology, v. 54, p. 475-483.

This paper also summarizes the geology of Kilauea's lower east rift zone, but it focuses more on the distribution, ages, recurrence intervals, and volumes of lava flows erupted during the past 2,360 years. The author briefly addresses volcanic hazards on the lower east rift zone and the potential impact of lava flows and rarer explosive eruptions on people and man-made structures. Explosive phreatomagmatic and phreatic eruptions resulted in deposition of lithic-rich tuff around Pu'ulena (between 1,270 and 490 years B.P.) and Kapoho Craters (between 340 and about 200 years B.P.).

Moore, R.B., and Trusdell, F.A., 1991, Geologic map of the lower east rift zone of Kilauea volcano, Hawaii: U.S. Geological Survey Miscellaneous Investigations Series Map I-2225, scale 1:24,000.

This map shows the distribution of the products of 112 separate eruptions that underlie the surface of the lower east rift zone and adjacent north and south flanks of Kilauea. About 75 percent of the area is covered by vent deposits and lava flows erupted during the past 400 years. The map distinguishes different tholeiitic basalt rock types on the basis of the relative abundances of olivine, plagioclase, and pyroxene phenocrysts.

Stearns, H.T., and Macdonald, G.A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Division of Hydrography Bulletin 9, 363 p.

Although superseded in many cases by more recent work, this lengthy report is still essential first reading for anyone interested in the geology of the Big Island. In addition to descriptions of each of the five volcanoes that form the island, the report describes historic eruptions of Kilauea, Mauna Loa, and Hualalai. The report also briefly describes the effects of bombing active Mauna Loa lava flows in 1935 and 1942 during attempts to protect Hilo.

Reports on specific historic eruptions that have affected areas of Kilauea now designated as geothermal subzones (no annotation provided):

<u>Lower east rift zone eruptions around 1790</u>:

see Moore and Trusdell, 1991; Moore, 1983, 1992 (all described above)

<u>1840</u>:

Macdonald, G.A., 1944, The 1840 eruption and crystal differentiation in the Kilauean magma column: American Journal of Science, v. 242, no. 4, p. 177-189.

Trusdell, F.A., 1991, The 1840 eruption of Kilauea volcano: Petrologic and volcanologic constraints on rift zone processes: M.S. Thesis, University of Hawaii-Manoa, 109 p.

<u>1955</u>:

Macdonald, G.A., and Eaton, J.P., 1964, Hawaiian volcanoes during 1955: U.S. Geological Survey Bulletin 1171, 170 p.

1960:

Richter, D.H., Eaton, J.P., Murata, K.J., Ault, W.U., and Krivoy, H.L., 1970, Chronological narrative of the 1959-60 eruption of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 537-E, 73 p.

1961:

Richter, D.H., Ault, W.U., Eaton, J.P., and Moore, J.G., 1964, The 1961 eruption of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 474-D, 34 p.

1963:

Moore, J.G., and Koyanagi, R.Y., 1969, The October 1963 eruption of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 614-C, 13 p.

1965:

Wright, T.L., Kinoshita, W.T., and Peck, D.L., 1968, March 1965 eruption of Kilauea Volcano and the formation of Makaopuhi lava lake: Journal of Geophysical Research, v. 73, p. 3181-3205.

1968:

Jackson, D.B., Swanson, D.A., Koyanagi, R.Y., and Wright, T.L., 1975, The August and October 1968 east rift eruptions of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 890, 33 p.

1977:

Moore, R.B., Helz, R.T., Dzurisin, D., Eaton, G.P., Koyanagi, R.Y., Lipman, P.W., Lockwood, J.P., and Puniwai, G.S., 1980, The 1977 eruption of Kilauea Volcano, Hawaii: Journal of Volcanology and Geothermal Research, v. 7, p. 189-210.

1983-1993 and continuing:

Wolfe, E.W., Garcia, M.O., Jackson, D.B., Koyanagi, R.Y., Neal, C.A., and Okamura, A.T., 1987, The Puu Oo eruption of Kilauea Volcano, episodes 1-20, January 3, 1983, to June 8, 1984: U.S. Geological Survey Professional Paper 1350, Chapter 17, p. 471-508.

Heliker, C., and Wright, T.L., 1991, The Pu'u 'O'o-Kupaianaha eruption of Kilauea: EOS, Transactions, American Geophysical Union, v. 72, no. 47 (November 19, 1991), p. 521, 526, and 530.

B. MAUNA LOA

Lipman, P.W., and Banks, N.G., 1987, Aa flow dynamics, Mauna Loa 1984: U.S. Geological Survey Professional Paper 1350, Chapter 57, p. 1527-1567.

Although this report describes the major flow of only one eruption, the reported observations may be pertinent to future Mauna Loa eruptions and on assessments of volcanic hazards. The authors found that, despite the relatively high speed of the distal end of the flow early in the eruption, the flow front stagnated because the lava channel repeatedly was blocked by debris from the channel walls, causing ponding, channel overflows, and lateral breakouts far above the distal end. This stagnation reduced concern that the flow might reach Hilo.

Lockwood, J.P., Lipman, P.W., Petersen, L.D., and Warshauer, F.R., 1988, Generalized ages of surface lava flows of Mauna Loa Volcano, Hawaii: U.S. Geological Survey Miscellaneous Investigations Series Map I-1908, scale 1:250,000.

This map is the best currently available that portrays the general geology of all of Mauna Loa at a usable scale. It shows the distribution of Mauna Loa lava flows in five age groups. Flows of historic age cover about 13 percent of the volcano's surface. Several historic flows have covered parts of the Humu'ula Saddle.

Lockwood, J.P., and Lipman, P.W., 1987, Holocene eruptive history of Mauna Loa Volcano: U.S. Geological Survey Professional Paper 1350, Chapter 18, p. 509-535.

This well-illustrated report points out that 90 percent of Mauna Loa's surface is covered with flows less than 4,000 years old. The rate of lava production during historic time (A.D. 1843 and later) is higher than during the previous 650 years.

Lockwood, J.P., Dvorak, J.J., English, T.T., Koyanagi, R.Y., Okamura, A.T., Summers, M.L., and Tanigawa, W.R., 1987. Mauna Loa 1974-1984; A decade of intrusive and extrusive activity: U.S. Geological Survey Professional Paper 1350, Chapter 19, p. 537-570.

This report describes multidisciplinary studies of the two most recent eruptions of Mauna Loa, including detailed chronologies. Seismicity increased one to four years prior to each eruption. Inflation of the summit resumed immediately after the end of the 1984 eruption.

C. MAUNA KEA

Wolfe, E.W., Wise, W.S., and Dalrymple, G.B., in press, Geology and petrology of Mauna Kea Volcano, Hawaii--A study of post-shield volcanism: U.S. Geological Survey Professional Paper.

This lengthy report, preprints of which can be obtained from the senior author, is the only comprehensive modern description of Mauna Kea. It describes in detail the alkalic and transitional basalts that cap the tholeiitic shield. The authors generally follow the stratigraphic nomenclature of Stearns and Macdonald (1946), recognizing the older Hamakua Volcanics and younger Laupahoehoe Volcanics, as well as interbedded glacial deposits. The most recent eruptions occurred during the period 7,100-4,400 years B.P. Mauna Kea is considered dormant, and seismic monitoring indicates that no magmatic activity has occurred during the past several decades.

Wolfe, E.W., and Morris, J., 1989, New geologic map of the Island of Hawaii (abs.): New Mexico Bureau of Mines & Mineral Resources Bulletin 131, p. 297.

This map (scale 1:100,000), which is in review, portrays the generalized geology of each of the five volcanoes that comprise the Island of Hawai'i. We include it in this section because it best depicts the relationship of relatively young Mauna Kea and Mauna Loa lava flows in the vicinity of the Humu'ula Saddle.

II. ANALYSES AND MITIGATION OF VOLCANIC HAZARDS ON THE ISLAND OF HAWAI'I

Analyses of hazards

Mullineaux, D.R., Peterson, D.W., and Crandell, D.R., 1987, Volcanic hazards in the Hawaiian Islands: U.S. Geological Survey Professional Paper 1350, Chapter 22, p. 599-621.

This comprehensive report, an update of an earlier version by Mullineaux and Peterson (1974), summarizes the hazards that accompany volcanic eruptions in Hawai'i. Hazards that have affected people and artificial structures in the past include lava flows, tephra falls, volcanic gases, and pyroclastic surges. Lava flows cause the most structural damage. The authors suggest that the most effective mitigation procedures include land-use planning prior to eruptions and evacuation when necessary. They discuss the effectiveness of barriers, diversion channels, explosives, and cooling of lava with water. Maps of the Island of Hawai'i show zones of relative risk of people and structures being affected by lava flows, tephra, ground fractures, and subsidence.

Heliker, C., 1990, Volcanic and seismic hazards on the Island of Hawaii: U.S. Geological Survey General Interest Publication , 48 p.

This well illustrated report, written mainly for the general public, describes potential hazards that the people of the Island of Hawai'i face from eruptions, earthquakes, and tsunamis. The author presents maps showing the relative likelihood of burial by lava flows in various parts of the island. These maps are intended to guide the public in the selection of sites to buy land or build a house.

Wright, T.L., Chun, J.Y.F., Esposo, J., Heliker, C., Hodge, J., Lockwood, J.P., and Vogt, S.M., 1992, Map showing lava-flow hazard zones, Island of Hawaii: U.S. Geological Survey Miscellaneous Field Studies Map MF-2193, scale 1:250,000.

This map is updated from the one presented in Heliker (1990), using more recently available mapping (Wolfe and Morris, 1989; Moore and Trusdell, 1991).

Mitigation of hazards

Several attempts have been made to disrupt the natural flow of lava during eruptions, chiefly by using explosives or building barriers. The following reports (not annotated) discuss these attempts in Hawai'i in some detail:

Lockwood, J.P., and Torgerson, F.A., 1980, Diversion of lava flows by aerial bombing--lessons from Mauna Loa Volcano, Hawaii: Bulletin Volcanologique, v. 43-4, p. 727-741.

Macdonald, G.A., 1958, Barriers to protect Hilo from lava flows: Pacific Science, v. 12, p. 258-277.

Macdonald, G.A., and Eaton, J.P., 1964, Hawaiian volcanoes during 1955: U.S. Geological Survey Bulletin 1171, 170 p.

Macdonald, G.A., 1962, The 1959 and 1960 eruptions of Kilauea volcano, Hawaii, and the construction of walls to restrict the spread of the lava flows: Extrait Bulletin Volcanologique, v. 24, p. 249-294.

Richter, D.H., Eaton, J.P., Murata, K.J., Ault, W.U., and Krivoy, H.L., 1970, Chronological narrative of the 1959-60 eruption of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 537-E, 73 p.

III. ANALYSES OF GROUND DEFORMATION ON THE ISLAND OF HAWAI'I

Ando, M., 1979,The Hawaii earthquake of November 29, 1975; low dip angle faulting due to forceful injection of magma: Journal of Geophysical Research, v. 84, p. 7616-7626.

Seismic and geodetic data are used to conclude that earthquake motion of the south flank of Kilauea volcano occurred along a low angle fault at 9-10 km depth. It also demonstrates that the sea floor was subject to coseismic uplift, in contrast to subsidence of the subaerial edifice.

Arnadottir, T.A., Segall, P., and Delaney, P.T., 1991, A fault model for the 1989 Kilauea south flank earthquake from leveling and seismic data: Geophysical Research Letters, v. 18, p. 2217-2220.

This paper presents a preliminary examination of leveling data traversing the lower east rift zone and recording up to 24 cm of subsidence attributable to the magnitude 6.1 earthquake of 26 June 1989. The best-fit dislocation accounting for the leveling data is 12 km wide and 20 km long, shallowly dipping to the northwest and trending parallel to the east rift zone at 4 km depth. This representation of the earthquake source predicts 1 m of slip.

Delaney, P. T., Fiske, R.S., Miklius, A., Okamura, A.T., and Sako, M.K., 1990, Deep magma body beneath the summit and rift zones of Kilauea Volcano, Hawaii: Science, v. 247, p. 1311-1316.

This report summarizes motions on Kilauea between 1970 and 1990, particularly those after the magnitude 7.2 earthquake of 1975. It documents subsidence along the lower east rift zone at rates of 2 cm/yr and extension along baselines measured northward from the rift zones of 1-5 cm/yr. Motions are attributed to adjustment of a deep magma body following the 1975 earthquake.

Delaney, P. T., Miklius, A., Arnadottir, T.A., Okamura, A.T., and Sako, M.K., in press, Motion of Kilauea volcano during continuous eruption from the Puu Oo and Kupaianaha vents, 1983-1991: submitted to Journal of Geophysical Research (57 ms pages, 29 figures, 3 tables).

This manuscript presents a detailed examination of geodetic data collected on Kilauea from 1983 through 1991. It demonstrates that subsidence along the lower east rift zone continued through 1991; subsidence locally accelerated during the two years following the magnitude 6.1 earthquake of 1989. Geodetic stations along the coast south of the east rift zone moved seaward at rates of about 5 cm/yr.

Lipman, P.W., Lockwood, J.P., Okamura, R.T., Swanson, D.A., and Yamashita, K.M., 1987, Ground deformation associated with the 1975 magnitude 7.2 earthquake and resulting changes in activity of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 1276, 45 p.

This report presents an analysis of motions accompanying the magnitude 7.2 south flank earthquake of 1975. The maximum subsidence was 3 m along the coast south of Kilauea summit, and 8 m of extension occurred from Mauna Loa across Kilauea's summit and south flank. Displacements along the lower east rift zone were considerably less; subsidence was everywhere less than 1 m and horizontal displacements less than 2 m.

Swanson, D.A., Duffield, W.A., and Fiske, R.S., 1976, Displacement of the south flank of Kilauea Volcano; the result of forceful intrusion of magma into the rift zones: U.S. Geological Survey Professional Paper 963, 39 p.

In addition to making the case that rift zone dike intrusions are responsible for seaward displacements of Kilauea's south flank, this paper offers the only modern summary of early 20th century triangulation, showing that seaward migration has occurred since the earliest surveys in 1896 and 1914.

Yamashita, K.M., and Furukawa, B.T., 1988, Elevations and descriptions for second order level benchmarks surveyed by the Hawaiian Volcano Observatory on the island of Hawaii: U.S. Geological Survey Open-File Report 88-358, 104 p.

Results of leveling in east Hawaii during this century are compiled in this report. Although not interpretive, it is the most comprehensive summary of measured vertical motions, tabulating all level surveys from the tide gauge site in Hilo during 1912, 1926, 1958, 1971, 1975, 1976, and 1979.

Decker, R.W., Koyanagi, R.Y., Dvorak, J.J., Lockwood, J.P., Okamura, A.T., Yamashita, K.M., and Tanigawa, W.R., 1983, Seismicity and surface deformation of Mauna Loa volcano, Hawaii: Eos, v. 64, p. 545-547.

This paper predicted the 1984 eruption of Mauna Loa. Increased seismicity and rates of deformation measured around the summit caldera of Mauna Loa indicated that magma was being stored in a shallow summit reservoir prior to 1984. Extension of monitor line lengths across the caldera continued after the 1975 eruption at rates of 20-50 mm/yr. All deformation appeared to have been confined to the general summit area.