DOE/OR/22089--4

U. S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

ANNOTATED BIBLIOGRAPHY, SEISMICITY OF AND NEAR THE ISLAND OF HAWAII AND SEISMIC HAZARD ANALYSIS OF THE EAST RIFT OF KILAUEA

by
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(Open File Report 93-551B)

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

March 28, 1994

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March 17, 1993
revised May 14, 1993

SECTIONS:
1. SEISMICITY OF HAWAII AND KILAUEA VOLCANO
2. OCURRENCE, LOCATIONS AND ACCELERATIONS FROM LARGE HISTORICAL HAWAIIAN EARTHQUAKES
3. SEISMIC HAZARDS OF HAWAII
4. METHODS OF SEISMIC HAZARD ANALYSIS

1. SEISMICITY OF HAWAII AND KILAUEA VOLCANO

Bryan, C.J. and C.E. Johnson, 1991, Block tectonics of the island of Hawaii from a focal mechanism analysis of basal slip, Bulletin of the Seismological Society of America, v. 81, pp. 491-507.

Examines the tectonics of the three mobile flanks of Kilauea and Mauna Loa Volcanoes using focal mechanisms of recent earthquakes. The slip vectors of earthquakes point seaward. Each flank is thus a block moving seaward on a basal slip plane. This slip plane is the source area for large Hawaiian earthquakes. This model has been accepted for Kilauea's south flank since the mid 1970's, and this is the first paper to study three different flanks.

Coffman, J.L., C.A. von Hake and C.W. Stover eds., 1982, Earthquake history of the United States, Nat. Ocean. and Atmos. Admin. and U.S. Geological Survey publication 41-1 revised, 258 pp.

Lists earthquakes in Hawaii from 1834 to 1970 with their approximate locations, and maximum intensities and magnitudes when available. Data are less complete during the early part of this history. This source plus the isoseismal data and list of intensity V earthquakes from 1833-1915 of Wyss and Koyanagi (1993) provide the best pre-instrumental summary of earthquake intensity data available for Hawaii. Includes a short verbal description of felt and damage areas. The Hawaii section is 6 pages.

Hawaiian Volcano Observatory, 1969-1987, Summaries 49-72 (1968 through 1973, issued quarterly) and Summaries 74-85 (1974 through 1985, issued annually), published by the Hawaiian Volcano Observatory.

Nakata, J.S., R.Y. Koyanagi, W.R. Tanigawa, A.H. Tomori and P.G. Okubo, 1991, Hawaiian Volcano Observatory summary 89 part 1, seismic data, January to December 1989, U.S. Geological Survey Open-File Report 91-564, 102 pp.

Tomori, A.H., J.S. Nakata, P.G. Okubo, W.R. Tanigawa and J.P. Tokuuke, 1991, Hawaiian Volcano Observatory summary 90 part 1, seismic data, January to December 1990, U.S. Geological Survey Open-File Report 91-578, 79 pp.

The annual HVO Summaries reviews the geologic history for the year, the seismic network and instrumentation, and the data processing procedures. The more recent summaries include tables of earthquake counts, earthquake maps and lists of earthquake locations. The summaries themselves are not very useful for earthquake hazard studies, but represent the earthquake catalog. The catalogue consists of computer files of earthquake magnitudes and locations. The unpublished computer files are used for plotting maps and for gauging the level of seismicity at different magnitude levels for different areas.

Copies of the summaries will not be supplied to the DOE unless specifically requested. Publication of the summaries indicates that the earthquakes have been processed and are available for analysis in computer form.

Klein, F.W., 1982, Earthquakes at Loihi submarine volcano and the Hawaiian hotspot, Jour. Geophysical Res., v. 87, pp. 7719-7726.

Examines the earthquake swarms observed at Loihi submarine volcano located 35 km off the coast of Hawaii south of Kilauea Volcano. Magnitude 4 to 5 events have been observed at Loihi. Loihi earthquakes during 1971-72 indicate summit swarms followed by larger flank earthquakes. This succession indicates a probable intrusion or eruption followed by slip within the adjacent and presumably mobile flank. Loihi's flanks could produce magnitude 6 earthquakes with an unknown recurrence time.

Klein, F.W. and R.Y. Koyanagi, 1985, Earthquake map of south Hawaii 1968-1981, U.S. Geological Survey Miscellaneous Ivestigations Map I-1611, 1:100,000.

Microearthquakes are shown as dots whose color indicates depth. Shows the active source areas of seismicity, especially Kilauea Volcano and its flanks. Accompanying text gives an introductory interpretation of the seismicity.

Klein, F.W., R.Y. Koyanagi, J.S. Nakata and W.R. Tanigawa, 1987, The seismicity of Kilauea's magma system, in Volcanism of Hawaii, R.W. Decker, T.L. Wright and P.H. Stauffer, eds., U.S. Geological Survey Professional Paper 1350 chapter 43, pp. 1019-1186.

Contains maps, depth slices, cross sections and interpretations of Kilauea's seismicity from the earthquake catalog gathered by the Hawaiian Volcano Observatory. Discusses three earthquake families: (1) those close to active volcanic rifts and conduits, (2) those in Kilauea's mobile flanks which are the largest magnitude and not directly caused by magma pressure, and (3) deeper mantle earthquakes related to the vertical feeder conduits and deformation of the mantle under the load of the volcanic pile. Contains a detailed look at the first group (1) of earthquakes which are directly related rift and summit intrusions and eruptions. Also includes but not extensively discuss maps of seismicity under the ocean surrounding Kilauea Volcano.

Klein, F.W., and R.Y. Koyanagi, 1989, The seismicity and tectonics of Hawaii, in The Eastern Pacific Ocean and Hawaii, volume N of the Decade of North American Geology, J. Winterer, D. Hussong and R. Decker eds., Geological Society of America, pp. 238-252.

Provides an overview of the seismicity and tectonics of Hawaii including Kilauea, the island of Hawaii, the adjacent ocean, and the island chain. Shows the source regions of the largest earthquakes recorded during 1968-1987.

Koyanagi, R.Y., 1981, Seismicity of the Lower East Rift Zone of Kilauea Volcano, Hawaii, 1960 to 1980, U.S. Geological Survey Open-File Report 81-984, 26 pp.

Presents map plots, cross sections and strain release maps of Kilauea and Lower East Rift earthquakes for the years 1976-77. Also shows time history plots and frequency vs. magnitude plots for the 1960-80 time period including the February and May 1970 earthquake swarms. These earthquake data are useful to understanding earthquake occurence, and thus are relevant for some parts of a seismic hazard study of the geothermal development areas.

Macdonald, G.A., Hawaiian volcanoes during 1952, U.S. Geological Survey Bulletin 1021-B, 108 pp. plus 14 plates.

Pages 35-44 of this report discuss an earthquake swarm off the south coast of Hawaii in March and April 1952. The earthquake sequence may have been at Loihi submarine volcano or may have accompanied seaward motion of the submarine south flank of the island. Instrumental coverage was not adequate enough to get reliable earthquake locations and infer the causative mechanism. The largest events reached MM intensity IV along Hawaii's south coast.

Micro-geophysics Corporation, 1975, Seismicity report on Pahoa prospect, Hawaii County, Hawaii, Micro-geophysics Corporation, 607 Tenth St., Golden CO 80401, 303-279-0226, 21 pp.

Reports a short field study with portable seismographs on Kilauea's Lower East Rift Zone. The 42 local microearthquakes located south of the rift zone were in the same pattern as in the longer time periods studied by the HVO seismic net. This study was of a prospecting nature to look for local earthquake anomalies and has no apparent relevance to seismic hazards on Hawaii.

Wyss, M., 1986, Regular intervals between Hawaiian earthquakes: implications for predicting the next event, Science, v. 234, pp. 726-728.

This paper notes that mainshocks in the Kaoiki area west of Kilauea Caldera experienced magnitude 5.5-6.6 earthquakes at intervals of 10.5 +/- 1.5 years during 1941-1983. This is very useful for understanding Hawaii tectonics and for intermediate term earthquake prediction in this area. The fact that moderate earthquakes can be expected to recur in this area is relevant to hazard analysis. The hypothesis of this paper could be used to calculate how the probability of strong ground shaking changes on Kiauea with time. Hazards calculated over a 50 year period would include several moderate earthquakes at Kaoiki, however.

Wyss, M., R.Y. Koyanagi and D.C. Cox, 1992, The Lyman Hawaiian earthquake diary, 1833-1917, U.S. Geological Survey Bulletin 2027, 34 pp.

A list of earthquakes with felt descriptions kept by Mrs. S.J. Lyman and her daughter in Hilo, Hawaii. The descriptions can be interpreted as intensities and form a mostly complete list of earthquakes with Hilo intensities greater than or equal to V. Includes a cumulative plot of number of events with intensity V or larger versus time. Intensity V earthquakes average 3.5 events per year.

Wyss, M., F.W. Klein and A.C. Johnson, 1981, Precursors to the Kalapana M=7.2 earthquake, Jour. Geophysical Res., v. 86, pp. 3881-3900.

Wyss, M., A.C. Johnson and F.W. Klein, 1981, Multiple asperity model for earthquake prediction, Nature, v. 289, pp. 231-234.

Wyss, M., 1986, Seismic quiescence precursor to the 1983 Kaoiki (Ms = 6.6), Hawaii, earthquake, Bulletin of the Seismological Society of America, v. 76, pp. 785-800.

Wyss, M. and Zhengxiang Fu, 1989, Precursory seismic quiescence before the January 1982 Hilea, Hawaii, earthquakes, Bulletin of the Seismological Society of America, v. 79, pp. 756-773.

These are the major papers by Max Wyss on seismic rate changes before major Hawaiian earthquakes. Each event was preceded by a statistically significant drop in background seismicity. Seismic quiescense is often controversial in other areas where the rate changes may result from earthquake catalog artifacts or when the method of accessing the statistical significance is questionable. This topic is important for earthquake preparation models and earthquake prediction. Seismic quiescense has no effect on the long term probability of strong ground shaking, but may be useful in altering the probability months or years before an earthquake. This is only possible when seismicity rates are carefully monitored within a seismic network.

Wyss, M., B. Liang, W.R. Tanigawa, and Xiaoping Wu, 1992a, Comparison of orientations of stress and strain tensors based on fault plane solutions in Kaoiki, Hawaii, Jour. Geophysical Res., v. 97, pp. 4769-4790.

Liang, B. and M. Wyss, 1991, Estimates of orientations of stress and strain tensors based on fault-plane solutions in the epicentral area of the great Hawaiian earthquake of 1868, Bulletin of the Seismological Society of America, v. 81, pp. 2320-2334.

Gillard, D., M. Wyss and J.S. Nakata, 1992, A seismotectonic model for western Hawaii based on stress tensor inversion from fault plane solutions, Jour. Geophysical Res., v. 97, pp. 6629-6641.

Wyss, M., D. Gillard and B. Liang, 1992b, An estimate of the absolute stress tensor in Kaoiki, Hawaii, Jour. Geophysical Res., v. 97, pp. 4763-4768.

These papers develop focal mechanism solutions for the south flank of Mauna Loa Volcano and for the Kona area of west Hawaii, invert them for the tectonic stress tensor, and infer the absolute stress values at Kaoiki. This work is very valuable for modeling the nature of the stress field causing earthquakes but does not address the Kilauea seismic hazard issue directly. Wyss et al. (1992a), Bryan and Johnson (1991) and Jackson et al. (1992) reach similar tectonic interpretations of the Kaoiki area as combining strike-slip shearing between two expanding volcanoes and basal sliding of Mauna Loa's south flank. Gillard et al. (1992) and Bryan and Johnson (1991) both interpret west Hawaii as slipping westward by basal sliding.

2. OCURRENCE, LOCATIONS & ACCELERATIONS FROM LARGE HISTORICAL HAWAIIAN EARTHQUAKES

The best studied large historic earthquakes are the Kau earthquake of April 2, 1868, the Kalapana earthquake of November 29, 1975, and the Kaoiki earthquake of November 16, 1983.

Ando, M., 1979, The Hawaii earthquake of November 29, 1975: low dip angle faulting due to forceful injection of magma, J. Geoph. Res. v. 84, pp. 7616-7626.

Uses local and teleseismic p waves, surface waves, tsunami recordings, aftershock distribution, crustal strain and coastal subsidence to infer the mechanism of the Kalapana earthquake. Concludes that Kilauea's south flank slid laterally on a plane dipping 20 degrees SSE on the sediment layer at the base of the volcanic pile.

Bryan, C.L., 1992, A possible triggereing mechanism for large Hawaiian earthquakes derived from analysis of the 26 June 1989 Kilauea south flank sequence, Bulletin of the Seismological Society of America, v. 82, pp. 2368-2390.

Examines the locations, focal mechanisms and tectonics of the 1989 earthquake and its aftershocks. A difference in the short period and long period mechanisms of the mainshock suggest that the plane of rupture changed orientation as the rupture progressed. Unlike the 1975 M7.2 Kalapana earthquake, aftershocks of the 1986 M6.1 Kilauea south flank earthquake extend about 10 km offshore.

Buchanan-Banks, J.M., 1987, Structural damage and ground failures from the November 16, 1983 Kaoiki earthquake, Island of Hawaii, U.S. Geological Survey professional paper 1350 chapter 44, pp. 1187-1220.

Documents the observed structural and ground failures, landslides and peak accelerations measured from accelerometers accompanying this magnitude 6.6 earthquake. Intensities and damage descriptions are given for 31 places and peak accelerations for 15 accelerometers on the island. The largest acceleration was 0.67 g at the Hawaii Volcano Observatory where acceleration exceeded 0.1 g for 8.5 seconds. The peak accelerations at the stations closest to the geothermal development were 0.18 g in Pahoa and 0.12 g at the Wahaula maintenance center in Hawaii Volcanoes National Park. Accelerations measured at sites underlain by at least 0.5 m of volcanic ash were significantly higher.

Crosson, R.S. and E.T. Endo, 1982, Focal mechanisms and locations of earthquakes in the vicinity of the 1975 Kalapana earthquake aftershock zone 1970-1979: implications for tectonics of the south flank of Kilauea Volcano, Island of Hawaii, Tectonics, v. 1, pp. 495-542.

Uses focal mechanisms of earthquakes on the south flank of Kilauea Volcano to infer seaward and SSE directed slip of the south flank on a plane dipping 2 degrees to the west. Small event mechanisms before and after the Kalapana earthquake are very similar to that of the mainshock. This is a key paper on south flank tectonics. There are serious errors in the appendix figures but the conclusions are generally accepted.

Furumoto, A.S. and R.L. Kovach, 1979, The Kalapana earthquake of November 29, 1975: an intra-plate earthquake and its relation to geothermal processes, Physics of the Earth and Plan. Int. v. 18, pp. 197-208.

The focal mechaniam of the Kalapana earthquake is deduced from P arrivals at local and teleseismic stations. The nodal plane dipping 4 degrees to the NW was chosen as the slip plane because it matched structures seen on "the voluminous seismic, gravity and magnetic data collected ... in surveys ... carried out over the Puna District in search of geothermal resources..." This is the only relation discussed in the paper between the earthquake and geothermal processes, although there is a cross section showing the earthquake slip plane under Kilauea's south flank and the geothermal reservoir under the East Rift Zone. Except for dip of the slip plane, the interpretation of the Kalapana earthquake mechanism is similar to that of Ando (1979).

Harvey, D. and M. Wyss, 1986, Comparison of a complex rupture model with the precursor asperities of the 1975 Hawaii Ms=7.2 earthquake, J. of Pure and Applied Geophysics, v. 124, pp. 957-973.

Analyzes the two accelerograms of the Kalapana earthquake as the result of a propagating rupture. The earthquake emitted most of its seismic energy from six major patches or asperities on the rupture plane. The asperities modulated the amplitude of the accelerograms in time as if from six subevents. The approximately 7 km spacing between asperities located at 9 km depth does not permit confident modeling of spatial variations of peak ground shaking along the south flank from the two accelerograms and the modeling of this paper.

Hitchcock, C.H., 1912, The Hawaiian earthquakes of 1868, Bulletin of the Seismological Society of America, v. 2, pp. 181-192.

Description of the 1868 earthquakes and the accompanying eruptions and tsunamis.

Jackson, M.D., E.T. Endo, P.L. Delaney, T. Arnadottir and A.M. Rubin, 1992, Ground ruptures of the 1974 and 1983 Kaoiki earthquakes, Mauna Loa Volcano, Hawaii, Jour. Geophysical Res., v. 97, pp. 8775-8796.

Presents the observed ground ruptures and fits them into the tectonic context of the aftershock distribution and earthquake focal mechanisms and slip vectors. The strike slip observed is about 0.5 m from surface cracks and 1.5 m at depth from geodetic data. Notes that 3 major ground ruptures are visible in 1500 year old lava flows but moderate earthquakes have occurred with a roughly 10 year interval in recent years.

Koyanagi, R.Y., E.T. Endo, W.R. Tanigawa, J.S. Nakata, A.H. Tomori and P.N. Tamura, 1984, Kaoiki, Hawaii earthquake of November 16, 1983: a preliminary compilation of seismographic data at the Hawaiian Volcano Observatory, U.S. Geological Survey Open-File Report 84-798, 36 pp.

Presents a series of aftershock maps, cross sections, time plots, focal mechainism maps, aftershock decay plots and isoseismal maps of the 1983 Kaoiki earthquake. The intensity reached MM IX in the epicentral area. Includes plots of intensity and peak acceleration as functions of distance from the epicenter.

Lipman, P.W., J.P. Lockwood, R.T. Okamura, D.A. Swanson and K.M. Yamashita, 1985, 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 pp.

Analyzes the geodetic changes and ground deformation resulting from the Kalapana earthquake. Benchmarks on the south coast moved up to 8 m seaward and subsided up to 3.5 m. The report documents the faulting, landslides, ground cracks, subsidence and slumping of Kilauea's south flank during the Kalapana earthquake. Dip slip on the Hilina Pali fault scarps was as much as 1.5 m.

Nielsen, N.N., A.S. Furumoto, W. Lum and B.J. Morrill, 1977, The Honomu, Hawaii, earthquake, report of inspection, National Academy of Science, Washington D.C., 79 pp.

Reports some of the seismologic characteristics, the structural and landslide damage, soil response and observations of seismoscopes and accelerographs from the April 26, 1983 Honomu earthquake. The earthquake was a deep (48 km) event under Hawaii's Hamakua coast. Accelerograms were recorded at Namakani Campground on Hawaii and one station on Oahu. Aftershocks recorded with portable seismographs on ash covered sites had about 3 times larger amplitudes than those on lava flows.

Rojahn, C. and B.J. Morrill, 1977, The island of Hawaii earthquakes of November 29, 1975: strong motion data and damage reconnaissance report, Bulletin of the Seismological Society of America, v. 67, pp. 493-515.

Includes copies of accelerograms of the three local accelerometers that recorded the Kalapana earthquake. An acceleration of 0.22 g was recorded at the Hilo station 43 km from the epicenter. Moderate structural damage is documented in the epicentral and Hilo areas.

Switzer, J.C. and R.L. Porcella, 1988, Catalog of U.S. Geological Survey strong-motion records, 1988, U.S. Geological Survey Circular 1057, 28 pp.

Switzer, J.C. and R.L. Porcella, 1990, Catalog of U.S. Geological Survey strong-motion records, 1990, U.S. Geological Survey Circular 1093, 24 pp.

These publications list peak accelerations from two earthquakes not published anywhere else. The Pahala earthquake of July 4, 1988 (M5.2) recorded on two accelerographs. The Mauna Kea earthquake of August 2, 1990 (M4.7) triggered four accelerographs, but will not be used in the analysis because source and receivers are on an older, more ash covered volcano than Kilauea.

Tilling, R.I., R.Y. Koyanagi, P.W. Lipman, J.P. Lockwood, J.G. Moore and D.A. Swanson, 1976, Earthquake and related catastrophic events, Island of Hawaii, November 29, 1975: a preliminary report, U.S. Geological Survey circular 740, 33 pp.

Discusses structural damage, felt intensities, tsunami heights and damage, subsequent Kilauea eruption, coastal subsidence, surface faulting in the Hilina Fault system, landslides, ground cracks, rockfalls and a preliminary interpretation of the cause of the earthquake.

Unger, J.R. and P.W. Ward, 1979, A large, deep Hawaiian earthquake - The Honomu event of April 26, 1973, Bulletin of the Seismological Society of America, v. 69, pp. 1771-1781.

Reports the mainshock location and focal mechanism, and aftershock locations and rates from the April 26, 1983 M=6.2 Honomu earthquake. The earthquake was a deep (48 km) event under Hawaii's Hamakua coast.

Wood, H.O., 1914, On the earthquakes of 1868 in Hawaii, Bulletin of the Seismological Society of America, v.4, pp. 169-203.

Contains personal accounts, descriptions and damage reports of the 1868 earthquake. Includes an isoseismal map, narrative of the accompanying eruptions and tsunamis and lists of aftershocks.

Wyss, M., 1988, A proposed source model for the great Kau, Hawaii earthquake of 1868, Bulletin of the Seismological Society of America, v. 78, pp. 1450-1462.

Proposes that the source area of this magnitude 8 earthquake was southward slip of the upper crust of the block of the island south of Mauna Loa's rift zones. The source mechanism is thus similar to but the slip area is several times larger than that of the M7.2 1975 Kalapana earthquake on Kilauea's south flank. Includes an isoseismal map showing MM intensities up to XI in the source area and IX in Kilauea's east rift zone.

Wyss, M., and R.Y. Koyanagi, 1993, Isoseismal maps, macroseismic epicenters and estimated magnitudes of historic earthquakes in the Hawaiian Islands, U.S. Geological Survey Bulletin 2006, 93 pp.

Provides data for large historic earthquakes including approximate epicenters and magnitudes, and observed intensities on Kilauea's east rift zone. Includes a table of earthquakes with felt intensities larger than or equal to V starting in 1833. The isoseismal maps are also useful for estimating the attenuation of ground motion with distance in Hawaii. The earthquake list when used with recent instrumentally located earthquakes forms the known earthquake catalog for Hawaii.

3. SEISMIC HAZARDS OF HAWAII

Algermissen, S.T., D.M. Perkins, P.C. Thenhaus, S.L. Hanson and B.L. Bender, 1990, Probabilistic earthquake acceleration and velocity maps for the United States and Puerto Rico, U.S. Geological Survey miscellaneous field studies map MF-2120, two oversize sheets.

Federal Emergency Management Agency, 1985, National Earthquake Hazards Reduction Program recommended provisions for the development of seismic regulations for new buildings, 1985 edition, part 2, commentary: Earthquake hazards reduction series 18, Building seismic safety council, 200 pp.

The Algermissen map plots contours of acceleration and velocity values expected with a 90% probability of not being exceeded within 50 years. Values for Hawaii were not computed with a probabalistic ground model by the authors but were taken from the FEMA publication. The FEMA results are "weighted averages of ground motion estimates." The map shows a 90% probability that points on the south side of Hawaii Island will not exceed an acceleration of 0.30 g within 50 years, i.e. there is a 10% chance that more than 0.30 g will occur. The map has poor resolution and has only one contour (0.30 g) passing through the middle of the island.

Heliker, C., 1990, Volcanic and seismic hazards on the island of Hawaii, U.S. Geological Survey general interest publication available from the USGS, 48 pp.

Includes a short (7 pages including figures) section on earthquake hazards written for the general public. The article discusses earthquake types, volcanic earthquakes, historic damaging and large magnitude earthquakes, and the uncertinties in estimating ground motion. The shortness of the article reflects the little that has been published on quantifying earthquake hazards in Hawaii.

Johnson, C.E. and R.Y. Koyanagi, 1987, Earthquake hazards of Hawaii: evaluation, monitoring, and risk assesment (abstract), Abstracts with programs, Cordilleran section, Geological Society of America, v. 19, p. 392.

Mentions some factors in Hawaiian earthquake hazards including shaking, subsidence and tsunamis from local earthquakes and tsunamis from circum-Pacific earthquakes.

Johnson, C.E. and R.Y. Koyanagi, 1988, A Monte-Carlo approach applied to the estimation of seismic hazard for the state of Hawaii (abstract), Seismological Res. Lett., v. 59, no. 1, p. 18.

Evaluates hazards from three types of earthquake sources: shallow magma driven sequences (M<3) in the rift zones, lower crustal (M˜7) events related to basal sliding of the volcanic edifice, and mantle events (M˜6) caused by lithospheric bending. The abstract does not present results, but states that hazards agree with those calculated from historical intensities.

Wyss, M., and R.Y. Koyanagi, 1992, Seismic gaps in Hawaii, Bulletin of the Seismological Society of America, v. 82, pp. 1373-1387.

Argues on tectonic grounds that the entire south half of Hawaii Island is capable of producing large (magnitude 6 or greater) earthquakes. This extends the potential earthquake source areas beyond the volcano flanks where earthquakes have been observed historically. The gaps identified are in Kona and are about 70 km from Kilauea's east rift zone.

4. METHODS OF SEISMIC HAZARD ANALYSIS

The principal methods of estimating strong ground motion use (1) the historical intensity observations and a relation between intensity and acceleration, or (2) the historical and intrumental seismicity and an expression for acceleration given magnitude and distance to the earthquake. These relations have been developed for the conterminous United States and can be checked against the very limited data which exists for Hawaii. Calculating the probability of strong accelerations also requires a frequency-magnitude distribution of earthquake occurence.

Algermissen, S.T., D.M. Perkins and P.C. Thenhaus, 1982, Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States, U.S. Geological Survey Open-File Report 82-1033, 99 pp.

Formulates the problem of estimating the probability of strong motion from assumed seismic sources and applies it to the conterminous United States. Breaks the problem into 3 steps: (1) delineate seismic sources, (2) analyze the magnitude distribution of historic earthquakes in each seismic source, and (3) calculate the extreme cumulative probability of ground motion for some period of time. The paper explains the procedure in detail and provides the formulas used.

Bender, B., and D.M. Perkins, 1987, SEISRISK III: A computer program for seismic hazard estimation, U.S. Geological Survey Bulletin 1772, 48 pp.

Bender, B., and D.M. Perkins, 1982, SEISRISK II: A computer program for seismic hazard estimation, U.S. Geological Survey Open-File Report 82-293, 103 pp.

Computer program for the calculation of probable peak ground acceleration. This program was used by Algermissen et al. for the contiguous United States calculations. The program only performs the geometrical and statistical parts of the calculation: the user must regionalize the earthquake sources, enter the rate of seismicity at each magnitude band for each source, and enter the dependence of peak ground acceleration on distance and earthquake magnitude. The program calculates the acceleration levels that have a specified probability of not being exceeded during the exposure time of the site to the earthquake hazard.

Campbell, K.W, 1989, The dependence of peak horizontal acceleration on magnitude, distance and site effects for small-magnitude earthquakes in California and eastern North America, Bulletin of the Seismological Society of America, v. 79, pp. 1311-1346.

A principal reference on the calculation of peak ground acceleration expected on a given soil type for an earthquake of assumed magnitude and distance. The expected ground acceleration can be inferred from the historical seismicity observations.

Cornell, A., 1968, Engineering seismic risk analysis, Bulletin of the Seismological Society of America, v.58, pp. 1583-1606.

Original paper formulating the concept of seismic risk as a return period or probability of a particular level of ground motion at a site near a seismically active area. Subsequent studies such as Algermissen et al. (1982) are variations on Cornell's method.

Joyner, W.B. and D.M. Boore, 1981, Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California, earthquake, Bulletin of the Seismological Society of America, v.71, pp. 2011-2038.

An principal reference on the calculation of peak ground acceleration expected on a given soil type for an earthquake of assumed magnitude and distance. The expected ground acceleration can be inferred from the historical seismicity observations.

Joyner, W.B. and T.E. Fumal, 1985, Predictive mapping of earthquake ground motion, in Evaluating earthquake hazards in the Los Angeles region - an earth-science perspective, J.I. Ziony, ed., U.S. Geological Survey Professional Paper 1360, pp. 203-220.

Treats the problem of estimating peak ground motion from an earthquake of assumed magnitude and distance and calculation of the motion for a given return period. Also applies the method to an area near Los Angeles. Specifically treats the calculation of peak ground motion from a fault whose maximum earthquake and recurrence time are known. This is an alternate way to check the calculation from a source with a distribution of smaller magnitude earthquakes. This reference also estimates the error in the probable ground motion.

Krinitzsky, E.L., F.K. Chang and O.W. Nuttli, 1988, Magnitude-Related earthquake ground motions, Bulletin of the Association of Engineering Geologists, v.25, pp. 399-423.

An alternate reference on the calculation of peak ground acceleration expected on a given soil type for an earthquake of assumed magnitude and distance. Their relation predicts slightly higher acceleration values than either Joyner and Boore (1981) or Campbell (1989). The expected ground acceleration can be inferred from the historical seismicity observations.

Krinitzsky, E.L. and F.K. Chang, 1988, Intensity-Related earthquake ground motions, Bulletin of the Association of Engineering Geologists, v.25, pp. 425-435.

McGuire, R.K., 1984, Ground motion estimation in regions with few data, Proceedings of the 8th World Conference on Earthquake Engineering, v. 2, pp. 327-334.

Murphy, J.R. and L.J. O'Brien, 1977, The correlation of peak ground acceleration amplitude with seismic intensity and other physical parameters, Bulletin of the Seismological Society of America, v.67, pp. 877-915.

Trifunac, M.D. and A.G. Brady, 1975, On the correlation of seismic intensity scales with the peaks of recorded strong ground motion, Bulletin of the Seismological Society of America, v.65, pp. 139-162.

Wyss, M., and R.Y. Koyanagi, 1992, Isoseismal maps, macroseismic epicenters and estimated magnitudes of historic earthquakes in the Hawaiian Islands, U.S. Geological Survey Bulletin 2006, 93 pp.

These are the most relevant references on the relation between peak ground acceleration and intensity. The expected ground acceleration can be inferred from the historical intensity observations. Wyss and Koyanagi (1992) have compared measured peak accelerations with associated intensity observations for Hawaii. Their's is the primary reference for this relation for Kilauea Volcano. Their relation is comparable to that of Krinitzsky and Chang (1988) for hard sites in the near field, but gives significantly higher acceleration values than either the Trifunac and Brady (1975) or Murphy and O'Brien (1977) relations. Krinitzsky and Chang (1988) give separate relations for hard sites and soft sites in both the near and far field. The Murphy and O'Brien (1977) relation is based on a large number of observations. An estimate of the error in the acceleration can be inferred by comparing the different studies.

Nicholl, J.J., J. Ake and D. Butler, 1988, Seismic hazard estimation for geothermal areas, Geothermal Resources Council Tranactions, v. 12, pp. 413-416.

Restates the standard methodology (Cornell, 1968) for probabalistic seismic hazard analysis. Calculates the hazard at the Geysers geothermal area from the Healdsburg Fault and the induced seismicity of the Geysers production zone. The only special variation on a standard hazards calculation relevant to hazards in an active geothermal system is the inclusion of the observed induced seismicity at the Geysers.

Seed, H.B. and I.M. Idriss, 1982, Ground motions and soil liquefaction during earthquakes, Earthquake Engineering Research Institute, 134 pp.

An alternate reference on the peak ground acceleration expected from an earthquake at different distances. Also quantifies the amplification from surface soils. Their relation is not very useful because it is only for magnitudes around 6.6.

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5/20/94

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