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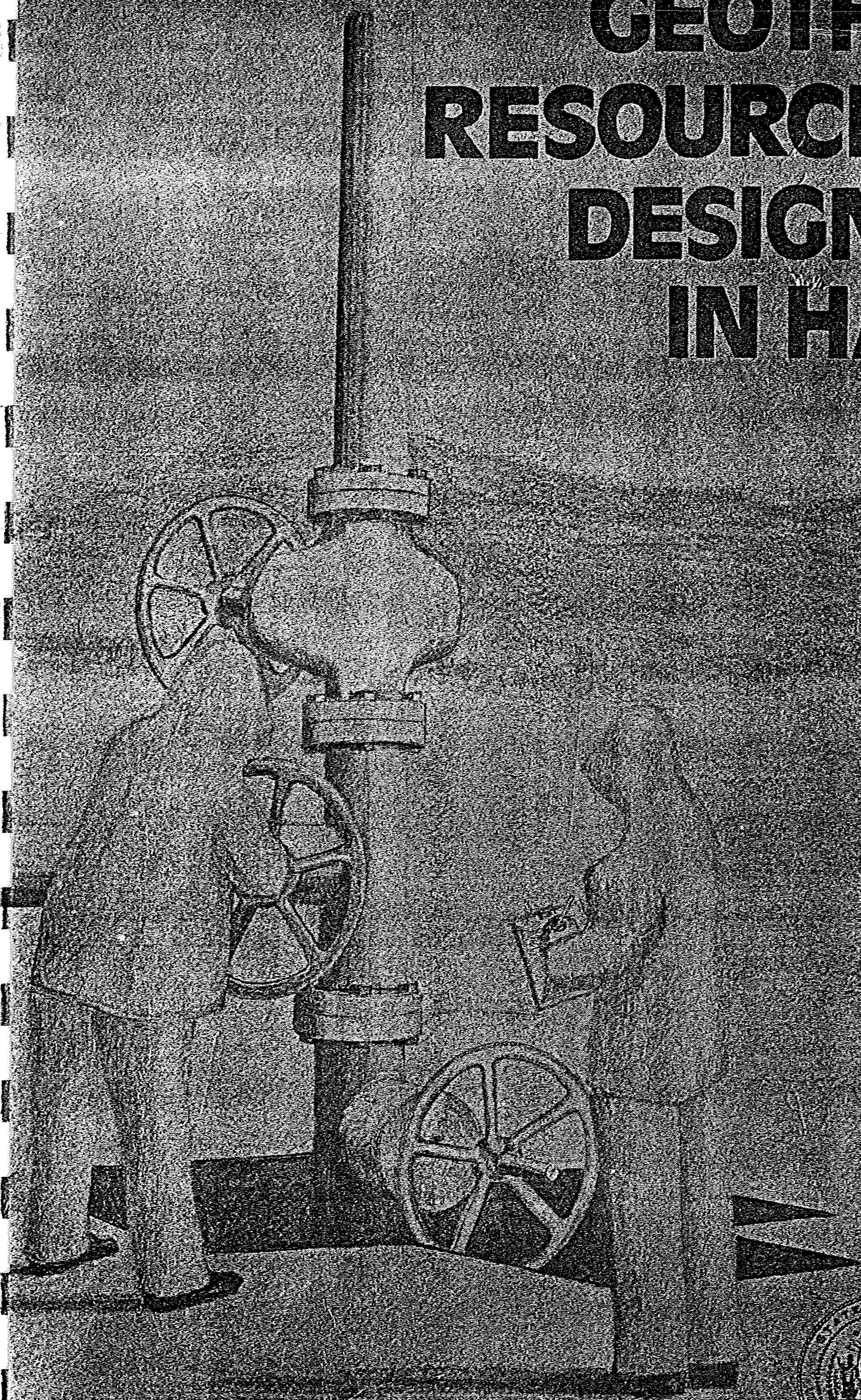
GEOTHERMAL RESOURCE SUBZONE DESIGNATIONS IN HAWAII



Department of Planning and Economic Development

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PREFACE

Harnessing Hawaii's abundant sources of renewable energy to reduce our dependence on petroleum is a major goal of the State. Of the many forms of renewable energy sources locally available, geothermal energy represents the State's largest and most promising near-term source for the generation of baseload electricity. The technology for the use of geothermal energy has been proven commercially viable throughout the world and the resource appears to be available in large quantities, especially on the Island of Hawaii.

To facilitate the orderly development of geothermal energy in Hawaii, Act 296, Session Laws of Hawaii 1983, was signed into law on June 14, 1983, by Governor George R. Ariyoshi. Act 296 provides for the establishment of geothermal resource subzones where exploration, development, or production of electricity from geothermal resources may take place in consonance with the State's interest in preserving Hawaii's unique social and natural environment.

Prior to subzone designation, Act 296 requires a geothermal resource assessment and impact analysis. Factors to be considered include: an area's geothermal production potential, prospects for energy utilization, potential geologic hazards, social and environmental impacts, potential economic benefits, and land use compatibility. The Department of Land and Natural Resources conducted the resource assessment and impact analysis, and provided recommendations to the Board of Land and Natural Resources, which is charged with the responsibility of designating geothermal resource subzones in the State of Hawaii. This report is an edited compilation of the many technical reports published during the subzone designation process in the years 1983 to 1985, and a summary of subzone designations.

The Department of Planning and Economic Development gratefully acknowledges the timely support of the U.S. Department of Energy, which provided financial assistance for conducting the geothermal subzone assessment and analysis.

Kent M. Keith
Director of Planning and
Economic Development and
State Energy Resources Coordinator

ACKNOWLEDGMENTS

This report was written by Joseph Kubacki, with contributions from Dean Nakano, Sherrie Samuels, and Environmental Capital Managers, Inc. Technical supervision and assistance was provided by Manabu Tagomori, Takeshi Yoshihara, Donald Thomas, and George Walker. The cover was designed by Stewart Wastell, mapping by William Koyanagi, and typing by Doris Hamada.

A special thanks goes to the scientists who volunteered their time and effort to participate in the Geothermal Resources Technical Committee. Their advice and input to the Department of Land and Natural Resources was a major factor in determining those areas having the greatest geothermal resource potential.

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INTRODUCTION

The Board of Land and Natural Resources is charged with the responsibility of designating geothermal resource subzones in the State of Hawaii under authority of Act 296, Session Laws of Hawaii 1983. Act 296 provided that only those areas designated as geothermal resource subzones may be used for the exploration, development, or production of electricity from geothermal resources.

Prior to subzone designation, Act 296 requires a geothermal resource assessment and impact analysis. Factors to be considered include: an area's geothermal production potential, prospects for energy utilization, potential geologic hazards, social and environmental impacts, potential economic benefits, and land use compatibility. The staff and consultants of the Hawaii Department of Land and Natural Resources, Division of Water and Land Development, examined the subzone factors in the following series of reports published during 1983 to 1985.

- Plan of Study for Designating Geothermal Resource Subzones.
- Assessment of Available Information Relating to Geothermal Resources in Hawaii.
- Public Participation and Information Program for Designation of Geothermal Resource Subzones.
- Geothermal Resource Developments.
- Rules on Leasing and Drilling of Geothermal Resources.
- Statewide Geothermal Resource Assessment.
- Social Impact Analysis of Potential Geothermal Resource Areas.
- Economic Impact Analysis of Potential Geothermal Resource Areas.
- Environmental Impact Analysis of Potential Geothermal Resource Areas.
- Geologic Hazards Impact Analysis of Potential Geothermal Resource Areas.
- Geothermal Technology.

- A Report on Geothermal Resource Subzones for Designation by the Board of Land and Natural Resources.
- Proposed Kilauea Middle East Rift Geothermal Resource Subzone.
- Proposed Kilauea Southwest Rift Geothermal Resource Subzone.

The objective of these reports was to provide information to the Board of Land and Natural Resources for its designation of geothermal resource subzone areas.

LEGAL AUTHORITY

Act 296, SLH 1983, relating to geothermal energy, is the basis for this effort. This Act delegates the responsibility of designating geothermal resource subzones to the Board of Land and Natural Resources (BLNR). Section three of this Act also requires the BLNR to "adopt, amend, or repeal rules related to its authority to designate and regulate the use of geothermal resource subzones in the manner provided under Chapter 91." These rules are promulgated in Title 13, Chapter 184, "Designation and Regulation of Geothermal Resource Subzones" of the DLNR Rules and Regulations. Finally, Act 151, SLH 1984, clarified various aspects of existing geothermal development activities within the State and the roles of State and County governments.

Act 296, Session Laws of Hawaii 1983

Act 296, SLH 1983, relating to geothermal energy, was signed into law on June 14, 1983, by Governor George R. Ariyoshi (see Appendix A).

Some highlights of Act 296, SLH 1983, include:

* Provision for the designation of geothermal resource subzones in each of the four State land use districts--Conservation, Agriculture, Urban, and Rural.
* The BLNR is charged with the responsibility of designating geothermal resource subzones.

* The BLNR shall adopt administrative rules to designate geothermal resource subzones.

* The administration of the use of subzones for geothermal development activities shall be governed as follows:

    * BLNR for conservation districts.

    * Existing State and County laws for agriculture, urban, and rural districts.

* No Land Use Commission approval is necessary for the use of subzones.

* Upon request, a contested case hearing shall be conducted by the BLNR or County agency prior to the issuance of a geothermal resource permit.

* Any property owner may petition the BLNR to have an area designated as a geothermal resource subzone.

* An Environmental Impact Statement (EIS) is not required for the assessment of areas.

* The BLNR beginning in 1983 shall conduct a county-by-county assessment of potential geothermal resource development areas. The assessment shall be revised or updated at the discretion of the BLNR once every five years beginning in 1988.

Pursuant to the provisions of Act 296, SLH 1983, a county-by-county assessment of areas with geothermal potential for the purpose of designating geothermal subzones was made. This report addresses the various factors as given below:

1. The area's potential for the production of geothermal energy;

2. The prospects for the utilization of geothermal energy in the area;

3. The geologic hazards that potential geothermal projects would encounter;

4. Social and environmental impacts;

5. The compatibility of geothermal development and potential related industries with present uses of surrounding land and those uses permitted under the general plan or land use policies of the county in which the area is located;

6. The potential economic benefits to be derived from geothermal development and potential related industries; and

7. The compatibility of geothermal development and potential related industries with the uses permitted under the Hawaii Revised Statutes (HRS), sections 183-41 and 205-2, where the area falls within a conservation district.

In addition, the board shall consider, if applicable, objectives, policies and guidelines set forth in Part I of Chapter 205A, and the provisions of Chapter 226 of the HRS.

Title 13, Chapter 184

In accordance with Chapters 91 and 205 of the HRS and Act 296, SLH 1983, public hearings on the "Proposed Rules for the Designation and Regulation of Geothermal Resource Subzones" were held on May 22, 1984 on all islands by the DLNR.

These proposed rules, formally adopted on July 13, 1984, describe the procedure for initiating the designation of subzones, establish criteria, provide for the modification and withdrawal of existing subzones, and provide for the regulation of geothermal resource subzones.

Act 151, Session Laws of Hawaii 1984

On May 25, 1984, Act 151, SLH 1984, was signed into law by Governor George R. Ariyoshi (See Appendix A). This Act clarifies the rights of existing lessees holding geothermal mining leases issued by the State and geothermal developers holding exploratory and/or development permits from either the State or County governments. Act 151, SLH 1984, also clarifies the respective roles of the State and County governments in connection with the control of geothermal development within geothermal resource subzones.

Some of the highlights of Act 151, SLH 1984, include:

- Permits geothermal development activities within Urban, Rural, Agricultural, and Conservation land use districts.

- Defines geothermal development as "the exploration, development or production of electrical energy from geothermal resources."

* Lands subject to existing State geothermal mining leases within an agricultural district which have been subsequently issued a special use permit by the County for geothermal development activities are declared a geothermal resource subzone for the duration of the lease.

* Clarifies the governing jurisdiction of the State and County governments in the geothermal development approval process, and also exempts the permit process from special use permit procedures under Section 205-6, HRS.

* Clarifies the permit-issuing County agency by defining "appropriate county authority" as the "county planning commission unless some other agency or body is designated by ordinance of the county council."

* Further clarifies the roles of the State and County governments in connection with land use designations and the permit approval process.

* Mandates that the county authority, in the absence of a mutually agreed upon extension, must provide a decision on a complete and properly filed application within six months.

PLAN OF STUDY

In September 1983, the Department of Land and Natural Resources (DLNR) drafted a Plan of Study which charted the following four-phase study approach for designating geothermal resource subzones.

Phase I. Statewide Geothermal Resource Assessment

This phase interpreted and analyzed geotechnical information to determine potential geothermal resource areas on all of the major islands. Due to the time constraint of completing the work by December 1984, available studies were used heavily with minimal new data gathering. First-cut subzones based only on the availability of geothermal resources were mapped to conclude Phase I work.

Phase II. An Analysis of Potential Impacts from Geothermal Development

An impact analysis relating to power utilization, geologic hazards, social and environmental impacts, land use compatibility, and economics was conducted on the first-cut subzones completed in Phase I. Several disciplines participated in this phase. Overlay mapping of the impacts was extensively used to identify highly sensitive impact areas. Adjustments to the first-cut subzones were made to conclude Phase II work.

Phase III. Public Participation and Information

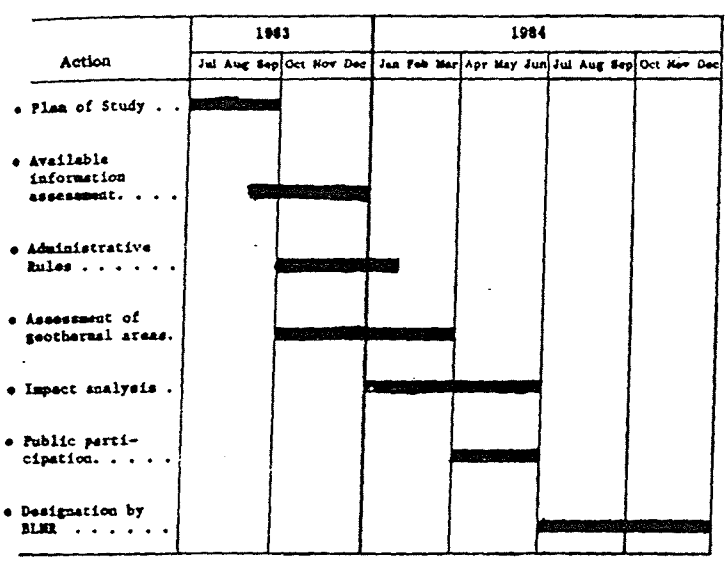
This phase involved communities located in close proximity to the identified subzones. Informational meetings were conducted to explain the technical work and the impact analyses. Comments from the public were solicited and considered in determining the location of geothermal resource subzones.

Phase IV. BLNR Designation of Geothermal Resource Subzones

The BLNR was briefed by the staff of the Division of Water and Land Development on both the technical and impact analyses. Public input was described and documented. This phase culminated in public hearings and designation of geothermal resource subzones by the BLNR.

Schedule for Designating Subzones

The overall time schedule estimated the completion of the work by December 1984. This Plan of Study provided a schedule for performance of each of the major tasks required by the subzone assessment process. As work continued, some minor adjustments were made, but generally work proceeded as originally scheduled. The critical dates and actions are identified in the following chart:



COMMUNITY INPUT

Various channels and methods of community input were involved in the geothermal subzone assessment. These channels included public informational meetings, political representatives, regulatory agencies, public and contested case hearings, and community surveys (e.g., by the Puna Hui Ohana and by SMS Research, Inc).

Throughout the process, from the enactment of Act 296 to the Proposal for Designating Geothermal Resources Subzones by the BLNR, public comments and participation have been invited from various interested parties to assist the DLNR and the BLNR.

Public informational meetings were held by the DLNR on the Islands of Hawaii and Maui to encourage public participation throughout the planning process.

Other sources of community input included the planning processes, goals, objectives, and development policies formulated and adopted in community plans that become a part of the County General Plans and the State Plan. Also, the policies that are set forth in the geothermal subzone enabling Acts were drafted by district representatives in the State Legislature.

During the course of the subzone assessment, several public information and participation meetings were held and conducted by the staff of DLNR's Division of Water and Land Development. Following are the dates and places of community meetings held:

May 8, 1984	- Hilo, Hawaii
May 9, 1984	- Kahului, Maui
May 29, 1984	- Hilo, Hawaii
May 30, 1984	- Kahului, Maui
July 10, 1984	- Puna, Hawaii
July 11, 1984	- Volcano, Hawaii
July 27, 1984	- Ulupalakua, Kanaio, Maui
March 13, 1985	- Keaau, Hawaii

March 14, 1985	- Pahala, Hawaii
May 15, 1985	- Pahoa, Hawaii
May 16, 1985	- Pahala, Hawaii

To ensure full public participation, the time, place, and purpose of these meetings were announced in newspapers, radio announcements, and letter invitations. The objective of these meetings was to open lines of communication between the public and the DLNR. In addition, on July 29, 1985, the DLNR mailed letters to concerned parties requesting written comments and information on the proposed geothermal resource subzones. The meetings reported the most likely locations of geothermal resources and focused on the identification of impact issues.

Island of Hawaii, Generally

Support for geothermal resource exploration, development, and production on the Island of Hawaii has been voiced by the Mayor, County Council, Chamber of Commerce, and several communities in the Puna area.

Opposition was expressed for specific elements of the overall development, such as emissions and noise emanating from geothermal resource activities, but not necessarily with development of geothermal resource energy as an alternate energy source for Hawaii.

Puna Community

Comments received at public information meetings in Hilo and at Puna indicate that geothermal resource activities, if done with due regard to local concerns, would not be detrimental to the area.

Volcano, Keaau, and Kalapana Communities

Concerns regarding geothermal resource development were generally expressed at all of the public information meetings. These concerns included adverse effects on forests, bird habitats, proximity to the Hawaii Volcanoes National Park, and the lowering of property values. The current Puu O'o volcanic flows were cited as a potential hazard to development activities and system reliability. Other issues included size of the proposed geothermal resource subzone, buffer zone size, and geothermal effluent disposal.

Pahala Community

Issues raised regarding the proposed Kilauea southwest rift zone included the size of the 90 percent resource probability area, land use compatibility, aesthetics, geothermal development as a violation of the religious tenets relating to the Hawaiian volcano goddess Pele, Pele's alleged disapproval of proposed geothermal development as expressed by the current eruptive phases at Puu O'o, geothermal effluent disposal, development of other forms of alternate energy resources, and employment opportunities generated by geothermal development.

POTENTIAL FOR THE PRODUCTION OF GEOTHERMAL ENERGY

The statewide geothermal resource assessment was the first phase in the process of designating Geothermal Resource Subzones (GRS) on a county-by-county basis pursuant to the Plan of Study prepared by the Department of Land and Natural Resources.

Act 296, SLH 1983, mandated that this subzone work be done by utilizing available information. Therefore, the initial assessment phase focused upon interpreting current geotechnical data to identify potential geothermal resource areas on all of the major islands. The resource assessment concluded with mapping of geothermal resource areas using estimated percent probabilities of locating geothermal resources.

GEOTHERMAL RESOURCES TECHNICAL COMMITTEE

DLNR selected a committee of technical experts who are closely associated with the field of geothermal research in the State of Hawaii. This Geothermal Resources Technical Committee, after evaluating currently available information, identified potential geothermal resource areas on a county-by-county basis.

The members of this Committee were selected on the basis of their area of expertise and their availability to assist the DLNR in the evaluation of technical data relevant to the identification of potential geothermal resource areas.

It should be noted that other technical experts were considered during the committee selection process, but due to individual problems in scheduling and workload, those contacted declined DLNR's request for assistance.

A list of the participating committee members and their areas of technical expertise follow:

Mr. Manabu Tagomori - Area of expertise: Engineering
Chief Water Resources and Flood Control Engineer
Division of Water and Land Development
Department of Land and Natural Resources

Dr. Donald Thomas - Area of expertise: Geochemistry
Project Leader, Direct Heat Resources Assessment Project
Hawaii Institute of Geophysics, University of Hawaii

Dr. Bill Chen - Area of expertise: Reservoir engineering
Project Manager, HGP-A Wellhead Generator Project
Participated in the Hawaii Geothermal Project as reservoir engineer.
University of Hawaii - Hilo

Mr. Dallas Jackson - Area of expertise: Geology and Geophysics
Principle investigator for geoelectrical studies at the Hawaiian Volcano Observatory.
Participated in self-potential research related to geothermal resource.
U.S. Geological Survey, Hawaiian Volcano Observatory.

Dr. James Kauahikaua - Area of expertise: Geophysics
Research includes geoelectrical studies such as resistivity surveys related to the identification of geothermal resource.
U.S. Geological Survey

Mr. Daniel Lum - Area of expertise: Geology - Hydrology
Head, Geology and Hydrology Section
Division of Water and Land Development
Department of Land and Natural Resources

Dr. Richard Moore - Area of expertise: Geology
Chief of "Geology and Petrology of Hualalai Volcano" project.
Research includes geological mapping and the study of geothermal potential on Hualalai and Kilauea Volcanoes.
U.S. Geological Survey, Hawaiian Volcano Observatory.

Dr. John Sinton - Area of expertise: Geology
Participated in geological mapping studies for the preliminary State-wide Geothermal Assessment Program.
Hawaii Institute of Geophysics, University of Hawaii

Mr. Joseph Kubacki and Mr. Dean Nakano, having expertise in the areas of Energy Science and Geology respectively, provided staff assistance to the Committee in researching literature and compiling minutes of the Committee meetings.
Division of Water and Land Development
Department of Land and Natural Resources

ASSESSMENT APPROACH AND CRITERIA

A series of Committee meetings were scheduled during the Statewide Geothermal Resource Assessment phase. The first organizational meeting addressed the provisions of Act 296, the Administrative Rules, the Plan of Study, and the Assessment of Available Information Relating to Geothermal Resources. The Committee members were asked to review the bibliography of available information to determine if any significant literature had been omitted. It was also agreed that official notice be given to all newspaper agencies inviting the public to submit any additional data relevant to the assessment of potential geothermal resources. Subsequent Committee meetings were scheduled to evaluate each island's potential for geothermal resource on a county-by-county basis. The following is a list of the Geothermal Resources Technical Committee meetings:

Date	Place
March 16, 1984	Honolulu, Hawaii
March 30, 1984	Maui, Hawaii
April 9, 1984	Honolulu, Hawaii
April 18 & 19, 1984	Hilo, Hawaii
April 23, 1984	Honolulu, Hawaii
May 11, 1984	Honolulu, Hawaii
June 8, 1984	Honolulu, Hawaii

Due to the complexity of Hawaii's geologic structure and the variable nature of groundwater hydrology and geochemistry, the Committee did not rely on just one set of data or a single set of rules. The assessment of potential for each island was based on a qualitative interpretation of several regional surveys conducted in Hawaii during the last 15 to 20 years and any available deep exploratory drilling data. It was further noted that the use of probability ranges was appropriate in assessing geothermal resources, since probabilities would be more accurate than other subjective wording.

The Committee's assessment was based on the following types of geological, geophysical and geochemical data:

1. Groundwater temperature data. Near surface water having temperatures significantly above ambient, indicative of a possible nearby geothermal reservoir.

2. Geologic age. Recent eruptive activity and the evidence of surface features such as rift zones, calderas, vents, and active fumaroles.

3. Geochemistry. Groundwater having geochemical anomalies related to the interaction between high temperature rock and water.

Some of the indicators of thermally altered groundwater are anomalously high silica (SiO_2), chloride (Cl) and magnesium (Mg) concentrations. In addition, the evidence of above normal concentrations of trace and volatile elements such as mercury (Hg) and radon (Rn) may indicate leakage of geothermal fluids into nearby rock structures.

4. Resistivity. The electrical resistivity of the subsurface rock formation is affected by the salt content and temperature of circulating groundwater. Therefore, rocks saturated with warm saline groundwater have lower resistivities than rocks saturated with colder groundwater.

5. Infrared surveys. Infrared studies of land surface and coastal ocean water can identify thermal spring discharges and above ambient ground temperatures.

6. Seismic. Seismic monitoring of the frequency and clustering of earthquakes can identify earthquake concentrations that may be related to geothermal systems.

7. Magnetics. Aeromagnetic surveys have identified magnetic anomalies associated with buried rift zones and calderas. Also, rocks at high temperature or those that have been thermally altered have substantially different magnetic properties than normal rock strata.

8. Gravity. Gravity surveys can provide information on the location of subsurface structural features such as dense intrusive bodies and dike zones.

9. Exploratory drilling. Data acquired from deep exploratory wells can confirm the existence of high temperatures and determine if there is adequate permeability necessary for development.

10. Self potential. Self potential anomalies (natural voltages at the earth's surface) have been found to be highly correlated with subsurface thermal anomalies along the Kilauea east rift zone.

A more in-depth description of the various types of geothermal exploration techniques can be referred to in Appendix B.

STATEWIDE RESOURCE ASSESSMENT

The preliminary phase in the designation of Geothermal Resource Subzones is the determination of potential geothermal resource areas on a county-by-county basis. Upon evaluation of currently available geotechnical data, the Geothermal Resources Technical Committee identified the location and percent probability of finding Low Temperature (less than 125°C) Resources and High Temperature (greater than 125°C) Resources at depths less than 3 km.

A county-by-county listing of the areas that were evaluated and the Committee's conclusions follow:

HAWAII COUNTY

Kawaihae:

On the basis of groundwater temperature, chemical anomalies, resistivity interpretation indicating the presence of an intrusive body associated with the Puu Loa cinder cone, and the geologic age of this vent, the following probabilities are estimated:

- 45% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 10% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Hualalai:

Based on positive geothermal indications from geophysical data (resistivity, magnetics, and self potential) and the geologically young age of vents along the upper rift and summit, the following probabilities are estimated:

- 70% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- 35% or less chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Mauna Loa Southwest Rift:

On the basis of recent historic volcanic eruptions, seismic activity, and taking into consideration the absence of any other significant geophysical or geochemical anomalies, the following probabilities are estimated:

- 60% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- 35% or less chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

It should be noted that due to the limited amount of data, additional studies are warranted in the future in order to update our current assessment.

Mauna Loa Northeast Rift:

On the basis of geochemical and geophysical data for the lower rift near the vicinity of Mountain View and Keaau, it is unlikely that a geothermal resource would be found.

While upper-elevation seismic and self potential data and the recent 1984 Mauna Loa eruption indicate a geothermal resource, it should be noted that current drilling technology limits development to elevations of less than 7,000 feet above sea level. Based on available data the following probabilities are estimated:

- 60% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- 35% or less chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Kohala:

On the basis of the limited amount of geochemical and geophysical data, the geologic age of the Kohala volcano, and the fact that no significant anomalies were observed, the following probabilities are estimated:

- Less than 10% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.

- Less than 5% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

It was noted by the Committee that, due to the limited amount of information, future studies are warranted in order to update its current assessment.

Mauna Kea Volcano:

Strictly on the basis of geologic age and one groundwater temperature anomaly recorded at Waikii Well No. 5239-01, the following probabilities are estimated:

Mauna Kea Northwest Rift Zone:

- Less than 50% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 20% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Mauna Kea East Rift Zone:

- Less than 30% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 10% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

It is noted again, that due to the limited amount of available data, further studies are warranted in the future to update this current assessment.

Kilauea Southwest Rift:

On the basis of positive geophysical data, recent volcanic activity, and consideration given to the absence of any significant groundwater chemical anomalies, the following probabilities were concluded:

- Greater than 90% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Greater than 90% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

It should be noted that although the majority of the Kilauea Southwest Rift Zone is situated within the Hawaii Volcanoes National

Park and is therefore off-limits to geothermal development, the area was assessed for its geothermal resource potential by the Committee.

Kilauea East Rift:

Currently available studies indicate that a geothermal resource is present along the entire length of the Kilauea East Rift Zone. Commercially feasible quantities of steam have been confirmed by deep exploratory drilling on the lower rift zone. Therefore, on the basis of positive geochemical and geophysical data and the recent eruptive and intrusive activity along the Kilauea East Rift Zone, the following probability is estimated:

- Greater than 90% chance of finding a low temperature (50-125°C) and high temperature (greater than 125°C) resource at depths less than 3 km.

MAUI COUNTY

Olowalu-Ukumehame Canyon:

Based on currently available data (groundwater temperature, resistivity, magnetics, groundwater chemistry, and rift zone structure) that can identify geophysical and geochemical anomalies, and taking into consideration the geologic age of West Maui, the following probabilities are estimated:

- 75% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 15% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Lahaina-Kaanapali:

Based on the absence of any positive geochemical or geophysical data indicating above ambient subsurface temperatures, the following probability was concluded:

- Less than 5% chance of finding a low (50-125°C) or high (greater than 125°C) temperature resource at depths less than 3 km.

Honolua:

Due to the limited amount of data for the Honolua area and the absence of any positive geophysical or geochemical anomalies, the following probability was concluded:

- Less than 5% chance of finding a low (50-125°C) or high (greater than 125°C) temperature resource at depths less than than 3 km.

Haleakala Southwest Rift:

On the basis of currently available data, there is no direct evidence of warm water. However, based on the historic 1790 eruption and results of deep resistivity soundings, the following probabilities were concluded:

- 35% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- 25% or less chance of finding high a temperature (greater than 125°C) resource at depths less than 3 km.

Haleakala Northwest Rift:

Based on the absence of any significant geochemical or geophysical anomalies other than a weak resistivity anomaly, and due to the geologic age of the last eruption, the following probabilities were concluded:

- Less than 10% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 5% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Haleakala East Rift:

The limited amount of available data did not identify any significant anomalies. However, based on the geologic age of the Hana Series lava flows, the following probabilities for the Haleakala East Rift Zone were concluded:

- 35% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- 25% or less chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Molokai and Lanai:

On the basis of currently available data and the absence of any positive geophysical or geochemical anomalies, the probability of a geothermal resource is as follows:

- Less than 5% chance of finding a low (50-125°C) or high temperature (greater than 125°C) resource at depths less than 3 km.

However, additional studies are warranted in the future in order to update our current assessment.

CITY AND COUNTY OF HONOLULU

Waianae Volcano:

On the basis of geologic age, weak resistivity, groundwater temperature, and geochemical anomalies, the probabilities for a geothermal resource are estimated as follows:

- 15% or less chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 5% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Koolau Volcano:

Due to the geologic age of the Koolau Volcano and the absence of any significant geochemical, self potential, magnetic or resistivity anomalies, the following probabilities were concluded:

- Less than 10% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.
- Less than 5% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

KAUAI COUNTY

Kauai:

On the basis of currently available information, the geologically old age of Kauai's volcanic activity and the absence of any significant geothermal related anomalies, the probabilities for a geothermal resource are as follows:

- Less than 5% chance of finding a low temperature (50-125°C) resource at depths less than 3 km.

- Less than 5% chance of finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Minutes of the Geothermal Resources Technical Committee meetings are contained in Appendix D.

A complete list of the percent probabilities for potential High and Low Temperature Geothermal Resource Areas in the State of Hawaii is presented on a county-by-county basis below:

PERCENT PROBABILITIES
(County-by-County)

Island/Area	High Temperature (greater than 125°C at depths less than 3 km)	Low Temperature (less than 125°C at depths less than 3 km)
KAUAI	Less than 5%	Less than 5%
OAHU		
Waianae	Less than 5%	15% or less
Koolau	Less than 5%	Less than 10%
MOLOKAI	Less than 5%	Less than 5%
LANAI	Less than 5%	Less than 5%
MAUI		
Olowalu-Ukumehame	Less than 15%	75% or less
Lahaina-Kaanapali	Less than 5%	Less than 5%
Honolua	Less than 5%	Less than 5%
Haleakala S.W. Rift	25% or less	35% or less
Haleakala N.W. Rift	Less than 5%	Less than 10%
Haleakala East Rift	25% or less	35% or less
HAWAII		
Kawaihae	Less than 10%	45% or less
Hualalai	35% or less	70% or less
Mauna Loa S.W. Rift	35% or less	60% or less
Mauna Loa N.E. Rift	35% or less	60% or less
Kohala	Less than 5%	Less than 10%
Mauna Kea N.W. Rift	Less than 20%	Less than 50%
Mauna Kea East Rift	Less than 10%	Less than 30%
Kilauea S.W. Rift	Greater than 90%	Greater than 90%
Kilauea East Rift	Greater than 90%	Greater than 90%

POTENTIAL GEOTHERMAL RESOURCE AREAS

The conclusions of the Technical Committee demonstrated that no single geothermal exploration technique, except for exploratory drilling, is capable of positively identifying a subsurface geothermal system. Instead, identification is based on several methods resulting in an estimate of geothermal potential for a given area.

The results of the Technical Committee's evaluation of currently available data provide an estimate of percent probability for high temperature (greater than 125°C) and low temperature (less than 125°C) geothermal resources.

A key criterion in the preliminary subzone designation is the assessment of an area's geothermal potential for production of electrical energy, as mandated by Act 296. The consensus of the Technical Committee was that current technology would require the resource to have a temperature greater than 125°C at a depth of less than 3 km.

One of the most important conditions in a productive geothermal system is a permeable zone that permits adequate recharge of water to the reservoir. This criterion was not addressed during the resource assessment process, since only exploratory drilling and flow testing of deep exploratory wells can confirm the nature of an aquifer.

Upon evaluation of the data and a review of the list of percent probabilities, the Technical Committee identified seven High Temperature Potential Geothermal Resource Areas. The criterion for selection of high temperature resource areas was agreed to be those areas having an assessed probability of at least 25 percent for finding a high temperature (greater than 125°C) resource at depths less than 3 km.

Two location maps (Figures 1 and 2) for the Islands of Maui and Hawaii and a list of these High Temperature Potential Geothermal Resource Areas follow:

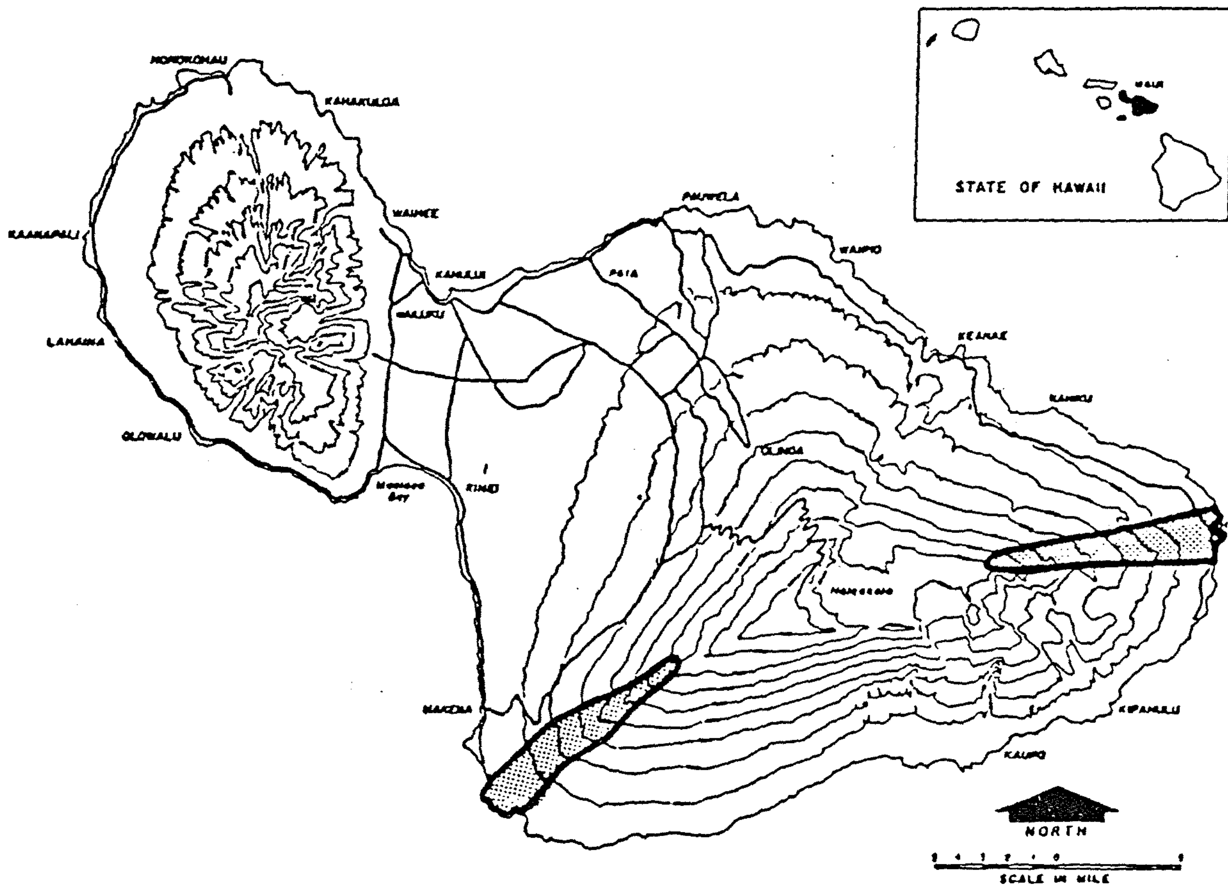


Figure 1.

HIGH TEMPERATURE POTENTIAL GEOTHERMAL RESOURCE AREAS

Island of Maui

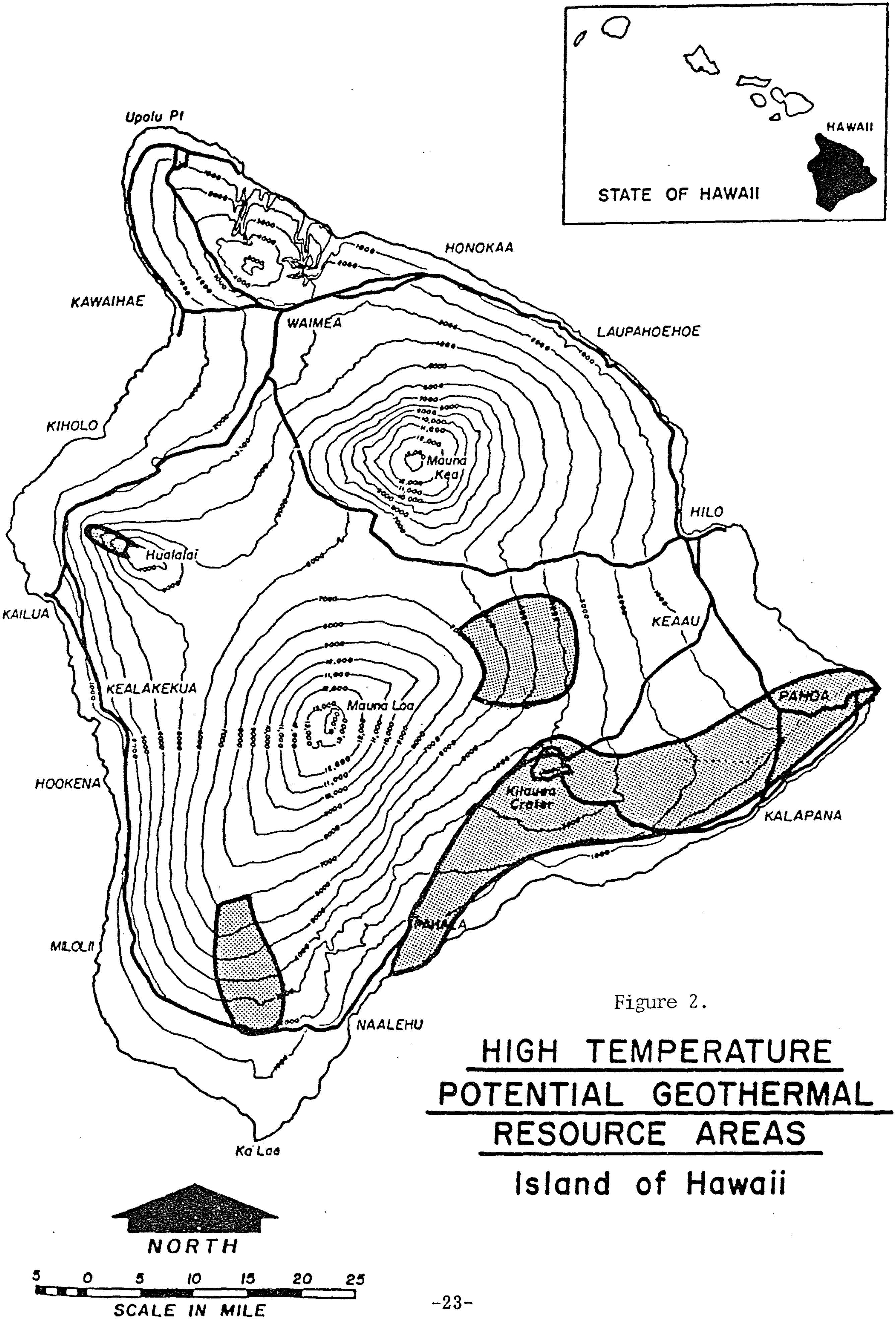


Figure 2.

HIGH TEMPERATURE POTENTIAL GEOTHERMAL RESOURCE AREAS

Island of Hawaii

High Temperature Potential Geothermal Resource Areas
(greater than 125°C at depths less than 3 km)

	Percent Probability
Maui:	
Haleakala S.W. Rift Zone	25% or less
Haleakala East Rift Zone	25% or less
Hawaii:	
Hualalai	35% or less
Mauna Loa S.W. Rift Zone	35% or less
Mauna Loa N.E. Rift Zone	35% or less
Kilauea S. W. Rift Zone	Greater than 90%
Kilauea East Rift Zone	Greater than 90%

On the basis of the Committee's conclusions and the specific provision for electrical power generation set forth in Act 296, these seven High Temperature Potential Geothermal Resource Areas were identified and mapped. The Committee members agreed that equal weight would be given to all positive data and the probability areas mapped would be below the 7000-foot elevation due to the limits of current drilling technology.

The use of dashed lines in identifying certain Potential Geothermal Resource Areas indicated that mapping was based on a limited amount of data. The Committee could not scientifically justify using a solid line to clearly locate certain resource areas on the basis of sparse data. The use of a solid line to draw a boundary of percent probability was restricted to those resource areas having a substantial data base upon which to make a decision as to the location of the resource.

Site location and sectional maps of Maui and the Island of Hawaii depicted in Figures 3 to 9 show High Temperature Potential Geothermal Resource Areas and boundary lines of resource probability.

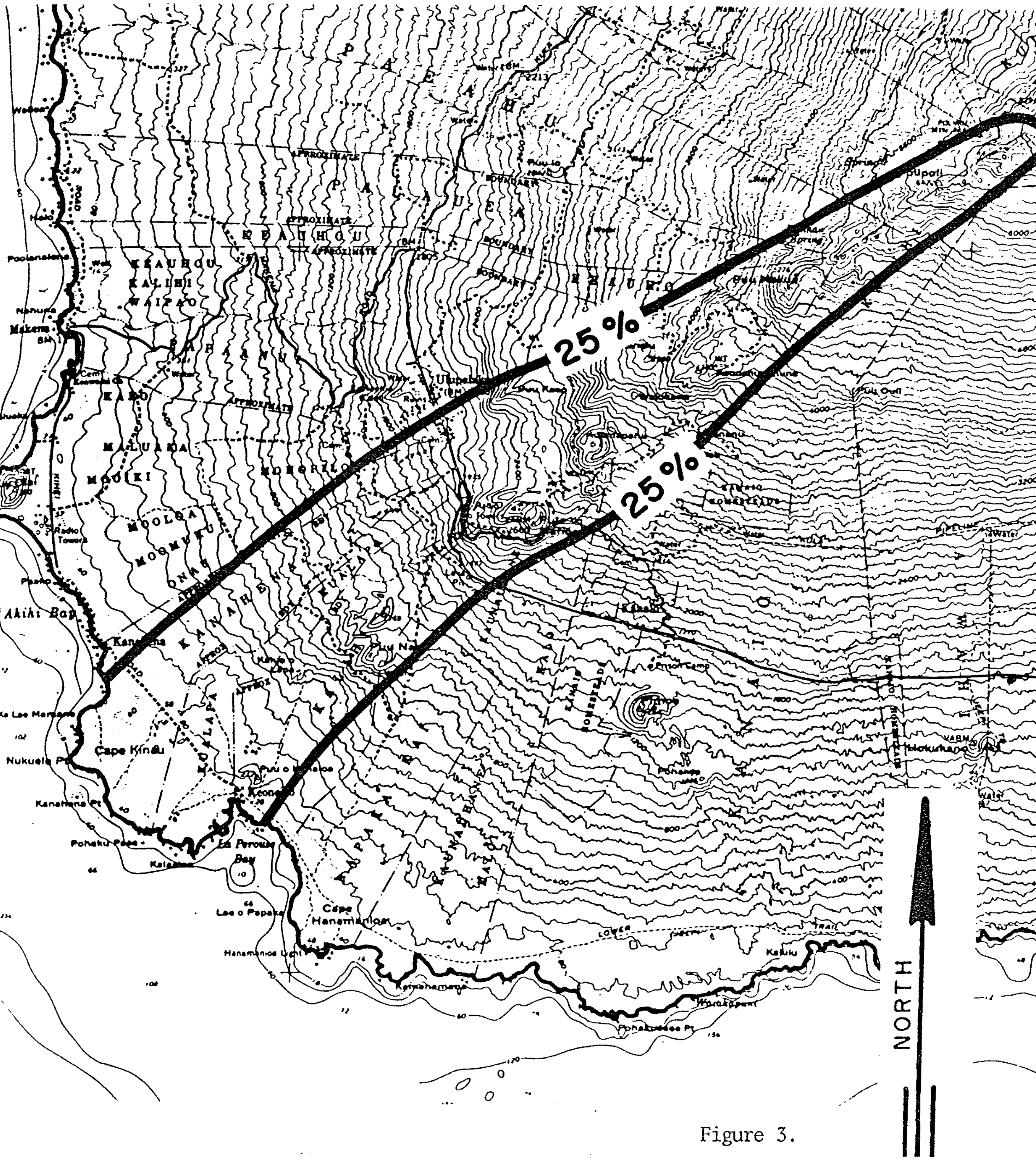


Figure 3.

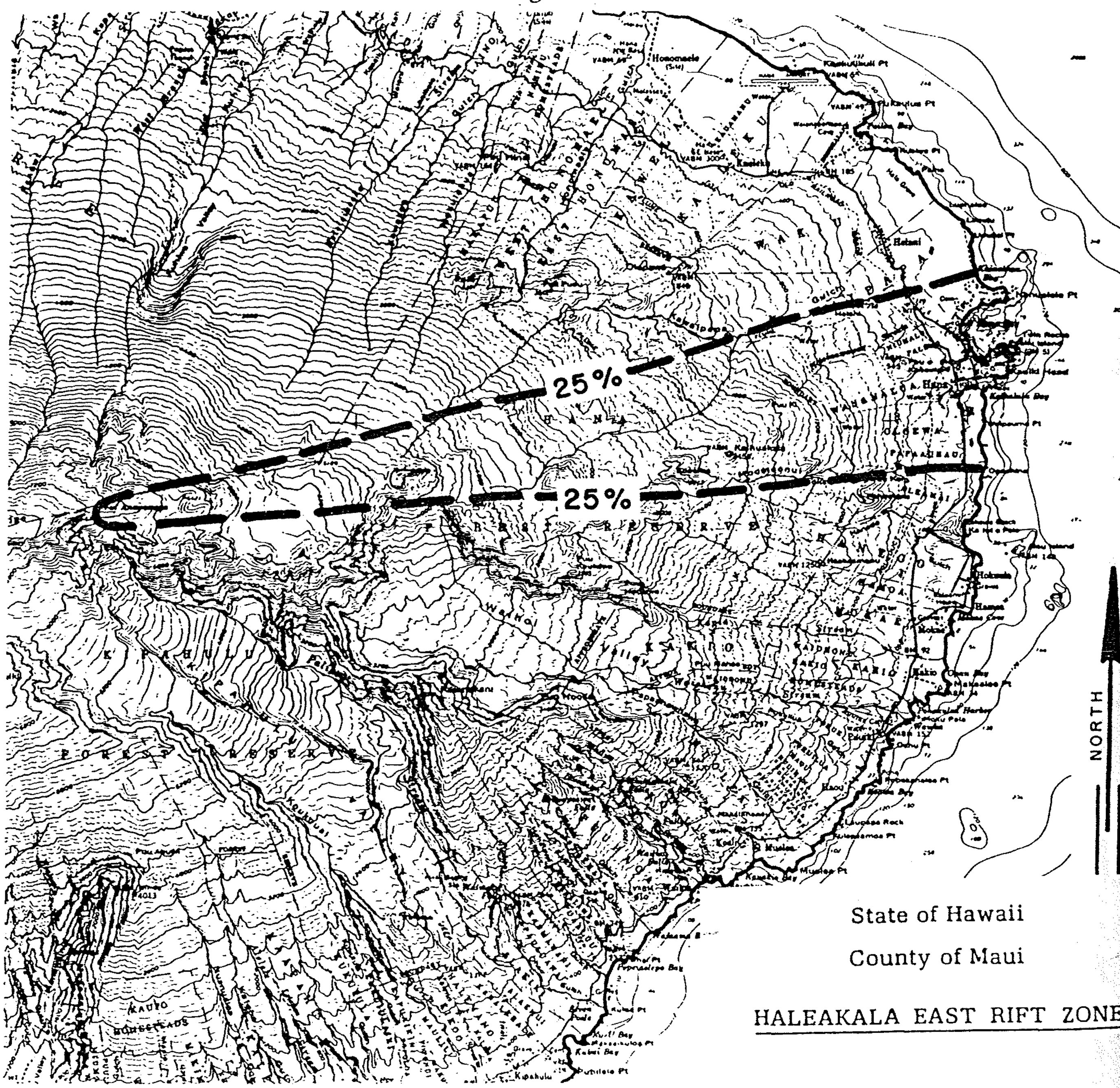
Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.

State of Hawaii

County of Maui

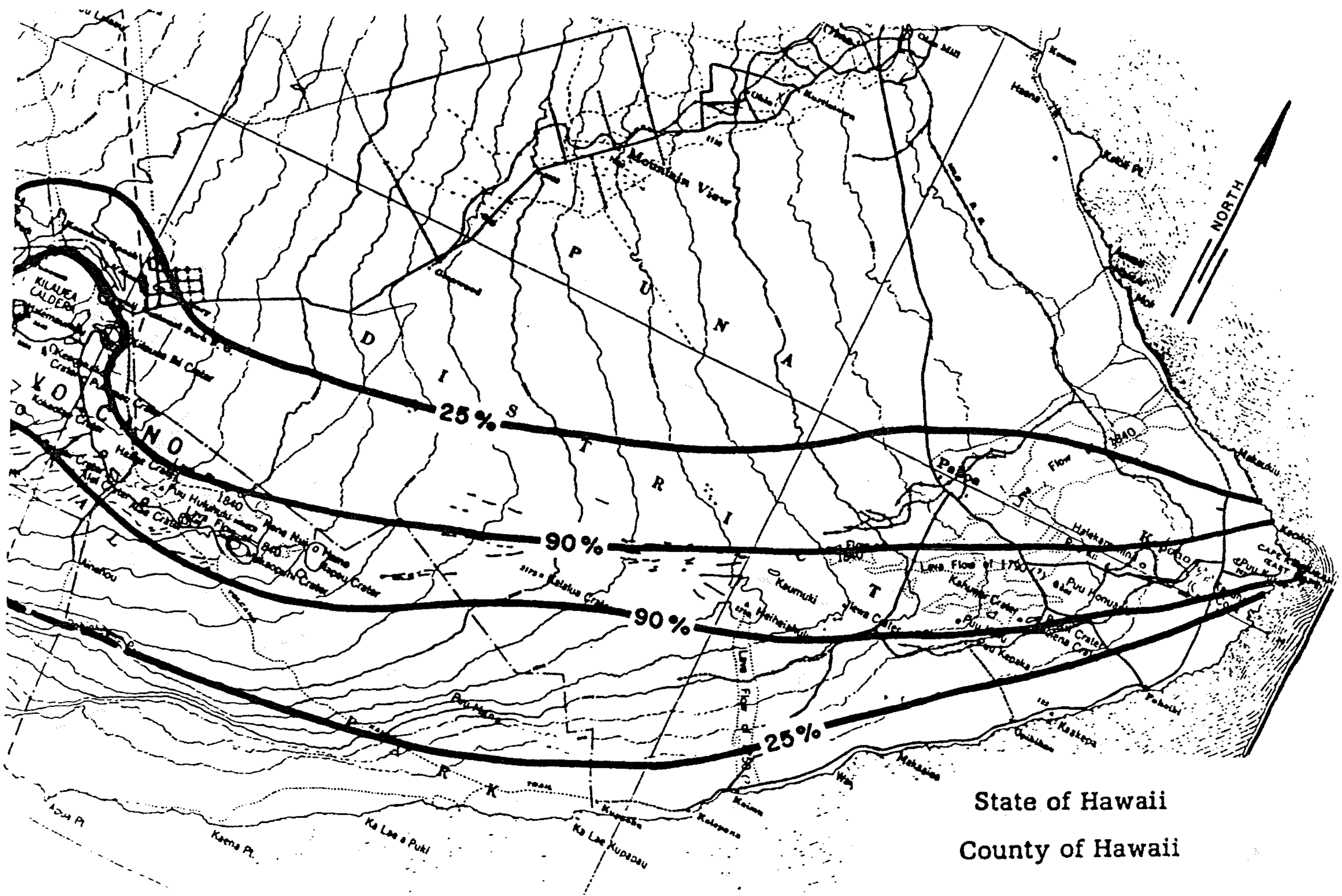
<u>HALEAKALA SW RIFT ZONE</u>

Figure 4.



Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.

Figure 5.



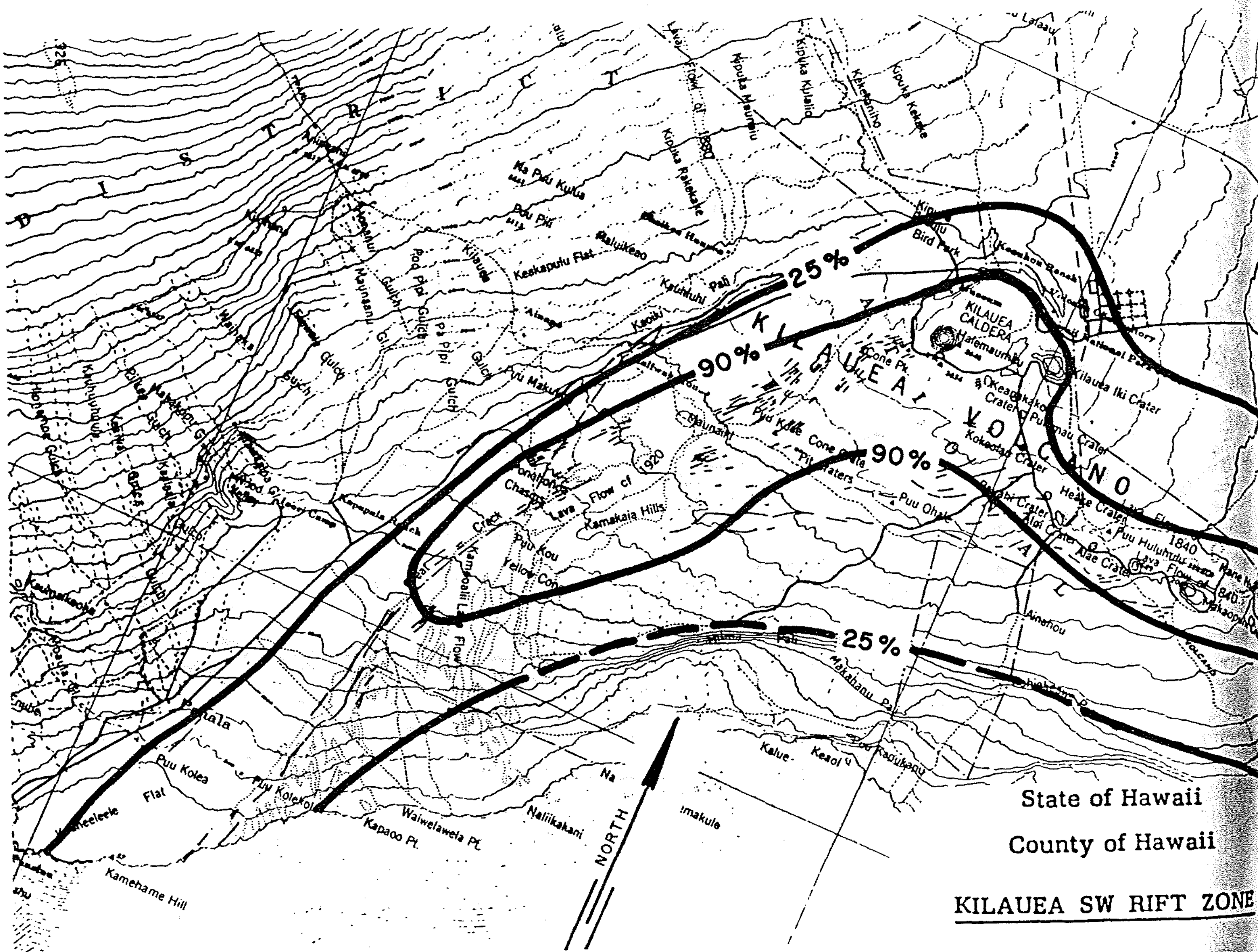
State of Hawaii

County of Hawaii

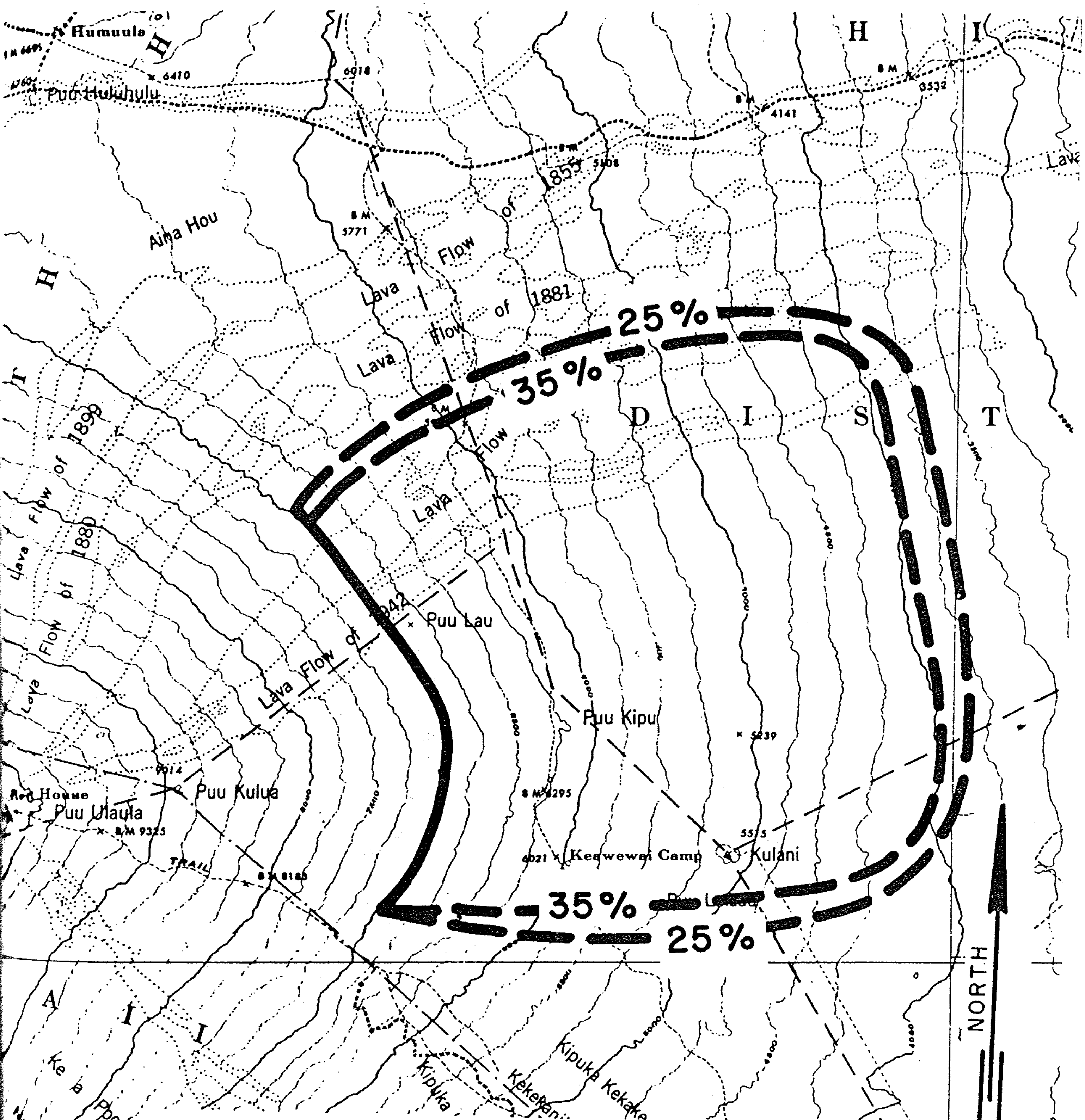
KILAUEA EAST RIFT ZONE

Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.

Figure 6.



Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.



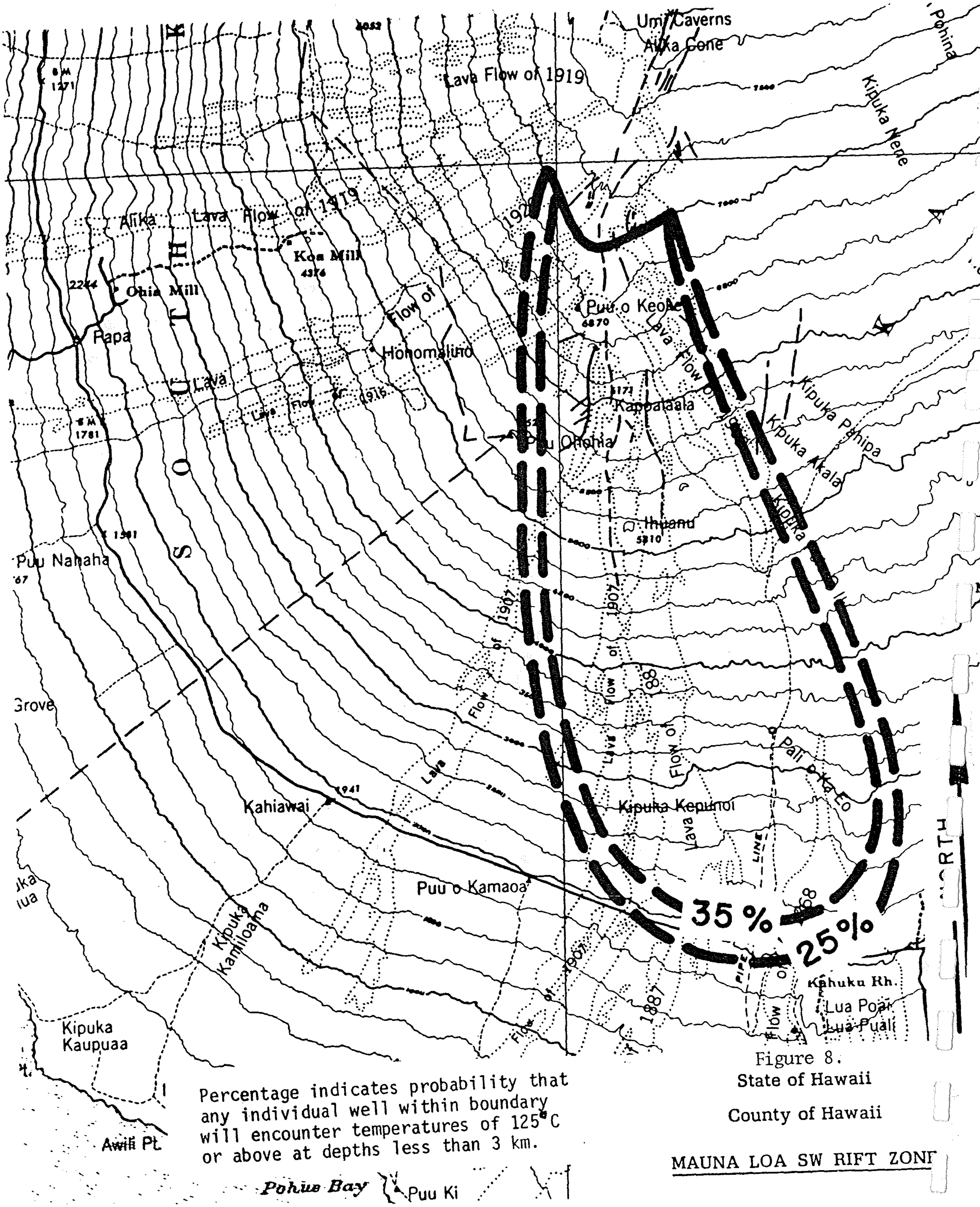
Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.

Figure 7.
State of Hawaii

County of Hawaii

MAUNA LOA NE RIFT ZONE

Scale: 1"=2 miles

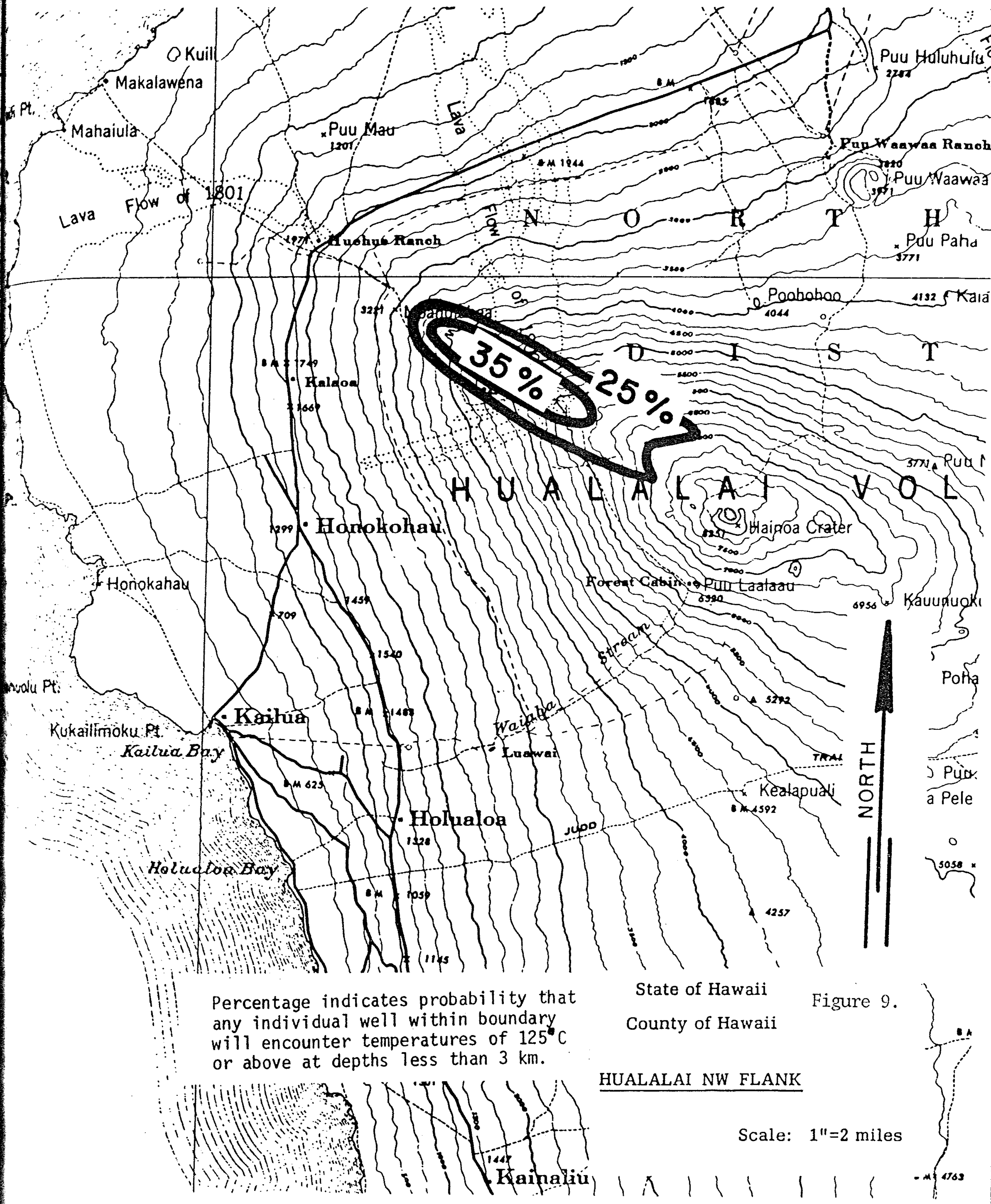


Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.

Figure 8.
State of Hawaii

County of Hawaii

MAUNA LOA SW RIFT ZONE



Percentage indicates probability that any individual well within boundary will encounter temperatures of 125°C or above at depths less than 3 km.

State of Hawaii

County of Hawaii

HUALALAI NW FLANK

Figure 9.

Scale: 1"=2 miles

OTHER GEOTHERMAL RESOURCE AREAS

Low Temperature Potential Geothermal Resource Areas, although not yet viable for electrical energy production based on current geothermal utilization technology, have a number of feasible direct-heat applications. Marketing opportunities for geothermal heat in the near future will be dependent upon the identification of low temperature resource areas. In addition, future site-specific surveys are warranted in these areas to re-evaluate their potential for high temperature electrical power generation.

The Geothermal Resources Technical Committee identified 12 Low Temperature Potential Geothermal Resource Areas. The basis for selection was agreed to be those areas having an assessed probability of at least 15 percent chance of finding a low temperature (less than 125°C) resource at depths less than 3 km. A list of five selected areas and a location map (Figure 10) follow:

Low Temperature Potential Geothermal Resource Areas
(less than 125°C at depths less than 3 km)

Statewide	Percent Probability
Waianae, Oahu	15% or less
Olowalu-Ukumehame, Maui	75% or less
Kawaihae, Hawaii	45% or less
Mauna Kea N. W. Rift, Hawaii	Less than 50%
Mauna Kea East Rift, Hawaii	Less than 30%

Note: Not included in the list are the seven High Temperature Potential Geothermal Resource areas that also have low temperature potential.

A brief abstract of various types of direct-heat applications* for geothermal energy follows:

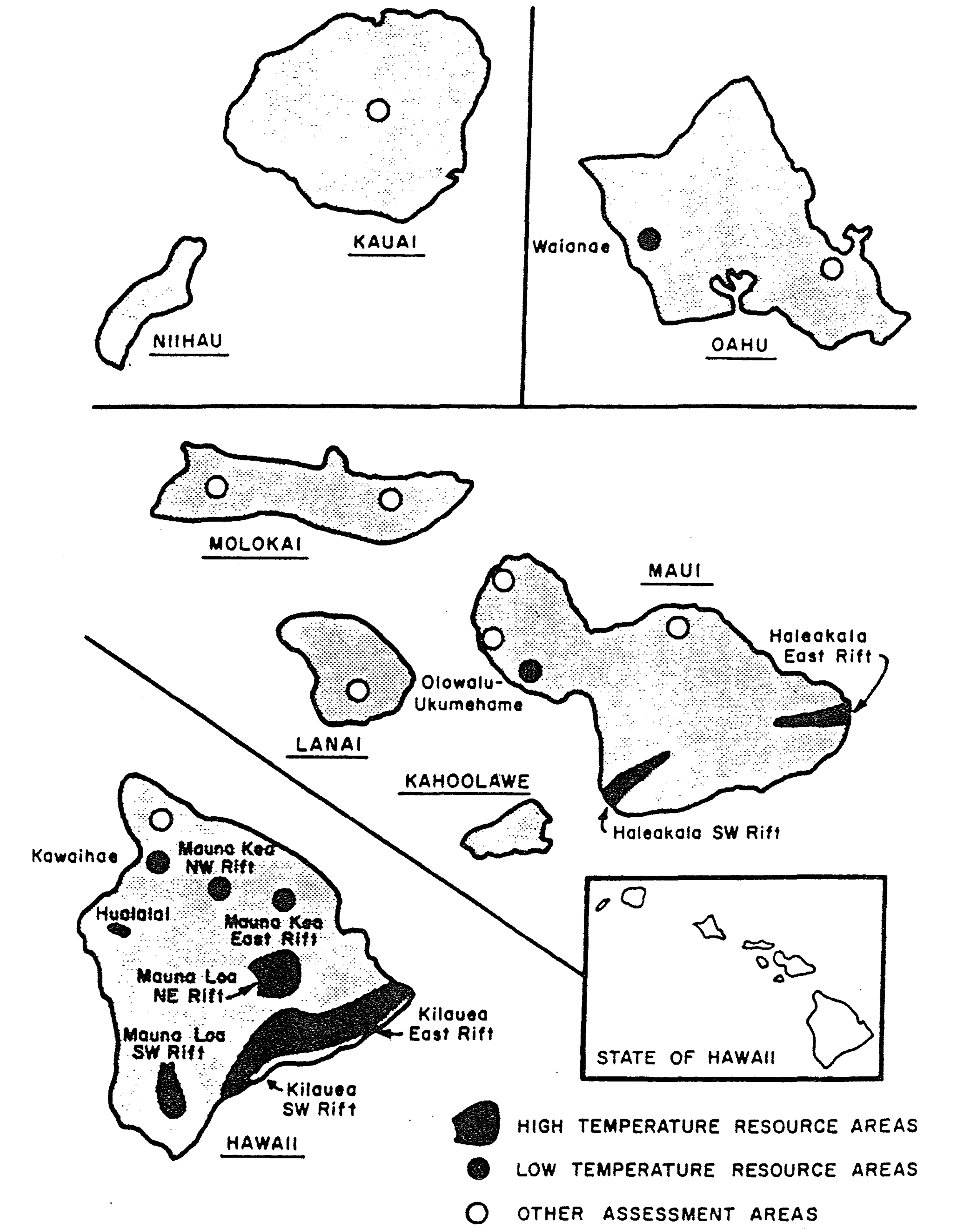
Tourism/spa:

The visitor trade may find a market for geothermal resources in the form of spas or the heating and cooling of hotel complexes.

*A later chapter, "Potential Economic Benefits from Geothermal Development", provides more information on direct-use applications.

Figure 10.

STATEWIDE GEOTHERMAL RESOURCE ASSESSMENT



Agriculture:

The processing of sugarcane and the heating of greenhouses and poultry operations could benefit from direct heat utilization.

Food Processing:

The use of a moderate temperature resource in the processing of fruits and vegetables is another possible market in Hawaii. The food processing industry could utilize geothermal energy for the processing of macadamia nuts, coffee, guava, papaya, and bananas.

Aquaculture:

Aquaculture activities can benefit from low temperature resources. Geothermal fluids can be used to maintain optimum growing temperatures for farming operations.

Existing process activities that do not require electricity may be able to use the waste heat produced from electrical power generation. Multiple applications of direct-heat may reduce some of the costs and result in a more efficient use of geothermal energy.

CONCLUSIONS

The results of the Statewide Geothermal Resource Assessment have identified several areas in the State of Hawaii that may have significant geothermal potential. Evaluation and identification of these potential geothermal resource areas were based on currently available information on geology, geophysics, geochemistry, and deep exploratory drilling data.

A committee of technical experts was selected, on the basis of experience and area of expertise, to identify and provide an estimate of the percent probabilities for finding high temperature (greater than 125°C) and low temperature (less than 125°C) geothermal resources at depths less than 3 km.

The findings of the committee resulted in the identification of seven High Temperature and five Low Temperature Potential Geothermal Resource Areas. These areas and their respective percent probability are presented as follows:

Location	High Temp. Resource	Low Temp. Resource
Hawaii County:		
1) Hualalai	35% or less	70% or less
2) Mauna Loa S.W. Rift	35% or less	60% or less
3) Mauna Loa N.E. Rift	35% or less	60% or less
4) Kilauea S.W. Rift	Greater than 90%	Greater than 90%
5) Kilauea East Rift	Greater than 90%	Greater than 90%
6) Kawaihae	--	45% or less
7) Mauna Kea N.W. Rift	--	Less than 50%
8) Mauna Kea East Rift	--	Less than 30%
Maui County:		
9) Haleakala S.W. Rift	25% or less	35% or less
10) Haleakala East Rift	25% or less	35% or less
11) Olowalu-Ukumehame	--	75% or less
City and County of Honolulu:		
12) Waianae	--	15% or less

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PROSPECTS FOR UTILIZATION OF GEOTHERMAL RESOURCES

Various public and private groups are actively involved in the development of geothermal resources in Hawaii.

A consortium comprised of the Hawaii Department of Planning and Economic Development, the County of Hawaii, and the University of Hawaii undertook exploration and development activities in the Kilauea Lower East Rift Zone which resulted in the Hawaii Geothermal Project three megawatt geothermal electrical generation facility. Two private developers, the Puna Geothermal Venture and Barnwell Industries, are also involved in geothermal exploration in the Kilauea Lower East Rift Zone.

The True/Mid-Pacific Geothermal Venture is actively involved in securing exploration and development rights in either the Kilauea Upper or Middle East Rift Zone. If these efforts are successful, it is likely that the Venture will also seek to explore the Haleakala Southwest Rift Zone.

Some Mainland developers have also expressed interest in exploring and developing the Kilauea Southwest Rift Zone.

The present demand for extra base-load electrical capacity on the Island of Hawaii is about 13 megawatts. An optimistic scenario would place anticipated demand for geothermal power on the Island of Hawaii at about 50 MW by the year 2000. This assumes retirement of some existing generating facilities and a modest increase in electrical demand. Also, a State- and Federally-funded undersea cable project is progressing which, if ultimately successful, may result in an inter-island electrical grid. This could increase the demand for geothermal electricity from the Island of Hawaii to over 500 megawatts.

POTENTIAL IMPACT FROM GEOLOGIC HAZARDS

LAVA FLOWS

Lava flows are generated in most volcanic eruptions in Hawaii and can cover extensive areas extending out to more than 10 km from the source; be they from a vent or a long linear fissure or crack. Lava tends to flow freely in a fairly predictable course determined by ground slope. However, ridges built by cooling lava on the sides of a flow may create channels and divert lava from the steepest slope. Flows from earlier phases of an eruption can quickly change the topography and expected course of the flow. In a somewhat similar manner, other natural and man-made obstacles can divert lava flows.

Most lava flows are thin, about one meter near vent areas increasing commonly to about five meters at the flow's distal part; although some individual flows (e.g., Pu'u O) have been significantly thicker. Structures more than five meters high are not immune from burial by lava. There is a strong tendency for many lava flow units to be generated during a single eruption. These flows will superpose upon one another, particularly near the vent where accumulations over 10 meters thick may be constructed by accretion of many individually thin layers.

Lava flows vary in their flow behavior. Thick distal aa flows tend to bulldoze, crush, bury, and burn any surface structures in their path. The more fluid, newly erupted, proximal (near-vent) lava tends to flow around obstacles. A fluid flow could enter buildings and may not cause much structural damage beyond igniting flammable materials and softening and distorting some of the metalwork. In principle, fluid pahoehoe lava could subsequently be removed and the building reoccupied. In principle this would also apply to flows covering protective well cellars and thin pahoehoe flows surrounding transmission piping (see mitigation below).

Removal of cooled lava would be feasible if the flows were sufficiently thin and friable, and if the eruption was not lengthy. Using Kilauea as an example, since 1800, the average duration of an eruption has been about 60 days, with many lasting only one day and some, such as the Mauna Ulu and the current Pu'u O eruptions, lasting years.

Since the crust tends to insulate underlying lava, cooling time for lava increases exponentially with the thickness of the flow. It would take about 200 days for one meter (1000 days for four meters) of lava to cool to 200°C (extrapolated from Peck, 1974). However, cooling time can be significantly reduced if great amounts of water are applied to a cooling flow area. (See section on lava cooling effort at Heimaey Island, Iceland.)

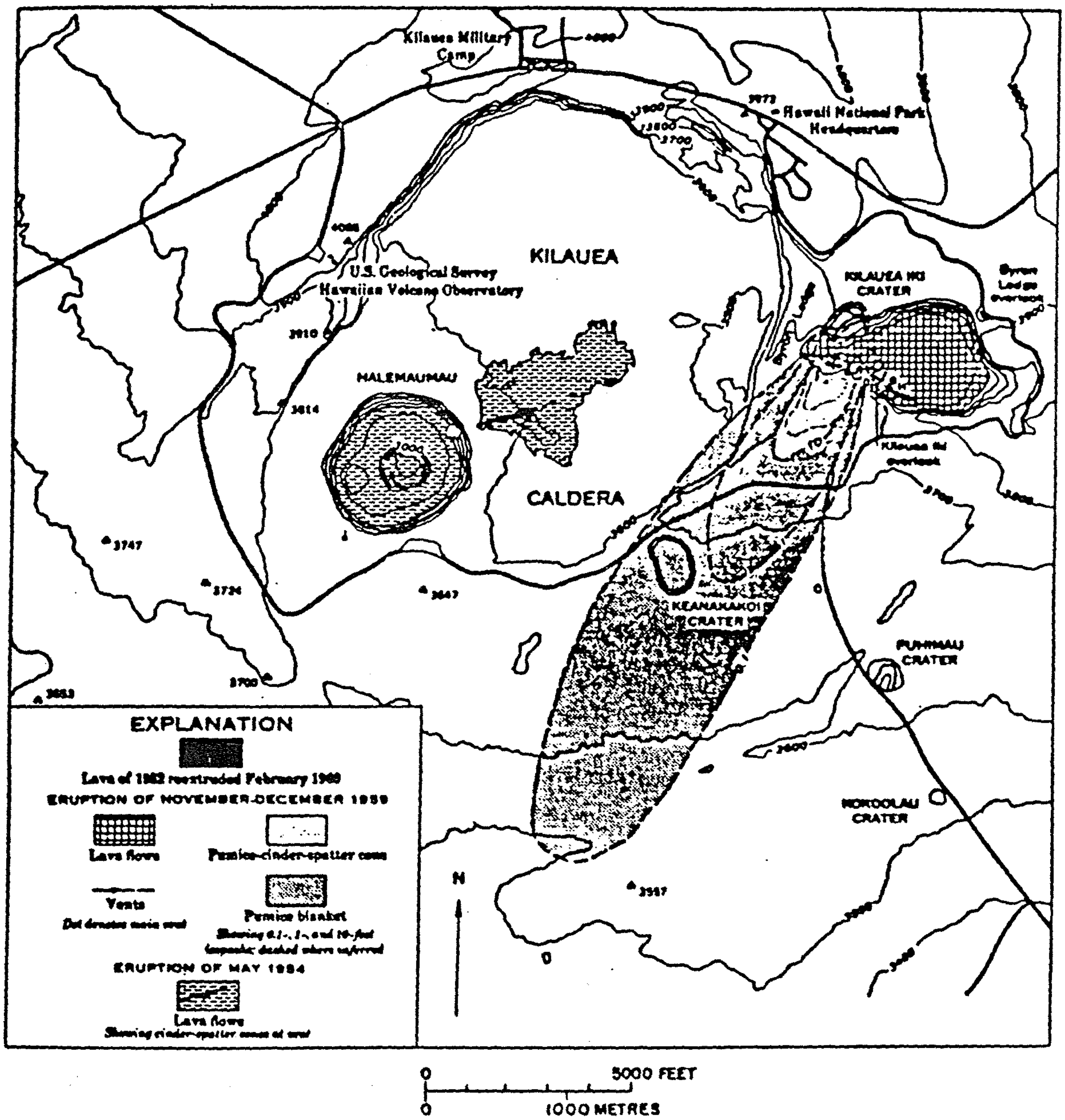
Thus, recovery from a deep or long enduring flow could take many months. Mitigation techniques may significantly reduce risk from flows. A long recovery time would not be acceptable to a damaged electric utility power plant unless sufficient reserve capacity were available.

Past volcanic activity can suggest future activity; however, it is not possible to detail the specific time and place of future eruptions. Summit swelling and increasing swarms of volcanic earthquakes can warn of impending eruptions.

PYROCLASTIC FALLOUT

Explosive eruption fountains may eject rock fragments of many sizes and types. The weight and depth of fallout can be appreciable as far as even 500 or 1000 meters away from an eruptive vent or fissure. Large fragments tend to fall close to the vent, building cones that may be tens of meters high. Smaller particles can form a long, narrow blanket many feet thick downwind of the vent. Figure 11 shows a pumice blanket originating from Kilauea Iki vent. Cones tend to be higher and fallout more extensive on older volcanoes such as Haleakala than on younger volcanoes like Mauna Loa or Kilauea. Some cones on Haleakala exceed 100 meters high.

Figure 11.



Map of the Kilauea summit area, showing extent of pumice blanket from Kilauea Iki vent in 1959. (In Mullineaux and Peterson, 1974, from Richter and others, 1970)

The probability of an eruption being powerfully explosive (with resultant increased debris) increases as the coast is approached and is near 100% for a vent within about one km of the coast. Steam generated by magma from the near-surface groundwater promotes such explosiveness. An example of potential damage from pyroclastic fallout is given by the 1960 Kapoho eruption where some buildings were destroyed because of the weight of cinder and ash upon their roofs (Macdonald, 1962). Other dangers from fallout include lung irritation, poor visibility, anxiety or panic, blockage of escape routes, and severe cleanup problems.

GROUND CRACKS

Cracks, which may open as much as several feet, can be the surface expression of dikes that fail to reach the surface. These cracks can produce a surface graben several meters wide and deep in which the ground is let down between two parallel cracks. This type of cracking related to magma movements is concentrated in volcanic rift zones which are clearly defined and narrow features (see Figure 12). Cracks could also open outside a rift zone; not enough information is available to access the probability, but it decreases rapidly as the distance from the rift zone increases.

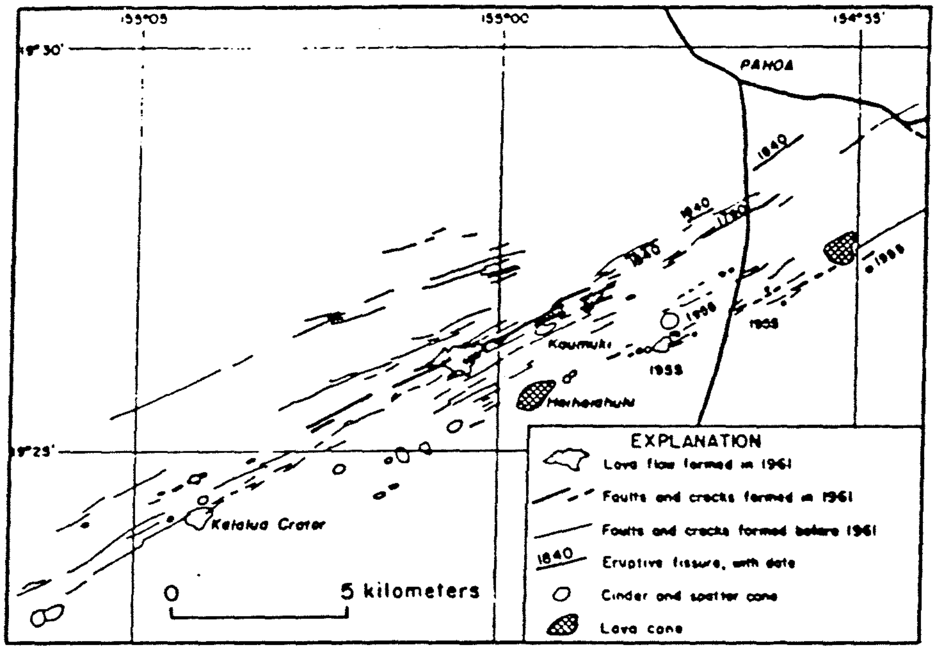
Ground cracking can also be associated with earthquakes, resulting from tectonic activity. Their formation is often accompanied by a relative vertical or lateral displacement of the ground on either side. Tectonic ground cracking is usually localized in definable zones; e.g., the Hilina and Koae fault systems at Kilauea (see Figure 13).

Ground cracking across a geothermal plant could cause a suspension of operation, depending on the extent and location of damages.

Pipes carrying steam between the wells and plant are likely to remain undamaged by moderate ground cracking, since they are designed with expansion joints at regular intervals.

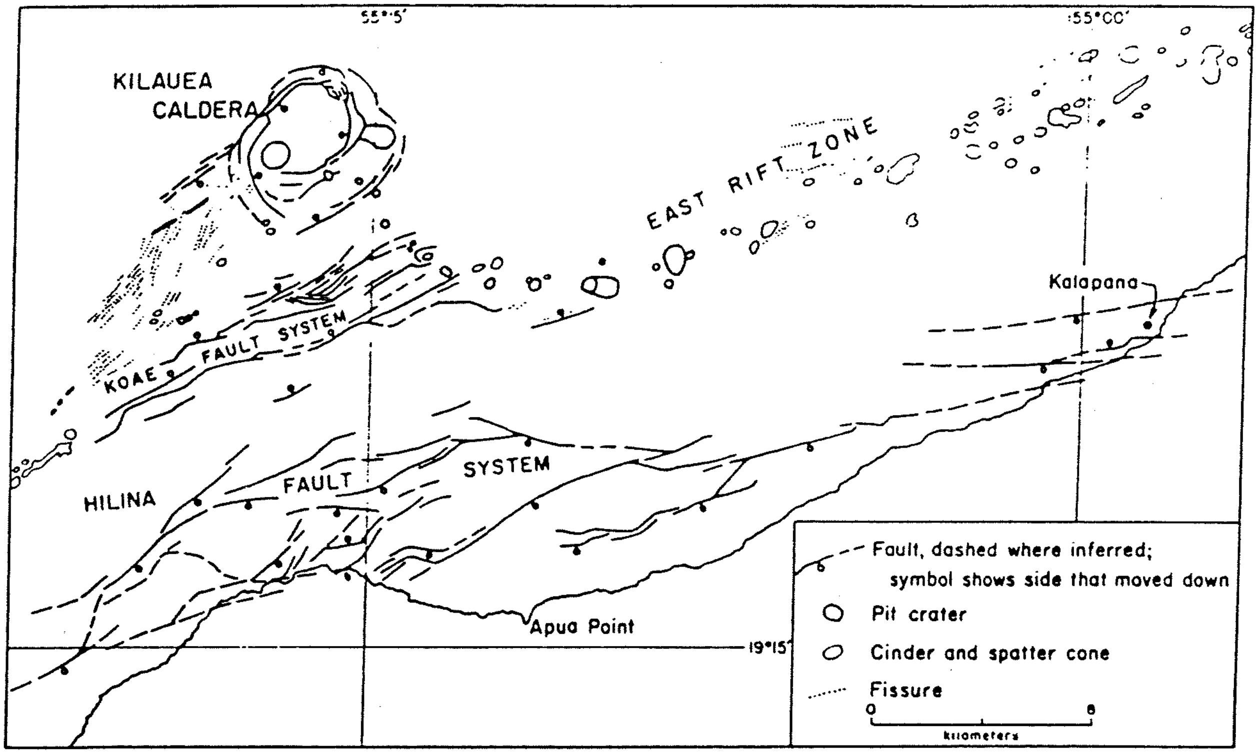
Ground cracking close to a well bore might open up an alternate path for the steam and cause its loss from the well. It is unlikely for

Figure 12.



Map of part of the east rift zone of Kilauea showing faults, cracks, and lava flows formed in 1961. (In Holcomb, 1980; modified after Richter et al., 1964)

Figure 13.



Map showing the pattern of faults in the Hilina fault system, on the southern flank of Kilauea volcano. (In Macdonald et al., 1983; modified after Stearns and Macdonald, 1946) a crack to intercept a well bore due to the vertical pitch of most cracks.

GROUND SUBSIDENCE

On the Mainland, subsidence due to contraction of clay or sand formations may result from the withdrawal of geothermal fluids in those formations. In Hawaii, subsidence from geothermal fluid withdrawal is not likely to be a problem since the islands are generally composed of dense yet porous, self-supporting basaltic rock, especially in geothermal production zones. Of more concern is the volcanic or tectonic subsidence which usually occurs on or about active rift zones, e.g., Kilauea.

Small to large grabens may result with the subsidence of rock blocks (usually rectangular) which are downthrown along or between cracks, e.g., 1960 Kapoho graben (see section on ground cracks).

Subsidence and cracking may also be associated with tectonic earthquakes, e.g., subsiding slump blocks in the Hilina fault system at Kilauea (Figure 13).

Collapsing pit craters and lava tubes can result in very severe localized subsidence. Pit craters usually occur within a summit or upper rift zone of a volcano. Figure 14 explains their formation which can result in subsidence up to hundreds of feet. Fragile, near-surface lava tubes (usually found in pahoehoe flows) are subject to collapse from heavy surface activity. A geologic site survey could reveal these hazards.

Aside from the immediate effects subsidence may have on the foundation and contents of a power plant, subsidence also increases the hazards from lava flows since flows usually seek lower areas.

EARTHQUAKES

Most earthquakes in Hawaii are volcanic, resulting from near-surface magma movements. They are small in magnitude and

Figure 14.

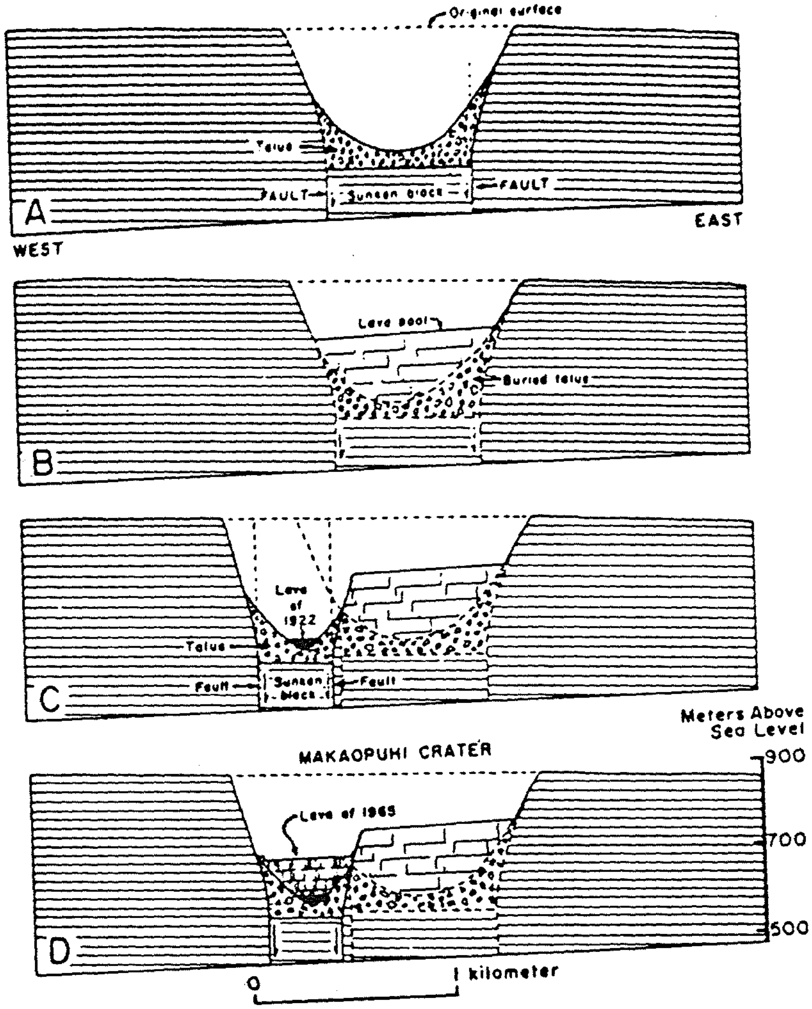


Diagram showing the manner of formation of Makaopuhi, a double pit crater. *A*, A subcircular fault block sinks, leaving a crater at the surface. (The position and attitude of the faults is hypothetical.) The upper walls of the crater collapse to form taluses (piles of rock fragments) that hide the lower walls. *B*, Lava pouring into the crater collects in a deep pool, the surface of which solidifies to form a nearly flat floor. *C*, A second block sinks, making a second crater that cuts across the western edge of the first one. The pool of lava in the bottom of the second crater is from a small eruption in 1922. *D*, A much larger eruption (in 1965) forms a pool 90 meters deep in the second crater. Note the slump scarps at the edge of the new lava floor, formed as lava in the central part of the crater drains back into underlying vents.

Formation of pit craters. (Macdonald et al., 1983) usually cause little direct damage. Larger earthquakes tend to be tectonic, generally resulting from the movement of large rock bodies. The largest Hawaii earthquake occurred on the Island of Hawaii in 1868, having a magnitude of 7.5.

Major earthquake shaking can easily damage buildings, especially those poorly constructed. Indirect damage may be caused by the smaller but more frequent volcanic earthquakes; e.g. collapse of lava tubes, landslides, and compaction (Mullineaux and Peterson, 1974). It is recommended that power plants be constructed to withstand shaking from a 7.5 magnitude earthquake (Stearns).

TSUNAMIS

Tsunamis are large sea waves usually generated by movement of large submarine rock masses although some are caused by volcanic eruptions. These devastating waves can travel great distances at speeds of almost 500 mph and move on shore turbulently or merely rise quietly. The highest reported wave in Hawaii, of 60 feet above sea-level, resulted from a local earthquake on the Island of Hawaii in 1868 (Macdonald et al., 1983). Much larger tsunamis have been reported elsewhere.

Thus, tsunami hazard is probably localized to a zone of land at most two km wide around the coast, and at elevations below about 75 feet. This should not pose a significant danger to geothermal developments which are likely to be situated at higher elevations.

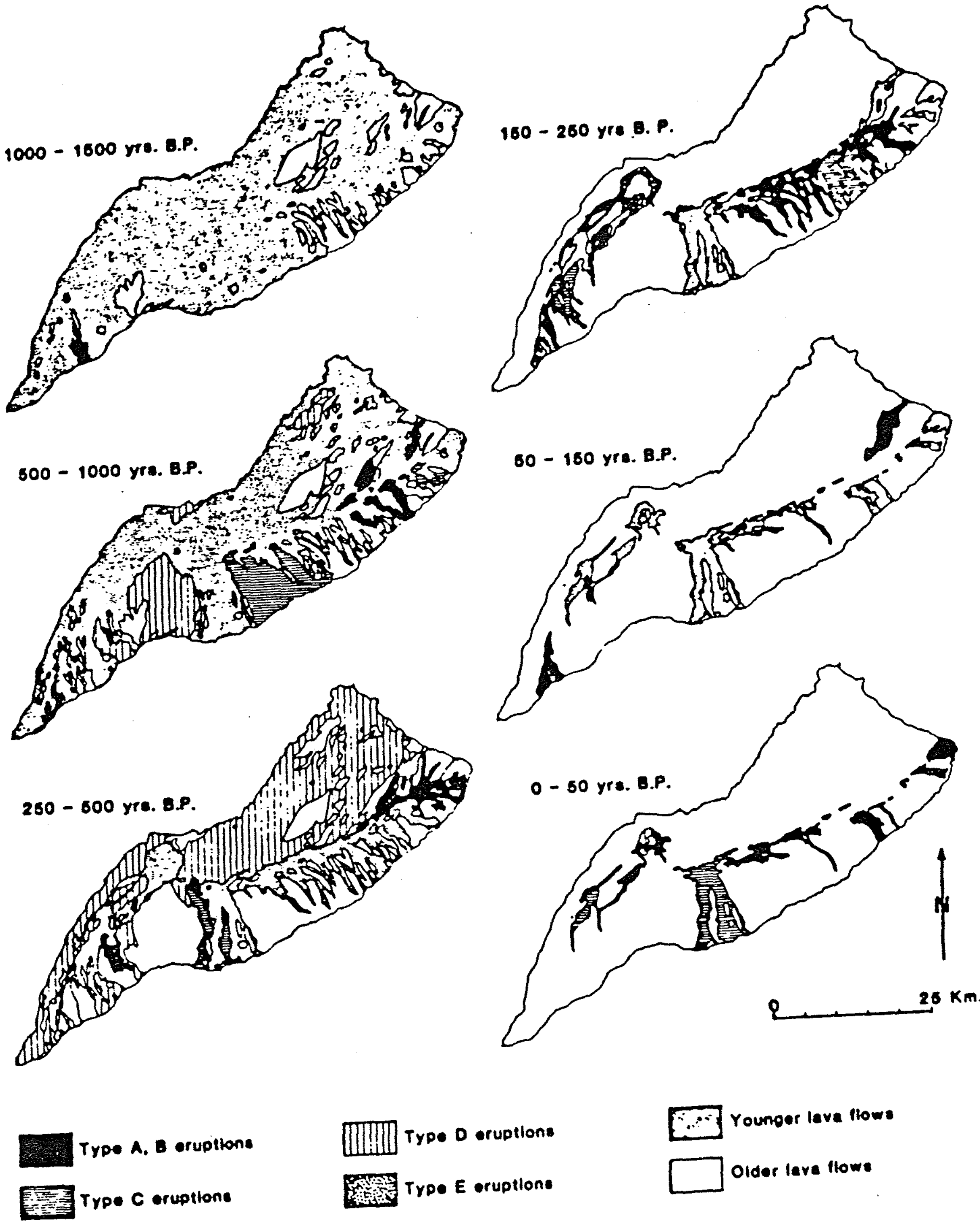
MEASURES TO MITIGATE DAMAGE FROM GEOLOGIC HAZARDS

Various methods which could be used to mitigate dangers from geologic hazards are listed below. No attempt is made to prioritize methods since priorities may differ with the risks at each specific site.

A survey should be conducted on each development site to closely examine topography and structural integrity of the surface and subsurface areas.

- Keep the power plant as far outside the rift zone as is possible since volcanic activity is concentrated there, e.g., lava flows, lava tubes, cracking, subsidence, pit craters, grabens, swelling. The piping distance from the well field to the power plant is limited due to increased thermal losses with distance; for example, the Kahauale'a site development map shows a maximum distance of about 2½ miles from its farthest well to a power plant.
- Power plants and wells should be constructed on the highest ground available. Even a very small hill or ridge could offer considerable protection from lava flows. Channels and valleys should be avoided, even if upslope, as lava flows tend to be channeled into, and be deepest in, these relatively low areas.
- If a sufficiently large hill is not available, a plant or well could be protected by constructing an earth-and-rock platform several meters high. Depending on the perceived risk from flow hazard, wells or plants can be sufficiently fortified to withstand almost any lava flow (Mullineaux and Peterson, 1974). A cost/risk analysis would have to be made.
- Another well-protection alternative is to enclose the wellhead in a concrete cellar allowing the lava to flow above rather than around the wellhead. Recovering a well covered with a thick flow could be quite arduous and time consuming. The precise effect the lava's heat would have on the wellhead mechanisms is not known.
- To complement the platform, a berm or wall could be constructed to divert lava flows. The embankment should be several meters high around the upslope and cross-slope sides of the structure. (See section on diversion walls below.)
- Available information indicates that the northern flank of Kilauea's rift zones are safer than the southern. For example, ground movements are more frequent on the Kilauea east rift zone's southern flank. By referring to Figure 15 it is apparent that

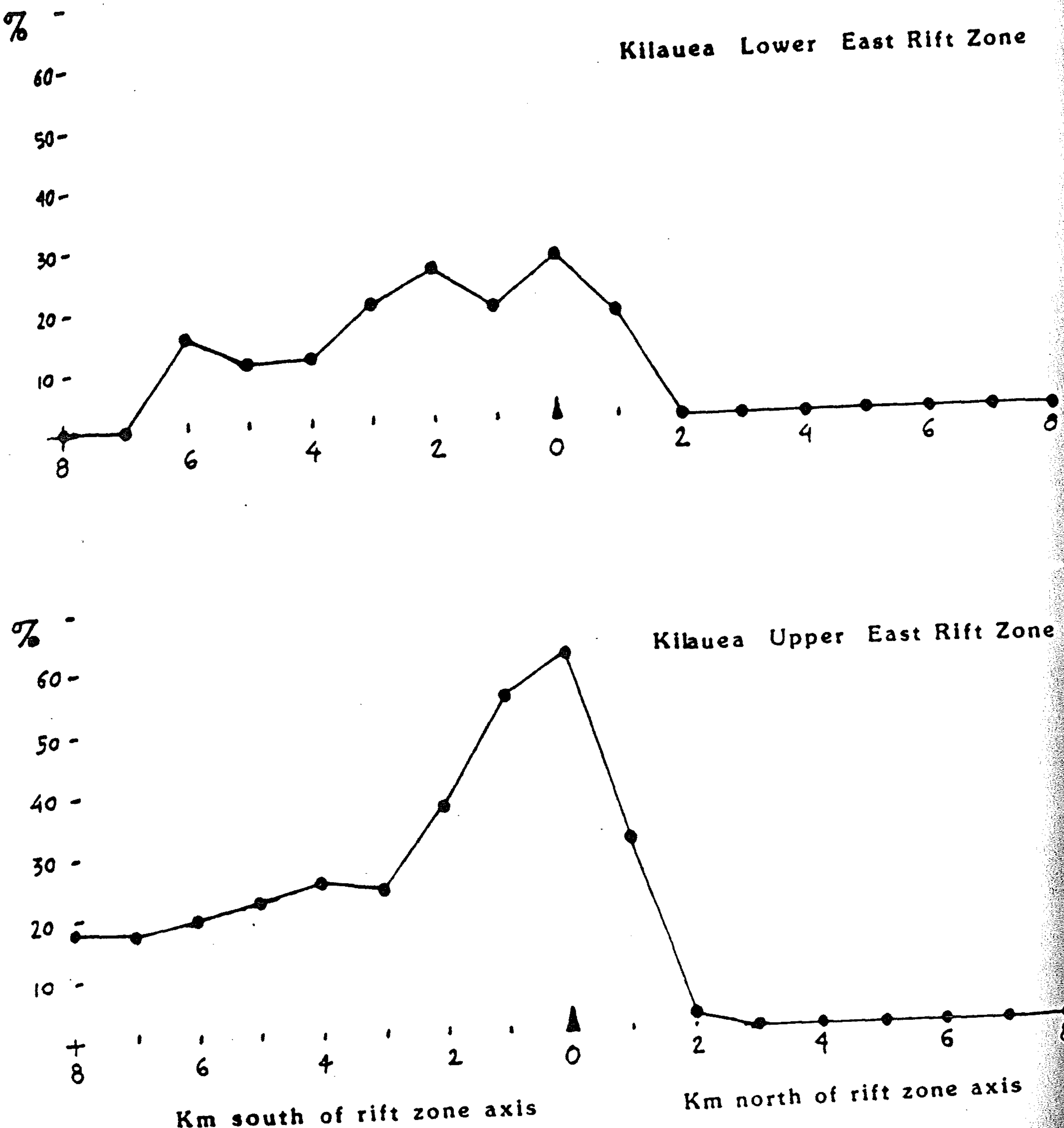
Figure 15.



Summary of Kilauea's eruption history during the last 1500 years. (Holcomb, 1980) over the past 250 years the vast majority of erupted lava on Kilauea's rift zones has flowed over the southern slopes. Figure 16 depicts the percentage of ground covered by lava in the past 30 years, as distance varies north and south of the Kilauea east rift zone axis. A similar relationship does not appear to apply to volcanoes at other proposed geothermal areas in Hawaii.

- A geologic survey may identify near-surface lava tubes which could collapse under construction.
- Power plants should be modular and somewhat portable so that, if all fortifications fail, units might be salvaged and reused. This tends to encourage use of smaller decentralized plants.
- Steam transmission piping may be protected from a thin, fluid pahoehoe flow by installing support structures on the downslope side of the piping. Thick aa flows would probably disrupt surface piping. Underground piping may offer more protection but installation and maintenance would be quite costly.
- Comprehensive evacuation plans should be designed to assure worker safety. Warning time prior to inundation can be as little as one hour (Moore, 1984). Procedures should be established to protect equipment. Multiple access roads should be provided in the event one is covered by a flow.
- The development should coordinate contingency planning with government field geologists (e.g., Hawaiian Volcano Observatory) and local civil defense authorities to ascertain when an eruption appears imminent and what subsequent action should be taken. Escape and abandonment procedures may be flexible but should be predetermined and clear. The developers have been giving this area their attention.
- If a lava flow is impending during well drilling, the well can be fitted with a pressure and temperature resistant "bridge plug" to safely isolate and protect the lower, resource-bearing, portion of the well. These plugs can be installed in one hour (Niimi, 1984).

Figure 16.



Percentage of ground covered by lava flows, from 1954 to 1984, as it varies with distance north and south of Kilauea's east rift zone axis. If 30 years is the assumed life of a geothermal power plant, these figures suggest the probability that sites may be threatened by burial during their lifetime, as based on Kilauea's history from 1954 to 1984.

- Trip wires, placed in the expected path of a lava flow, can alert development personnel as to the distance and speed of the oncoming flow. The crew can then take appropriate action in accord with their preexisting evacuation plan (Niimi, 1984).
- Protecting structures or machinery against damage by pyroclastic fallout might be achieved by enclosing those parts vulnerable to abrasion or contamination. Building roofs should be strong, having a sufficient pitch so that pyroclastic fallout does not accumulate. Access to roofs should be easy so that, if necessary, they can be manually kept cleared of pyroclastic material.
- Plant generators can be specifically designed to be adjustable to some ground surface tilting or subsidence (Capuano, 1984).
- Steam transmission piping can be made with expansion joints to accommodate appreciable subsidence and ground movements.
- Plants should be constructed to withstand an earthquake of 7.5 (Stearns).
- Power plants should not be constructed in coastal regions, if risk from tsunamis is to be avoided.
- In extraordinary and particular situations, bombing a lava channel may cut the feed to a flow-front and prevent or slow further advance in the front area (see section on bombing lava channels).
- If warranted by volcanic risk, adequate spacing between developments should be maintained so that one eruption would not likely endanger more than one development. It is a common utility practice to maintain reserves sufficient to prevent a major blackout. Reserve requirements (and associated costs) may be limited by using small decentralized power plants rather than one large plant.
- If geothermal development investors assume a major portion of the economic risk of loss resulting from geologic hazards, then developers would have a clear economic incentive to utilize appropriate mitigation measures and to select sites which offer the optimum balance of safety and productivity.

- It is generally assumed that the resource developers will bear the risks of loss associated with their activities. However, if the utility owns the power plant, there may be some question as to whether the investors or the rate-payers will bear the risks of loss. This assumption of risk would be reflected in the cost of electricity from geothermal plants. It may be better that this cost be apparent "up front" rather than be delayed and possibly deferred to rate-payers in the event of a catastrophe. In the past, there have been some instances where hazard losses were recovered by the utility from rate revenues (e.g., Hilo tsunami of 1960). Policy regarding assigning and clarifying risks of loss may be implemented by imposing conditions to be met by development investors prior to the granting of a geothermal resource permit by the State (Conservation district) or Counties (Urban, Rural, or Agriculture districts).

PAST ATTEMPTS TO MITIGATE GEOLOGIC HAZARDS

Construction of Walls to Restrict Lava Flows in Kapoho, Hawaii

Macdonald (1962) wrote an excellent article on walls built to restrict lava flows during the 1959 and 1960 Kilauea eruptions. The 1960 eruption resulted in a flow of 113 million cubic meters of lava, burying about six square kilometers of land including most of Kapoho village. Both dams (which tend to impound flows) and diversion barriers (which alter flow course) were constructed. Diversion barriers are more likely to be successful in most situations.

Some of Macdonald's conclusions regarding the effectiveness and nature of the walls are presented:

- Walls must be constructed of heavy materials; not cinder as lava tends to burrow under it. Lava-rock is preferred; especially aa clinker since it is easily bulldozed and its spiny character allows the rock to bind well.

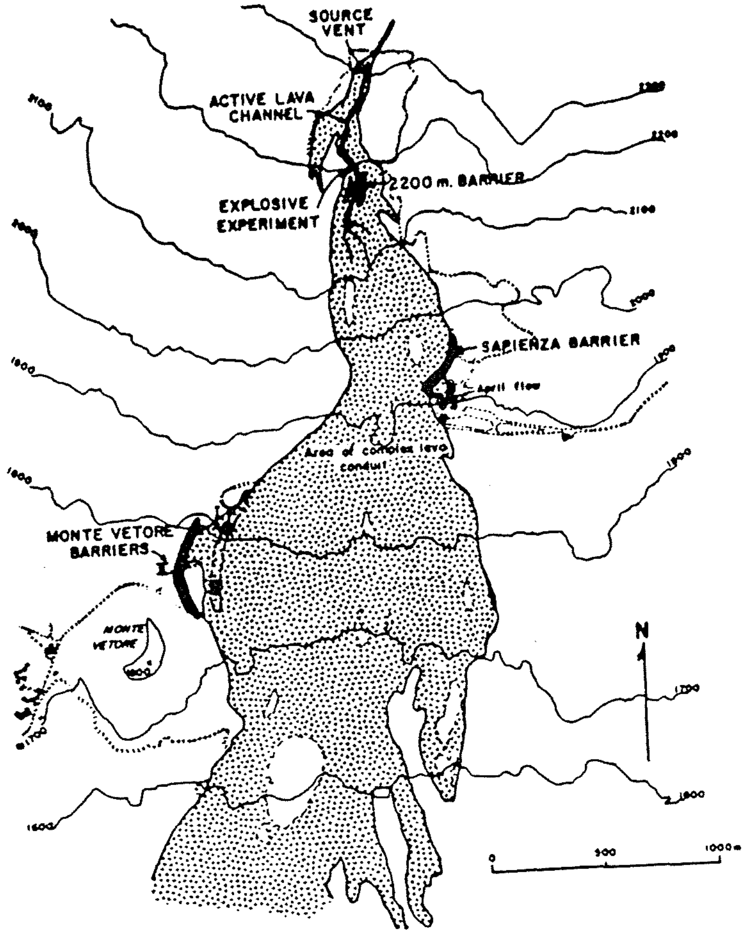
- Walls must have a broad base and adequate height to prevent overflow; e.g., if flow is expected to be 10 meters thick, the base should be about 30 meters wide.
- Exterior walls should be gently sloped to lessen erosion should an overflow develop.
- If the wall is a diversion barrier, a smooth unobstructed path or channel should be along the inside of the wall to promote diverted flow. In addition, the channel must also have sufficient slope to promote flow, i.e., at least two percent.
- Yielding of walls to lava pressure was limited to only a few places where the wall was built from light cinder.

Macdonald summarizes the success of the Kapoho walls by noting that "they have demonstrated that properly constructed walls will endure the thrust of even thick lava flows without yielding; and that walls with adequately sloping unobstructed channels behind them will successfully change the course of a flow." Others believe that "structures of sufficient size and strength could be constructed to divert lava flows as large as any historic flow...if the need were great enough a carefully planned, small-scale system might be feasible and effective" (Mullineaux and Peterson, 1974).

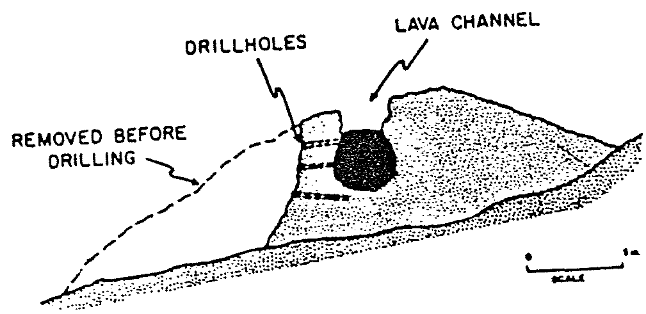
Use of Lava Diversion Walls and Explosives on Mount Etna, Italy

In 1983, lava flows from Mt. Etna in Italy threatened two towns downslope of an active vent (Figure 17A). In response to the situation, a lava diversion program was initiated to mitigate damages from the lava flows. This included two diversion barriers and the use of explosives.

With explosives, it was intended to create a significant diverting leak in a channel supplying lava to the flow front. A portion of the lava channel was removed by heavy equipment to provide for proper placement of the explosives (Figure 17B). It was observed that efforts to cool the drill (using water and dry ice) cooled the lava, thereby reducing the cross-sectional area of the lava tube and causing the lava to "back-up" and overflow the lava tube; this resulted in



a



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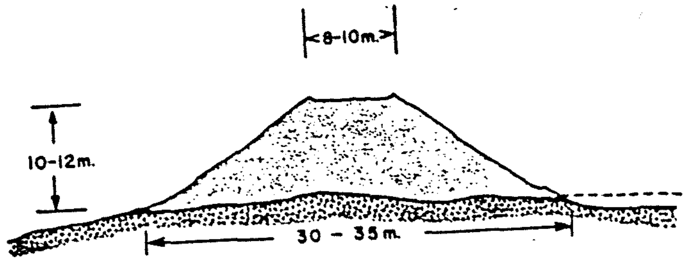


c

Figure 17A. 1983 lava flow on Mt. Etna in Italy.
Figure 17B. Cross-section of explosives placement area.
Figure 17C. Typical barrier cross-section
(Figures from Lockwood, 1983)

some unintended but welcomed lava diversion. Four hundred kg of explosives were finally inserted and detonated which caused a small lava flow away from the main lava tube.

The diversion barriers were quite substantial (Figure 17C); one being 150,000 m^3 and 500 m long, the other 120,000 m^3 and 300 m long. Work continued while lava was accumulating on the interior of the diversion wall. The first barrier, though eventually overtopped, caused major channels to be diverted from one town. The second barrier also succeeded in diverting the lava away from a second town.

This effort was quite substantial, utilizing 100 pieces of major equipment and over 100 men (working 90 hours per week), at a cost of $3 million. However, savings due to prevention of property loss were estimated at $5-25 million. (See Williams and Moore, 1977.)

Pumping Water on Lava Flows in Kapoho, Hawaii

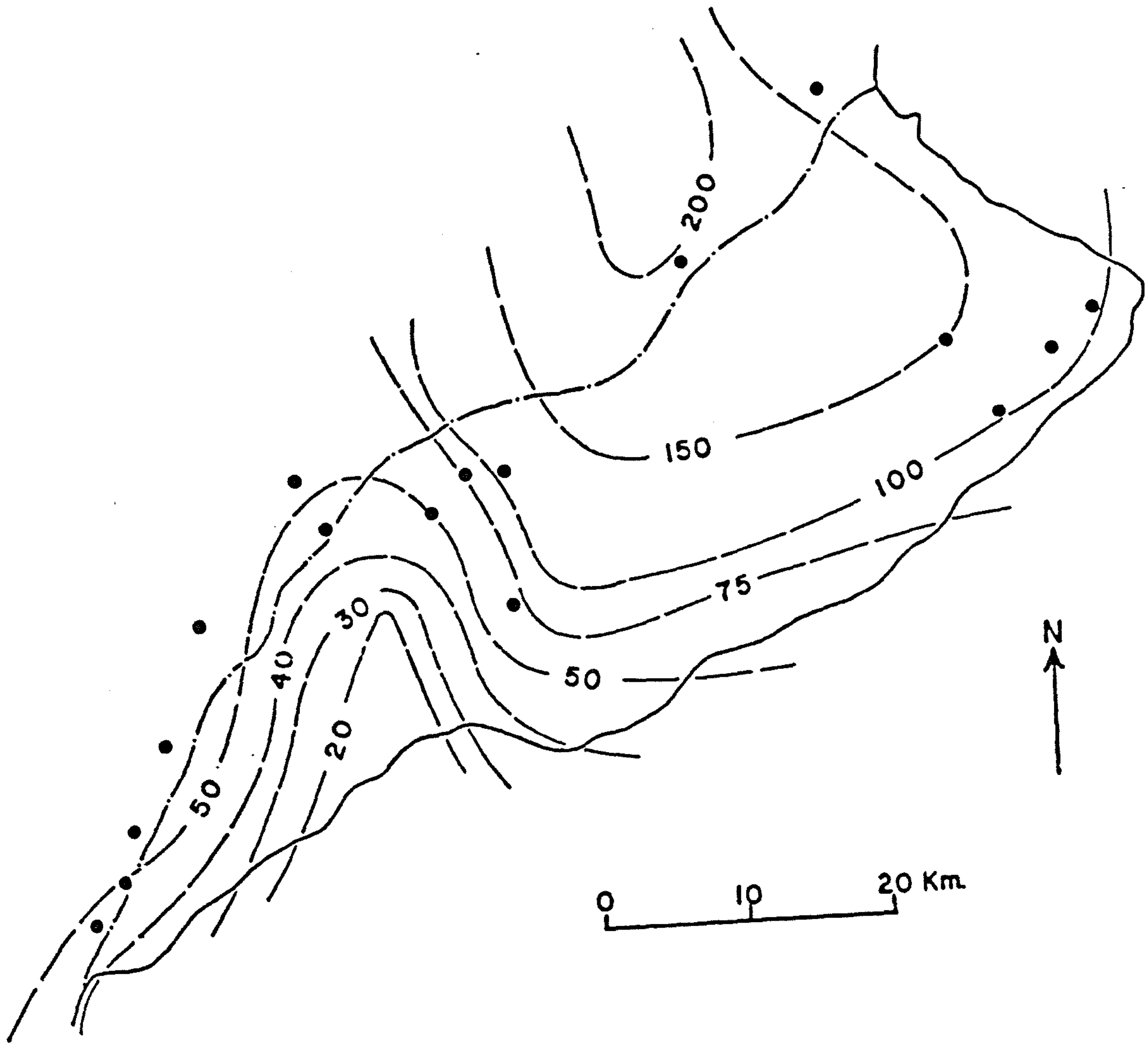
Water may chill and partially congeal a flow margin. During the 1960 Kapoho flow, the Hawaii Fire Department pumped water on the flow margin. Macdonald (1962) found that "it was possible to locally check the advance of the flow margin. Although the check is temporary, it is sometimes possible in that way to gain the short time--up to several hours--that may be needed to remove furnishings or other materials from a building, or even to remove the building itself."

This has obvious application to a geothermal development. If warranted, a sufficient supply of water might be kept on hand for lava cooling purposes; possibly from the same source as the power plant cooling water. The amount of rainfall and associated catchment and groundwater availability in geothermal areas should also be considered (e.g., Figure 18).

Pumping Water on Lava Flows on Heimaey Island, Iceland

In 1973, when lava flows threatened a coastal town on Heimaey Island, Iceland, a program was designed to: (1) slow advancing lava by pumping great volumes of seawater over the flow and (2) divert the lava flow using a diversion barrier. The water-pumping program was

Figure 18.



Rainfall of Kilauea. (In Holcomb, 1980; after Taliaferro 1959) the largest ever attempted. Seventy-five men working at times around the clock, sprayed approximately 7.3 million cubic yards of seawater onto the lava flow at a cost of $1.5 million. The pumped water converted 5.5 million cubic yards of molten lava into solid rock, cooling the lava 50 to 100 times more rapidly than self-cooling. A specialized system of pumps and piping was utilized. (See Lockwood, 1983.)

Bombing of Lava Channels on Mauna Loa, Hawaii

This technique can only be used in appropriate situations, i.e., to breakdown walls of near-vent lava channels, clogging them, thereby lessening the supply of lava to distal lava flow fronts. This would promote spreading of the flow in the bombed areas. Bombing of Mauna Loa flows was tried twice; but was not particularly useful in those situations (Macdonald, 1962). The legal ramifications of damages caused by diverting flow paths should be researched.

Emergency Planning at the Geothermal Development in Krafla, Iceland

In 1975 an emergency situation developed at Krafla, in Northern Iceland. A geothermal power plant under construction was located within one kilometer of the locus of ground deformation and seismic activity of the type that proceeds volcanic eruptions. This activity continued for over five years with construction proceeding normally though several small lava eruptions occurred within two kilometers of the plant. Careful contingency plans were designed for the evacuation of site workers, but the lava flows did not directly contact the power plant. On one occasion lava did rise into one of the well bore-holes without significant effect. Construction was concluded and the geothermal development is now operating.

This particular development is sited in a rift zone similar to the Hawaii rift zones. Detailed emergency planning should draw upon the contingency plans which resulted from this experience in Iceland. (See Tryggvason, 1973.)

GEOLOGIC HAZARD ANALYSIS

MAUI

A Maui volcanic hazard map has been prepared by D. Crandell (1983) which describes the frequency of past eruptions.

Haleakala Southwest Rift Zone

Flows range from 200 to 20,000 years old. Six flows have erupted in this area within the last 1000 years. Based on past activity, the average rate of eruption is one per 150-200 years. The last flow occurred in 1790 by the coast; it was the largest (6 km^2) of the more recent flows. See Figures 19 and 20.

Haleakala East Rift Zone

The most recent flow on the east side of Haleakala is just north of this geothermal resource area between Olopawa and Puu Puou; it is about 500 years old. Based on past activity, the average rate of eruption is one per 10,000 years.

The above risk from volcanic hazards includes dangers from lava flows and other attendant phenomenon such as pyroclastic fallout, cracking, subsidence, swelling, and emission of volcanic gases.

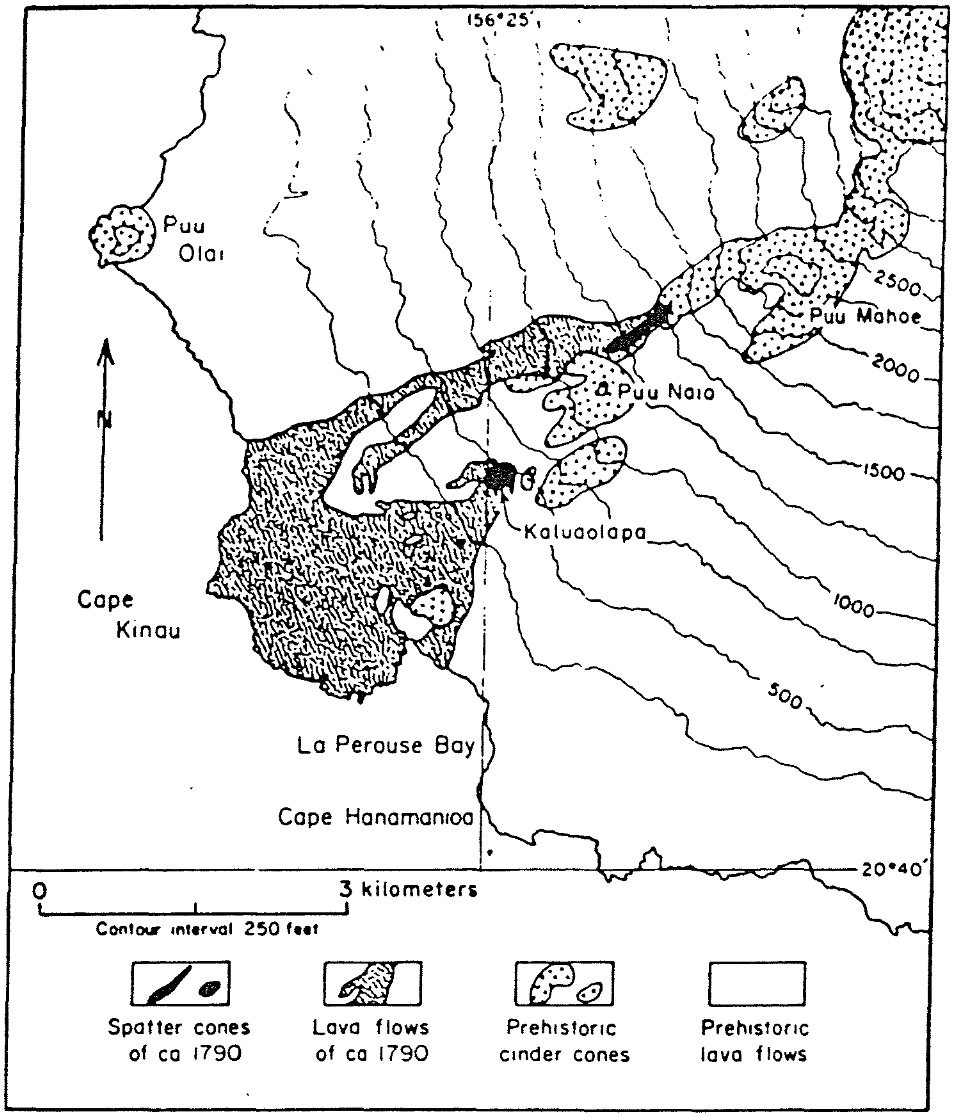
The most recent earthquake near Maui occurred in 1938, 40 miles off the northern coast of East Maui. Some damage to roads and buildings on Maui and Molokai was reported (Macdonald et al., 1983). Cracking and subsidence may also be associated with large earthquakes.

Crandall (1983) states that although Haleakala's "eruptive history suggests that an eruption could occur on Haleakala within the next hundred years, there is as yet no way to predict a specific time or place of the next eruption."

HAWAII

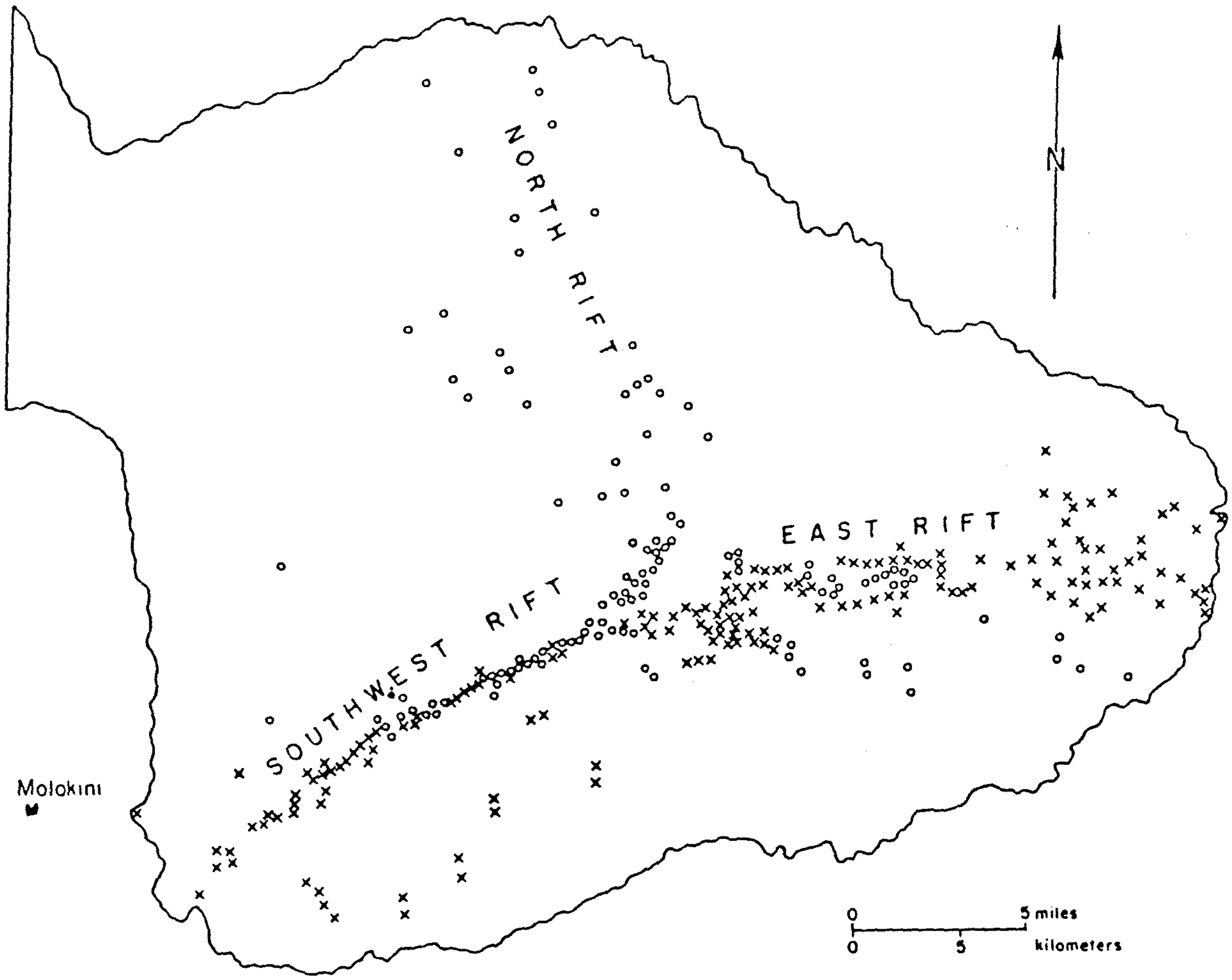
Figures 15, 16, 21, and 22 show the locations of historic lava flows and fault systems. Figures 23 through 26 show relative zones of risk from flows, fallout, subsidence, and ruptures.

Figure 19.



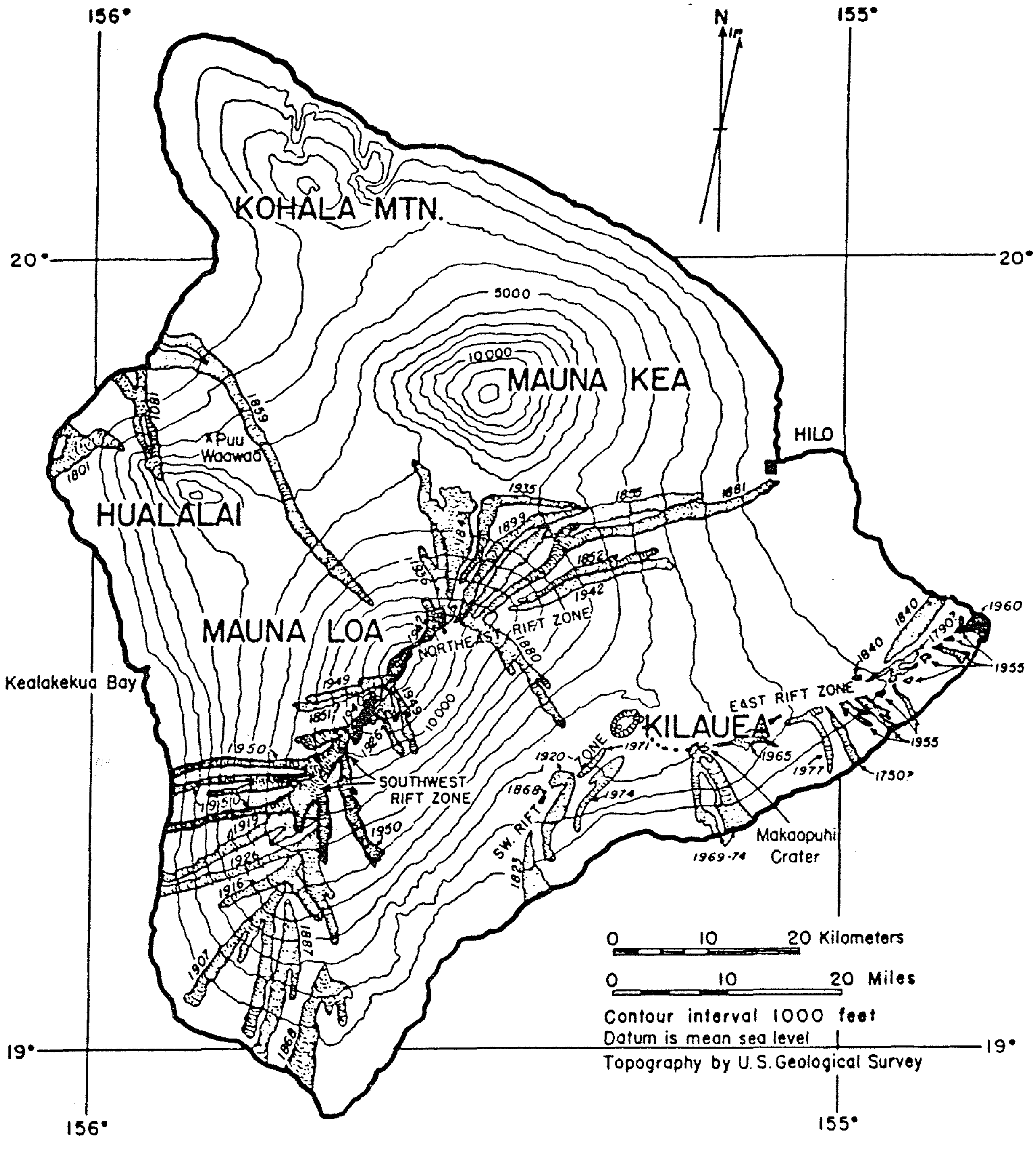
Map of the southwestern part of Haleakala volcano, island of Maui, showing the lava flows of the 1790 eruption and the spatter cones at their vents. (In Macdonald et al., 1983; modified after Stearns and Macdonald, 1942)

Figure 20.



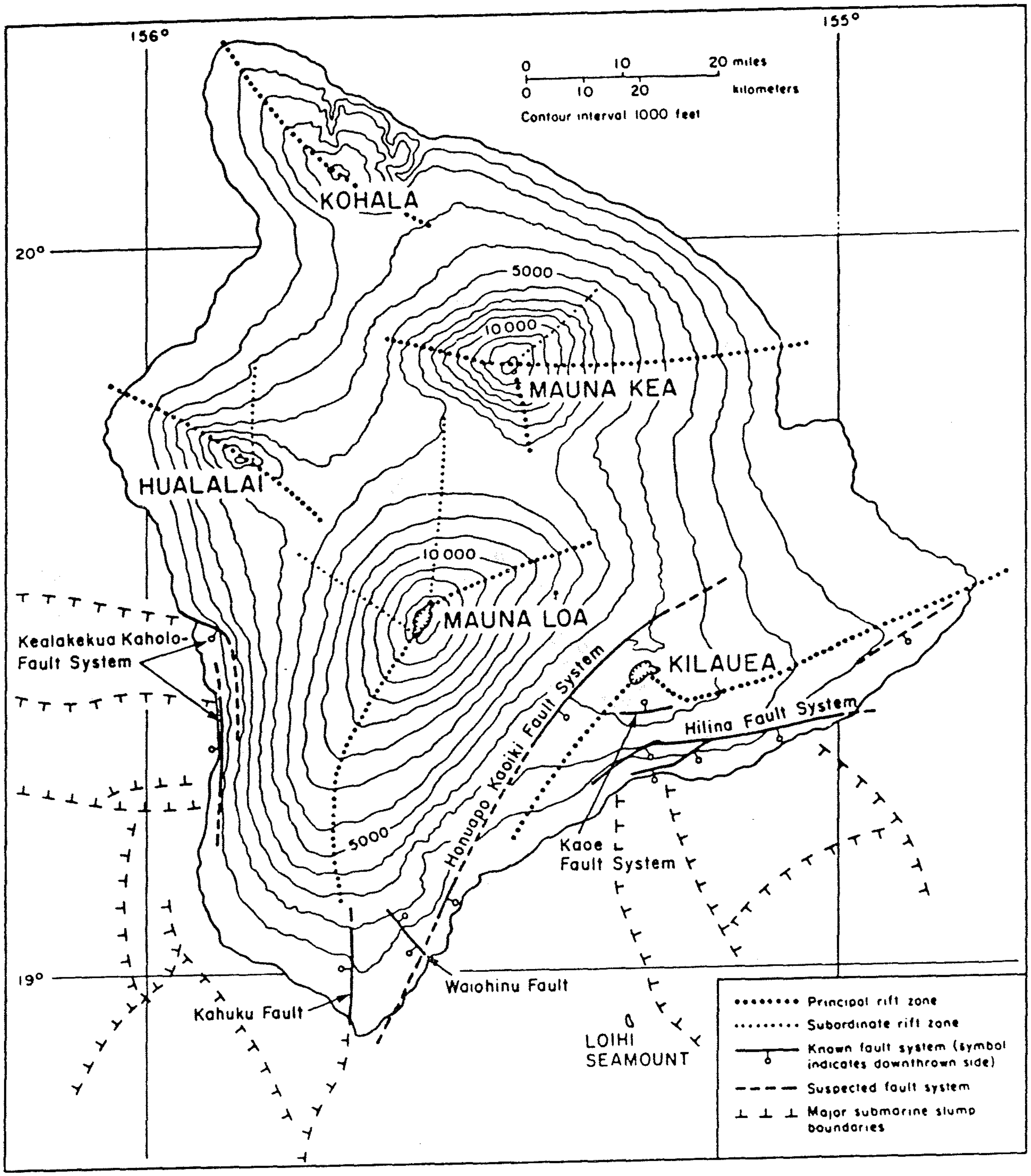
Map of Haleakala volcano, showing vents of the Kula (circles) and Hana (crosses) Volcanic Series. Molokini Islet is a tuff cone on the southwest rift zone of Haleakala. (In Macdonald et al., 1983; after Stearns and Macdonald, 1942)

Figure 21.



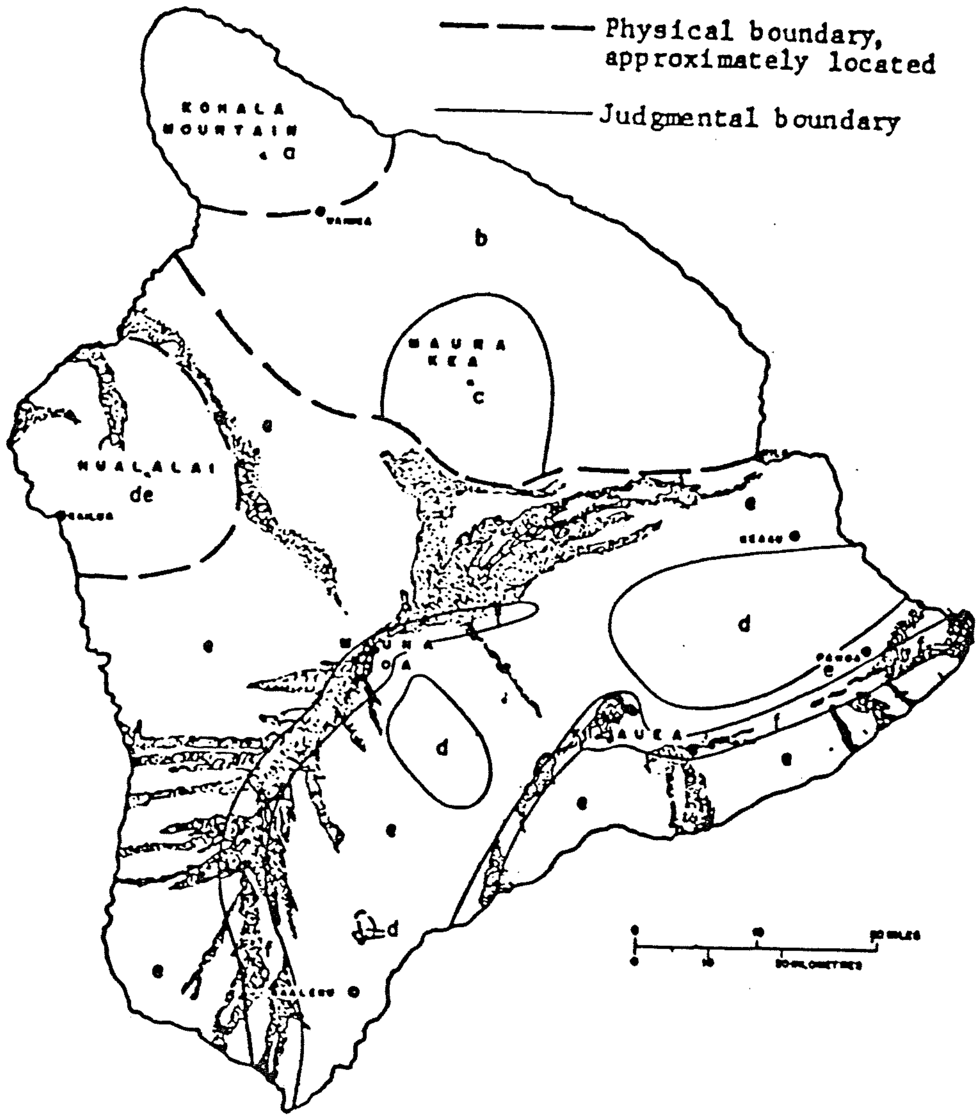
Map of the island of Hawaii, showing the five major volcanoes that make up the island, and the historic lava flows. (Macdonald et al., 1983)

Figure 22.



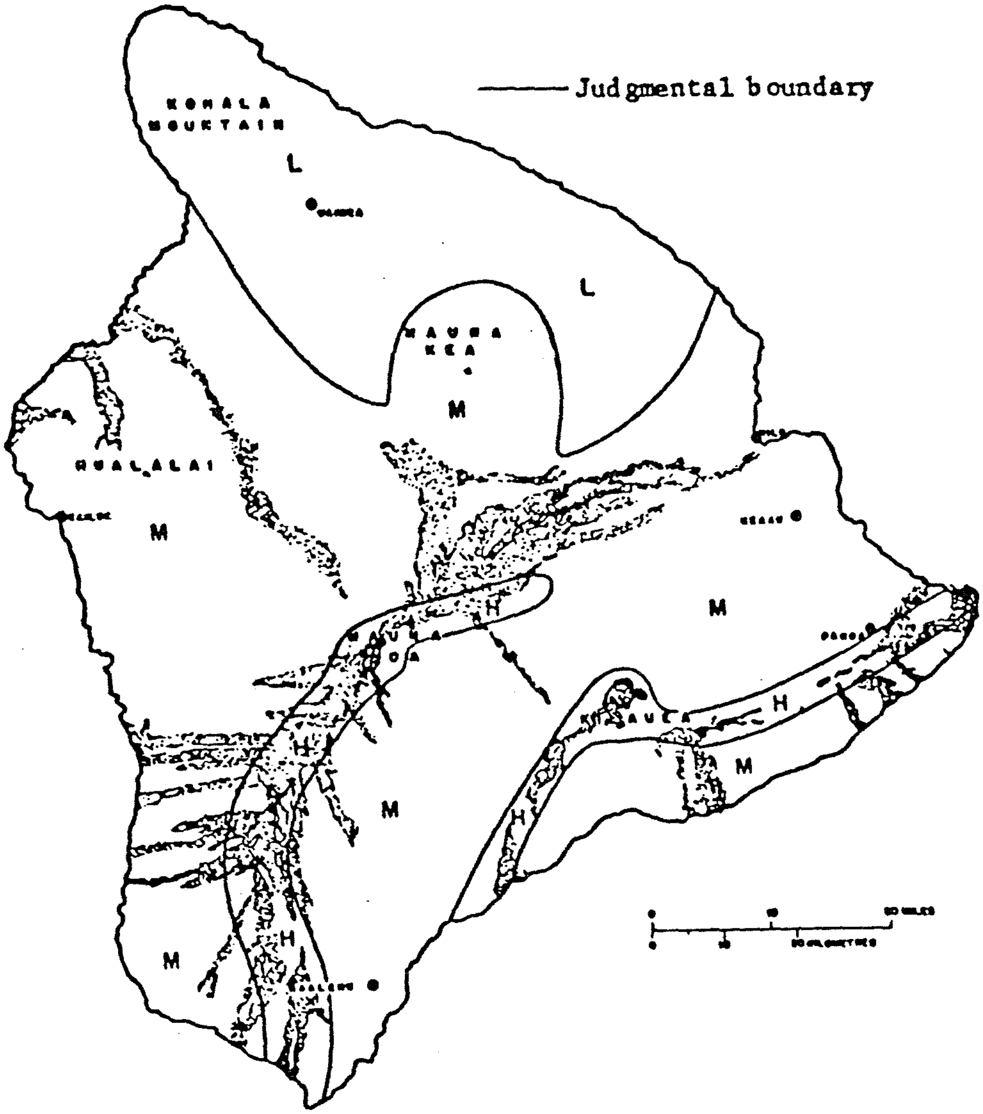
Map showing volcanic rift zones and faults on the island of Hawaii. (In Macdonald et al., 1983; submarine slumps after Normark et al., 1978)

Figure 23.



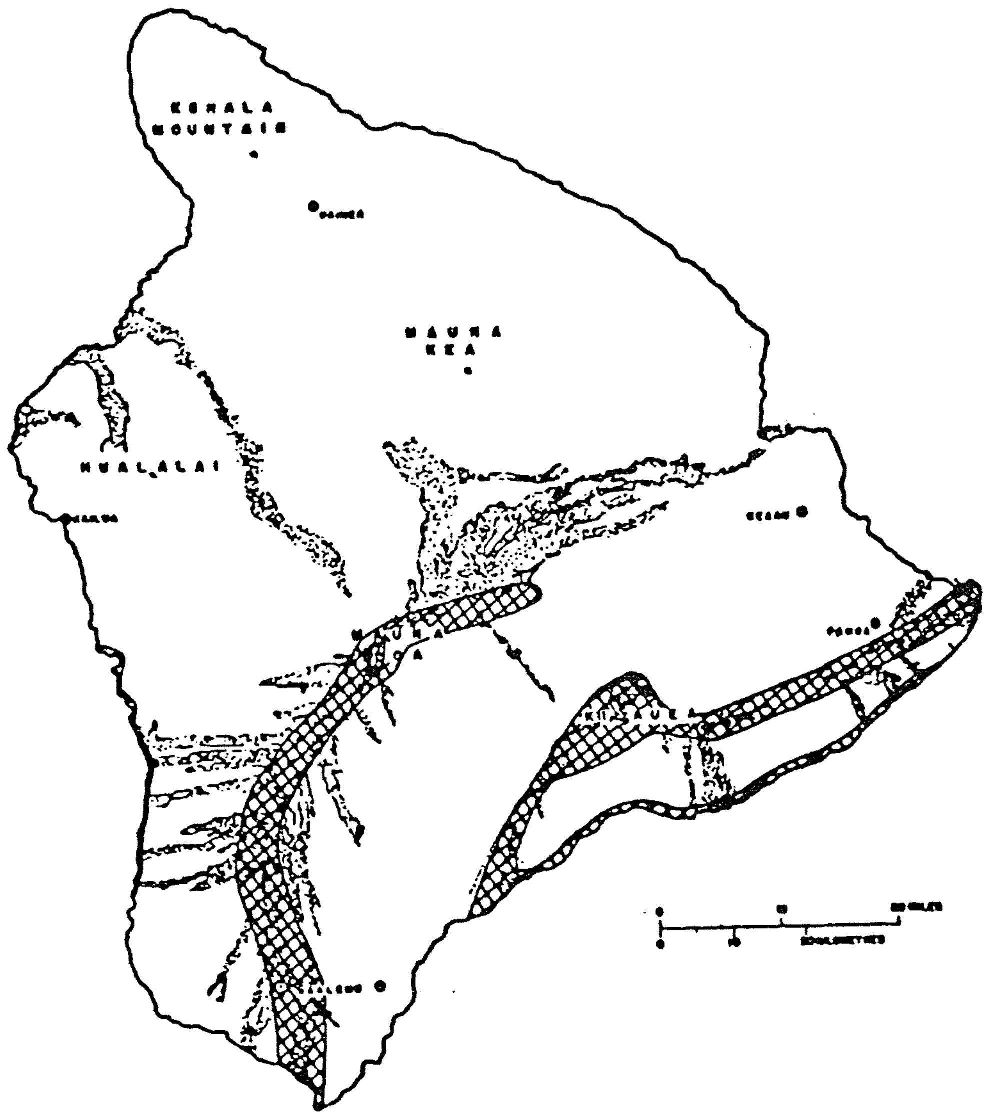
Zones of relative risk from lava-flow burial. Risk increases from "a" through "f". (Mullineaux and Peterson, 1974)

Figure 24.



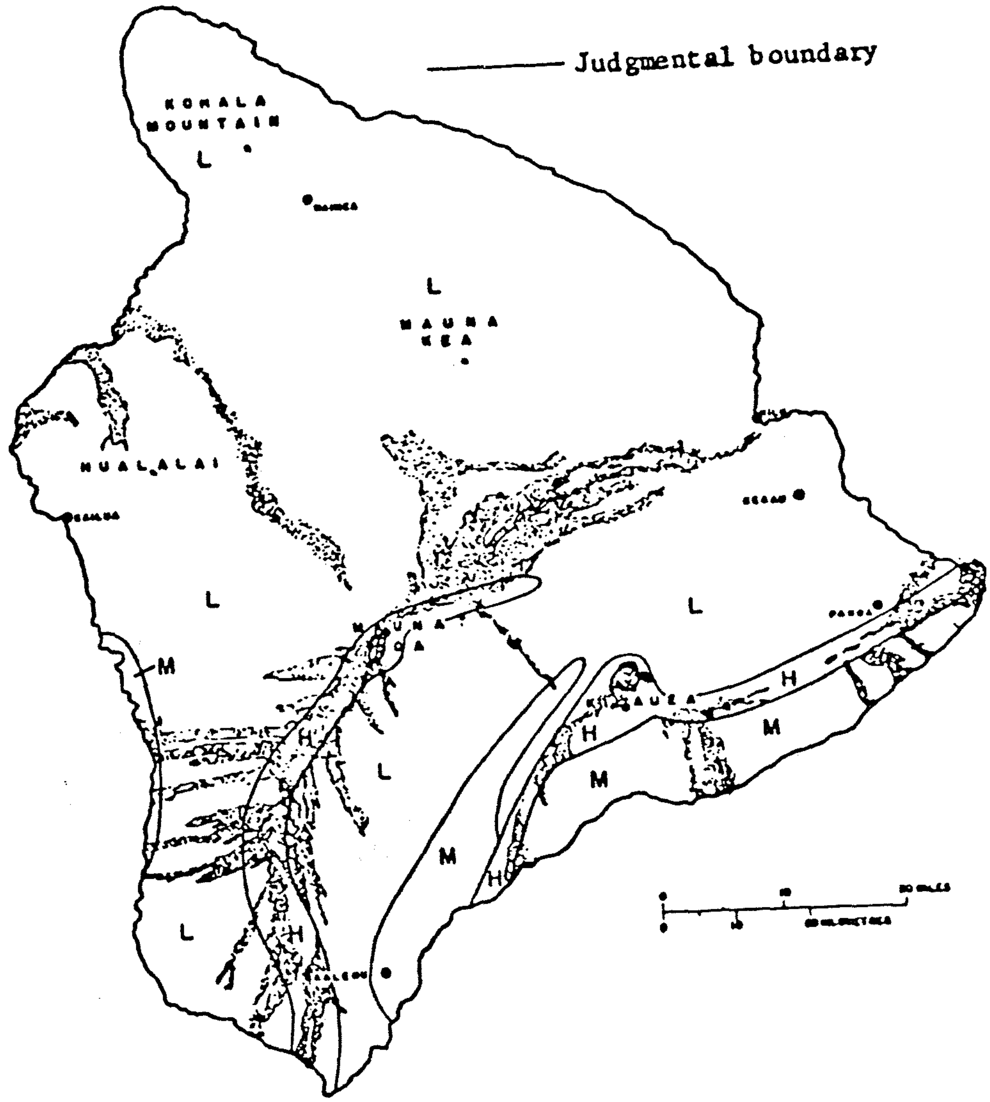
Zones of relative risk from falling volcanic fragments: H, high; M, medium; L, low. (Mullineaux and Peterson, 1974)

Figure 25.



Volcano rift and shoreline zones subject to relatively high risk from subsidence (cross hachured). (Mullineaux and Peterson, 1974)

Figure 26.



General areas of high (H), medium (M); and low (L) risk fro surface ruptures. (Mullineaux and Peterson, 1974)

Hualalai

The only historic eruption of Hualalai occurred in 1801. It produced two large flows covering 46 km^2 east and north towards the ocean.

Several thousand earthquakes, from a source beneath Hualalai, shook the island in 1929. This may indicate subsurface magmatic movement or a readjustment or settling of the mountain.

Eruptions and earthquakes (and associated cracking, fallout, subsidence, etc.) may occur here in the future but it is not possible to predict the precise time and place of future activity.

Mauna Loa Southwest Rift Zone

- There have been seven eruptions on the southwest rift zone since 1832; an average of one eruption every 22 years.
- The latest and largest flow occurred in 1950 covering an area of 91 km^2. The average flow has been about 34 km^2.
- Hawaii's largest earthquake (magnitude 7.5) occurred in 1868 near the southern tip of the island.
- Eruptions and earthquakes (and associated hazards of ash fallout, ground deformation, cracking, and subsidence) are likely to occur here in the future but it is not possible to predict the precise time and location of future activity.
- There is no danger from tsunamis in this geothermal resource area since its lowest elevation is about 1500 feet.

Historic Eruptions of Mauna Loa Southwest Rift

Date	Duration (days)	Repose since last eruption (months)	Altitude of vent (m)	Area of flow (km^2)	Volume (m^3)	Average thickness (m)
Mar. 1868	15	--	990	223.7	140,000,000	5.9
Jan. 1887	10	226	1710	29.4	220,000,000	7.5
Jan. 1907	15	240	1860	21.1	75,000,000	3.5
May 1916	14	112	2220	17.2	60,000,000	3.5
Sept. 1919	42	41	2310	23.9	255,000,000	10.7
Apr. 1926	14	77	2280	34.8	110,000,000	3.2
June 1950	23	290	2400	91.0	440,000,000	4.8
Total	133	986		441.1	1,300,000,000	
Average	19	164 (13.7 yrs.)	1967	63.0	186,000,000	5.6 (18 ft.)

Source: Modified after Macdonald, et al., (1983).

Mauna Loa Northeast Rift Zone

- There have been seven eruptions on the northeast rift zone since 1832; an average of one every 22 years. Most eruptions originated at elevations higher than the proposed 7000' resource area cut-off; but flows commonly travel into this area.
- The largest flow, in 1880, covered an area of 62 km^2. The average flow has been about 37 km^2.
- The most recent flow, in spring 1984, covered an area of over 30 km^2 and stopped close to Hilo, Hawaii.
- Earthquakes with magnitudes above six have occurred in the saddle area between Mauna Loa and Kilauea, e.g., magnitude 6.7 in November 1983.
- Eruptions and earthquakes (and associated hazards of ash fallout, ground deformation, cracking, subsidence, etc.) are likely to occur here in the future but it is not possible to predict the precise time and place of future activity.

- There is no danger from tsunamis in this geothermal resource area since its lowest elevation is about 3500 feet.

Historic Eruptions of Mauna Loa Northeast Rift

Date	Duration (days)	Repose since last eruption (months)	Altitude of vent (m)	Area of flow (km^2)	Volume (m^3)	Average thickness (m)
Feb. 1852	20	--	2520	28.6	100,000,000	3.5
Aug. 1855	450	40	3150(?)	31.7	110,000,000	3.5
Nov. 1880	280	288	3120	62.4	220,000,000	3.5
July 1899	19	215	3210	42.1	145,000,000	3.5
Nov. 1935	42	435	3630	35.9	115,000,000	3.2
Apr. 1942	13	76	2760	27.6	75,000,000	2.7
Mar. 1984	--	503	3600	30+	300,000,000	4.8
Total	824	1557		258+	1,065,000,000	
Average	137 (4.5 mo.)	260 (22 yrs.)	3141	37	152,000,000	3.5 (11½ ft.)

Source: Modified after Macdonald, et al, (1983).

Kilauea Southwest Rift Zone

- There have been five eruptions on the southwest rift zone since 1750; an average of one every 47 years.
- The largest flow, in 1919, covered an area of 13 km^2. The average flow has been about seven km^2.
- The most recent volcanic activity occurred in 1982, when magma moved into the rift zone. This caused ground cracking but no lava erupted.
- The southern flanks of Kilauea's rift zones are more prone to be covered by lava flows than are the northern flanks due to its topography (see Figure 15).

- Earthquakes with magnitudes above six have occurred in the saddle area between Mauna Loa and Kilauea, the largest being of magnitude 6.7 in November 1983.
- Eruptions and earthquakes (and associated hazards of ash fallout, ground deformation, cracks, subsidence, etc.) are likely to occur here in the future; but it is not possible to predict the precise time and place of future activity. Intervals between historic eruptions in the southwest rift zone have varied from three years (1971 to 1974) to 52 years (1919 to 1971).
- There may be some danger from tsunamis and ground subsidence in the coastal portion of this geothermal resource area.

Historic Eruptions of Kilauea Southwest Rift

Date	Duration (days)	Repose since last eruption (months)	Altitude of vent (m)	Area of flow (km^2)	Volume (m^3)	Average thickness (m)
May 1823	Short	--	400	10	11,000,000	1.1
Apr. 1868	Short	539	770	.1	183,000	1.8
Dec. 1919	221	620	900	13	45,300,000	3.5
Sept. 1971	5	615	1000	3.9	7,700,000	2.0
Dec. 1974	1	38	1080	7.5	14,300,000	1.9
Total		1812		34.5	78,483,000	
Average	Short	453 (38 yrs.)	830	6.9	16,000,000	2.7 (9 ft.)

Source: Modified after Macdonald, et al., (1983).

Kilauea Upper East Rift Zone

For purposes of this hazard analysis the east rift zone is divided into upper and lower segments. A line extending roughly north of Kalapana distinguishes these two areas (See line A-A, Figure 21). Eruptions at the caldera area were not considered as a rift zone eruption.

- There have been 21 eruptions on the upper east rift zone since 1750; an average of one every 11 years.
- The largest flow, the Mauna Ulu flow of 1972, covered an area of 35 km^2. The average flow has been about six km^2. However, the greater volumes of the more recent eruptions may be a better guide to future events than the generally small-volume historic eruptions prior to 1969.
- The current Pu'u O eruption has covered an area over 30 km^2. This eruption began in January 1983 and has been through 42 phases so far. The localized present danger will subside after the Pu'u O eruption is determined to have ended by qualified geologists.
- The southern flanks of Kilauea's rift zones are much more prone to be covered by lava flows than are the northern flanks due to its topography (See Figure 9). Figure 16 graphically depicts the percentage of ground covered by lava flows, from 1954 to 1984, as it varies with distance north and south of the rift zone axis.
- The largest recent earthquake (magnitude 7.2) occurred in 1975 about five km southwest of Kalapana. It resulted in cracking, subsidence, and a tsunami (Macdonald et al., 1983).
- Most volcanic cracking and subsidence are centered about the rift zone. However, there is considerable faulting associated with the Koae and Hilina fault system south of the caldera (See Figure 13).
- There may be some danger from tsunamis and ground subsidence in the coastal portion of this geothermal resource area.
- As Kilauea is highly active, eruptions and earthquakes (and associated hazards of ash fallout, ground deformation, cracks, subsidence, etc.) will occur here in the future; but it is not possible to predict the precise time and place of future activity. Intervals between historic eruptions in the upper east rift zone have varied from days apart (1973) to 38 years (1923 to 1961).

Historic Eruptions of Kilauea Upper East Rift*

Date	Duration (days)	Repose since last eruption (months)	Altitude of vent (m)	Area of flow (km²)	Volume (m³)	Average thickness (m)
May 1840	26	--	900	3.4**	41,000,000**	12
May 1922	2	983	800	.1	?	--
Aug. 1923	1	16	900	.5	73,000	.2
Sept. 1961	3	456	500	.8	2,200,000	2.8
Dec. 1962	2	15	950	.1	310,000	3.1
Aug. 1963	2	9	900	.2	800,000	4.0
Oct. 1963	1	2	900	3.4	6,600,000	1.9
Mar. 1965	10	17	750	7.8	16,800,000	2.2
Dec. 1965	1	9	920	.6	850,000	1.4
Aug. 1968	5	40	650	.1	130,000	1.3
Oct. 1968	15	2	850	2.1	6,600,000	3.1
Feb. 1969	6	4	900	6.0	16,100,000	2.7
May 1969	867	3	940	12.5	176,700,000	14.1
Feb. 1972	455	4	940	35.1	119,600,000	3.4
May 1973	1	0	990	.3	1,200,000	4.0
Nov. 1973	30	6	925	1.0	2,700,000	2.7
Dec. 1973	203	0	940	8.1	28,700,000	3.5
July 1974	3	0	1040	3.1	6,600,000	2.1
Sept. 1977	18	38	550	7.8	32,900,000	4.2
Nov. 1979	1	25	970	.3	580,000	1.9
Jan. 1983	520+	39	750	30+	200,000,000+	6.7
Total	2172	1668		126	667,643,000	
Average	103 (3.5 mo.)	83 (7 yrs.)	855	6	32,000,000	7.6 (25 ft.)

* In this report, a line extending roughly north of Kalapana distinguishes the lower and upper east rift zone (see Figure 21). Eruptions in the caldera area were not considered as a rift zone eruption.

**The 1840 flow occurred roughly 1/5 within the upper east rift and 4/5 within the lower east rift; the appropriate fractional portion is shown in the table.

Source: Modified after Macdonald, et al. (1983).

Kilauea Lower East Rift Zone

- There have been five eruptions on the lower east rift zone since 1750; an average of one every 47 years.
- The largest flow, in 1955, covered an area of 16 km². The average flow has been about 11 km².
- The most recent flow, in 1960, covered an area of about 11 km² near and in Kapoho.
- The southern flanks of Kilauea's rift zones are much more prone to be covered by lava flows than are the northern flanks due to its topography (See Figure 15). Figure 16 graphically depicts the percentage of ground covered by lava flows, from 1954 to 1984, as it varies with distance north and south of the rift zone axis.
- Intervals between historic eruptions have varied from five years (1955 to 1960) to 115 years (1840 to 1955). It is not possible to predict the precise time and place of future eruptions.
- The earthquake of 1868 on the southern tip of the island was the largest earthquake in this area (magnitude 7.5).
- There may be some danger from tsunamis and ground subsidence in the coastal portion of this geothermal resource area.

Historic Eruptions of Kilauea Lower East Rift*

Date	Duration (days)	Repose since last eruption (months)	Altitude of vent (m)	Area of flow (km²)	Volume (m³)	Average thickness (m)
1750 (?)	--	--	510	4.1	14,200,000	3.5
1790 (?)	--	480	300	7.9	27,500,000	3.5
May 1840	26	605	350	13.8**	164,000,000**	11.9
Feb. 1955	88	1384	175	15.9	87,600,000	5.5
Jan. 1960	36	56	35	10.7	113,200,000	10.6
Total		2525		52.4	406,500,000	
Average	50	631 (53 yrs.)	274	10.5	81,000,000	9.5 (31 ft.)

* In this report, a line extending roughly north of Kalapana distinguishes the lower and upper east rift zone (See Figure 21). Eruptions in the caldera area were not considered as a rift zone eruption.

**The 1840 flow occurred roughly 1/5 within the upper east rift and 4/5 within the lower east rift; the appropriate fractional portion is shown in the table.

Source: Modified after Macdonald, et al., p. 64 (1983).

GEOLOGIC HAZARDS - KILAUEA MIDDLE EAST RIFT ZONE

The following paragraphs supplement the subzone assessment of geologic hazards, providing a description of the geologic activity which has occurred in or near the Kilauea middle east rift zone.

Lava Flows

Although eruptions have occurred more frequently in the upper rift zone, substantial volcanic risk is present along the entire Kilauea east rift zone. Historic eruptions which have flowed at least partially into the proposed Kilauea middle east rift geothermal resource subzone (GRS) are listed in the table below and depicted in Figure 27.

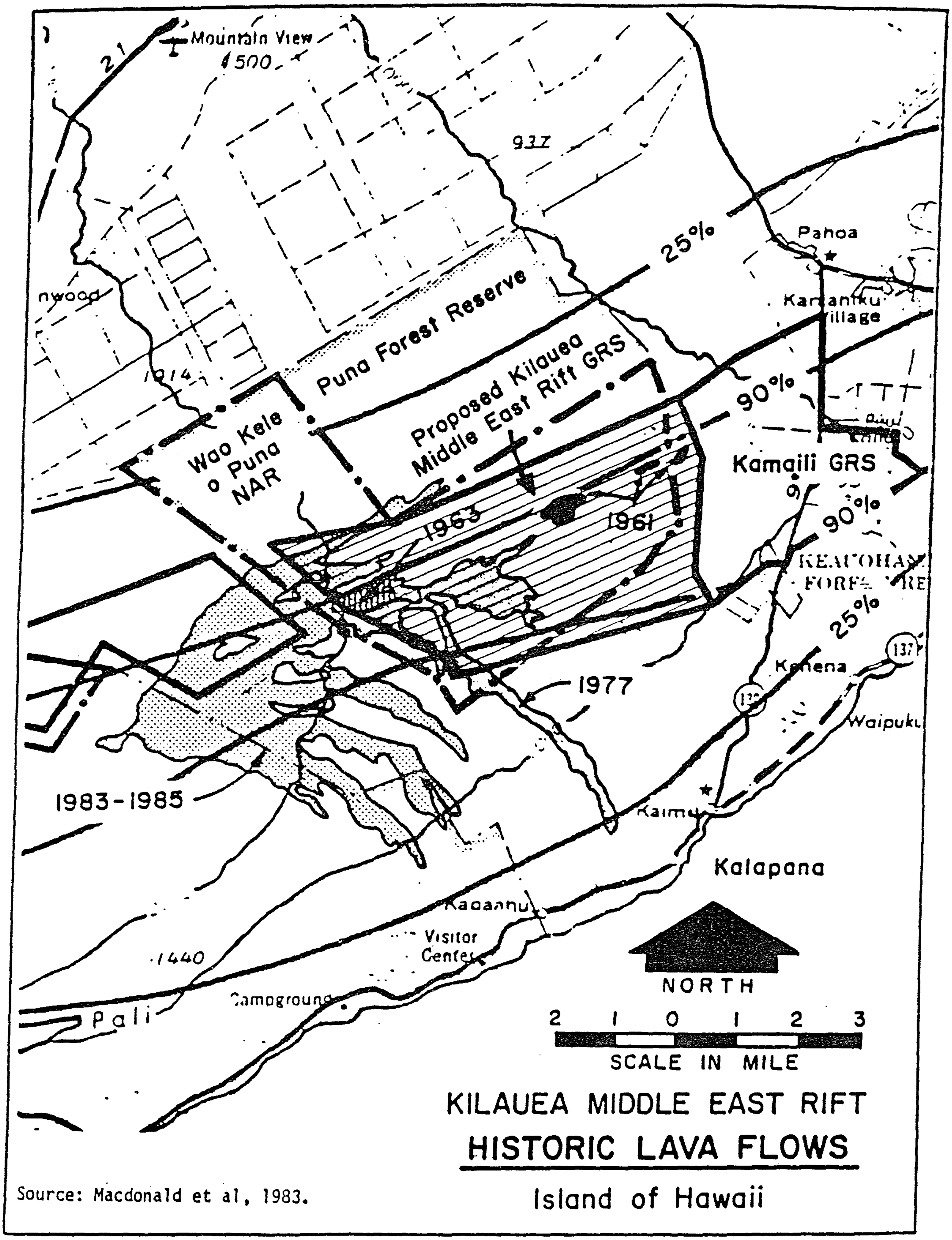
Date of Outbreak	Duration	Area (km^2)	Volume (m^3)
1750 (approximate date)		4.1	14,200,000
1961, September 22	3 days	.8	2,200,000
*1963, October 5	1 day	3.4	6,600,000
1977, September 13	18 days	7.8	32,900,000
*1983, January to present	2 years+	37+	335,000,000+

*Eruption originated uprift and flowed into the proposed Kilauea middle east rift GRS.

The elevation of mildly sloping ridges north of the middle east rift zone axis may offer some protection from lava hazards. Heiheiahulu Crater in the southeast portion of the proposed GRS may be considered as an elevated geothermal site. Other mitigation techniques outlined in the primary geologic hazards assessment may be appropriate. Steep slopes of up to 80 percent within the southern part of the proposed Kilauea middle east rift GRS can provide a likely path for and increase the speed of lava flows originating upslope.

Within the past 24 years four eruptions have covered parts of this proposed GRS. These flows have been concentrated in the western part of the proposed GRS. The 1961 flow covered 1 percent of the proposed GRS, the 1963 flow 2 percent, the 1977 flow

Figure 27.



KILAUEA MIDDLE EAST RIFT

HISTORIC LAVA FLOWS

Island of Hawaii

Source: Macdonald et al, 1983.

10 percent and the present Puu O'o flows 9 percent. The total percentage of land in the proposed GRS covered by these recent flows is about 22 percent. This figure can be extrapolated over the expected 30-year useful life of geothermal plant equipment. Based on these recent eruptions we might expect about 27 percent of the land area in the proposed GRS to be covered by lava in the next 30 years. Puu O'o is presently providing the least resistive path to the surface for intrusive magma in the Kilauea east rift zone. It is unlikely that eruptions will occur downrift while the Puu O'o eruptions continue. However, it is not possible to accurately predict the precise time and place of future activity.

Decentralized facilities, strategic siting, and prudently constructed lava diversion platforms and barriers can be expected to mitigate the hazard risk from future flows. However, nothing can eliminate the substantial hazard from lava flows.

Pyroclastic Fallout

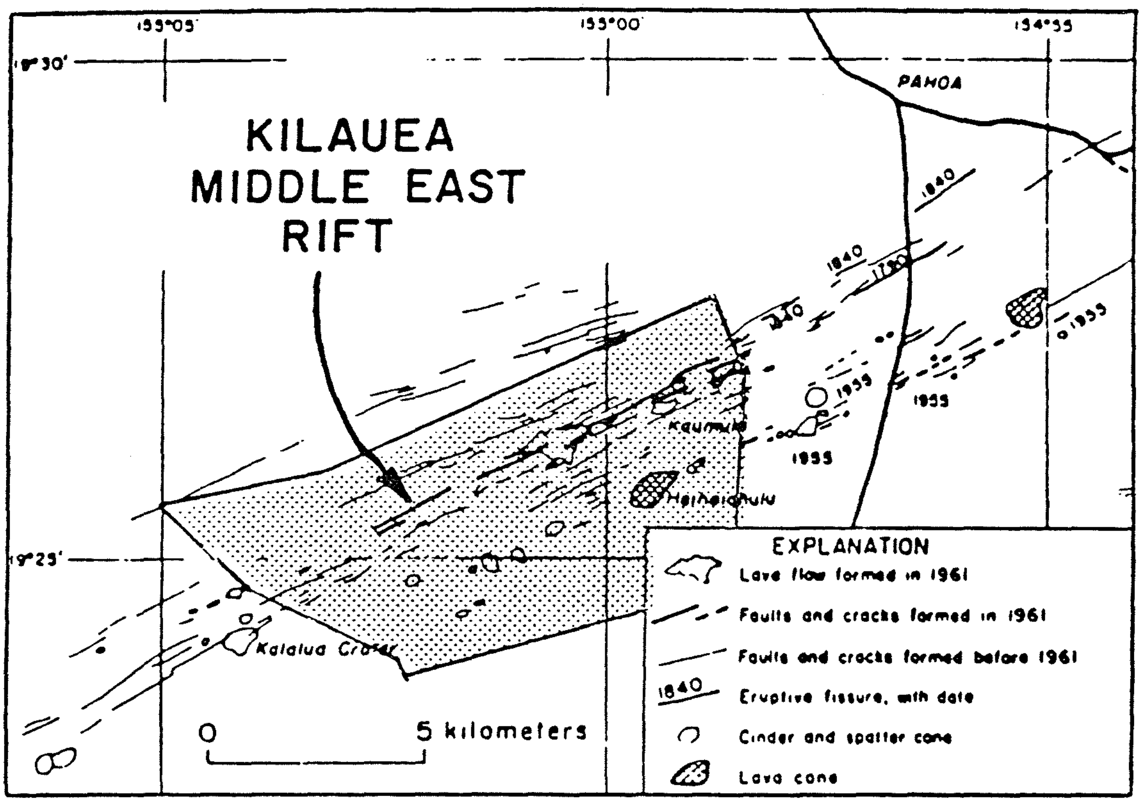
Weight and depth of pyroclastic fallout is greatest around an eruptive vent. However, fallout can be appreciable 500 to 1000 m downwind of a vent. In 1959, a light pumice blanket extended 4000 m southwest from Kilauea Iki vent. In February 1985, high fountaining during the 30th phase of the Puu O'o eruption and strong NE Kona winds resulted in an appreciable amount of "Pele's hair" falling out over Hilo.

Protecting structures or machinery against damage by pyroclastic fallout may be achieved by enclosing those parts vulnerable to abrasion or contamination.

Ground Cracks

Volcanic cracking is concentrated along the rift zone axis. A significant number of volcanic cracks are situated within the proposed Kilauea middle east rift GRS. Many cracks may be associated with a single volcanic event, as evidenced by the cracks formed during the 1961 eruption (Figure 28). Contingency planning should include the

Figure 28.



Map of the Kilauea middle east rift zone showing area faults and cracks. The proposed Kilauea middle east rift geothermal resource subzone is superimposed.
Source: Modified after Richter, 1964; in Macdonald, 1983.

best available methods for sealing a well bore should a crack intercept a producing well.

Earthquakes

Most earthquakes in Hawaii are volcanic, which are small in magnitude and cause little direct damage. Larger tectonic earthquakes tend to be situated in the saddle area between the calderas of Kilauea and Mauna Loa, and also in the Koae and Hilina fault systems--south of Kilauea's caldera. Recent earthquakes above magnitude six have occurred in the saddle area, e.g., the Kaoiki earthquake in November 1983 (magnitude 6.7). The largest recent earthquake (magnitude 7.2) occurred in 1975 about five km southwest of Kalapana.

Subsidence

On the Mainland, subsidence due to contraction of clay or sand formations may result from the withdrawal of geothermal fluids in those formations. In Hawaii, subsidence from geothermal fluid withdrawal is not likely to be a problem; since the islands are generally composed of dense, yet porous, self-supporting basaltic rock, especially in geothermal production zones. Of more concern is the volcanic or tectonic subsidence which may occur on or about active rift zones.

As a result of volcanic activity, small to large grabens may result with the subsidence of rock blocks (usually rectangular) which are downthrown along or between cracks, e.g., 1960 Kapoho graben. Subsidence may also be associated with tectonic earthquakes, collapsing lava tubes and pit craters.

Tsunamis

Tsunami hazard is probably localized to a zone of land at most two km wide around the coast, and at elevations below about 75 feet. This will not be a hazard to developments in the proposed Kilauea middle east rift GRS as elevations are generally above 1400 feet.

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SOCIAL IMPACTS FROM GEOTHERMAL DEVELOPMENT

The assessment of social impacts was based on available information on the public's perception and attitudes regarding the impact of geothermal development on health, noise, religious practices, aesthetics, lifestyle, culture, and community setting. Technical aspects of noise and factors affecting health are discussed in the environmental section of this report.

Health

The health aspects of geothermal resource development involve primarily the effects of chemical, particulate, and trace element emissions on the physical environment and on residents in the vicinity. Hydrogen sulfide (H_2S), due primarily to its "rotten egg" smell at certain concentrations, is the most significant gas found in geothermal emissions.

Two community surveys produced information relating to perceptions and concerns about the effects of geothermal development on elements of physical environment such as air quality. The first was done by a community association in Puna, the Puna Hui Ohana. In this survey, 351 native Hawaiian residents in the Puna area were interviewed. The results were prepared in a report, Assessment of Geothermal Development Impact on Aboriginal Hawaiians, published in February 1982. In response to the question of "What kind of change would geothermal development bring about on the physical environment (noise, air quality, visual environment) of Puna," out of the 253 responses, 56 said it would be "slightly bad" and 114 said it would be "very bad."

The second survey study was conducted for the State Department of Planning and Economic Development and the Hawaii County Planning Department by SMS Survey, Inc. The Puna Community Survey, completed in April 1982, interviewed 778 residents in the Puna area. The study reported only one-fifth of the total survey respondents as mentioning that they felt that they had been affected by the geothermal wells in Puna. Of those indicating they were affected, the negative effects mentioned were "health problems" and "smell."

Noise

Although noise levels associated with geothermal energy development and operation are comparable with those of industrial or electrical plants of similar size, plant construction and operation in a quiet rural area may produce noise which should be controlled and monitored. In terms of people's perceptions of and concerns with the noise factor, the SMS Puna Community Survey reported that of the 18 percent who responded "yes" to the question of whether they or their households had been affected by the wells in Puna in any way, 22 percent mentioned they were affected by "noise."

Religious Practices

The practice of the ancient Hawaiian religion has included belief in and worship of the volcano goddess Pele. Some Hawaiian practitioners consider the lands adjacent to Kilauea Crater as sacred and the home of Pele.

These practitioners consider the connections made with Pele in the past by their ancestors and today by themselves and their families, as essential to their daily life activities.

To some native Hawaiians, Pele is regarded as aumakua (personal or family god) and akua (god), and personal offerings have been made to Pele by religious practitioners for many years.

Some Hawaiians also identify themselves as the bloodline of Pele and believe that their existence and theology is threatened by the potential changes that may result from geothermal development. They also believe that geothermal development may forever extinguish or destroy essential parts of Hawaiian heritage, culture, and religion.

Certain practitioners interpret the continuous eruptions at Puu O'o as signs of Pele's disapproval of geothermal activity and that Pele in her manifestation as steam cannot be sold for monetary gains. They are concerned about traditional Hawaiian beliefs regarding the use of steam, suggesting that Pele would be offended by geothermal development.

The recognition and use of geothermal energy has been recorded in the history of the Hawaiian Islands by the Reverend William Ellis whose journal has been published in many editions. Explorers identified numerous fumaroles and thermal features on Kilauea and Mauna Loa volcanoes as early as 1825. Early Hawaiians are recorded using steam emanating from fissures along the rift zone for cooking. William Ellis notes in his Journal published in 1825 that offerings to Pele consisting of hogs, dogs, fish, and fruits were frequently made on heiaus (places of worship) at Kilauea-Iki, and that these offerings were always cooked in the steaming chasms or the adjoining ground, lest Pele reject them. Ellis also notes that the ground in the vicinity of Kilauea was so hot that those who came to the mountains to gather wood and to fell trees and hollow them for canoes "always cooked their own food, whether animal or vegetable, simply by wrapping it in fern leaves and burying it in the earth," a method quite similar to the Hawaiian imu (ground oven). At Kilauea on Hawaii, Handy and Handy's "Native Planters in Old Hawaii" describes how whole trunks of hapu'u pulu (fern trees) were thrown into steam fissures, covered with leaves, and when cooked were split open and the starch core used as food for pigs.

The use of warm springs also was not unknown, since Ellis notes that at Kawaihae on the western shore of the Island of Hawaii, warm springs provided a refreshing morning bath. The spring water was described as being "comfortably warm" and "probably impregnated with sulfur." He also notes medicinal qualities were ascribed to it by those who used it.

Aesthetics

"The Puna Community Survey" by SMS Research Inc. reported that of the perceived negative impacts relating to the geothermal development, 5 percent felt that it "looks bad." The area respondents with the greatest percentage were Keaau residents, with 25 percent of the factors mentioned being under the category of negative appearance.

In some areas with potential geothermal resource development, the plant installation may be relatively hidden from nearby or medium-distanced residents and visitors. However, consideration of aesthetic aspects should include careful siting, tasteful design, and effective landscaping.

Techniques for preserving aesthetic aspects of the landscape and natural vistas include attractive design, and painting of the structures with colors which blend with the natural setting.

A drill rig and platform may reach heights of approximately 150 feet. Rigs at various locations within a subzone may be visible above the tree line from view corridors into the development area.

It is possible that moist warm air from the cooling towers will condense as it rises under certain atmospheric conditions to form a small cloud mass similar to that often observed near cracks and puu's along the remote part of the Kilauea east rift zone east of Mauna Ulu under the same conditions. During normal atmospheric conditions, some visible vapors are expected from the cooling towers.

In areas where development activity is close to National or State Parks, or recreation areas, estimates of potential visual impacts along sensitive view corridors should be made. Terrain analyses can be conducted to determine locations outside the project area from which drilling rigs, powerlines, power plant facilities, etc., can be seen, and to assess the visual impacts in relationship to size, distance, color, shape, and other related factors.

Depending upon the terrain within and adjacent to a proposed project site, such an analysis may be required in environmental impact assessments for the development of specific sites within a geothermal resource subzone during the subsequent permitting process.

Lifestyle, Culture, and Community Setting

The lifestyle, culture, and community setting or atmosphere of an area are very much interrelated and represent a major concern in terms of the effects of any introduced changes; especially when the changes may be in the direction of industrial development in a relatively rural setting. The Puna area has the most information and the input to date on these aspects in relation to geothermal development. This information may be applicable to other localities. Each community, however, will have its own unique background, perceptions, and goals.

Much about the cultural background, beliefs, practices, and lifestyles of the native Hawaiian residents in Puna were reported and discussed in the survey by the Puna Hui Ohana's Assessment of Geothermal Development Impact on Aboriginal Hawaiians. On attitudes towards the effects of geothermal development, the survey reported "A large number of impacts were perceived as negative by the respondents; and only one, economic impact, was reported to be clearly positive. Yet the question asking about the 'overall' impact of geothermal development in Puna produced responses averaging in the "neither good nor bad" middle ground. There seems to be a balancing of the potential economic benefits of geothermal development with the environmental and social costs of development."

In the SMS study, The Puna Community Survey, respondents asked to name the best things about life in Puna today cited a great variety of factors. Forty-nine percent of the factors or items mentioned were in the category of lack of population and development, e.g., country atmosphere, rural area, uncrowded, etc. Forty percent of the factors cited were in the category of physical environment, and 33 percent of the elements cited were in the social/lifestyle factors group.

The survey also reported that the greatest divergence among attitudinal responses was between the Keaau and Kapoho-Kalapana planning areas, Keaau residents being the most concerned with economic development and jobs while Kapoho-Kalapana respondents were "suspicious of it." This was analyzed in the report to be a function of the uncertainties and anxieties among Keaau residents concerning the closing down of the Puna sugar plantation, whereas Kapoho-Kalapana's current rural character would be more affected by geothermal-related activities.

In April 1980, 3,700 persons were living in Kau which constituted roughly four percent of the Big Island's population. The Kau district is largest in size and ranks eighth in terms of population. Kau's population density is 3.7 persons per square mile versus 22.8 persons per square mile for the County of Hawaii as a whole. Within the Kau District, roughly 44 percent (1,619) of the residents were living in the town of Pahala.

In April 1980, 11,751 persons were living in Puna which constituted roughly 13 percent of the Big Island's population. The Puna district is the third largest in terms of size and population. Puna's population density is 27 persons per square mile versus 22.8 persons per square mile for the County of Hawaii as a whole. Within the Puna District, roughly 20 percent (2,238) of the residents were living in the towns of Keaau, Mountain View, and Pahoa.

Property in the Kilauea middle east rift zone is owned by two large area landowners, the State of Hawaii and Campbell Estate. Smaller holdings owned by various individuals are found along the coast and in agricultural zoned areas in the Kalapana and Kaimu areas makai of the rift zone.

Property within the Kilauea southwest rift zone is owned by the State of Hawaii, the Federal government (Hawaii Volcanoes National Park), Bishop Estate, Kau Agri-Business, International Air Service Co., Seamountain Hawaii, C. Brewer, and a number of small parcel landowners.

The low magnitude of change in lifestyle and social interaction that may be brought about by new residents may be a small part of the lifestyle, culture, community, and traffic changes already taking place in the area.

As geothermal development occurs, each new increment of land area should be archaeologically surveyed by a qualified archaeologist after specific sites for development activity are determined and before land clearing begins. If archaeological sites are found, they should be described and assessed as to significance, and measures taken to ensure avoidance or mitigation of potential impacts from geothermal developments.

Kilauea East Rift Zone, Hawaii

In this area on the Island of Hawaii, the primary factor would be in terms of lifestyle, culture, and community setting. Assuming a level of 20 MW to 30 MW geothermal production with the addition of some 25 workers as estimated in the economic assessment section, the potential effects should not be great. (The Upper Puna area had a count of 7,055 residents in 2,381 households, and the Lower Puna area had a count of 4,696 residents in 1,450 households in the 1980 U.S. Census.) The housing situation may be somewhat affected. A small magnitude of change in lifestyle and social interaction may be brought about by new residents. However cultural, community, and traffic changes are already taking place in the area as a result of the influx of new residents in recent years. Although air and water quality and noise factors should be considered, they could be controlled and monitored. Also important is the preservation of natural beauty and aesthetics, which could be achieved by well planned siting, landscaping, and well designed plant architecture.

Kilauea Southwest Rift Zone, Hawaii

In this area on the Island of Hawaii, the primary significant social factor would be in terms of lifestyle, culture, and community setting as they are experienced by the people in Kau; assuming a level of geothermal operation of 20 MW to 30 MW, the potential effects should not be great.

The Kau district had a count of 3,699 residents and 1,180 households in the 1980 U.S. Census. In the economic assessment the housing stock in this area is estimated to be sufficient to satisfy the housing demand resulting from a 20 MW to 30 MW geothermal plant being located within the district. The health and noise factors are important depending on where in the region a plant is located, but as discussed before, the air/water quality and noise factor should be controlled and monitored. A portion of Kau is encompassed by the Hawaii Volcanoes National Park where the preservation of natural beauty and heritage is an important factor. Good aesthetics may be achieved by well-planned siting, landscaping, and well-designed plant architecture for possible future geothermal facilities nearby.

Mauna Loa Northeast Rift Zone, Hawaii

This zone encompasses primarily the people in the Upper Puna area. Their lifestyle and community setting may be somewhat less rural than that of the coastal Puna area. A signficant portion of the residents have jobs in Hilo and vicinity. The air and water quality, noise, and aesthetics should, as mentioned before, be controlled and monitored.

Mauna Loa Southwest Rift Zone, Hawaii

This zone encompasses the southern portion of the Kau area. Social factors are similar to those discussed in the Kilauea Southwest Rift Zone section, as the areas are in close proximity to each other.

Hualalai Northwest Rift Zone, Hawaii

In this area on the Island of Hawaii the primary social factor may be in terms of lifestyle, culture, and community setting as experienced by the people of North Kona. However, this area has experienced much growth in recent years and is exposed to the presence of resort operations and the influx of visitors from many parts of the world. In 1980 Kailua-Kona had a count of 6,138 residents, with 2,077 households. The North Kona area had a count of 7,610 residents, with 2,525 households. In the economic assessment of geothermal activities in this rift zone, the potential increase of households should not pose a significant problem barring any major change in the housing market. The elements of air and water quality, noise, and aesthetics are all important considerations for this area. The preservation of a quality environment should be achievable by careful control and monitoring of any emissions, effluents and noise, and with well-planned siting and landscaping of plant complexes.

Haleakala Southwest Rift Zone, Maui

This rift zone encompasses a portion of the coastal Makena area of southwest Maui Island and a portion of the upper Kula area (Ulupalakua). The Makena area had 1,277 residents with 474 households, and the Upper Kula area reported 3,850 residents and 1,317 households in the 1980 U.S. Census. Recent resort development has occurred in the Kihei-Makena coastal area, introducing additional lifestyle and cultural elements into the general area. The potential effects on lifestyle, culture, and community introduced by an assumed 20 to 30 MW level of geothermal production should not be great. The control and monitoring of air and water quality and noise should be achievable. The preservation of the natural scenic beauty of the area, especially Upper Kula, should be a significant consideration and may be achievable by careful site selection, landscaping, and aesthetic facility designs.

Haleakala East Rift Zone, Maui

Hana, situated at the far end of Haleakala's east rift zone, is the largest community in east Maui with a 1980 U.S. Census count of 1,423 residents and 435 households. This community is rural/pastoral with agricultural and resort lifestyles. The primary significant social impact may be in terms of lifestyle, culture, and community setting. Given an assumed 20 to 30 MW geothermal plant, there may be an impact. With a potential addition of some 25 geothermal workers, there may be a shortage of housing units in the area. The preservation of natural beauty in this area would be an important consideration.

Depending on where in the region a geothermal plant might be located, the degree of control and monitoring of air, water, and noise may be significant. Preliminary environmental baseline studies are being made for the Haleakala east rift zone area.

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ENVIRONMENTAL IMPACTS FROM GEOTHERMAL DEVELOPMENT

Geothermal factors with a possible effect on the environment include air emissions, liquid effluent, noise, visual aesthetics, and physical disturbance during construction.

Air Emissions

The most significant geothermal emission is hydrogen sulfide (H_2S). Chemical analyses on unabated, undispersed, geothermal steam at the Hawaii Geothermal Project-Abbott (HGP-A) indicate H_2S concentrations of 900 parts per million by weight (ppmw)* (Thomas, 1983). Other potential geothermal reservoirs in Hawaii may vary. H_2S abatement systems and normal air dispersion will drastically reduce the concentration of any emissions from a point source.

The State Department of Health (DOH) has proposed Ambient Air Quality Standards to control H_2S emissions from geothermal wells and power plants (Chapters 11-59 and 11-60 of the DOH Administrative Rules). The developer must obtain from the DOH an "authority to construct" prior to geothermal well or power plant construction and a "permit to operate" prior to connecting a well to a power plant (§11-60-23.1(d)). Geothermal wells and plants would have to show compliance with the State standards adopted. Current technology indicates that geothermal development activities can occur while meeting either the standards being considered or California standards which govern emissions from the largest geothermal development in the world.

A preliminary assessment of the levels of H_2S which can be expected from geothermal developments in Hawaii has been prepared by

*One ppm is approximately equivalent to one drop in 15 gallons. One part per billion (ppb) is approximately equivalent to one drop in 15,000 gallons.

J. Morrow (1985). He concludes that under the most unfavorable atmospheric conditions a 25 MW plant with at least 98 percent H_2S removal efficiency appears capable of meeting the proposed State increment and ambient standards under normal and abnormal (steam stacking) operating conditions. A higher level of abatement efficiency by H_2S control systems may be necessary for larger plant sizes or when weather conditions work against normal dispersion of emissions.

The State DOH will set all standards necessary to protect the public health. Geothermal developers must demonstrate that these standards will be met both prior to construction and during operation. Technologies exist which have demonstrated abatement of H_2S emissions by approximately 99 percent. (For general information on geothermal wells, power plants, and abatement see Appendix C, "Geothermal Technology" and also U.S. Environmental Protection Agency publication "Evaluation of BACT and Air Quality Impact of Potential Geothermal Development in Hawaii.")

Effects of Hydrogen Sulfide in Humans

The National Research Council Committee on Medical and Biological Effects of Environmental Pollutants issued a report in 1979 titled "Hydrogen Sulfide." They report that "the odor of H_2S is nothing more than an unpleasant nuisance....yet at higher concentrations it is a deadly poison...its typical 'rotten egg' odor is detectable by olfaction at very low concentrations [0.035 ug/liter or 25 ppb] in the air. Exposures to these low concentrations have little or no importance to human health. Thus, this olfactory response is a safe and useful warning signal that a hydrogen sulfide source is nearby. However at higher concentrations [280 ug/liter or 200 ppm] H_2S is distinctly dangerous...(at sufficient concentrations) hydrogen sulfide is an irritant gas. Its direct action on tissues includes local inflammation of the moist membranes of the eye and respiratory tract."

The California Department of Health Service (1980) reported that "we have not become aware of any complaints of ill health due to H_2S where the 30 ppb standard has been enforced in California...there is no evidence that a more restrictive standard would achieve a perceptible improvement in the public health."

The World Health Organization (1981) reported that "H_2S in concentrations of the order of the odor threshold has not been shown to have any significant biological activity in man or animals." Human responses to H_2S are listed in Figure 29.

In February 1984, the Hawaii DOH conducted a door-to-door health interview survey of a residential community, Leilani Estates, located near the three MW HGP-A geothermal power plant in the Puna District. The primary purposes of this survey were to establish the health status of Leilani Estates and to compare it to Hawaiian Beaches Estates and other areas of Hawaii. The rates of chronic respiratory conditions including bronchitis/emphysema, asthma, hayfever, sinusitis, and other respiratory system disease were found to be similar in Leilani Estates and Hawaiian Beaches Estates from January 1983 to January 1984. These conditions have been most often associated with long-term exposure to air pollutants.

Most H_2S information pertains to its short-term effects. Information on long-term, low-level effects of H_2S is limited. The following report on H_2S levels in New Zealand considers long-term effects.

S.M. Siegel (1984), in a preliminary report for the Hawaii Natural Energy Institute, investigated the effects of H_2S at Rotorua, New Zealand. The air in Rotorua contains emissions from volcanic vents and has a 200 MW geothermal electric plant (unabated H_2S emissions) situated nearby. Within Rotorua 32 sites were sampled for H_2S. Some sites having high H_2S concentrations include: two school sites at 30-50 ppbv, two hospitals at $\geq$50 ppbv and two hotels at 50 ppbv. Hospital records from an area with a relatively high level of H_2S were compared with hospital records from an area with very low H_2S levels (no volcanic or geothermal plant emissions in latter area). Siegel found that "the incidence of diseases sampled, whether potentially related to H_2S exposure or not is not significantly different in the two Hospital Board Districts. Especially important are the absence of extra cases relating to blood-forming organs; central or sensory nerve functions; respiration; or dermatitis." He also compared infant

Figure 29.

Effects of hydrogen sulfide exposure at various concentrations in air

Effect	Concentration		Duration of exposure	Reference
	mg/m³	ppm		
Man				
Approximate threshold for odour	0.0007—0.2	0.0005—0.13	A few seconds to less than 1 min	Yant (1930); Ryazanov (1962); Adams & Young (1968); Leonardos et al. (1969); Lindvall (1970); Thiele (1979); Winneke et al. (1979)
Threshold of eye irritation	16—32	10.5—21	6—7 h	Elkins (1939) Nesswetha (1969)
Acute conjuctivitis (gas eye)	75—150	50—100	> 1 h	Yant (1930)
Loss of sense of smell	225—300	150—200	2—15 min	Sayers et al. (1925)
Animals[a]				
Local irritation and slight systemic symptoms; possible death after several hours	750—1050	500—700	< 1 h	Haggard (1925)
Systemic symptoms; death in less than 1 h	1350	900	< 30 min	Haggard (1925)
Death	2250	1500	15—30 min	Haggard (1925)

[a] These observations were made in experimental animals. However, there are no better quantitative data available concerning man with respect to exposure to hydrogen sulfide at high concentrations. Source: Hydrogen Sulfide (1981), World Health Organization.

Note: The above concentrations are stated in parts per million (ppm). The Hawaii Department of Health incremental standard has been stated in parts per billion, i.e. 25 ppb or .025 ppm which is within the range of the odor threshold stated in the above table.

mortality rates in three areas and found that their mortality rates were "not in any way concerned with H_2S exposure." Siegel concludes that "there is no question that Rotorua is odorous and objectively high in H_2S, often well above the California (and Hawaii) air quality standard of 30 ppbv. Rotorua and its environs have, by U.S. standards, such high levels of H_2S in residential, hospital, school, recreational and resort locations, yet reveal no evidence of health impairments."

Effects of Hydrogen Sulfide on Plants

Thompson and Kats (1978) report pronounced stimulation of growth with alfalfa, sugar beets, and lettuce at low dosages of H_2S (30-100 ppb). At higher dosages (300-3000 ppb), H_2S fumigation caused leaf lesions, defoliation, and reduced growth in some plants. They noted that the "use of continuous, unvarying fumigation levels for exposing plant species may be unrealistic when compared to the exposures experienced by vegetation in the field, where the vagaries of wind, convection, etc., cause varying dilution effects."

The Natural Energy Laboratory of Hawaii will administer the Puna Research Center which will be operational by 1986. It will accommodate geothermal research which can investigate the effects of H_2S on food crops and native Hawaii plants.

Direct physical disturbance by geothermal construction activities should be carefully planned to minimize damage in prime environmental areas. Native forests may be susceptible to invasion by exotic species along roadways or other cleared areas. Weed control programs may be required which can minimize these impacts.

Liquid Effluent from Geothermal Development

Significant elements in geothermal brine include silica, chloride, and sodium (See Figure 30 for listing of elements in HGP-A brine). If not disposed of properly these elements have the potential to pollute potable water. Disposing of or minimizing the solids from silica deposition is a subject of concern whether the brine is discharged into a surface percolation pond or injected into deep rock strata. Some

Figure 30.

Element	Concentration, ppm[a]
Arsenic	0.01 - 0.001[b]
Barium	2
Boron	2
Calcium	218
Cadmium	<1.0[c]
Carbonate	75
Chloride	7200
Cobalt	0.014
Copper	<0.004
Gold	<0.00004
Iron	0.02
Lead	<1[c]
Lithium	0.034
Magnesium	0.131
Manganese	0.034
Mercury	<0.001
Molybdenum	0.067
Nickel	<0.02
Niobium	<0.4
pH	7.4[d]
Phosphorous	0.2
Platinum	<0.006
Potassium	600
Silica	800
Silver	<0.02
Sodium	3700
Strontium	2.0
Sulfate	50
Sulfide	17
Tantalum	<0.001
Thallium	<1[c]
Tin	<0.2
Titanium	0.006
Uranium	0.16
Vanadium	0.016
Zinc	0.012

[a] Liquid samples taken from cyclone separator (Thomas, 1983a).
[b] Rough estimate based on preliminary analysis, Thomas, 1983b.
[c] Thomas, 1982b. 'Less than' signs indicate detection limit of analyzer.
[d] Before atmospheric flashing, Thomas, 1982a.

Particulate Composition of HGP-A Brine.
(Source: Dames & Moore, 1984)

future projects at the Puna Research Center will investigate solutions to the problem of silica deposition. Aesthetic considerations may require brine disposal by injection. Geothermal development permits should indicate what method of brine disposal will be required.

The State DOH has established an Underground Injection Control program designed to protect the State's underground sources of drinking water. These laws will regulate underground injections of geothermal fluids so that underground sources of drinking water are not polluted.

Groundwater monitoring and control can be required by development permits. The Board of Land and Natural Resources (BLNR) Decision and Order which allowed limited geothermal exploration at Kahaualea included the following sections: §9.2.6 requires water analyses during initial well drilling; §9.6.9 prohibits pollution of ocean and rivers by geothermal brine; and §9.6.10 states that no substances from geothermal wells shall be allowed to flow on the ground in such a manner as to create a health hazard.

Noise Concerns

The impact and intrusiveness of noise from geothermal development activities on the surrounding environs is dependent on the meteorological conditions; the intensity of the noise source; the measures taken to reduce the noise level; the sound propagation conditions existing between the source and listener; the ambient or background noise at the receptor; and the activity at the receptor area at the time of the noise event.

As any geothermal project progresses, noise propagation information will be obtained and will serve as guidance for the design of noise mitigation measures required of the power plants, particularly for power plants located close to noise sensitive residential and park areas.

The source of noise impact from the proposed geothermal resource subzone would arise from (a) construction of roads, pipelines, and buildings; (b) geothermal well drilling, testing, and venting; and (c) geothermal power plant operations.

During the initial phases of field development, persons in the immediate vicinity of a geothermal site may be exposed to noise levels varying from 40 to 125 decibels, depending upon the distance from the well site.

Noise generated by construction activity will involve the use of standard construction equipment such as bulldozers, trucks, and graders operating in the same manner, and over a limited time period as for any other typical project. No unusual noise events of long duration are involved.

Within 100 feet of the drill rig, noise varies from 60 to 98 decibels with muffler. Initial venting noise varies from 90 to 125 decibels which may be mitigated using a stack pipe insulator or cyclone muffler. Periodic operational venting noise is about 50 decibels using a pumice filled muffler. The use of noise abatement procedures during venting, such as portable or in-place rock mufflers, can reduce noise levels from the drill site.

Power plant buildings and barriers can be designed to optimize the orientation and degree of closure to contain noises from the turbine, generator, and transformers.

The County of Hawaii Planning Department has issued Noise Level Guidelines which have been incorporated into County permits controlling geothermal activities (in areas zoned Urban, Agricultural, or Rural). These guidelines include the following:

a. That a general noise level of 55 dBA during daytime and 45 dBA at night not be exceeded except as allowed under b. For the purposes of these guidelines, night is defined as the hours between 7:00 p.m. and 7:00 a.m.;

b. That the allowable levels for impact noise be 10 dBA above the generally allowed noise level. However, in any event, the generally allowed noise level should not be exceeded more than 10% of the time within any 20-minute period; and

c. That the noise level guidelines be applied at the existing residential receptors which may be impacted by the geothermal operation.

The "Guidelines" specify that acceptable geothermal noise guidelines should be at a level which reasonably assumes that the Environmental Protection Agency and U.S. Department of Housing and Urban Development criteria for acceptable indoor noise levels can be met, and that the sound level measurements should take place at the affected residential receptors that may be impacted by the geothermal operation.

For example, the design standard for the HGP-A Wellhead Generator Project specifies that the noise level one-half mile from the well site must be no greater than 65 decibels (comparable to the sound of air conditioning at 20 feet). Construction of a rock muffler at the facility has reduced noise levels to about 44 decibels (equivalent to light auto traffic) at the fence line of the project.

The type of housing normally found near the vicinity of the proposed geothermal resource subzone, will result in noise reduction from outside to inside of at least 15 decibels. Thus, an outside noise level of 45 dBA will reduce to an inside level of 30 decibels or less, which is less than the EPA's limiting standard of 32 decibels level to prevent sleep modification.

The Hawaii Board of Land and Natural Resources (BLNR) has also similarly controlled noise associated with geothermal activities in areas zoned conservation. The BLNR Decision and Order of February 25, 1983, which allowed limited geothermal exploration on a portion of the Kahaualea land parcel in Puna, Hawaii, included the following noise level restrictions:

§9.3.5 - A general noise level of 55 dBa during daytime and 45 dBa at night shall not be exceeded except as allowed for impact noise. For the purposes of these guidelines, night is defined as the hours between 7:00 p.m. and 7:00 a.m. These general noise levels may be exceeded by a maximum of 10 dBa for impact noise; however, in any event, the generally allowed noise level shall not be exceeded more than 10 percent of the time within any 20-minute period with the exception of venting operation in accordance with Chapter 183 of Title 13 of the Board's Administrative Rules and this order.

The above decibel limits are related to everyday sounds in Figure 31.

The State Department of Health (DOH) has issued noise regulations for Oahu. Presently the DOH does not control noise on a state-wide level.

Aesthetic Concerns

Visual impacts of geothermal developments in or near national parks, recreation areas, etc., may be minimized by considering sensitive view corridors during site selection. Siting close to forest areas will minimize development visibility; however, this advantage must be balanced with possible damage that may occur to the forest. Aesthetics may also be improved by tasteful development design, landscaping, and painting of structures in colors to blend with the background.

Visibility of steam emissions from cooling towers will vary with output and atmospheric conditions; however, use of drift eliminators can reduce the size of the vapor plume. Silica deposition from surface disposal of geothermal brine can also create an aesthetic problem. Brine could be injected into deep rock strata. As an alternative, research may provide an aesthetic and environmentally acceptable brine treatment process.

EVALUATION OF ENVIRONMENTAL IMPACTS IN POTENTIAL GEOTHERMAL RESOURCE AREAS

Evaluation of possible environmental impacts in potential geothermal resource areas was accomplished by reviewing available

Figure 31.

Sound Levels and Human Response

Common Sounds	Noise Level (dB)	Effect
Air raid siren	140	Painfully loud
Jet takeoff (200 ft) Auto horn (3 ft) Discotheque	120	Requires maximum vocal effort
Alarm clock (2 ft) Hair dryer	80	Annoying
Freeway traffic Man's voice (3 ft)	70	Telephone use difficult
Air conditioning (20 ft)	60	Intrusive
Light auto traffic (100 ft)	50	Quiet
Living room Bedroom	40	
Library Soft whisper (30 ft)	30	Very quiet

This decibel (dB) table compares some common sounds and shows how they rank in potential harm to hearing. Note that 70 dB is the point at which noise begins to harm hearing. To the ear, each 10 dB increase seems twice as loud. (Source: U.S. Environmental Protection Agency) information for each geothermal resource area. Information on meteorology, surface water, groundwater, underground injection control areas, existing land uses, flora, fauna, and historic and archaeological sites was developed and evaluated on a series of overlay maps for each geothermal resource area.

Kilauea East Rift Zone

Under trade wind conditions, during the day, northeast trade winds pass through the entire rift zone. Wind speeds vary from light to fast depending on the topography. The southern half of the rift zone usually has moderate to fast trade winds, while the northern half tends to have light to moderate wind speeds. At night, the moderate northeast trades pass through the eastern end of the zone while gentle to moderate northerly downslope drainage winds pass through the remainder of the rift zone.

Under non-trade wind conditions, during the day, gentle to moderate sea-breeze upslope winds from the southeast through southwest pass through the rift zone. At night, gentle to moderate downslope winds from the higher elevations drain down through the rift zone from north to west.

Rainfall is heavy over most of the eastern half of the rift zone--over 100 inches a year. Rainfall drops off sharply at the western end of the rift zone from 100 inches a year to 35 inches a year in a short distance of less than two miles.

Hawaii Volcanoes National Park Headquarters at 3,970 feet elevation, Pahoa at an elevation of 650 feet, and Pohoiki at an elevation of 10 feet can be used as representative temperature stations in the rift zone. Pahoa, The National Park Headquarters, and Pohoiki have average annual maximum and minimum temperatures of 68.1°F and 52.9°F, 78.2°F and 63.4°F, and 81.2°F and 67.2°F, respectively.

There are no known surface streams or natural water storage features in the Kilauea east rift zone, with the exception of Green Lake in Kapoho Crater.

Groundwater occurs as dike water and basal water in the Kilauea east rift zone. The only known perched water exists north of Mountain View.

Basal water underlies all of the Kilauea east rift zone except where dikes occur. Hydraulic gradients along the northeast coast of Puna range between two and four feet per mile, with water-table elevations of 12 to 18 feet above sea level five to six miles inland. Along the southeastern coast, gradients range between one and two feet per mile, with water-table elevations of three to four feet above sea level a mile and a half inland. The main reason for the difference in hydraulic gradients between the northeast and southeast coasts is the amount of rainfall per unit of surface area and the barrier effect of the east rift zone on groundwater movement. The effectiveness of the east rift zone as a barrier to groundwater movement is demonstrated by the difference in basal water-table levels.

The only significant source of saline water that contaminates the basal aquifer is sea water, with a chloride content of approximately 19,000 mg/l. Because of the effects of mixing, most groundwater at the coast is brackish. Salinity and temperature vary greatly north and south of the rift zone. Wells and shafts north of the rift zone are characterized by lower temperatures and lower salinities. Wells in and near Keaau have water temperatures of 66° to 68°F. The water temperature of wells near Pahoa ranges between 72° and 74°F. Wells located more than three miles inland generally have a chloride concentration of less than 20 mg/l. South of the rift zone, high well-water temperatures and salinities are encountered. The water temperature of the Malama-Ki Well, No. 2783-01, in 1962 was 127-130°F with salinity between 5500 and 7000 mg/l at pumping rates of 100 to 480 gpm. The water temperature of thermal test well No. 3 in 1974 was 199°F, with salinity of 2000 mg/l. The average chloride content of groundwater south of the rift zone is probably greater than 3000 mg/l, probably due in part to heating of sea water by volcanic activity below the basal lens. The warmer, less dense sea water rises, contaminating the fresh water in the basal aquifer.

Kilauea Lower East Rift Zone

Property in the lower or western portion of the Kilauea east rift zone is owned by six large area landowners and numerous small area landowners. Large area landowners include the State of Hawaii, Bishop Estate, Campbell Estate, Puna Sugar Company, Kapoho Land Development Corporation, and Tokyu Land Development Corporation.

Property within the Kilauea lower east rift zone is classified as Agricultural, Conservation, Urban, and Rural. It should be noted that existing land uses in Agricultural zoned areas include both cultivated and uncultivated land, and agricultural subdivisions. Agricultural subdivisions are designated by the County of Hawaii as A-1a, meaning an agricultural subdivision of one acre lots. Five one-acre subdivisions are located within the rift zone boundaries, and include Leilani Estates, and Nanawale Subdivision. Conservation areas include Forest Reserve lands, the Wao Kele O Puna Natural Area Reserve, and the Kapoho Lava flow of 1960. Urban areas within the rift zone boundaries include Pahoa, Kaniahiku Village, and a small portion of the Kapoho Beach Lots.

Forested areas in the lower east rift zone consist primarily of Category 2 and 2A forest, mature native forest with over 75 percent native cover and native scrub and low forest. Isolated areas of Category 1-- exceptional native forest with over 90% mature cover and closed canopies--do exist in the Keauohana Forest Reserve, consisting of ohi'a-lama forest, in the vicinity of Puu Kaliu and at higher elevations in the Wao Kele O Puna National Area Reserve. Category 3, bare lava, cleared land is more evident in the coastal area, especially in the Kapoho area, at Cape Kamukahi.

Five historic sites are located in the lower east rift zone:

Site No. 7388 - Pahoa District, town.

Site No. 4295 - Pualaa Complex, including an ancient holua slide.

Site No. 2501 - Kapoho Petroglyphs, considered unique, and placed on the State Register of Historic Sites.

Site No. 7492 - Lyman Historic Marker.

Site No. 2500 - Kukii Heiau, remains of heiau built by Umi on his tour of Hawaii after coming to power.

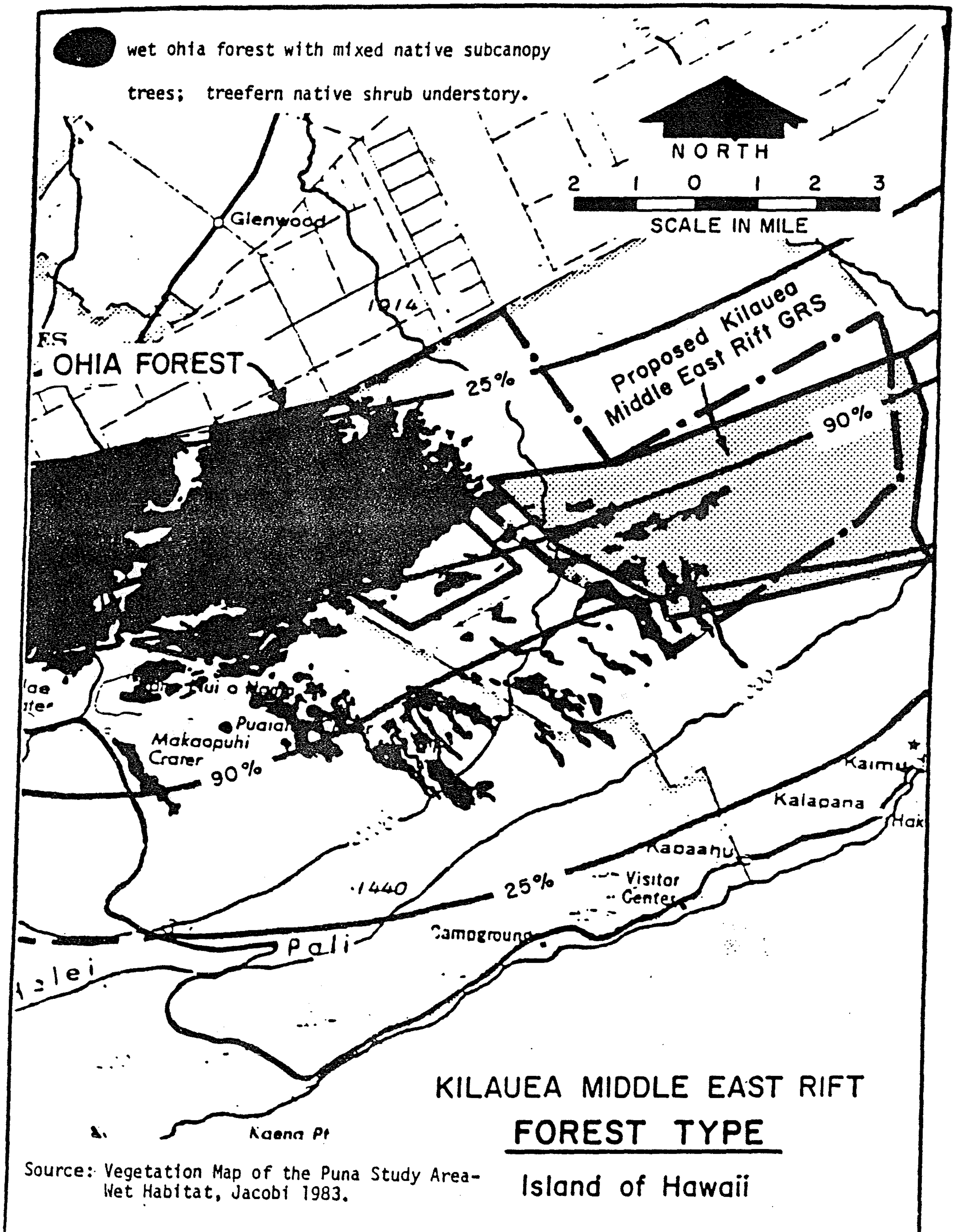
Development of geothermal resources in the Kilauea lower east rift zone has been underway since 1973-74 with the issuing of geothermal resource mining leases for four areas, designated GRML R-1, R-2, R-3, and R-4. Development of additional sites in this zone area should not impact any endangered species essential habitat, but may impact existing communities in terms of noise and aesthetics. The provision of a buffer zone will help to mitigate such impacts. Air quality should not be impacted, since it is expected that given the current level of abatement technology, geothermal facilities can comply with the proposed State air quality standards for geothermal development.

Kilauea Middle East Rift Zone

A detailed vegetation survey of the Puna, Hawaii, area was conducted by J.D. Jacobi (1983). The surveyed areas were mapped into approximately eight vegetation categories. (See "Vegetation Map of the Puna Study Area-Wet Habitat," U.S. Fish and Wildlife Service, Mauna Loa Field Station, Hawaii.)

Figure 32 shows the highest quality native vegetation in the Kilauea middle east rift zone area. It is classified as "wet ohia forest with mixed native subcanopy trees; treefern native shrub understory." The greatest quantity of this prime native vegetation class is uprift and outside of the proposed Kilauea middle east GRS; however, some areas exist in the western part of this proposed GRS. Aside from its intrinsic value, this vegetation can provide a source of native seed for bare lava areas in the region. Other vegetation in the southwestern part of this proposed GRS is classified as "closed canopy, wet ohia forest with mixed native subcanopy trees; treefern, native shrub understory with some introduced shrubs and ferns." There are also small sections of ohia-kukui forest in the southwestern section. The kukui trees may have been planted by the early Hawaiians.

Figure 32.



Source: Vegetation Map of the Puna Study Area-
Wet Habitat, Jacobi 1983.

The northern part of this proposed GRS includes a large section of vegetation classified as "open canopy, wet ohia forest with mixed native subcanopy trees; treefern native shrub understory with some introduced shrubs and ferns."

The southeastern section of this proposed GRS includes a large section of vegetation classified as "wet pioneer ohia community (trees less than 10m tall)."

A significant part of this proposed GRS is comprised of mostly bare recent lava (1963 to 1985 flows) (See geologic hazards section).

The "Puna Geothermal Area Biotic Assessment," published in April 1985 by the University of Hawaii, Department of Botany, indicates that a number of plant species found within the Kilauea east rift zone area are Category 1 candidates for listing as endangered by the U.S. Fish and Wildlife Service. Of the 19 Category 1 species collected in the University's survey, only two are found within the proposed GRS--Bobea timonioides, a medium-sized tree, and Cynea tritomantha.

A Category 1 species is one for which the U.S. Fish and Wildlife Service has sufficient information to support the biological appropriateness of listing as endangered, but for which additional data is required concerning the environmental and economic impacts of listing the species and designating a critical habitat for it.

Bobea timonioides, also known as 'akakea, is found in Ohia forest types. It was sighted at three locations in this proposed GRS, at one site in the designated Kapoho GRS, and at two sites along the lower rift zone outside this proposed GRS.

Cynea tritomantha var. tritomantha, known as 'aku'aku, was sighted in the northeast corner of the proposed Kilauea middle east rift GRS. It should be noted that the endemic fern, Adenophorus periens, was sighted mostly outside of this proposed GRS to the west and north.

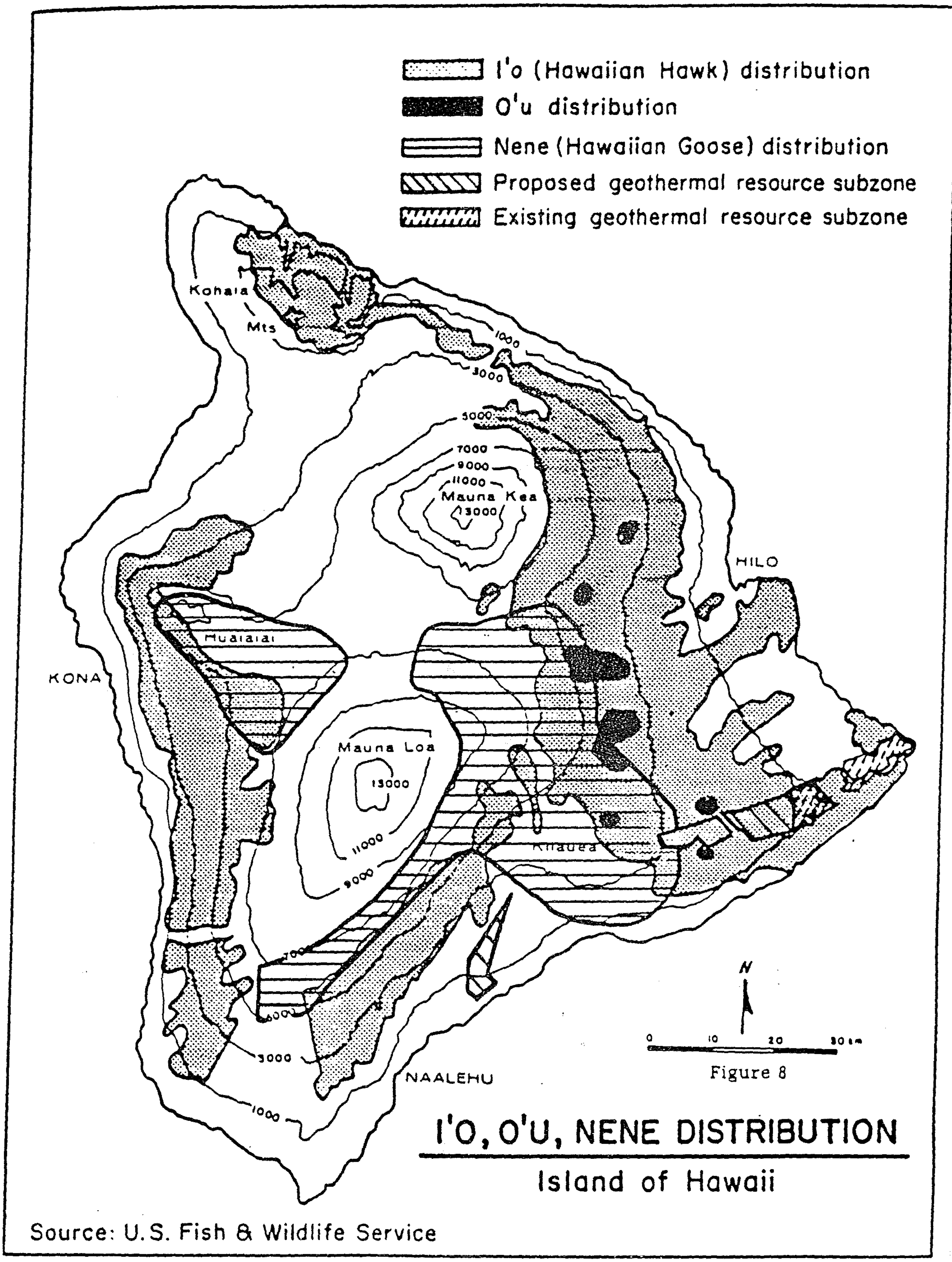
Any impact of geothermal development on these plant species may be avoided by careful facility siting and through the permitting process.

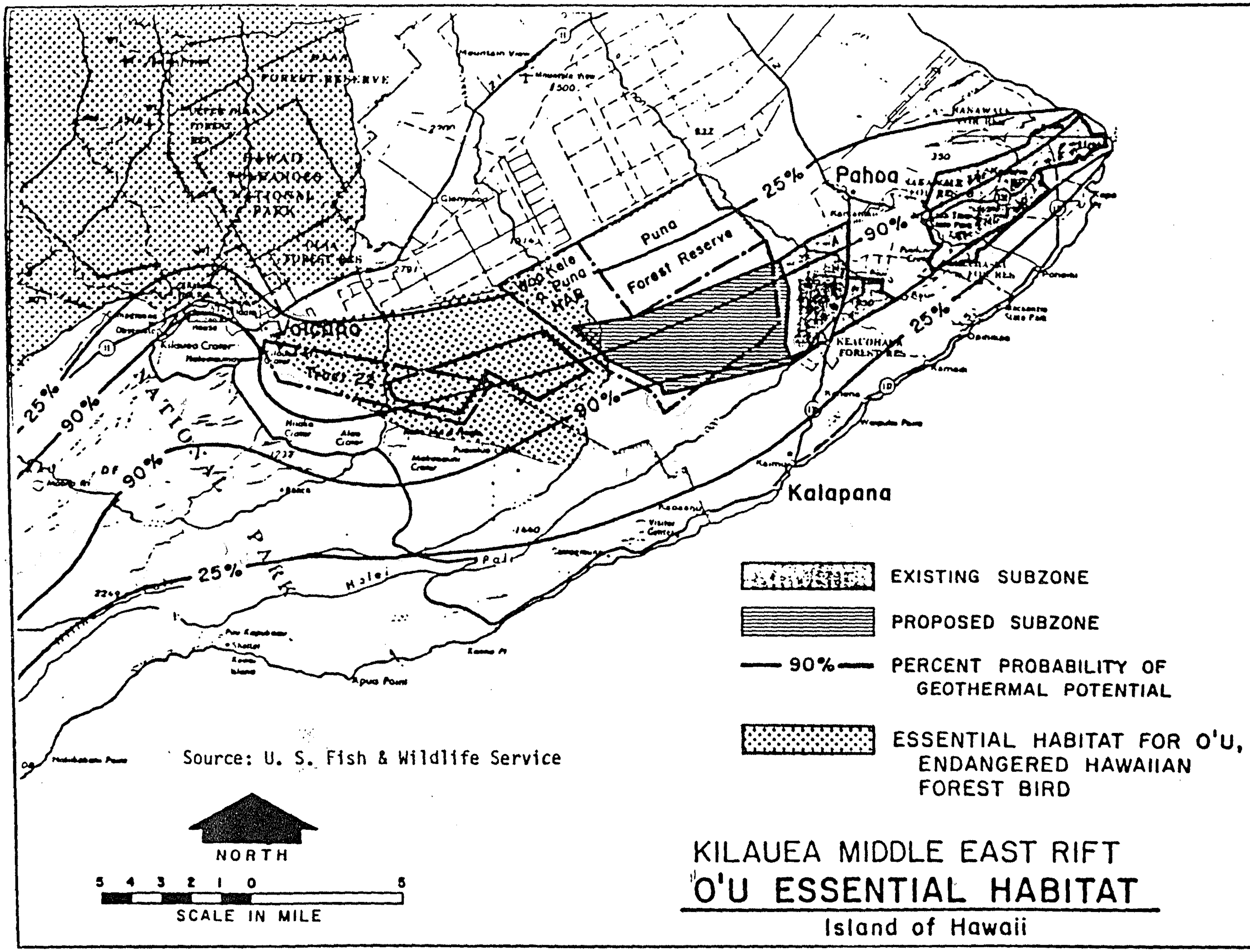
Endangered birds sighted on the Kilauea middle east flank include the O'u, the I'o (Hawaiian Hawk), and the Nene (Hawaiian Goose). The distributional area of these birds for the Island of Hawaii is depicted in Figure 33. Distributional areas indicate those areas where these birds have been sighted. Possible reasons for the declining population of Hawaii's endangered birds include avian disease, animal competition, collecting and hunting, elimination or degradation of habitat, and predation.

The Hawaii Forest Bird Recovery Plan describes the O'u as a rather large bird (about 6 inches). The males have bright yellow heads clearly separated from dark green backs and light green underparts. The female lacks the yellow head. Their straw-colored parrot-like bill is distinctive. Less than 40 O'u were recorded during the 13,500 count periods conducted during the Hawaii Forest Bird Survey. The O'u population on the Big Island has been estimated at about 500 birds. O'u sightings have been reported west and north of the proposed Kilauea middle east rift GRS (Figure 33). The authors of the Hawaii Forest Bird Recovery Plan have recommended, and the U.S. Fish and Wildlife Service has approved, an essential habitat for the O'u (Figure 34) which is believed to be necessary for the O'u to be restored to non-endangered status. The lower habitat boundary has been set at the 2000-foot elevation, and as such includes only a small portion of the proposed GRS. The proposed GRS should therefore have no significant adverse impact on the survival of the O'u.

The endangered I'o or Hawaiian Hawk is a roaming bird which has been sighted throughout the Puna area (Figure 33). The I'o population is currently estimated to be 1400-2500 birds, all on the Big Island. Light and dark color variations exist for the I'o. The light phase I'o has a generally dark brown head and back with a white chest and belly. The dark phase I'o is generally dark brown all over. I'o were also sighted frequently during the University of Hawaii's recent botanical survey, over a wide range of ecosystem types including agricultural lands. Well sites and power plants should be sited so as to avoid known I'o nesting sites.

Figure 33.


I'o (Hawaiian Hawk) distribution
O'u distribution
Nene (Hawaiian Goose) distribution
Proposed geothermal resource subzone
Existing geothermal resource subzone
Kohala Mts
Mauna Kea
Mauna Loa
Hualalai
Kilauea
KONA
HILO
NAALEHU
1000
3000
5000
7000
9000
11000
13000
Figure 8
I'O, O'U, NENE DISTRIBUTION
Island of Hawaii
Source: U.S. Fish & Wildlife Service



Pahoa
Kalapana
Puna Forest Reserve
Wao Kele o Puna NAR
Volcano
Kilauea Crater
25%
90%
EXISTING SUBZONE
PROPOSED SUBZONE
90% PERCENT PROBABILITY OF GEOTHERMAL POTENTIAL
ESSENTIAL HABITAT FOR O'U, ENDANGERED HAWAIIAN FOREST BIRD
Source: U. S. Fish & Wildlife Service
NORTH
5 4 3 2 1 0 5
SCALE IN MILE
KILAUEA MIDDLE EAST RIFT
O'U ESSENTIAL HABITAT
Island of Hawaii

The State Division of Fish and Game has conducted a project for the last 30 years to propagate Nene for release into the wild. Once plentiful, the endangered Nene population had dwindled to an estimated 30 birds in 1952. Through controlled propagation efforts their population on the Island of Hawaii had increased to 300 birds in 1980. Figure 33 depicts their primary range which is approximately 10 km to the west of the proposed Kilauea middle east rift GRS. Nene are not known to nest in the proposed GRS. Their present range is thought to be from 3800 feet to 8000 feet on the slopes of Mauna Loa.

Kilauea Upper East Rift Zone

Property in the Kilauea upper east rift zone is owned by four large area landowners--the Federal government (Hawaii Volcanoes National Park), the State of Hawaii, Bishop Estate, and Campbell Estate. Smaller holdings of various individuals are found in the Royal Gardens Subdivision along the coast and in urban and agricultural districts in the Kilauea-Olaa area.

The Kilauea upper east rift zone is primarily classified "Conservation," with "protective," "resource," and "limited" subareas. Exceptions are the Ainahou Ranch land and Royal Gardens Subdivision, which are designated for agricultural use, and the urban and agricultural districts in the Kilauea-Olaa area.

Existing land uses include the Hawaii Volcanoes National Park (the largest area), forested areas in Kahauale'a, a grazed area in the vicinity of Ainahou Ranch, the Wao Kele O Puna Natural Area Reserve, and the Volcano and Royal Gardens Subdivisions. Portions of the Kilauea Forest Reserve, Kilauea Military Camp, and Kilauea Golf Course are also in the area. The Campbell Estate/True Mid-Pacific Geothermal Development area has been approved for exploration by the Board of Land and Natural Resources in 1983.

Forested areas in the Kilauea upper east rift zone are primarily Category 1 exceptional native forest (over 90 percent native cover and closed canopy) and Category 2 mature native forest (over 75 percent native cover interspersed with bare lava flows, dated 1968-1973, 1977, and 1983-84).

Essential endangered species habitat for the O'u encompasses a major portion of the Kahauale'a area, and extends into the Hawaii Volcanoes National Park land to the south. The Dark-Rumped Petrel is known to nest in Napau Crater, and I'o have established territory at Makapuhi Crater and at lower elevations in the vicinity of the Royal Gardens Subdivision.

There are no known archaeological sites within the Kilauea upper east rift zone.

Development of geothermal resources in the Kilauea upper east rift zone will be limited to areas outside the Hawaii Volcanoes National Park. Air quality within surrounding areas should not be impacted since it is expected that, given the current level of abatement technology, geothermal facilities can comply with the proposed State air quality standards for geothermal development.

Site development may impact endangered O'u habitat. However, as stated in the Kahaualea Environmental Impact Statement (June 1982), "the minimal removal of vegetation and trees within the Kahaualea project area should not significantly threaten the O'u" (pg. 5-11). It should also be noted that a portion of the O'u habitat has been lost due to recent lava flows.

Kilauea Southwest Rift Zone

Flora and Fauna. A forest map of the Kilauea southwest rift zone area has been prepared by the State Department of Land and Natural Resources, Division of Forestry and Wildlife (Figure 35). It shows that land in the proposed Kilauea southwest rift GRS is primarily non-forest grassland area mostly comprised of introduced broomsedge grass. The area also contains some scattered native and introduced shrubs and trees with small pockets of forest area. Agricultural uses include macadamia nut, sugarcane, and grazing areas.

Endangered birds include the I'o (Hawaiian Hawk) and the Nene (Hawaiian Goose). The distributional area of these birds for the

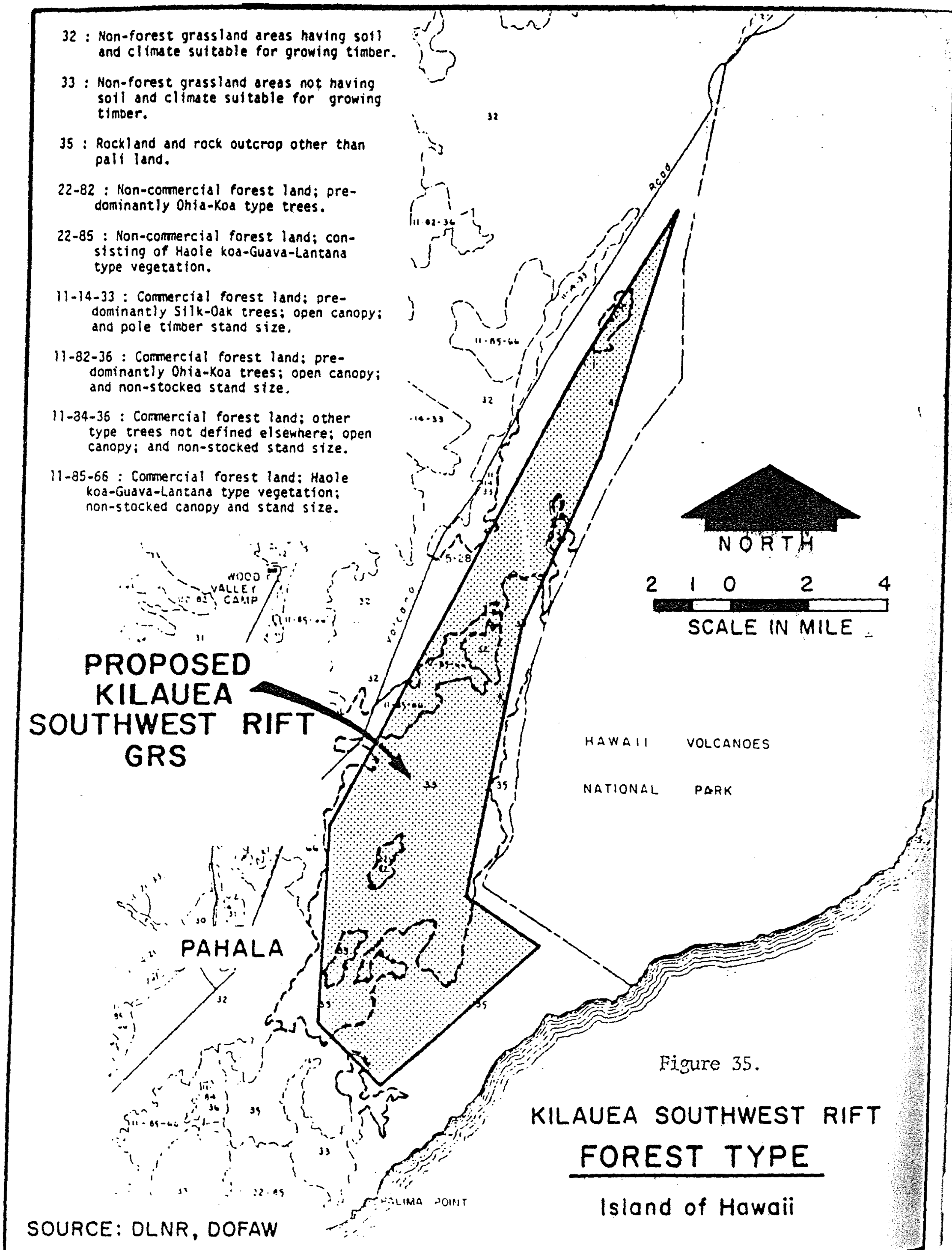


Figure 35.

KILAUEA SOUTHWEST RIFT

FOREST TYPE

Island of Hawaii

Island of Hawaii is depicted in Figure 33. Distributional areas indicate those areas where these birds have been sighted. Possible reasons for the declining population of Hawaii's endangered birds include avian disease, animal competition, collecting and hunting, elimination or degradation of habitat, and predation.

The endangered I'o or Hawaiian Hawk is a roaming bird which has been sighted throughout the Kilauea area over a wide range of ecosystem types, including agricultural lands. Part of the I'o distributional area is to the northwest of the proposed Kilauea southwest rift GRS.

The primary range of the Nene is to the northeast of the proposed Kilauea southwest rift GRS at elevations from 3800 to 8000 feet on the slopes of Mauna Loa.

Air and Water Conditions. Under trade wind conditions, during the day, moderate to moderately strong northeast trade winds are expected to sweep through the Kilauea southwest rift zone. At night, moderate drainage winds from the upper slopes of Mauna Loa should sweep through the rift zone from the north.

Under non-trade-wind conditions, during the day, light to moderate southerly sea-breeze upslope winds are expected to pass through the rift zone. At night, the light to moderate drainage winds from the north are expected to pass through the rift zone.

There is great variation in the amount of rainfall over this rift zone--from about 100 inches a year at the northern end of the rift zone near Hawaii Volcanoes National Park Headquarters to about 20 inches a year at the southern end of the rift zone near Hilina Pali in the Kau Desert. The greatest variation in rainfall is at the upper end of the zone where in the short distance of about a mile from the National Park Headquarters to Halemaumau, the rainfall drops from 100 inches a year to 50 inches a year. There are no rainfall stations in the Kau Desert.

Hawaii Volcanoes National Park Headquarters, at 3,970 feet elevation, with an average maximum and minimum temperature of 68.1°F and 52.°F, respectively, is the only temperature station in the rift zone.

There are few streams in the Kilauea southwest rift zone because the water quickly percolates into the young and highly permeable lava flows. A few well-defined stream channels are found between Waiahaka Gulch, near Kapapala Ranch, and Hilea Gulch. No stream has continous flow into the sea, and flood flows reach the sea infrequently and only for short periods.

Groundwater in the coastal areas of the rift zone is brackish; at higher elevations dike confined water is present. The State DOH's Underground Injection Control line is set at an elevation of 200 feet in most of the coastal areas but drops to an elevation of 100 feet within the rift zone near Waiapele Bay.

Mauna Loa Northeast Rift Zone (Kulani)

Trade winds during the day diverge around Mauna Loa and pass through the rift zone from the east to southeast. At night, reverse flow results from drainage of mountain-breeze downslope winds. Under non-trade conditions, light to moderate sea-breeze upslope winds flow through the rift zone from southeast to east. At night, mountain breeze downslope winds flow from the west.

Rainfall is heavy--150 inches a year at the 3500-foot elevation to 60 inches a year at the 7000-foot elevation. Kulani Camp receives 102 inches a year (elevation 5170 feet). Temperature at Kulani Camp ranges from an average annual maximum of 63.5°F to an average annual minimum of 46.5°F.

There are no known surface streams in this subzone area. Dikes occur above the 5400-foot elevation. The subzone area ranges in elevation from 3600 feet to 7000 feet.

Property within the proposed subzone is owned by Bishop Estate and the State of Hawaii, and is zoned Agricultural and Conservation. The nearest residential area is Kaumana on the north, approximately six miles from the subzone boundary. Volcano House in the National Park is approximately eight miles from the southern subzone boundary.

Existing land uses within the proposed subzone boundary include the Agricultural zoned grazing land belonging to Bishop Estate and the State's Kulani Honor Camp, located in a Conservation District Resource Subzone. The remaining lands within the rift zone area are forested and include portions of the Mauna Loa, Kilauea, and Upper Waiakea Forest Reserves and two game management areas on the northwest and southwest corners of the rift zone. Puu Makaala Natural Area Reserve is included in the southeast corner of the rift zone.

Forested areas consist of Category 1, exceptional native forest; closed canopy with over 90% native cover. The remaining forest areas, consist of Category 2, mature native forest with over 75% native canopy. Forested areas in the upper and northern portion of the proposed subzone are dissected by recent lava flows dated 1852, 1942, and 1984.

Category 1 forests include tall Metrosideros polymorpha (ohia lehua), and Acacia koa (koa) with native shrubs and tree ferns (cibotium spp. hapuu). Category 2 includes moderate to tall Ohia lehua and koa, with native shrubs and ferns. Category 2A includes scattered Ohia lehua and Mamane, in some areas.

Mauna Loa forests within the rift zone area provide habitat for four endangered forest bird species: the Hawaii Creeper, Akepa, Akiapola'au and the O'u, and the Nene. The Mauna Loa east rift forests have been designated as essential habitat for the four endangered forest birds. In addition the I'o (Hawaiian Hawk) is known to nest at two sites, one on the lower slopes of Kulani Cone and a second site directly due west at an elevation of 5500 feet. Development of a geothermal resource in areas other than the cleared grazed agricultural land may impact the four endangered forest bird species and the Nene by disturbing essential habitat areas.

It should be noted that the designated essential habitat area includes the grazed agricultural zoned areas belonging to Bishop Estate since these areas contain both Category 1 and 2 forests as well as open areas.

There are no known archaeological sites within the rift zone area.

Mauna Loa Southwest Rift Zone (Kahuku Ranch)

There are no wind data in the Mauna Loa southwest rift zone. Under trade wind conditions, during the day, the lower half of the rift zone is expected to have light to moderate easterly trade winds. The northern upper half of the rift zone will likely have light to moderate upslope winds from the south. During the night, light to moderate northerly downslope mountain winds usually flow through the rift zone.

Under non-trade wind conditions, during the day, light to moderate southerly upslope winds usually pass through the rift zone. During the night, gentle to moderate drainage winds from the higher slopes usually pass through the rift zone from the north. Precipitation ranges from 40 to 50 inches, decreasing at the upper elevations to 40 inches.

No surface streams are found within the subzone area. Dikes are found in the upper elevations of the rift zone area. Groundwater is fresh. The UIC line lies to the south outside the rift zone area. There are no existing wells within the rift zone area.

The rift zone area is almost wholly owned by the S.M. Damon Estate, except for a small portion on the eastern part of the rift zone which is State-owned.

Existing land uses within the rift zone area include grazing land, a portion of the sparsely settled Hawaiian Ocean View Estates, and forest lands. The rift zone extends makai of Highway 11, to the Kahuku Ranch area. The nearest population centers are to the east, Waiohinu and Naalehu towns, and the Kiolakaa-Keaa Homestead area. The rift zone area is classified Agricultural and Conservation.

Forested areas consisting mostly of mature native forest, with over 75 percent native cover, are interspersed with areas of bare lava from flows dated 1886, 1887, 1907, 1916, and 1926.

Above the 5000-foot elevation, forested and bare lava areas provide habitat for the Nene and two species of endangered forest birds, Hawaiian Creeper and Akiapolaau. On the eastern boundary between the 3000-foot and 3600-foot elevations, three species of endangered forest birds (Akepa, Akiapolaau and Hawaiian Creeper) occupy an area designated as exceptional native forest, with a closed canopy and over 90% native forest cover. The rift zone area lies to the east of the Manuka Natural Area Reserve.

Historic sites are found only at the rift zone perimeter at Kahuku Ranch. No significant archaeological or historic sites were recorded within the rift zone.

Development of geothermal resources in the lower, agricultural zoned portion of the rift zone may result in minimal environmental impact, provided a buffer area is maintained between the geothermal development site and the Hawaiian Ocean View Estates.

Hualalai Northwest Rift Zone

Although no wind instrumentation exists on Hualalai, knowledge of other upland areas indicated that light to moderate upslope sea breezes converge on Hualalai during the day. At night, the reverse gentle to moderate downslope mountain breezes diverge in all directions from the Hualalai Summit. Rainfall varies from light to moderate, from 30 to 40 inches a year.

There are no known surface streams in this area. However, south of the subzone area, man-made catchments and collecting ponds are used to provide water for ranch purposes. Dikes occur at elevations from 3400 feet to 7200 feet.

Property in the rift zone area is wholly owned by Bishop Estate and classified Conservation except for a triangular section on the southeast slope and two small segments along the northwest perimeter that are classified Agricultural. The nearest residential areas occur along the Mamalahoa Highway to the west. Kailua-Kona is located seven miles southwest of the subzone. Except for the triangular shaped agricultural land, which is grazed, all other land within the subzone is forested. Approximately one-half of the forested area lies within the Kaupulehu Forest Reserve.

Forested areas consist of mature native forest, with over 75 percent native canopy. Exceptional native forest with over 90 percent native canopy is found in the rift zone area between elevations of 4000 to 6500 feet. Species composition consists primarily of Metrosideros polymorpha (ohia lehua), Acacia koa (koa), and Sophora chrysophylla (mamane). The area is crossed by a single historic lava flow, the Kaupulehu Flow.

Hualalai slopes within the subzone area provide habitat for four endangered bird species. The species composition varies with elevation. Between 3200 feet and 6000 feet the Alala, Hawaiian Creeper and Akepa are found. Between 6000 and 7000 feet the Hawaiian creeper, Akepa and Nene are found. Above the 7000-foot elevation Nene are found.

No archaeological or historical sites have been recorded in the rift zone area.

Development of geothermal resources in areas other than the grazed agricultural zoned portion of the rift zone may impact the endangered species known to exist. The Alala (Hawaiian Crow) is reported to number fewer than 20. Disturbance of their Hualalai habitat may cause further decline of this species and possibly its extinction.

Haleakala Southwest Rift Zone

Wind data for coastal sites indicate that, under trade wind conditions during the day, light to moderate sea-breeze winds from the southeast and west flow from the coast to upper elevations. At night the reverse, mountain breeze downslope winds occur. Similar sea breeze and mountain breeze winds occur during non-trade-wind conditions.

Rainfall in the rift zone ranges from 16 inches a year in coastal areas to 54 inches a year near Polipoli Spring.

Average annual maximum and minimum temperatures at the coastal area of the rift zone are about 84°F and 64°F, respectively; at 3000 feet--72°F and 55°F; and at 7000 feet--63°F and 44°F.

There are no known surface streams in this geothermal resource area. Several springs along the mauka northern fringes of the area provide water for minor uses, including camp water for the Polipoli Mountain Park.

Groundwater in the rift zone is brackish below 1600 feet level and fresh above. However, the rift zone also contains dike-confined fresh groundwater.

Property within the rift zone is owned by the State of Hawaii, Ulupalakua Ranch, and other individual holders of smaller parcels. The coastal portions of the rift zone and mountain areas above 5000 feet are zoned Conservation--protective and resource, respectively. All mid-level areas not zoned Conservation are zoned for agricultural use.

The Ahihi-Kinau Natural Area Reserve from Kanahena to Keoneoio, including near-shore submerged lands, is located in the coastal portion of the rift zone. This Natural Area Reserve contains anchialine pools, marine ecosystems, and the latest lava flow (dated 1790) on the Island of Maui. Upslope, Ulupalakua Ranch land is used for grazing. The upper-most portion of the rift zone above 5000 feet is designated as the Kula and the Kahikinui Forest Reserves. Polipoli State Park is located in the northern part of the rift zone. The nearest urban or residential areas are Makena, one mile north of the rift zone area; Ulupalakua Ranch, immediately northwest of the rift zone along the Kula/Piilani Highway; and Keokea, approximately two miles northwest of the upper portion of the rift zone. "Science City" and the perimeter of the Haleakala National Park are located in the higher elevations of the rift zone.

Vegetation in the Haleakala southwest rift zone consists of native scrub vegetation and some exotic tree plantings as well as substantial areas of pastureland with occasional forested areas. The lower portions of the rift zone are barren lava with isolated pockets of Category 1, exceptional native forest with closed canopy of over 90 percent native cover.

There is no endangered species habitat in this rift zone, although the middle elevations contain some very valuable, although disturbed, dry native forest.

Development of geothermal resources within the grazed agricultural zoned portions of the rift zone should result in minimal environmental impact since no endangered species habitat is present.

There are five known archaeological sites in or on the perimeter of the rift zone:

1. Poo Kanaka Stone (Site #1021) located near the Kula Highway and has been placed on the State Register of Historic Sites;
2. Puu Naio Cave (Site #1009) located on the southwest rift zone boundary at an elevation of 1100 feet; also on the State Register;
3. Kalua O Lapa Burial Cave (Site #1017) located at the eastern boundary of the Ahihi-Kianu Natural Area Reserve;
4. Maonakala Village Complex (Site #1018) a coastal village site, also within the Natural Area Reserve;
5. La Perouse Archaeological District located at the southern boundary of the rift zone and on the State Register.

Makena residential and resort developments, Ulupalakua Ranch, and the Haleakala "Science City" upslope may be affected aesthetically. Air quality in urbanized areas will not be impacted since it is expected, given the current level of technology, that all air quality impacts can be abated so as to comply with the proposed State Air Quality Standards for geothermal resource development.

Haleakala East Rift Zone

In coastal areas during trade wind conditions, northeast trade winds prevail during the entire day and night. Wind speeds are moderate during the day and light at night. During non-trade wind conditions, the winds are almost calm during the night and light during the day.

In upper areas, northeast trade winds continue across the rift zone during the day and night. However, mountain breeze downslope winds meet the trades in the middle elevations of the rift zone. Under a non-trade wind condition, gentle to moderate daytime sea breezes flow upslope and night mountain breezes move downslope.

The average annual rainfall in the higher elevations of the rift zone is 200 inches with a maximum of over 300 inches on the northern side. Rainfall decreases toward the east to 65 inches a year at the coast.

At Hana Ranch the average annual maximum temperature is 80°F, and the average anuual minimum is 67.4°F.

Extrapolated average annual maximum and minimum temperatures at upper elevations are 72.4°F/56.8°F at 2500 feet; and 58.9°F/45.4°F at 7000 feet.

Streams in the Haleakala east rift zone are ephermal in spite of the high rainfall. The rocks are highly permeable, allowing all but the heaviest rains to sink rapidly into the ground. Rising from sea level at Hana Bay to the 7000-foot level near the eastern rim of Haleakala Crater, the area's rugged topography contains the headwaters of the several tributaries of Kawaipapa Gulch along the northern boundary of this potential geothermal resource area and Moomoonui Gulch along the southern boundary. The makai area contains the intermittent Holoinawawae Stream that empties into Hana Bay.

Dikes occur throughout the middle and lower portions of the rift zone. The State DOH's Underground Injection Control line is set at an elevation of 200 feet.

Property within the rift zone is owned by the Hana Ranch (lower elevations), the State of Hawaii (mid and upper elevations), and the Federal government (upper-most elevations). Smaller parcels in coastal areas belong to other landowners.

Lower elevation Hana Ranch land is zoned for agricultural use and is grazed. State land above the Hana Forest Reserve Boundary is classified Conservation (Protective and Resource Subzones) and is also designated as a public hunting area where wild pig and goat can be hunted year-round. The town of Hana and its rural community are located along the coast.

Forested areas above 3000 feet uniformly consist of Category 1 exceptional native forest, closed canopy with over 90 percent native cover. Below the 3000-foot level the forest is more disturbed and gradually blends into Category 2, mature native forest with over 75 percent native canopy. Below the 1000-foot level the forest gives way to pastureland with occasional forested areas.

Forested areas above the 5000-foot level provide habitat for three endangered forest birds, the Maui Parrotbill, the Crested Honeycreeper, and the Akepa. The Akepa habitat extends from lower elevations to the 4200-foot level.

All known archaeological sites are at or below the 200-foot level. Site No. 1078 at 200 feet is a fishing shrine which is on the State Register of Historic Places. Six other sites are located at lower elevations in coastal areas in Rural and Urban zoned areas.

Development of a geothermal resource in the Haleakala east rift zone in areas other than the grazed agricultural lands below the 1000-foot level may impact native forest bird habitat and above 4200 feet. the endangered forest bird habitat. However, development of a geothermal resource below the 1000-foot level in grazed agricultural land could place a well and power plant close to Hana. Quite clearly, the rural lifestyle of the Hana community could be affected.

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POTENTIAL ECONOMIC BENEFITS FROM GEOTHERMAL DEVELOPMENT AND RELATED INDUSTRIES

Economic Benefits from Geothermal Electrical Production Facilities

A significant amount of money will be directly injected into Hawaii's economy from geothermal capital investment, income, and taxes. The multiplier effect will distribute and enhance this injection of income throughout the Hawaii economy. Geothermal development will prevent some money from leaving the State to the extent that it displaces imported oil and to the extent geothermal revenues stay local. Presently oil imported into Hawaii costs over $1 billion annually.

As a consequence of high fuel costs, electricity rates in Hawaii are among the highest in the nation. Geothermal electricity should add a measure of stability to future pricing, should another oil crisis occur.

Development of geothermal resources can provide numerous job opportunities during the construction, maintenance, and operation of the roads, wells, and power generation facilities. The total number of employment opportunities will depend on specific development proposals. However, most jobs would be temporary construction jobs.

If we assume 25 project employees, direct wages may be about $560,000 annually and considering the multiplier effect it would total an estimated $1.3 million. This would result in some impact on the State and County economy, but not a significant impact. A greater potential for permanent jobs for local residents may be provided by direct use applications of geothermal heat.

Various sources of public revenue may result from a geothermal facility, including property tax, fuel tax, general excise tax, corporate and personal income tax, and possibly resource royalty income.

Geothermal Direct Use Applications

Direct use of geothermal heat should offer local residents many economic opportunities. The warm water effluent from a geothermal electric facility can provide an inexpensive source of process heat for various uses.

Some agricultural activities which can be supported by geothermal heat include: sugarcane processing, drying and dehydration of fruits and fish, fruit and juice canning, production of livestock feed from fodder, freeze drying of food and coffee, aquaculture and fishmeal production, refrigeration and ice making, soil sterilization, and fruit sterilization by dipping in hot water.

Industrial applications of direct geothermal heat may include extraction of potentially marketable minerals, such as silica or sulfur from geothermal fluids, production of cement building slabs, and production of liquid combustion fuels from biomass, e.g., bagasse or other agricultural by-products.

The Puna Research Center will explore the feasibility of some of the above direct use applications in Hawaii. The research facility, scheduled to be in operation in 1986, is State funded and administered by the Natural Energy Laboratory of Hawaii. It will be located adjacent to the HGP-A geothermal electric plant.

Other direct uses include hot geothermal mineral water spas which have proved to be of major commercial value in producing tourist revenue in Japan, Europe, U.S.S.R., and the Mainland United States, where millions visit these facilities annually. In places where fresh water is scarce, geothermal heat can be used to distill fresh water from saline water.

The transportability of geothermal heat is a significant limiting feature of direct use applications. Factors which influence transportability include initial and end-use temperatures, climate conditions, pipe insulation, and whether steam or hot water is transporting the heat. Hot water can be transported much farther than steam. Depending on the direct use application, hot water can be transported up to 10 miles. Thus, direct use facilities should be situated in close proximity to electric generation facilities.

It must be determined during subsequent permitting processes whether direct use applications of geothermal heat are an appropriate use in the areas subzoned for geothermal development (See section on compatibility).

If the benefits of direct use applications are to be available in several areas, then small decentralized geothermal facilities should be encouraged. Decentralized developments owned and operated by various developers may also promote competitive pricing for both electricity and process heat. With imaginative marketing, Big Island processed farm products can be sold worldwide.

Other Considerations

Current peak electrical demand on the Big Island is about 100 MW, with nighttime base demand of about 40 MW. An annual load growth of about 1 percent is expected. Electrical generation capacity on the Big Island is about 130 MW (including reserve capacity), with about 60 percent generated by oil, 33 percent by biomass, 5 percent by hydro, and 2 percent by geothermal. Biomass' significant contribution may change as sugar production (bagasse availability) is reduced; however, this may be offset by woodchipping. The Hawaii Electric Light Company is considering proposals from geothermal developers to provide future generation capacity.

As described above, the Big Island's demand for electricity is expected to be fairly stable. Considering existing electric generation capacity, the demand for geothermal electricity may be somewhat limited. However, two possible long-term scenarios would significantly increase the demand for geothermal electricity: (1) a deep water electrical transmission cable connecting the islands and/or (2) an energy intensive industry on the Big Island, e.g., manganese nodule processing. However, each of these projects require a thorough analysis of many issues, including environmental and social impacts and technical and economic feasibility. These issues are beyond the scope of this report. The State Department of Planning and Economic Development has been coordinating investigations in these areas.

COMPATIBILITY OF GEOTHERMAL DEVELOPMENT WITH PRESENT LAND USE

Under the provisions of Chapter 205-2 of the Hawaii Revised Statutes, Districting and Classification of Lands, there are four major land use districts for all lands in the State: (1) Urban, (2) Rural, (3) Agricultural, and (4) Conservation. The State Land Use Commission is responsible for these designations.

Urban districts include activities or uses allowed by ordinances and regulations of the County where the urban district is located.

Rural districts include low density residential lots where urban structures, streets, and services are absent, and also small farms. These districts may include contiguous areas not suited to low density residential lots or small farms because of local topography, soils, or other related characteristics.

Agricultural districts include activities or uses characterized by the cultivation of crops, orchards, forage, and forestry; animal husbandry and game and fish propagation; services and uses associated with the above activities including but not limited to living quarters or dwellings, mills, storage facilities, processing facilities, and roadside stands for the sale of products grown on the premises; agricultural parks; and open area recreational facilities.

Conservation districts include land necessary for protecting watersheds and water sources; preserving scenic and historic areas; providing parks, wilderness, and beaches; conserving endemic plants, fish, and wildlife; preventing floods and soil erosion; forestry; open space areas whose existing openness, natural condition, or present state of use, if retained, would enhance the present or potential value of abutting or surrounding communities, or would maintain or enhance the conservation of natural or scenic resources; areas of value for recreational purposes; and other related activities and permitted uses not detrimental to a multiple use conservation concept.

The Conservation areas are further divided into five subareas: protective (P), limited (L), resource (R), general (G), and special (SS). The protective subarea has as its objective the protection of valuable resources in such designated areas as restricted watersheds; marine, plant, and wildlife sanctuaries; significant historic, archaeological, geological, and volcanological features and sites; and other designated unique areas. The limited subareas are designated where natural conditions suggest constraints on human activities. The objective of the resource subarea is to develop, with proper management, areas to ensure sustained use of the natural resources of those areas. General subareas are open space where specific conservation uses may not be defined, but where urban use would be premature. Special subareas are specifically designated areas which possess unique developmental qualities which complement the natural resources of the area.

The DLNR's administrative rules define conservation to mean:

> "A practice, by both government and private landowners, of protecting and preserving, by judicious development and utilization, the natural and scenic resources attendant to land...to ensure optimum long-term benefits for the inhabitants of the State." (DLNR Rule 13-2-1)

Act 296, SLH 1983, and as amended by Act 151, 1984, specifically states that "geothermal resource subzones may be designated within the urban, rural, agricultural, and conservation land use districts established under Section 205-2, HRS. Only those areas designated as geothermal resource subzones may be utilized for geothermal development activities in addition to those uses permitted in each land use district under this chapter...Methods for assessing the compatibility of geothermal development within a conservation district, shall be left to the discretion of the Board and may be based on currently available public information."

In granting a conservation district use permit (CDUA No. HA 3/2/82-1463) for geothermal exploration, the Board of Land and Natural Resources (BLNR) stated that "the State recognizes that conservation lands vary in their use and importance in accordance with a wide variety of criteria. Both the Federal government and the State of Hawaii recognize that conservation lands involve multiple uses which range from absolute preservation to regulated uses...The range of activity permitted depends upon the ecological importance of the resource in the overall environment and the relative need for human activity within a restricted context." This balancing test may also be applied by the BLNR to conservation lands when subzoning is determined.

The Counties control land use within Urban, Rural, and Agricultural districts. The County of Hawaii has already permitted the drilling of several geothermal wells on land classified Agricultural near the HGP-A geothermal facility. County special use permits have included various conditions to protect the public from potential impacts from geothermal activities.

Land Use Classifications in Potential Subzone Areas

Kilauea Upper East Rift Zone. This proposed subzone area is situated within land classified Conservation-limited. Each area within the Conservation district has permitted uses. In each of these subareas (protective, limited, resource, and general) the use of the area for "monitoring, observing and measuring natural resources" is allowed. In addition, the use of lands within a Conservation district "where public benefit outweighs any impact on the conservation district" is permitted.

Kilauea Middle East Rift Zone. The great majority of the land within the proposed Kilauea middle east rift GRS is classified Conservation-protective. Portions of this Conservation area are also presently designated as the Wao Kele 'O Puna Natural Area Reserve and the Puna Forest Reserve. The extreme eastern and southeastern areas of this proposed GRS is classified Agricultural.

Kilauea Lower East Rift Zone. A portion of the area includes two current Geothermal Resource Mining Leases, R-2 and R-3, which were declared subzones through Act 151, SLH 1984. The proposed Kapoho subzone is within Agricultural and Conservation districts. The existing HGP-A geothermal facility demonstrates that with careful planning geothermal development can be compatible with existing uses in this area.

Kilauea Southwest Rift Zone. The greatest portion of land within the proposed Kilauea southwest rift GRS is classified Agricultural with a very small portion Conservation. This area presently includes grazing and macadamia nut and sugarcane farming.

With regard to Agricultural zoned land within the proposed Kilauea southwest rift GRS, the County will assess the propriety of geothermal development before granting their geothermal permits.

Potential geothermal direct use applications (See economics section) may complement present agricultural uses such that both uses may become more profitable. The potential for ecological disturbance is minimal since the area within the proposed Kilauea southwest rift GRS does not contain any prime native forest nor any endangered plants or animals.

Hualalai Northwest Rift Zone. This resource area is currently classified as Conservation-protective and resource.

Mauna Loa Southwest Rift Zone. This resource area is currently classified as Conservation-limited and Agricultural.

Mauna Loa Northeast Rift Zone. Some 75 percent of the assessed resource area is presently classified as Conservation-protective.

Haleakala East Rift Zone. This resource area is presently classified as Conservation-protective.

Haleakala Southwest Rift Zone. This resource area is classified as Agriculture and Conservation-protective, general, and resource.

CURRENT STATUS OF GEOTHERMAL RESOURCE SUBZONES IN HAWAII

Based upon currently available information on geothermal resources, 20 separate areas in the State of Hawaii were identified by the Geothermal Resources Technical Committee as having potential geothermal resources. Of these, five sites on the Island of Hawaii and two on the Island of Maui were determined to have sufficient probability of locating high temperature geothermal resources capable of producing electrical energy. High temperature was defined to be greater than 125 degrees celsius or 257 degrees fahrenheit at depths less than three kilometers or 9840 feet. Rock permeability, although necessary for geothermal fluid flow, was not addressed as it requires exploratory drilling for accurate local determinations.

The DLNR analyzed potential impacts from geothermal development in the seven high temperature resource areas. Factors included prospects for utilization, geologic hazards, social and environmental impacts, economic benefits, and land use compatibility. Other considerations included the established State objectives of energy self-sufficiency and reliability. Some generalizations were drawn. Local economic benefits are likely to result from development construction and operation, and possible direct use applications of geothermal heat. Decentralization of facilities, strategic siting, and lava diversion platforms and barriers may mitigate damage from lava flows. Various development risks may be caused by geologic hazards associated with geothermal resources areas. Geothermal design and systems for abatement and control can significantly reduce impacts from site construction, structure appearance, noise, hydrogen sulfide, silica deposition, and other possible problem areas. These items should receive detailed analyses during subsequent case-specific development permitting processes by the State and Counties. Refer to preceding chapters for a detailed discussion of impact factors.

The following geothermal resource areas were proposed as sites demonstrating an acceptable balance among the subzoning factors mentioned above.

Kilauea Lower East Rift, Island of Hawaii

This area shown in Figure 36 identifies two separate sites, the Kapoho section and the Kamaili section. The percent probability of locating high temperature geothermal resources has been estimated to be greater than 90 percent. Relatively recent local volcanic eruptions in the 1960's and 1970's indicate the availability of subterranean volcanic heat. The Hawaii Geothermal Project's Well A (HGP-A), drilled in 1976, has proven that a viable geothermal resource exists in this area. The Thermal Power Company has drilled three wells just north of the subzone, all of which encountered a resource capable of generating electric power. Other developers have drilled four wells slightly south of HGP-A on the seaward flank of the rift zone which proved to be hot but lacked the permeability necessary for a geothermal reservoir.

The Kapoho section contains three grandfathered subzones as established by the Legislature in Act 151, SLH 1984. The areas provide for 2000-foot buffer zones to sensitive environmental areas, such as the Natural Area Reserve System and prime forest areas. The area between the Kapoho and Kamaili sections was not considered for subzone designation because it contains the Leilani Estates housing development.

After considering the DLNR proposal and public comments voiced in the public hearings of August 7 and 8, 1984, in Pahoa and Hilo, the BLNR designated 6,800 acres as the Kapoho GRS and the Kamaili GRS.

Kilauea Upper East Rift, Island of Hawaii

The area depicted in Figures 37 and 38 was determined to have a 90 percent or greater probability of containing high temperature geothermal resources. The current volcanic activity centered on Puu O'o attests to the availability of heat. A substantial degree of risk from geologic hazards is associated with this activity. When the current eruptive phases of Puu O'o have ceased, drilling operations over the cooled flows is considered feasible.

Figure 36.

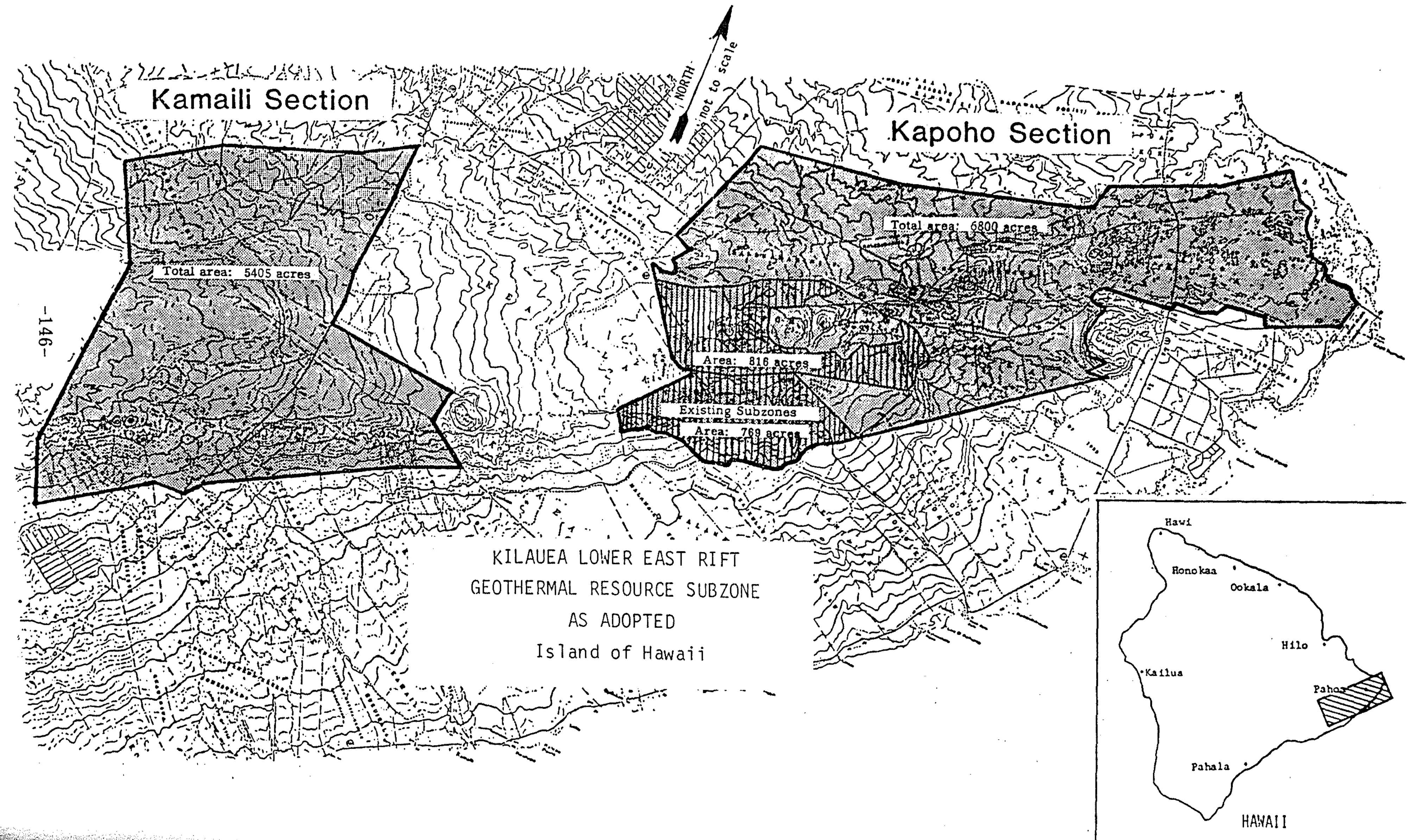
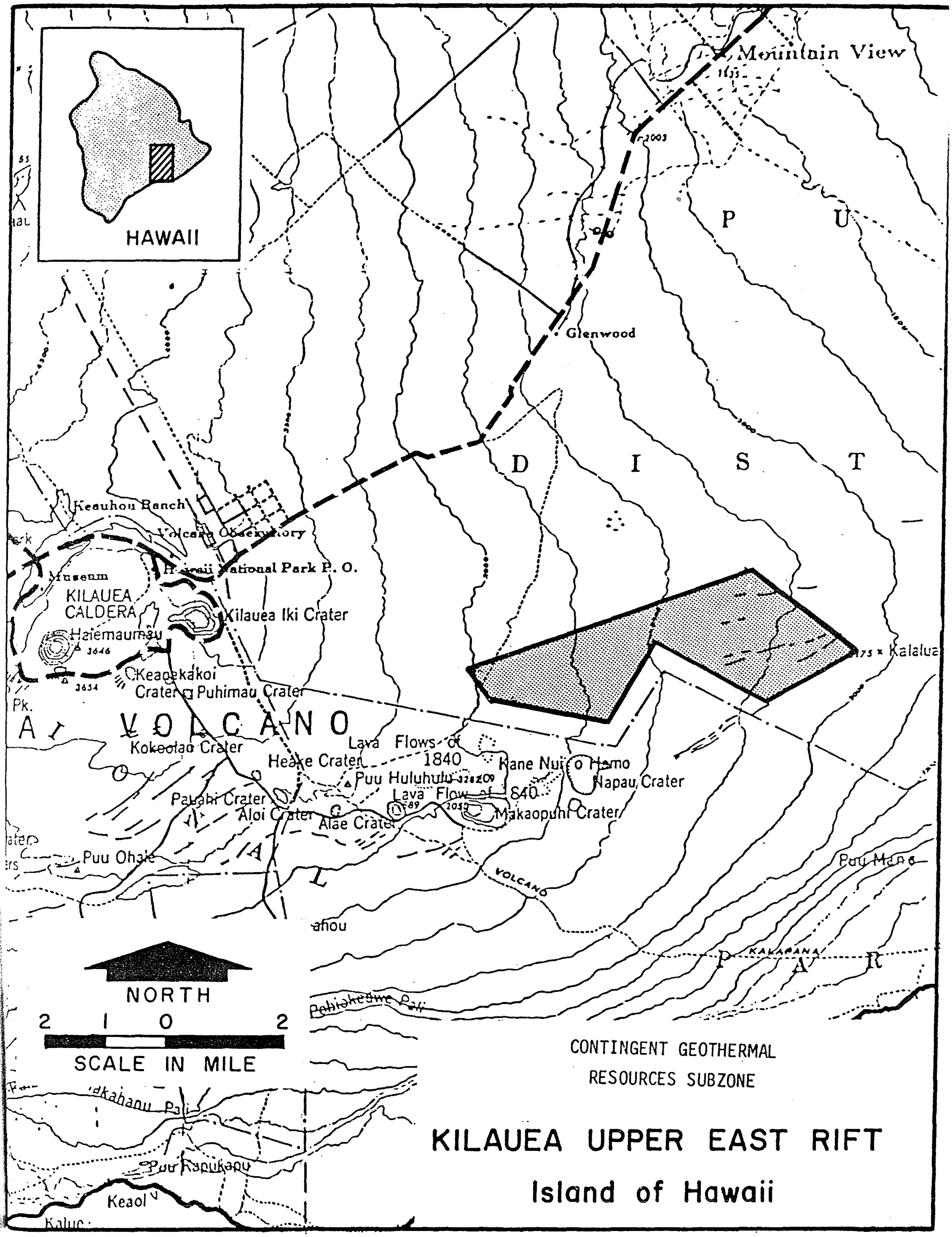

NORTH
not to scale
Kamaili Section
Kapoho Section
Total area: 5405 acres
Total area: 6800 acres
Area: 816 acres
Existing Subzones
Area: 769 acres
KILAUEA LOWER EAST RIFT
GEOTHERMAL RESOURCE SUBZONE
AS ADOPTED
Island of Hawaii
Hawi
Honokaa
Ookala
Hilo
Kailua
Pahoa
Pahala
HAWAII

Figure 37.


HAWAII
Mountain View
Glenwood
P
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Keauhou Ranch
Volcano Observatory
Hawaii National Park P. O.
Museum
KILAUEA
CALDERA
Kilauea Iki Crater
Halemaumau
3646
Keanakakoi
Crater
Puhimau Crater
Kalalua
VOLCANO
Kokoolau Crater
Lava Flows of
1840
Heake Crater
Puu Huluhulu
Kane Nui o Hamo
Napau Crater
Pauahi Crater
Lava Flow of 1840
Aloi Crater
Alae Crater
Makaopuhi Crater
Puu Ohale
VOLCANO
Puu Mane
P
A
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KALAPANA
Poliokeawe Pali
NORTH
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SCALE IN MILE
Puu Kapukapu
Keaoi
Kalue
CONTINGENT GEOTHERMAL
RESOURCES SUBZONE
KILAUEA UPPER EAST RIFT
Island of Hawaii

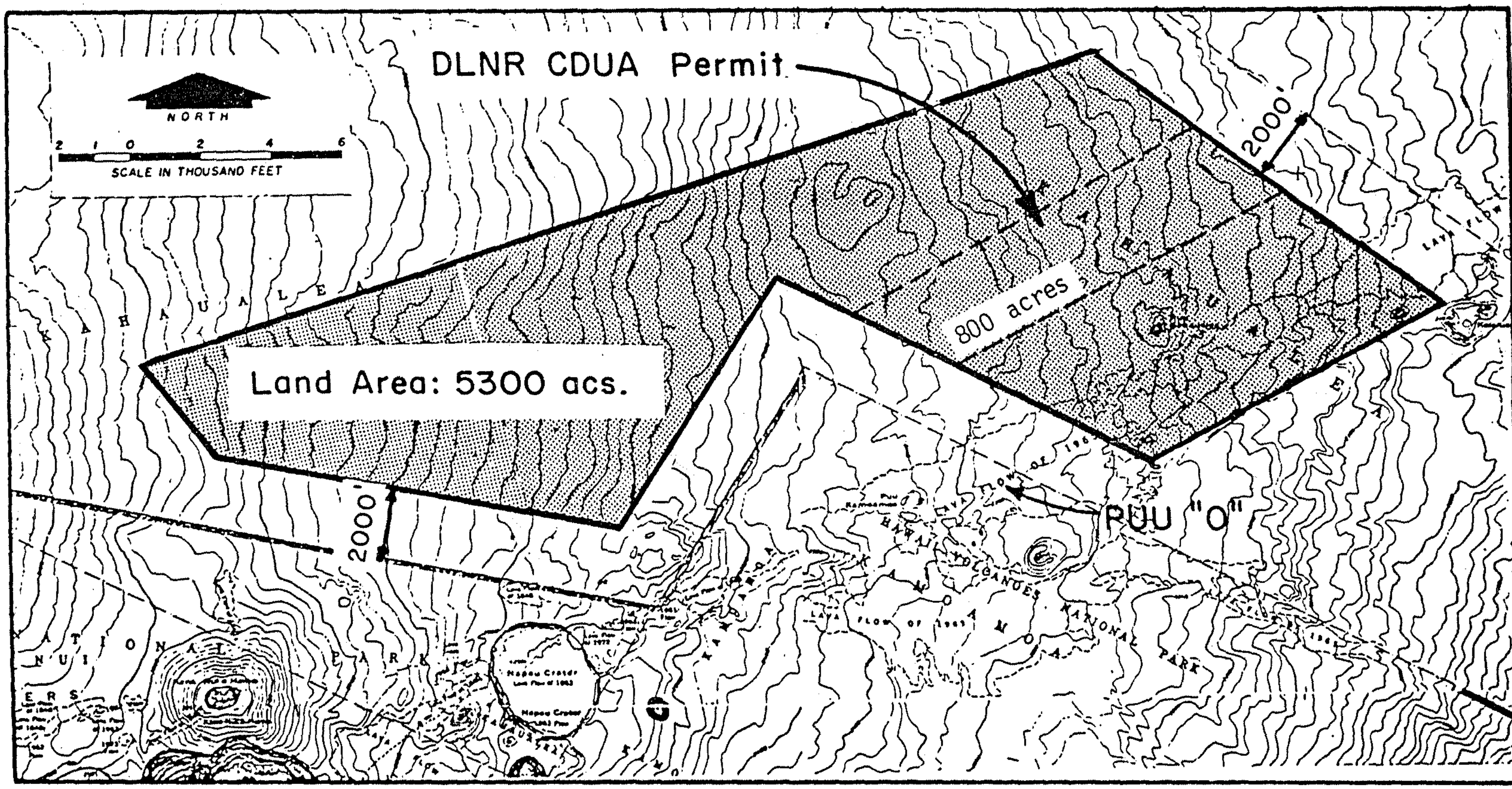


Figure 38.

CONTINGENT GEOTHERMAL
RESOURCES SUBZONE

KILAUEA UPPER EAST RIFT
Island of Hawaii

Environmental areas which may be encountered include the Hawaii Volcanoes National Park to the west, the Puna Forest Reserve to the east, and prime ohia forest to the north. Additionally, the endangered bird O'u and the rare adenophorus periens plant have been located in this area. To mitigate potential impacts, the proposed GRS area provides a 2000-foot buffer zone to both the National Park and the Forest Reserve. The encroachment into the ohia forest area has been limited by siting the proposed GRS close to the physical surface expression of the rift area. The closest population centers are significantly north of this proposed GRS.

The True/Mid-Pacific Geothermal Venture has indicated their intent to develop a geothermal electric facility in either the Kilauea upper or middle east rift area. Prior to enactment of Act 296, the BLNR had granted this developer a Conservation District Use Application Permit for limited exploratory drilling in the area shown in Figure 38.

The BLNR held public hearings on this proposed GRS on September 12, 1984, in both Hilo and the Hawaii Volcanoes National Park. Some local residents requested a contested hearing which the BLNR granted and heard on December 12-20, 1984. The BLNR decision (full text in Appendix A-9) held: (1) the 800-acre parcel depicted in Figure 38 is designated as a GRS when current nearby eruptive activity ceases; (2) the Campbell Estate and the State should consider a land exchange involving State-owned lands in the Kilauea middle east rift zone and Campbell Estate land at Kahaualea; (3) DLNR's Division of Water and Land Development is directed to assess the Kilauea middle east rift zone as a potential GRS; and (4) if the middle east rift area is not designated as a GRS or if the land exchange is not consummated, then the entire 5300 acres proposed shall be designated as the Kilauea upper east rift GRS.

The local residents who requested the BLNR contested hearing appealed the BLNR decision described above to the Hawaii Supreme Court. DOWALD immediately undertook the assessment of the Kilauea middle east rift area (following section) and proposed it for designation as a GRS. Campbell Estate and the State have made substantial progress in their efforts to achieve a land exchange.

Kilauea Middle East Rift, Island of Hawaii

On December 28, 1984, the BLNR rendered a decision on the proposed Kilauea upper east rift GRS (see preceding section) which directed DLNR's Division of Water and Land Development to assess the Kilauea middle east rift area. This area was not extensively assessed by DOWALD previously because of its Natural Area Reserve status.

The land area located between the western boundary of the Kamaili GRS and the eastern boundary of the Kahaualea land tract was examined for resource potential and evaluations were made on geological hazards, social, economic, and environmental impacts, and compatibility of geothermal development with present land use. The area was evaluated on the basis of potential impacts which may occur within the identified area and with consideration of statutory State energy objectives and policies. It was determined that an acceptable balance existed between these factors.

Based on the assessment factors above, the proposed Kilauea middle east rift GRS boundaries (Figure 39) were determined as follows:

- o Almost all of the land area contained in the proposed GRS is within the 90 percent probability area.
- o GRS boundaries were determined by utilizing existing metes and bounds where possible, to clearly define subzone limits.
- o The eastern boundary abuts the existing Kamaili GRS, straddling the 90 percent probability band and forming a contiguous land use designation. The BLNR decision had directed DOWALD to assess the Kilauea middle east rift zone beginning on the western boundary of the Kamaili GRS.

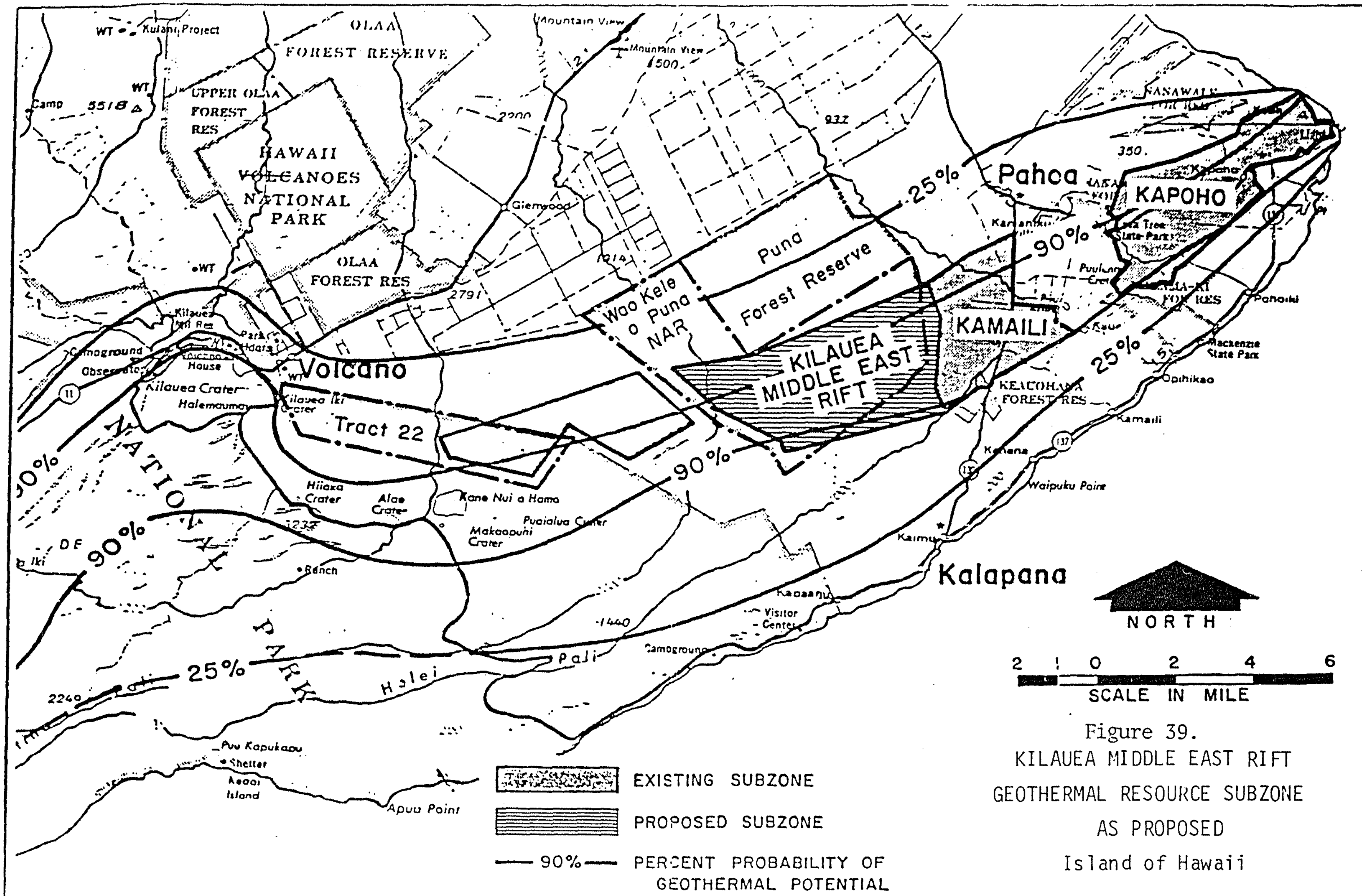


Figure 39.
KILAUEA MIDDLE EAST RIFT
GEOTHERMAL RESOURCE SUBZONE
AS PROPOSED
Island of Hawaii

- o The southern boundary closely parallels the 90 percent probability line and is limited because the resource potential of the area south of the 90 percent probability line is believed to diminish with distance from the rift zone. Permeability in areas south of the rift zone is expected to be low as a result of mineral deposition from salt water intrusion. Potential hazards from lava flows are greater south of the rift zone due to the southward sloping contour of the land. Also, earthquakes are relatively more frequent south of the rift zone.
- o The western boundary was determined assuming that Kahaualea would be designated as a Natural Area Reserve. The boundary provides a 2000-foot buffer between the GRS and Kahaualea to mitigate any possible effects on the prime native forest and wildlife at Kahaualea.

The BLNR held a public hearing in Pahoa on September 26, 1985, on the proposed Kilauea middle east GRS. Some local residents requested a contested hearing which the BLNR granted and heared on November 13-15, 1985. As a result of the contested hearing the BLNR modified the proposed GRS to provide a buffer for residents in the northeast area and for sensitive environmental areas in the southwest area (See Figure 40). The BLNR designated the modified area as a GRS in their Decision and Order of December 12, 1985 (See text appendix A-14). Some resident parties to the contested hearing appealed the BLNR decision to the Hawaii Supreme Court.

Kilauea Southwest Rift, Island of Hawaii

A portion of this proposed GRS (Figure 41) was determined to have a 90 percent or greater probability of containing a high temperature geothermal resource. Most of the area has a greater than 25 percent probability. Potential geologic hazards from eruptions and earthquakes are evident throughout this rift zone area.

A 1000-foot buffer between the proposed GRS and the Hawaii Volcanoes National Park was provided to mitigate any possible effects to the existing flora and fauna in the park. Likewise, an approximate

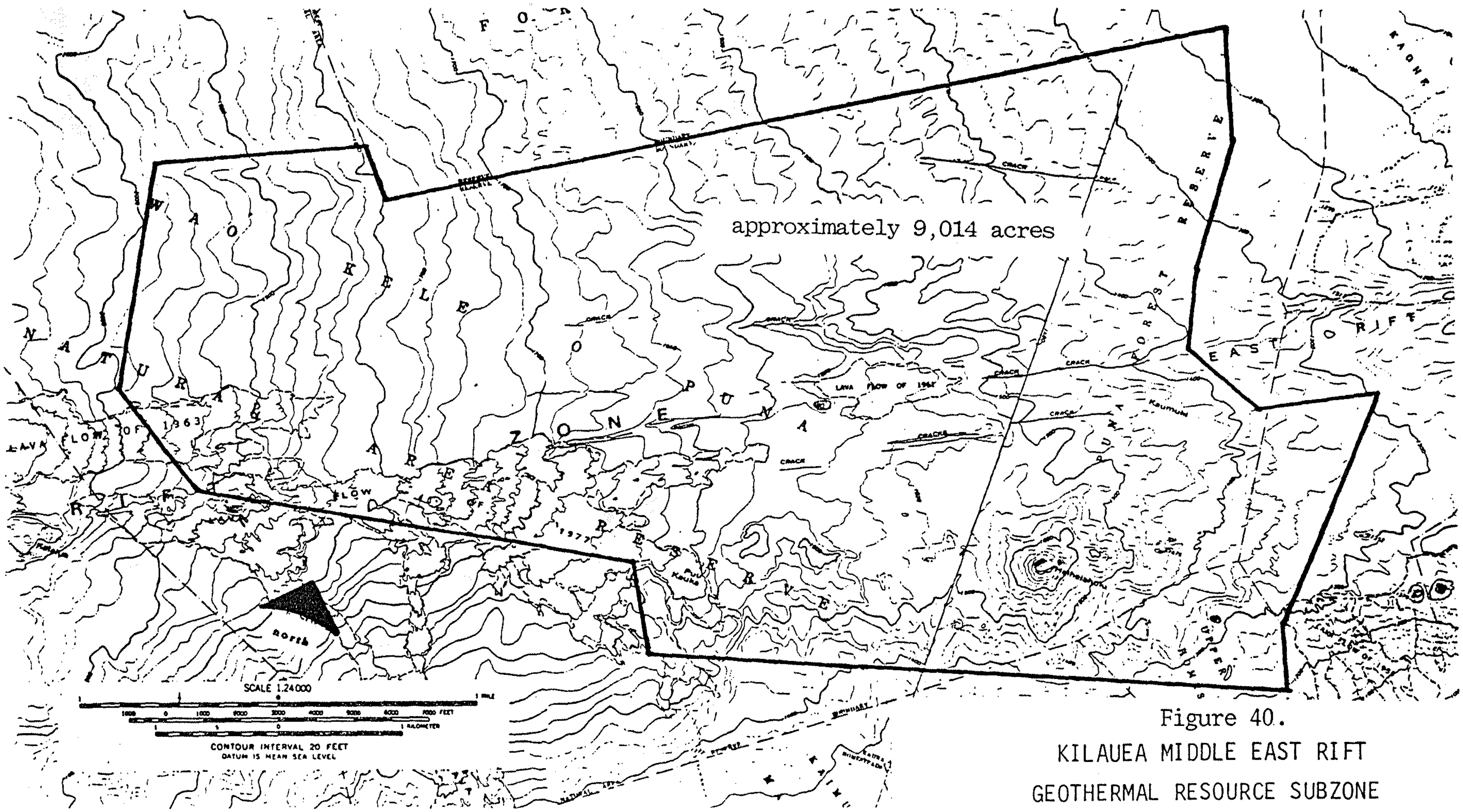


Figure 40.
KILAUEA MIDDLE EAST RIFT
GEOTHERMAL RESOURCE SUBZONE
AS ADOPTED
Island of Hawaii

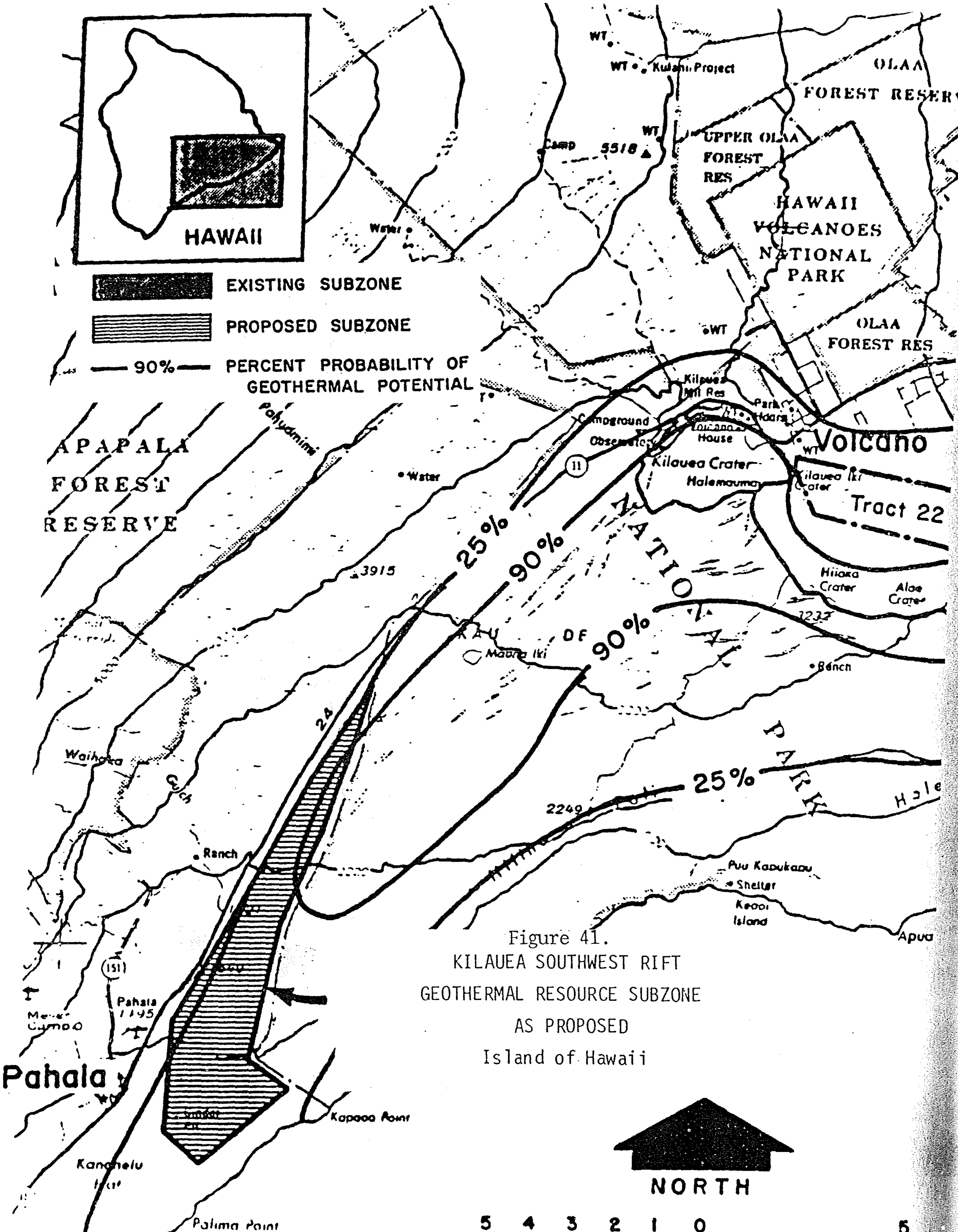


Figure 41.
KILAUEA SOUTHWEST RIFT
GEOTHERMAL RESOURCE SUBZONE
AS PROPOSED
Island of Hawaii

one mile buffer between the proposed GRS and Pahala community was provided to reduce any impacts from potential future activities within the proposed GRS. Scenic view corridors along Highway 11 should be protected during any subsequent development permitting process by requiring tasteful development, design, landscaping, and painting of structures.

The BLNR held a public hearing regarding this proposed GRS in Pahala on September 26, 1985. Some local residents requested a contested hearing. A BLNR decision on whether to grant the contested hearing is pending. As of this writing (April, 1986) the BLNR has not made a determination on designating a GRS in the Kilauea southwest rift area.

Haleakala Southwest Rift, Island of Maui

This proposed GRS shown in Figure 42 has a 25 percent probability of containing high temperature geothermal resources. Some danger from geologic hazards exists. The last area eruption occurred in 1790 by the coast. Population centers are somewhat removed from this subzone area. The southern boundary of the subzone has been sited approximately two miles upslope of the coast to avoid any possible impacts to the coastal Natural Area Reserve. Other boundaries were situated to exclude known archaeological sites.

The BLNR held a public hearing in Kula on September 10, 1984. After considering testimony presented at the hearing, the BLNR modified the proposed GRS slightly to provide an extended buffer area to residents in lower elevations north of the subzone area. The Haleakala southwest rift GRS as adopted is shown in Figure 43.

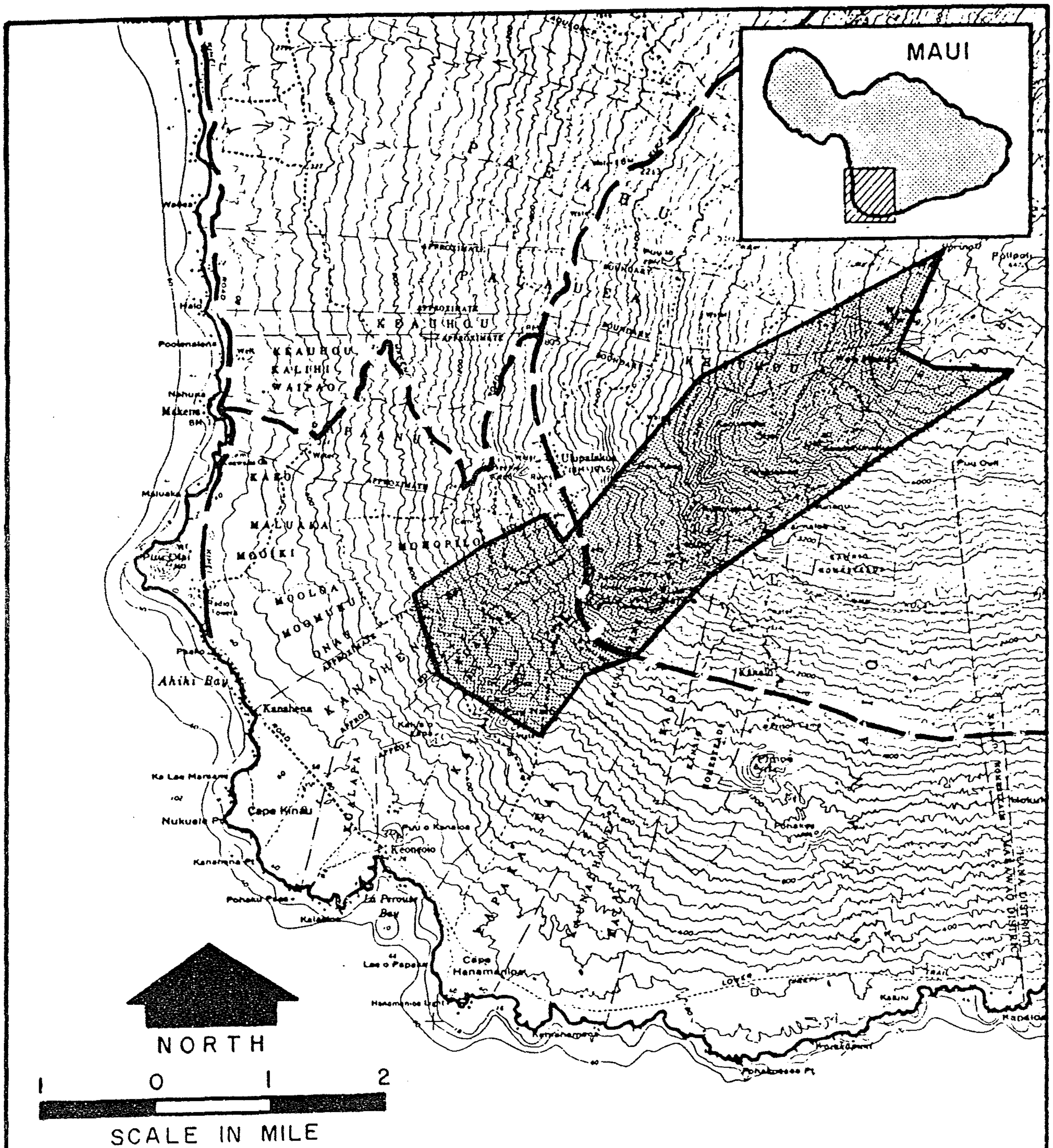


Figure 42.

HALEAKALA SOUTHWEST RIFT
GEOTHERMAL RESOURCE SUBZONE
AS PROPOSED
Island of Maui

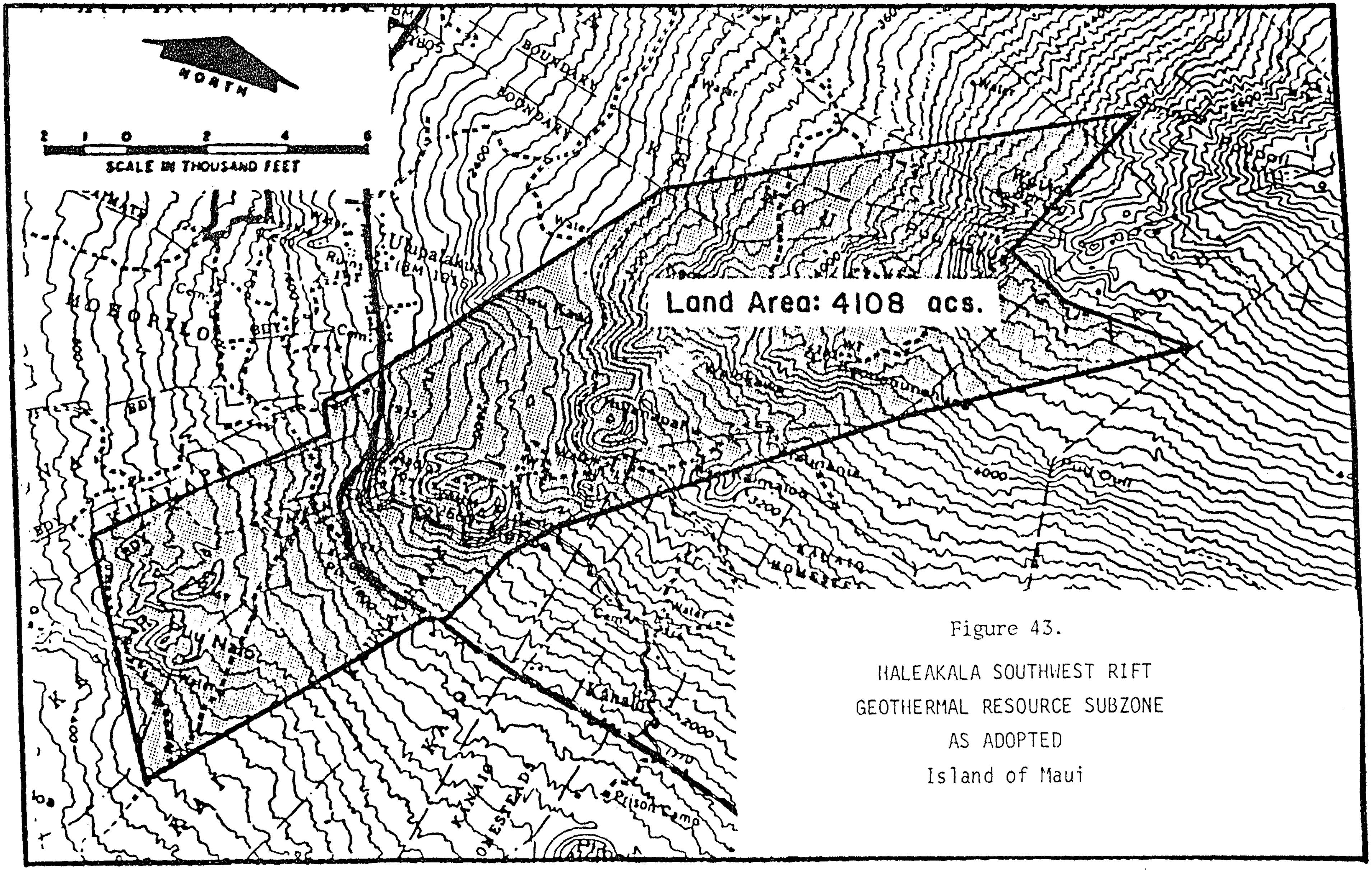


Figure 43.

HALEAKALA SOUTHWEST RIFT
GEOTHERMAL RESOURCE SUBZONE
AS ADOPTED
Island of Maui

Figure 44

STATUS OF GEOTHERMAL RESOURCE SUBZONES IN HAWAII
(as of March 1, 1986)

SUBZONE	HALEAKALA SOUTHWEST RIFT ZONE, MAUI	KILAUEA LOWER EAST RIFT ZONE (Kapoho & Kamaili)	KILAUEA UPPER EAST RIFT ZONE	KILAUEA MIDDLE EAST RIFT ZONE	KILAUEA SOUTHWEST RIFT ZONE
DOWALD PUBLIC MEETINGS:	5/9/84-Kahului 5/30/84-Kahului 7/27/84-Ulupalakua	5/8/84-Hilo 5/29/84-Hilo 7/10/84-Puna 7/30/84-Pahoa	5/8/84-Hilo 5/29/84-Hilo 7/11/84-Volcano	3/13/85-Keaau 5/15/85-Pahoa	3/14/85-Pahala 5/16/85-Pahala
BLNR PUBLIC HEARINGS:	9/10/84-Kula	9/11/84-Pahoa 9/12/84-Hilo	9/12/84-Hilo 9/12/84-Hawaii Volcano National Park	9/26/85-Pahoa	9/26/85-Pahala
BLNR CONTESTED CASE HEARINGS:	NONE	NONE	12/12-20/84-Hilo	11/13-15/85-Hilo	Contested case hearing requested on proposed GRS (Figure 41), pending BLNR decision to grant hearing.
BLNR DECISION:	10/16/84-BLNR designates 4,108 acres as Haleakala southwest GRS.	10/16/84-BLNR designates 6,800 acres as Kapoho GRS & 5,405 acres as Kamaili GRS.	12/28/84-See text of BLNR decision in Appendix A.	12/20/85-BLNR designates 9,413 acres as GRS (Figure 40). See text of BLNR decision in Appendix A.	Not rendered.
SUBZONE STATUS:	Existing GRS as shown in Figure 43.	Existing GRS as as shown in 36.	Contingent GRS (Figure 38) to be voided if land exchange suggested by BLNR decision of 12/28/84 is consummated. BLNR decision appealed to Hawaii Supreme Court.	Existing GRS (Figure 40) designation appealed to the Hawaii Supreme Court.	A request for a contested case hearing regarding designation is pending before the BLNR.

DOWALD = Division of Water and Land Development, Department of Land and Natural Resources
BLNR = Board of Land and Natural Resources
GRS = Geothermal Resource Subzone

APPENDIX A

ACT 296 S.B. NO. 903

A Bill for an Act Relating to Geothermal Energy.

Be It Enacted by the Legislature of the State of Hawaii:

SECTION 1. The legislature finds that the development and exploration of Hawaii's geothermal resources is of statewide concern, and that this interest must be balanced with interests in preserving Hawaii's unique social and natural environment. The purpose of this Act is to provide a policy that will assist in the location of geothermal resources development in areas of the lowest potential environmental impact.

SECTION 2. Section 182-4, Hawaii Revised Statutes, is amended to read as follows:

"**§182-4 Mining leases on state lands.** (a) If any mineral is discovered or known to exist on state lands, any interested person may notify the board of land and natural resources of his desire to apply for a mining lease. The notice shall be accompanied by a fee of $100 together with a description of the land desired to be leased and the minerals involved and such information and maps as the board by regulation may prescribe. As soon as practicable thereafter, the board shall cause a notice to be published in a newspaper of general circulation in the county where the lands are located, at least once in each of three successive weeks, setting forth the description of the land, and the minerals desired to be leased. The board may hold the public auction of the mining lease within six months from the date of the first publication of notice or such further time as may be reasonably necessary. Whether or not the state land sought to be auctioned is then being utilized or put to some productive use, the board, after due notice of public hearing to all parties in interest, within six weeks from the date of the first publication of notice or such further time as may be reasonably necessary, shall determine whether the proposed mining operation or the existing or reasonably foreseeable future use of the land would be of greater benefit to the State. If the board determines that the existing or reasonably foreseeable future use would be of greater benefit to the State than the proposed mining use of the land, it shall disapprove the application for a mining lease of the land without putting the land to auction.

The board shall determine the area to be offered for lease and, after due notice of public hearing to all parties in interest, may modify the boundaries of the land areas. At least thirty days prior to the holding of any public auction, the board shall cause a notice to be published in a newspaper of general circulation in the State at least once in each of three successive weeks, setting forth the description of the land, the minerals to be leased, and the time and place of the auction. Bidders at the public auction may be required to bid on the amount of annual rental to be paid for the term of the mining lease based on an upset price fixed by the board, a royalty based on the gross proceeds or net profits, cash bonus, or any combination or other basis and under such terms and conditions as may be set by the board.

(b) Any provisions to the contrary notwithstanding, if the person who discovers the mineral discovers it as a result of exploration permitted under section 182-6, and if that person bids at the public auction on the mining lease for the right to mine the discovered mineral and is unsuccessful in obtaining such lease, that person shall be reimbursed by the person submitting the highest bid at public auction for the direct or indirect costs incurred in the exploration of the land, excluding salaries, attorney fee's and legal expenses. The department shall have the authority to review and approve all expenses and costs that may be reimbursed."

SECTION 3. Chapter 205, Hawaii Revised Statutes, is amended by adding new sections to be appropriately designated and to read as follows:

"**§205- Geothermal resource subzones.** (a) Geothermal resource subzones may be designated within each of the land use districts established under section 205-2. Only those areas designated as geothermal resource subzones may be utilized for the exploration, development, production, and distribution of electrical energy from geothermal sources, in addition to those uses permitted in each land district under this chapter.

(b) The board of land and natural resources shall have the responsibility for designating areas as geothermal resource subzones as provided under section 205- The designation of geothermal resource subzones shall be governed exclusively by this section and section 205- , except as provided therein. The board shall adopt, amend, or repeal rules related to its authority to designate and regulate the use of geothermal resource subzones in the manner provided under chapter 91.

The authority of the board to designate geothermal resource subzones shall be an exception to those provisions of this chapter and of section 46-4 authorizing the land use commission and the counties to establish and modify land use districts and to regulate uses therein.

(c) The use of an area for the exploration, development, production and/or distribution of electrical energy from geothermal sources within a geothermal resource subzone shall be governed by the board within the conservation district and by existing state and county statutes, ordinances, and rules within the agricultural, rural, and urban districts, except that no land use commission approval shall be required for the use of subzones. The board and/or appropriate county agency shall, upon request, conduct a contested case hearing pursuant to chapter 91 prior to the issuance of a geothermal resource permit relating to the exploration, development, production, and distribution of electrical energy from geothermal resources. The standard for determining the weight of the evidence in a contested case proceeding shall be by a preponderance of evidence. Chapters 183, 205A, 226, and 343 shall apply as appropriate.

§205- Designation of areas as geothermal resource subzones. (a) Beginning in 1983, the board of land and natural resources shall conduct a county-by-county assessment of areas with geothermal potential for the purpose of designating geothermal resource subzones. This assessment shall be revised or updated at the discretion of the board, but at least once each five years beginning in 1988. Any property owner or person with an interest in real property wishing to have an area designated as a geothermal resource subzone may submit a petition for a geothermal resource subzone designation in the form and manner established by rules and regulations adopted by the board. An environmental impact statement as defined under chapter 343 shall not be required for the assessment of areas under this section.

(b) The board's assessment of each potential geothermal resource subzone area shall examine factors to include, but not be limited to:

(1) The area's potential for the production of geothermal energy;
(2) The prospects for the utilization of geothermal energy in the area;
(3) The geologic hazards that potential geothermal projects would encounter;
(4) Social and environmental impacts;
(5) The compatibility of geothermal development and potential related industries with present uses of surrounding land and those uses permitted under the general plan or land use policies of the county in which the area is located;

(6) The potential economic benefits to be derived from geothermal development and potential related industries; and

(7) The compatibility of geothermal development and potential related industries with the uses permitted under sections 183-41 and 205-2, where the area falls within a conservation district.

In addition, the board shall consider, if applicable, objectives, policies and guidelines set forth in part I of chapter 205A, and the provisions of chapter 226.

(c) Methods for assessing the factors in subsection (b) shall be left to the discretion of the board and may be based on currently available public information.

(d) After the board has completed a county-by-county assessment of all areas with geothermal potential or after any subsequent update or review, the board shall compare all areas showing geothermal potential within each county, and shall propose areas for potential designation as geothermal resource subzones based upon a preliminary finding that the areas are those sites which best demonstrate an acceptable balance between the factors set forth in subsection (b). Once such a proposal is made, the board shall conduct public hearings pursuant to this subsection, notwithstanding any contrary provision related to public hearing procedures.

(1) Hearings shall be held at locations which are in close proximity to those areas proposed for designation. A public notice of hearing, including a description of the proposed areas, an invitation for public comment, and a statement of the date, time, and place where persons may be heard shall be published and mailed no less than twenty days before the hearing. The notice shall be published on three separate days in a newspaper of general circulation state-wide and in the county in which the hearing is to be held. Copies of the notice shall be mailed to the department of planning and economic development, and the planning commission and planning department of the county in which the proposed areas are located.

(2) The hearing shall be held before the board, and the authority to conduct hearings shall not be delegated to any agent or representative of the board. All persons and agencies shall be afforded the opportunity to submit data, views, and arguments either orally or in writing. The department of planning and economic development and the county planning department shall be permitted to appear at every hearing and make recommendations concerning each proposal by the board.

(3) At the close of the hearing, the board may designate areas as geothermal resource subzones or announce the date on which it will render its decision. The board may designate areas as a geothermal resource subzones only upon finding that the areas are those sites which best demonstrate an acceptable balance between the factors set forth in subsection (b). Upon request, the board shall issue a concise statement of its findings and the principal reasons for its decision to designate a particular area.

(e) The designation of any geothermal resource subzone may be withdrawn by the board of land and natural resources after proceedings conducted pursuant to the provisions of chapter 91. The board shall withdraw a designation only upon finding by a preponderance of the evidence that the area is no longer suited for designation, provided that the designation shall not be withdrawn for areas in which active exploration, development, production or distribution of electrical energy from geothermal sources is taking place.

(f) This Act shall not apply to any active exploration, development or production of electrical energy from geothermal sources taking place on the effective date of the Act, provided that any expansion of such activities shall be carried out in compliance with its provisions."

SECTION 4. Statutory material to be repealed is bracketed. New material is underscored.[1]

SECTION 5. If any provision of this Act, or the application thereof to any person or circumstance is held invalid, the invalidity does not affect other provisions or applications of the Act which can be given effect without the invalid provision or application, and to this end the provisions of this Act are severable.

SECTION 6. This Act shall take effect upon its approval.

(Approved June 14, 1983.)

Note

1. No bracketed material. Edited pursuant to HRS §23G-16.5.

A Bill for an Act Relating to Geothermal Energy.

Be It Enacted by the Legislature of the State of Hawaii:

SECTION 1. The legislature finds that the rights of lessees holding geothermal mining leases issued by the state or geothermal developers holding exploratory and/or development permits from either the state or county government need to be clarified. The legislature finds that the respective roles of the state and county governments in connection with the control of geothermal development within geothermal resource subzones need to be clarified also. The purpose of this Act is to provide such further clarification.

SECTION 2. Section 205-5.1, Hawaii Revised Statutes, is amended to read as follows:

"[[ ]§205-5.1[ ]] **Geothermal resource subzones.** (a) Geothermal resource subzones may be designated within [each of] the urban, rural, agricultural and conservation land use districts established under section 205-2. Only those areas designated as geothermal resource subzones may be utilized for [the exploration, development, production, and distribution of electrical energy from geothermal sources,] geothermal development activities in addition to those uses permitted in each land use district under this chapter. Geothermal development activities may be permitted within urban, rural, agricultural, and conservation land use districts in accordance with this chapter. "Geothermal development activities" means the exploration, development or production of electrical energy from geothermal resources.

(b) The board of land and natural resources shall have the responsibility for designating areas as geothermal resource subzones as provided under section 205-5.2[.]; except that the total area within an agricultural district which is the subject of a geothermal mining lease approved by the board of land and natural resources, any part or all of which area is the subject of a special use permit issued by the county for geothermal development activities, on or before the effective date of this Act is hereby designated as a geothermal resource subzone for the duration of the lease. The designation of geothermal resource subzones shall be governed exclusively by this section and section 205-5.2, except as provided therein. The board shall adopt, amend, or repeal rules related to its authority to designate and regulate the use of geothermal resource subzones in the manner provided under chapter 91.

The authority of the board to designate geothermal resource subzones shall be an exception to those provisions of this chapter and of section 46-4 authorizing the land use commission and the counties to establish and modify land use districts and to regulate uses therein. The provisions of this section shall not abrogate nor supersede the provisions of chapters 182 and 183.

(c) The use of an area for [the exploration,] geothermal development[, production and/or distribution of electrical energy from geothermal sources] activities within a geothermal resource subzone shall be governed by the board within the conservation district and, except as herein provided, by [existing] state and county statutes, ordinances, and rules not inconsistent herewith within [the] agricultural, rural, and urban districts, except that no land use commission approval or special use permit procedures under section 205-6 shall be required for the use of such subzones. [The board and/or appropriate county agency shall, upon request, conduct a contested case hearing pursuant to chapter 91 prior to the issuance of a geothermal resource permit relating to the exploration, development, production, and distribution of electrical energy from geothermal resources. The standard for determining the weight of the evidence in a contested case proceeding shall be by a preponderance of evidence.] In the absence of provisions in the county general plan and zoning ordinances specifically relating to the use and location of geothermal development activities in an agricultural, rural, or urban district, the appropriate county authority may issue a geothermal resource permit to allow geothermal development activities. "Appropriate county authority" means the county planning commission unless some other agency or body is designated by ordinance of the county council. Such uses as are permitted by county general plan and zoning ordinances, by the appropriate county authority, shall be deemed to be reasonable and to promote the effectiveness and objectives of this chapter. Chapters 177, 178, 182, 183, 205A, 226, 342, and 343 shall apply as appropriate. If provisions in the county general plan and zoning ordinances specifically relate to the use and location of geothermal development activities in an agricultural, rural, or urban district, the provisions shall require the appropriate county authority to conduct a public hearing and, upon appropriate request, a contested case hearing pursuant to chapter 91, on any application for a geothermal resource permit to determine whether the use is in conformity with the criteria specified in section 205-5.1(e) for granting geothermal resource permits.

(d) If geothermal development activities are proposed within a conservation district, then, after receipt of a properly filed and completed application, the board of land and natural resources shall conduct a public hearing and, upon appropriate request, a contested case hearing pursuant to chapter 91 to determine whether, pursuant to board regulations, a conservation district use permit shall be granted to authorize the geothermal development activities described in the application.

(e) If geothermal development activities are proposed within agricultural, rural, or urban districts and such proposed activities are not permitted uses pursuant to county general plan and zoning ordinances, then after receipt of a properly filed and completed application, the appropriate county authority shall conduct a public hearing and, upon appropriate request, a contested case hearing pursuant to chapter 91 to determine whether a geothermal resource permit shall be granted to authorize the geothermal development activities described in the application. The appropriate county authority shall grant a geothermal resource permit if it finds that applicant has demonstrated by a preponderance of the evidence that:

(1) The desired uses would not have unreasonable adverse health, environmental, or socio-economic effects on residents or surrounding property; and

(2) The desired uses would not unreasonably burden public agencies to provide roads and streets, sewers, water, drainage, school improvements, and police and fire protection; and

(3) That there are reasonable measures available to mitigate the unreasonable adverse effects or burdens referred to above.

Unless there is a mutual agreement to extend, a decision shall be made on the application by the appropriate county authority within six months of the date a complete application was filed; provided that if a contested case hearing is held, the final permit decision shall be made within nine months of the date a complete application was filed."

SECTION 3. Notwithstanding the provisions of section 205-5.2, Hawaii Revised Statutes, regarding county-by-county assessment of areas with geothermal potential, the board of land and natural resources shall separately conduct an assessment of the area described on maps attached to the board of land and natural resources decision and order, dated February 25, 1983, which was the subject of a conservation district use permit. The assessment shall be in accordance with all provisions of Act 296, Session Laws of Hawaii 1983, regarding the procedures and standards for designation of an area as a geothermal resource subzone. The board of land and natural resources shall make its determination regarding the designation of all or any portion of the abovementioned area, as a geothermal resource subzone, on or before December 31, 1984.

SECTION 4. If any provision of this Act or the application thereof to any person or circumstance is held invalid, the invalidity does not affect other provisions or applications of the Act which can be given effect without the invalid provision or application, and to this end the provisions of this Act are severable.

SECTION 5. Statutory material to be repealed is bracketed. New material is underscored.

SECTION 6. This Act shall take effect upon its approval.

(Approved May 25, 1984.)

Decision and Order of the Board of Land and Natural Resources on the Proposed Geothermal Resource Subzone at Kahauale'a, Hawaii

Pursuant to Act 296, SLH 1983, Act 151, SLH 1984 and Title 13, Chapter 184 of the administrative rules of the Department of Land and Natural Resources, the Board of Land and Natural Resources has been assessing potential geothermal resource areas throughout the State. Under Act 151, SLH 1984, two areas in lower Puna, Hawaii, with existing wells were grandfathered as geothermal resource subzones. On November 16, 1984, this Board designated two additional subzone areas in lower Puna on the Island of Hawaii and one on the southwest rift of Haleakala, Maui.

Today the Board is acting upon a proposal to designate a portion of land at Kahauale'a, Hawaii. In consideration of the widespread interest which this proposal generated, the Board in its discretion conducted a contested case hearing from December 12-20, 1984 in Hilo, Hawaii. Parties to those hearings submitted their proposed findings of fact and conclusions of law to the Board this past Monday, December 24, 1984.

Under Act 151, SLH 1984, the Board must make a determination by December 31, 1984 regarding the designation of all or any portion of the land which the Board approved in its Conservation District Use Permit of February 25, 1984. That decision allowed Campbell Estate to conduct limited exploration on approximately 800 acres of land in Kahauale'a. The Board has reviewed and considered the proposed findings of fact and conclusions of law submitted by the parties. In view of the statutory deadline and the brief time available to the Board since it received the proposed findings, the decision today will be rendered orally. A full written decision and order will follow at a later date.

I. The Board of Land and Natural Resources approves the designation of the area described in the Board's Decision and Order of February 25, 1983 containing approximately 800 acres of surface area as a geothermal resource subzone upon the occurrence of the following events and upon the following conditions:

1. The cessation of volcanic acitivity in, around, and near the area permitted by the Board's February 25, 1983 Decision and Order. The determination that eruptive activity constituting a geologic hazard has ceased shall be made by the Board upon evidence and testimony from professional geologists from the Hawaii Volcanoes Observatory and the U. S. Geological Survey. Other professional geologists with special experience in this particular geographic area may be heard at the Board's discretion.

2. No new activity associated with the permitted area shall be considered until after the determination is made that geologically hazardous and eruptive activity in, near, and around the permitted area has ceased as provided for above.

II. The State of Hawaii formally requests the Estate of James Campbell to investigate and consider a land exchange involving State owned land in Kilauea middle east rift zone and Campbell Estate's lands at Kahauale'a (excluding Tract 22).

If the State of Hawaii and Campbell Estate should later consummate a land exchange involving lands at Kahauale'a for State or other lands upon which geothermal activities may take place, then the geothermal subzone designation in this Decision and Order shall cease to exist and shall have no force or effect in law, notwithstanding any further requirement for a contested case hearing in HRS 205-5.2(3) or any other provision of law to the contrary.

III. The Board of Land and Natural Resources on its own motion hereby directs the Division of Water and Land Development (DOWALD) of the Department of Land and Natural Resources (DLNR) to immediately undertake and conduct an assessment of the Kilauea middle east rift zone in and adjacent to the Natural Area Reserve beginning on the western boundary of the Kamaili geothermal subzone as a potential geothermal resource subzone. Although this area had not previously been evaluated due to its classification as a Natural Area Reserve, the Board now believes that the area should be reviewed.

IV. If a) the assessment of the Kilauea middle east rift zone does not result in a designation as a geothermal resource subzone in this area; or b) a land exchange between the State of Hawaii and the Estate of James Campbell is not consummated then the remainder of the 5300 acres proposed by DOWALD as a geothermal resource subzone in Kahauale'a heretofore not designated by this Decision and Order shall be and is hereby ordered to be so designated as a geothermal resource subzone.

V. If the land exchange described above is consummated, the Board of Land and Natural Resources strongly urges the federal government and the National Park Service to immediately seek to acquire Tract 22 (as described on its Master Plan), which the State will not itself seek.

VI. If the exchange described above does occur, the entire 5300 acres within the proposed subzone (exclusive of Tract 22) shall be included within the lands acquired by the State of Hawaii from Campbell Estate and shall be eliminated from the proposed subzone.

Honolulu, Hawaii   December 28, 1984.

IT IS SO ORDERED.

By the Board of Land and Natural Resources

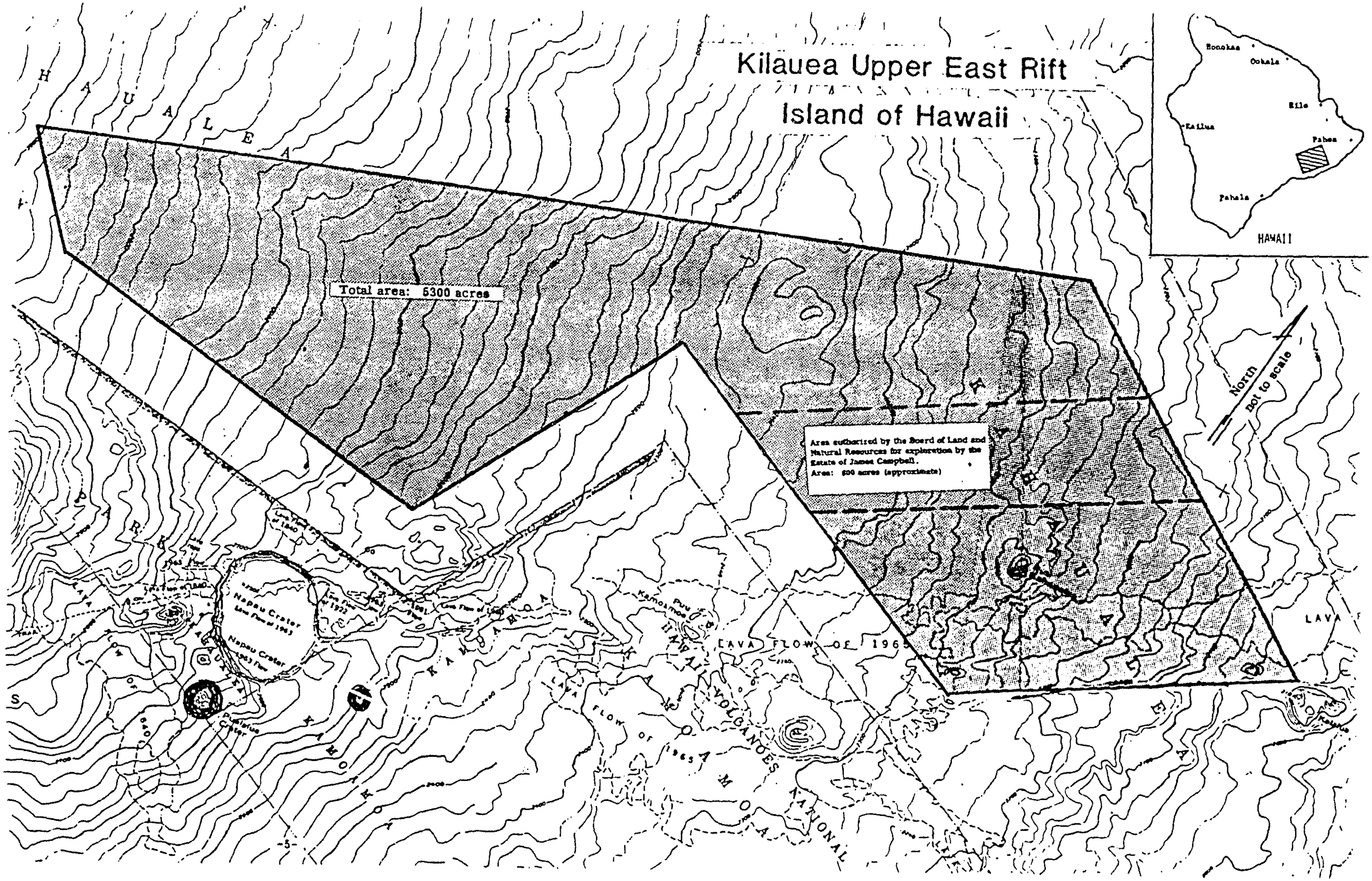
SUSUMU ONO, Chairperson
Board of Land and Natural Resources

MOSES KEALOHA

ROLAND HIGASHI

THOMAS YAGI

Decision and Order on the Proposed Geothermal
Resource Subzone at Kahauale'a, Hawaii.


Kilauea Upper East Rift
Island of Hawaii
Total area: 5300 acres
Area authorized by the Board of Land and Natural Resources for exploration by the Estate of James Campbell.
Area: 600 acres (approximate)
North
Not to scale
Honokaa
Ookala
Hilo
Kailua
Pahoa
Pahala
HAWAII
HAUALEA
PARK
KAMOAMOA
KAHAUALEA
LAVA FLOW OF 1965
HAWAII VOLCANOES NATIONAL
Napau Crater
Puu Kamoamoa
Pauahi Crater
LAVA

VII <u>Decision and Order</u> (Kilauea Middle East Rift GRS)

The Board of Land and Natural Resources after reviewing and weighing the evidence and testimony presented in this matter and pursuant to its duty under HRS 205-5.2, has made Findings of Fact and Conclusions of Law which shall be issued separately. In weighing the relative merits of each factor, the Board has established boundaries for a geothermal resource subzone in the Kilauea middle east rift zone, Puna, Hawaii, shown and incorporated by reference on the attached map.

This subzone shall be in substitution for the geothermal resource subzone in the Kilauea upper east rift in accordance with the provisions in the Board's Decision and Order of December 28, 1984.

THEREFORE, IT IS HEREBY ORDERED THAT: the area shown on the attached map which contains approximately 8447.2 acres is hereby designated as a geothermal resource subzone.

Dated: Kona, Hawaii, December 20, 1985.

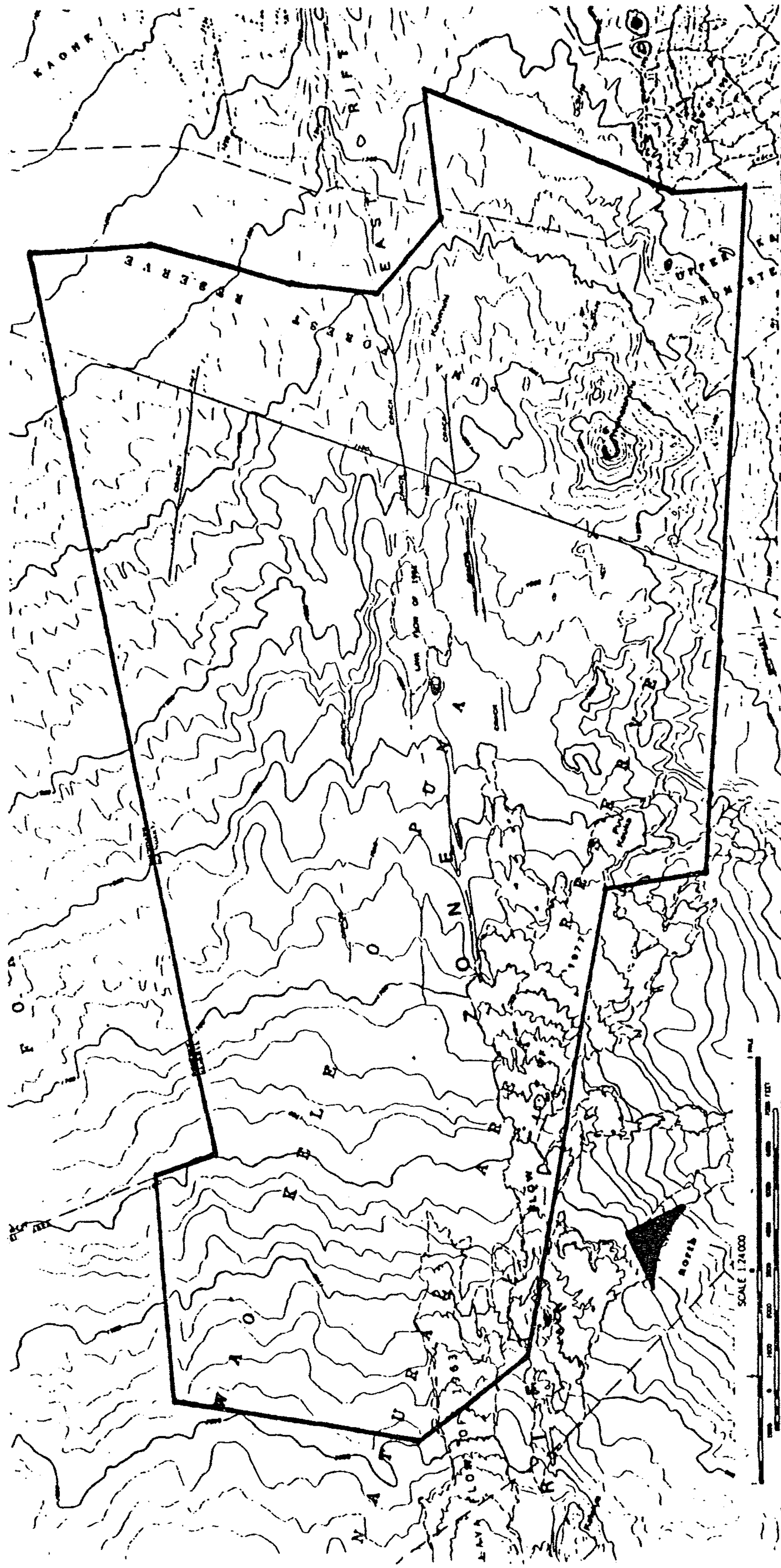
BOARD OF LAND AND NATURAL RESOURCES

SUSUMU ONO, Chairperson

J. DOUGLAS ING, Vice Chairperson

MOSES KEALOHA

ROLAND HIGASHI



KILAUEA MIDDLE EAST RIFT GEOTHERMAL RESOURCE SUBZONE
(APPROXIMATLEY 9,014 ACRES)

APPENDIX B

Geothermal Exploration Techniques

GEOTHERMAL EXPLORATION TECHNIQUES

The following is a simplified and condensed description of geothermal exploration techniques drawn from references listed at the end of this section.

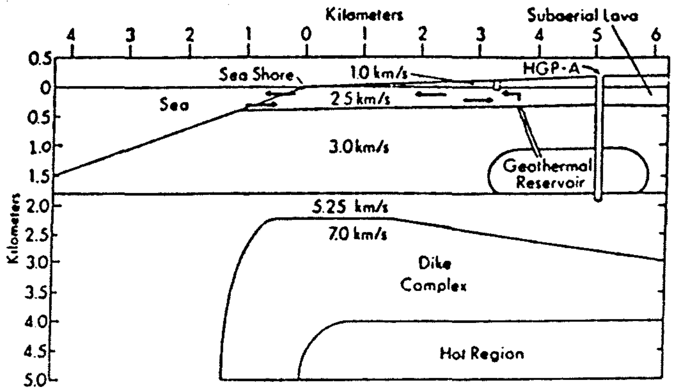
Surface Geology

The easily identified surface structure of island volcanic systems can quickly focus geothermal exploration to a broad area. A geothermal reservoir, the exploration target, usually consists of a permeable rock zone where very hot water is confined by hydrostatic pressure, low-permeability cap rock, or a self-sealing chemical process (see Figure 1). The ultimate heat source for a potential geothermal reservoir is the cooling magma within the caldera or the various volcanic rift zones where extensively fractured rock serves as a conduit for liquid magma (see Figure 2). Broad, gently sloping ridges radiating from the main volcanic caldera are indications of subsurface rift zones originating from the central magma chamber underlying the caldera. Other volcanic surface features include fumaroles (vents for hot volcanic gases), thermal springs, and cinder or spatter cones. To gain a better understanding of subsurface structures; geologic, geochemical, and geophysical techniques are usually integrated when exploring for geothermal reservoirs. While these techniques can infer geothermal resources, the only sure way to confirm the existence and potential production of a reservoir is to drill and test a well.

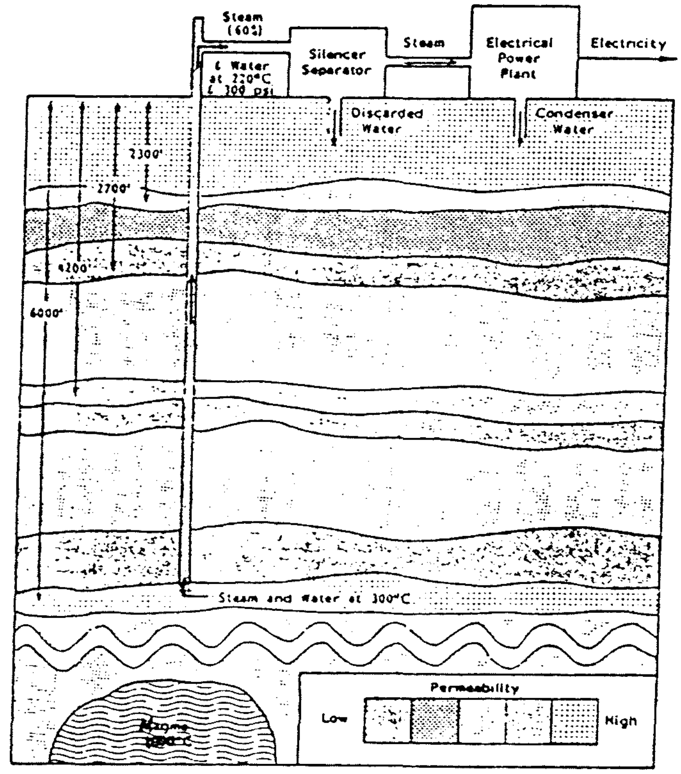
Thermal Surveys

Well temperature profiles and infrared imagery have been used in Hawaii to directly locate zones of near-surface heat which may be indicative of a nearby deeper geothermal resource. Precise interpretation is difficult as ascending geothermal fluids may take unpredictable paths.

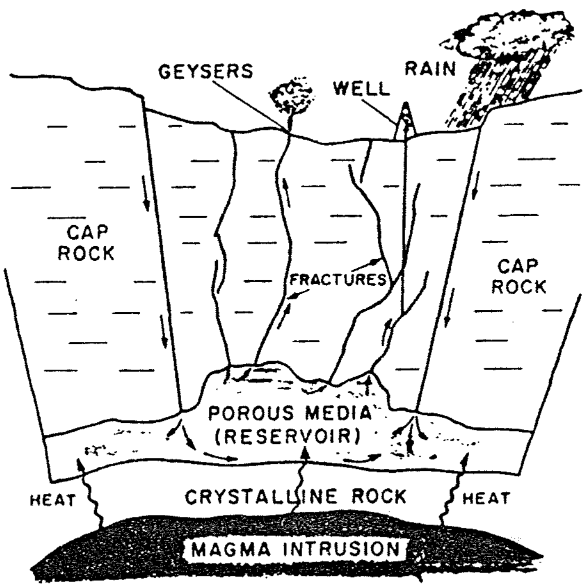
Well temperature data can be obtained by lowering a thermistor into the well hole. The electric resistance of the thermistor varies substantially with changes in ambient temperature allowing for a very accurate temperature reading. Several temperature variation factors must



1A



1B

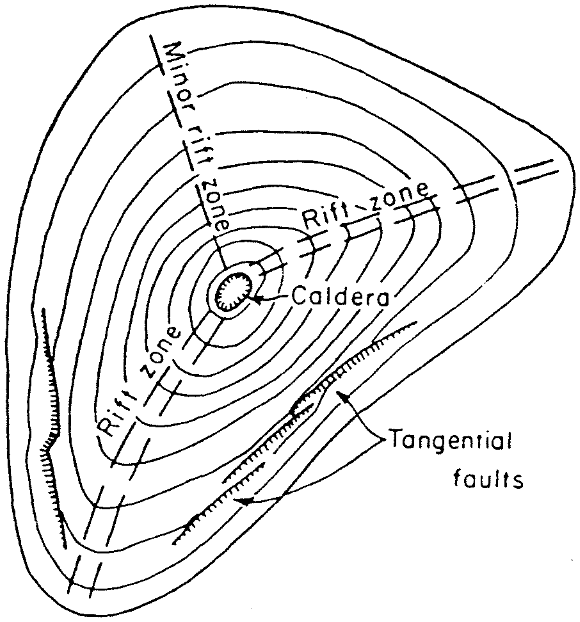


1C

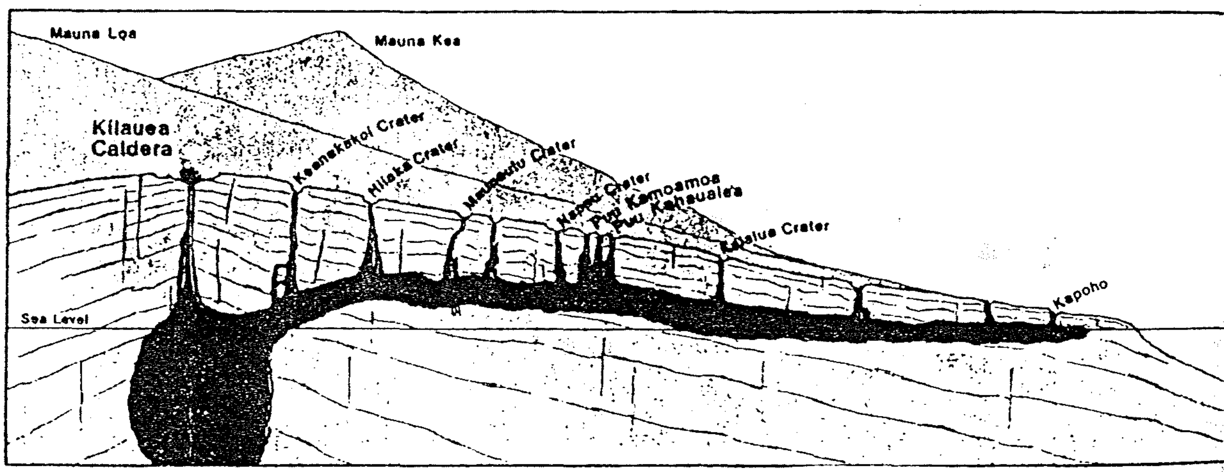
Figure 1A. Lateral view of geothermal reservoir and surrounding rock density structures in the vicinity of HGP-A. Seismic P-wave velocites are shown (Furumoto, 1978).

Figure 1B. Lateral view of rock permeability layers in vicinity of HGP-A (Goodman, et al, 1980).

Figure 1C. Generalized depection of a geothermal reservoir (Keslin, 1980).



2A



2B

Figure 2A Top view of a typical shield volcano, showing the caldera, radiating rift zones, and tangential faults (Macdonald, et al, 1983).

Figure 2B Lateral view of Kilauea volcanic complex, showing caldera, central magma chamber, rift zone, and Chain-of-Craters (Honolulu Advertiser, Nov. 7, 1983).

be considered when interpreting well temperature data. Infrequently pumped wells are usually selected to insure thermal equilibrium between the water and surrounding rock structure. Consideration must be given to temperature gradients occurring within the well bore which tend to cause convecting cells of water with vertical dimensions several times larger than the hole diameter. Daily and seasonal air temperature variations (quite minimal in Hawaii) can influence water temperatures. Other factors which may also influence groundwater temperature include: the source altitude of recharge fluids in an aquifer, frictional flow, mixing with irrigation water, mixing with saline water, and the targeted factor--geothermal activity. If conditions are right, a well temperature gradient can be established along the length of the well which may be extrapolated to infer temperatures in deeper areas.

Infrared surveys can accurately identify near surface warm water discharges and above ambient ground temperatures. The surveys are usually airborne and conducted at night to provide a greater thermal contrast. The infrared radiation associated with thermal areas can be detected either by special photographic techniques or by using an infrared scanner. The latter yields digital readings which can be reduced to an image with the aid of a computer. Figure 3 is an example of an infrared survey conducted over the island of Hawaii. Infrared surveys can be misinterpreted. Sometimes false positives (anomalous areas of heat) can be inferred where there are unusually high rates of solar insolation or high heat capacities of surface rocks. False negatives can be inferred where cold surface waters overlie deeper thermal fluids.

Groundwater Chemistry, Generally

Certain minerals tend to dissolve out of rocks at high temperatures and other minerals may form when hot water circulates through a geothermal reservoir. As a result, thermal groundwaters can undergo substantial chemical alteration in contrast to nearby cooler groundwaters. Some minerals that respond to warmer groundwater are silica, sodium, potassium, calcium and magnesium. Chemical alteration standards that would indicate a thermally anomalous region are somewhat specific to each site and are quite dependent on rock type and groundwater-route

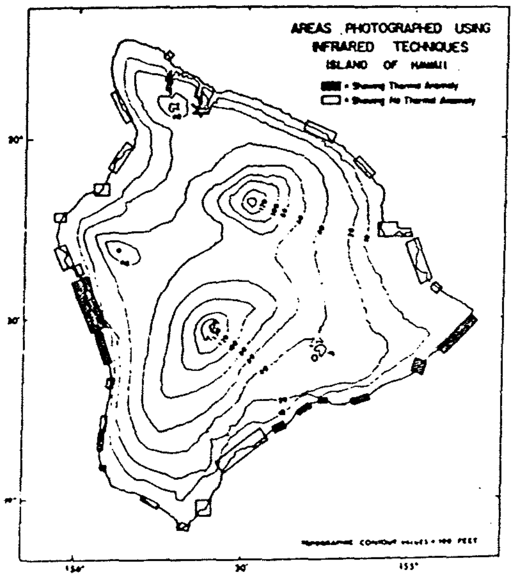


Figure 3. Infrared survey on island of Hawaii (in Thomas, 1979; from Fischer, et al, 1966).

variations in the hydrogeological system. However, some generalizations can be made.

Silica Tests

Two basic screening tests used in locating geothermally altered groundwaters involve temperature and silica concentrations. Concentrations of silica greater than 55 parts per million (ppm) for Oahu (due to human interference with the water cycle) and 30 ppm for other islands are generally considered anomalous. However, because of possible ambiguity in interpreting test data, another test, utilizing the chloride/magnesium (Cl/Mg) ratio in shallow groundwaters has been used to determine geothermal areas with more certainty.

Well test data having unusually high temperature readings or high silica concentrations may indicate a potential geothermal reservoir which can warrant further Cl/Mg ratio tests. Factors controlling the degree of silica concentration include water residence time, rainfall, agricultural activity, and variance in rock composition.

Chloride/Magnesium Ratios

The Cl/Mg ratio in groundwater is a good heat indicator since chloride content is unaffected by heat whereas magnesium is greatly depleted by thermal activity. Heat will usually increase the Cl/Mg ratio.

Depicted in figure 4, as rainwater travels to the basal (fresh) water table the Cl/Mg ratio varies from approximately 7/1 or greater for rainwater (small concentrations of sea salt), to about 2/1 in dike-impounded high-level water and 3/1 in streams (due to Mg dissolving into cool groundwater as it percolates through ground minerals). Sea water has a 15/1 ratio. When fresh water mixes with sea water, the Cl/Mg ratio can vary from 2 to 15 in the transition zone. Fresh water and sea water can be clearly distinguished since salt concentrations are significantly higher in brackish and sea water.

The basal lens aquifer (shown in Figure 5) may be distorted in areas where geothermal heat is transferred to underlying sea water. Normally island basal water floats on top of denser sea water in a lens-shaped configuration. However, if sea water is geothermally heated (e.g. in Kilauea's Lower East Rift Zone) its density is reduced causing it to mix more readily with overlying fresh water. In areas where water is less than 30% sea water, a Cl/Mg ratio greater than 15 may indicate a nearby geothermal reservoir; since heat will cause Mg to precipitate out of the water. If testing results indicate an unusually high Cl/Mg ratio, closer examination may be warranted to determine the cause of the anomaly.

Trace Element Chemistry

Analyses of soil gases for mercury, helium, radon, and other trace elements may indicate leakage of deep geothermal fluids and possibly the presence of hidden fracturing in nearby rock structures. However, soil type must be considered as it can significantly affect the degree of chemical concentration. Anomalous concentrations of these elements are mapped to designate potential geothermal areas.

Radon and helium are gaseous products from the decay of naturally occurring radioactive elements present in all rocks and soils. High concentrations of these elements in soil-gas are usually indicative of subsurface fracturing and may identify areas where geothermal fluids are migrating into shallow aquifers and are releasing dissolved gases.

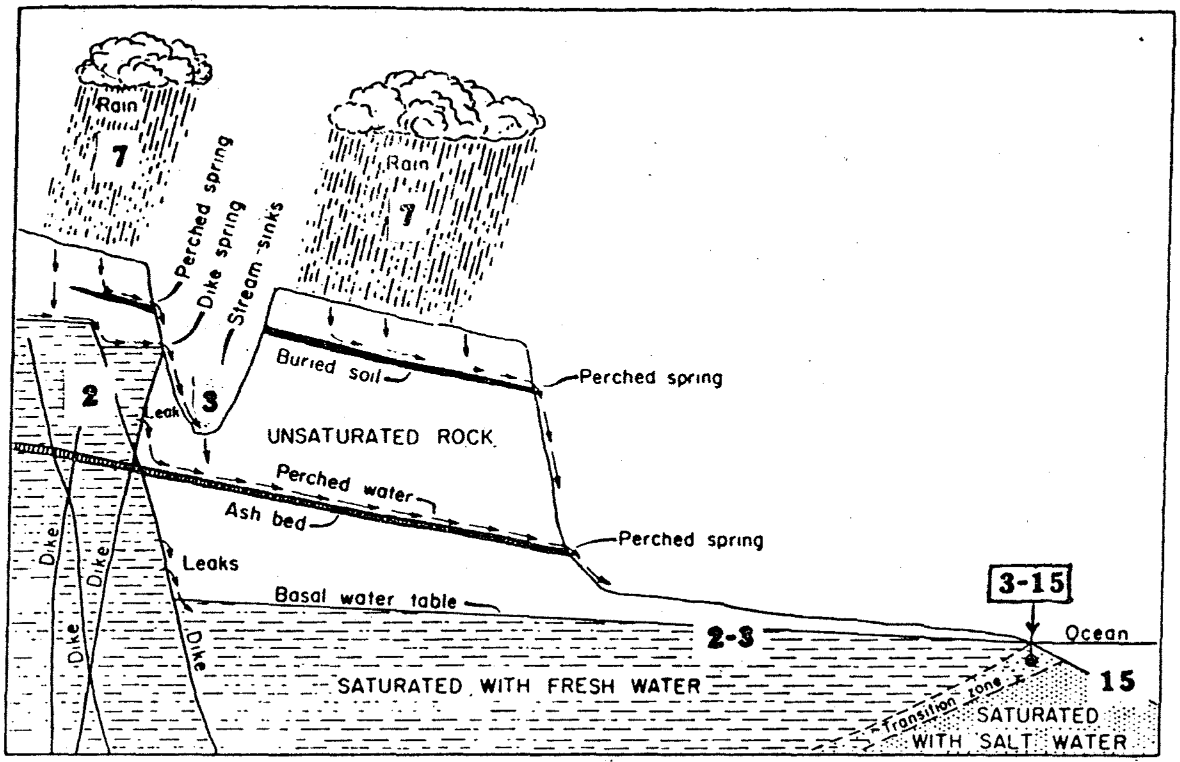


Figure 4. Diagram showing usual Cl/Mg ratios in rain water, perched water, streams, the basal water table, and in sea water (modified from Macdonald, et al, 1983).

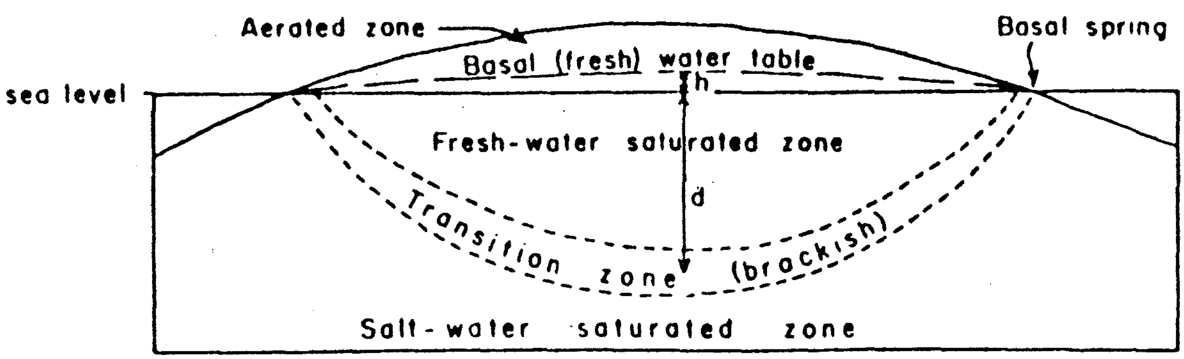


Figure 5. Normal island basal lens configuration (Macdonald, et al, 1983).

Elemental mercury is a slightly volatile element that has a strongly temperature-dependent vapor pressure; and thus tends to migrate away from thermal areas into cooler areas. Mercury concentrations tend to form "halos" around thermal springs or fumaroles.

Seismic Surveys

In Hawaii, geothermal reservoirs are most likely to be associated with rift zones which branch from the central magma chamber of a volcano. Seismic information is useful in determining the location, density, and structure of rift zones and whether they contain still molten or solidified magma. Although these rift zones are the source of geothermal heat, seismic data alone cannot determine the magnitude of heat nor the existence of a useable geothermal reservoir. Other geophysical and geochemical information must be considered to gain a better understanding of potential geothermal reservoirs.

As viscous magma intrudes into the earth's surface it puts stress on surrounding rock formations. As stress increases, the rock becomes strained, may deform, and may eventually fracture releasing heat and elastic energy in the form of shock waves; producing what is generally known as a volcanic earthquake. The exact site of the fracture is the focus or hypocenter. The point directly above on the surface is the epicenter. Most volcanic earthquakes are mild and require sensitive instruments for detection.

There are three basic types of seismic shock waves: P (primary) waves, S (secondary or shear) waves, and surface waves. The P waves are the fastest and move by alternately compressing and pulling the wave medium (e.g. rock) away from the hypocenter. S waves move in a shearing (side to side) motion at right angles to the direction of travel. Liquids (e.g. molten magma) cannot support S waves and can readily be identified by the absence of S waves. S waves travel about one-fourth to one-half the speed of the P wave. This relationship is known as Poisson's ratio. Surface waves, the slowest wave, travel in a circular rippling motion outward from the epicenter. Most seismic analyses utilize P waves which are the easiest to identify. By comparing speed and direction of direct, reflected, and refracted seismic waves (see Figure 6)

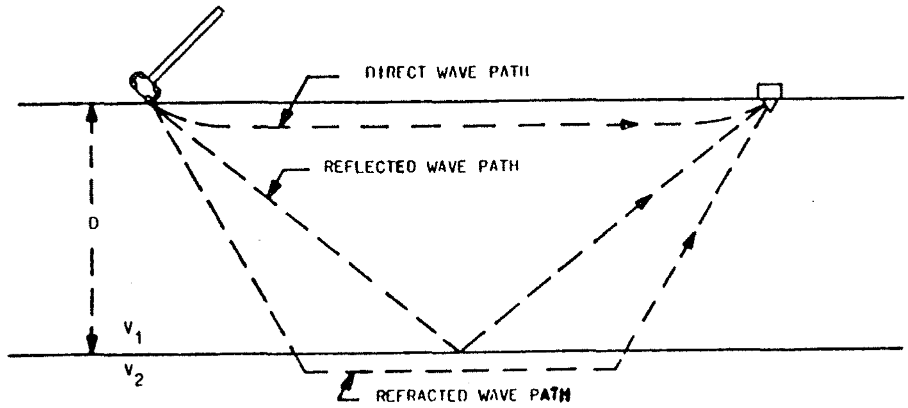


Figure 6. Direct, reflected, and refracted waves traveling through two rock strata of difference density (Mooney, 1973).

the structure and density of various rock layers or volcanic intrusions can be determined. Refraction studies are best suited for determining horizontal structures of dense bodies (e.g. rift zones).

Seismic surveys can be defined as either passive or active. Passive surveys utilize data from natural shock waves produced by the movement of volcanic intrusions to determine the structure of a rift zone and any attendant fracturing. Active surveys utilize shock waves induced by a detonated explosion to determine density and fracturing in underlying rock strata.

The frequency and magnitude of the various seismic waves is measured by a seismograph. It records data on a seismogram which can be interpreted to define rock density and structures usually associated with geothermal resources.

Gravity Surveys

Gravity surveys are of assistance in identifying subsurface rock structures by detecting variations in rock density. These surveys do not measure the absolute gravitational pull of the earth but rather contrast local density variations or anomalies. Data is collected by sensitive gravity instruments in air or, for more localized readings, on land.

In identifying a targeted structure such as a rift zone, raw data must be corrected to account for gravity variations due to latitude, elevation, and terrain. Gravity data alone cannot precisely determine the nature and position of subsurface structures even though density values for most rock types are known (e.g. basalt 2.9 g/cm^3). Data interpretation complications occur because gravity observations detect the sum of the gravitational attractions of all underlying rock layers. Separating the data into component structures is very difficult. An almost infinite number of subsurface structures can combine to result in an identical gravity reading. Other considerations, such as the presence of water or air in porous rock, can also significantly affect density. Therefore, integration of other geologic studies is very helpful in deducing the nature of subsurface structures. Gravity data is quite useful in confirming or narrowing other structural assessments (e.g. seismic, magnetic, and surface geology). In Hawaii, gravity surveys have helped to identify volcanic caulderas and attendant rift zone structures.

Magnetic Surveys

Magnetic surveys are useful in determining the structure and, at times, the temperature of volcanic rift zones and adjacent rocks. Magnetic surveys focus on local variations in magnetic properties of subsurface rock formations.

The ultimate cause of local magnetic anomalies is the planetary magnetic force field produced by the earth. It is believed that liquid iron within the earth's core rotates slowly relative to the solid mantle which surrounds it. This generates electric currents within the core which induce the magnetic field which surrounds the earth (see Figure 7). When a subsurface magma chamber cools (e.g. Kilauea's Lower East Rift Zone), mineral particles of magentite within the magma align in a direction parallel to the lines of force in the earth's magnetic field. When magma cools below the Curie point (about 580°C) the magnetic field generated by the magnetite increases drastically and can be easily detected at the surface.

Magnetic surveys in Hawaii have assumed that the hottest parts (those above the Curie temperature) of a rift zone , i.e. where magentism has not set, are least magnetic and represented by magnetic lows. As cooler (below the Curie temperature) areas of the rift zone are surveyed,

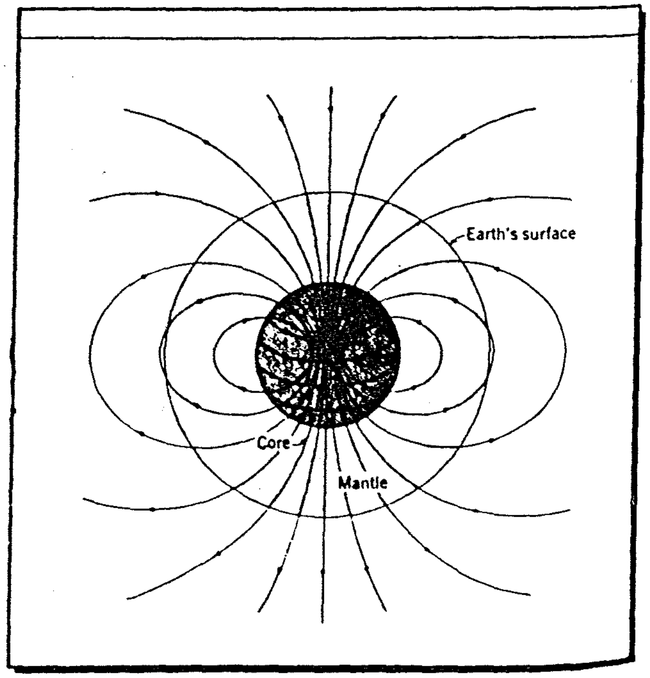


Figure 7. Electric currents, shown as lines on the earth's cove, are believed capable of producing the earth's magnetic field (Strahler, 1981).

magnetic highs are encountered due to the set magnetic alignment of magnitite. In comparison, a gravity survey is likely to register a "high" over the hottest part of the rift zone as density is greatest there.

Airborne magnetic surveys offer extensive and continuous coverage of deeper subsurface features. More costly land surveys are more precise, site specific, and yield information primarily about near surface features. Various corrections (e.g. diurnal variation correction) are made to standardize raw data. Magnetic storms and nearby cultural activities and fixtures should be avoided or taken into account.

Interpretation of magnetic data can be difficult since, as with gravity surveys, the composite effects of all underlying features are measured. Integration of magnetic surveys with other geologic surveys can reduce the potential for ambiguous interpretations.

Electrical Resistivity Surveys

Generally. Electrical resistivity surveys are attractive exploration tools since geothermal reservoir rock can be a relatively good conductor of electricity. By correctly interpreting data from the various rock resistivity surveys certain rock structures and properties can generally be determined at varying depths. Electrical resistivity, or inverse conductivity, will govern the amount of current actually passing through a rock structure. Dry rock is usually highly resistive to current. However the following factors can significantly reduce resistivity:

-- fresh-water saturated rock is significantly less resistive than dry rock;

-- saline-water saturated rock is significantly less resistive than fresh-water sasturated rock;

-- geothermally heated rock stimulates electron flow and reduces resistivity;

-- high rock porosity with water saturation reduces resistivity (deeper, pressurized rock is generally less porous); and

-- geothermal chemical alteration in rock reduces resistivity.

These factors must be carefully considered when data indicate an anomalously low resistivity.

Both direct current and inductive type resistivity surveys (described below) have been used in Hawaii to attain high rock structure definition. Due to the inherent sensitivities and normally shallow penetration of direct current methods, they are best suited to define resistivity within the upper layers of rock structures. Depending on the purpose of the survey, some resistivity interpretations can be graphed to provide a vertical profile or mapped to show horizontal structure.

Direct Current (DC) or Galvanic Type Resistivity Methods

The DC method (also known as the galvanic method) involves running electric current into the ground through source electrodes and detecting the resultant voltage with receiver electrodes at various locations (see Figure 8). As the distance between the source and receiver electrodes increases, depth penetration increases and the voltage received becomes weaker.

One particular type of electrode configuration used in DC surveys is the Schlumberger method (see Figure 9). Using this method, the electrodes are linearly spaced at progressively greater distances about a central pair of stationary, closely spaced, grounded voltage electrodes.

As current electrode spacing increases, depth penetration increases. The wire connecting the outer source electrodes generally varies from 3 to 1000 m. Rock resistivities can be interpreted from known current, measured voltage, and electrode spacing.

The dipole method of electrode configuration is shown in Figure 10. It is based on the same resistivity principles but different mathematical relationships are used to determine resistivity. The wire line connecting the source electrodes generally varies from 1 to 3 km, while the receiver line generally varies from 30 to 3000 m.

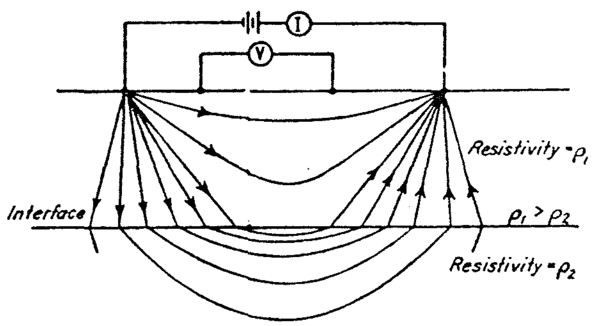


Figure 8.
DC electric flow pattern in rock beds of varying resistivities, where I=source current and V=voltage received (slightly modified from Dobrin, 1976).

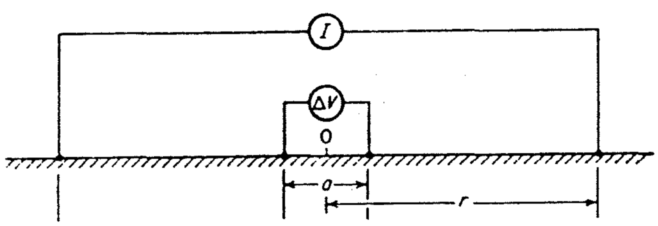


Figure 9.
The Schlumberger arrangement, where distance "a" and "r" may vary but infixed proportions to each other. If current (I) is fixed, measured voltage will vary with electrode spacing and rock resistivity (Dobrin, 1976).

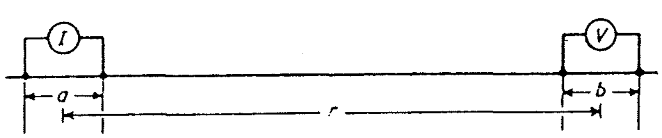


Figure 10.
Dipole electrode configuration (Dobrin, 1976).

Inductive Type Resistivity Methods

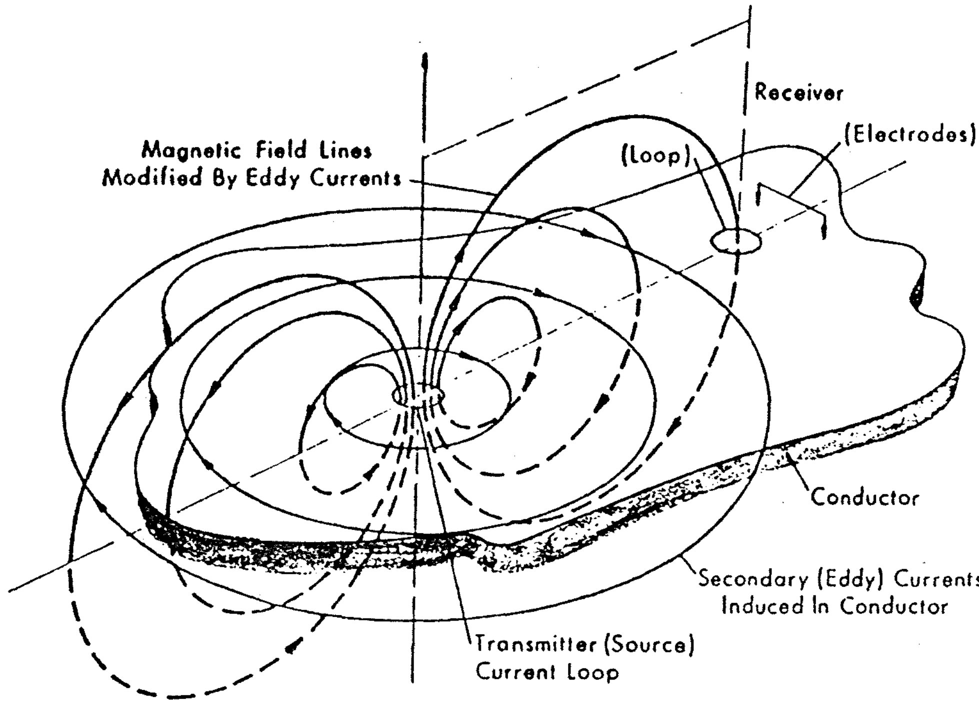
As with DC-galvanic type resistivity surveys, the objective in an inductive survey is to detect buried, conductive (low resistance) rock structures. Referring to Figure 11, the induction method generally involves pulsing a current through the source-transmitter at ground level which generates a primary electromagnetic (EM) field, somewhat similar to a radio wave. The primary EM field induces a secondary current within conductive rock structures below which, in turn, generate their own secondary EM field. This secondary EM field can be detected at ground level by a sensor-receiver. The source-transmitter is usually a large (about 1 km) grounded current line or loop. The secondary EM field is usually measured by a wire line, wire loop, or magnetometer.

Most inductive methods (e.g. the time-domain EM method) determine resistivity by shutting off or pulsing the primary current and monitoring the secondary EM waves for strength and rate of decay. EM waves emanating from rocks with lowest resistivity have greater strength and longer decay times.

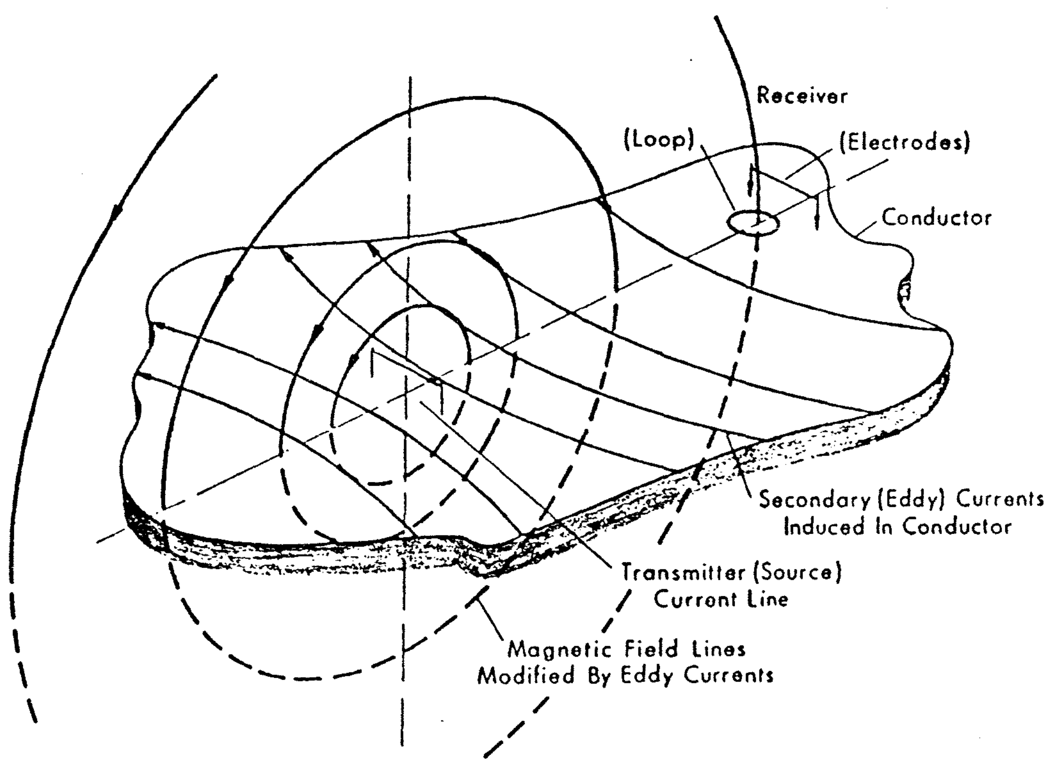
Inductive methods have an advantage over DC type methods in that deeper penetration can be achieved when using comparable amounts of current. Highly resistive rock structures, such as porous, gas-filled surface lava, will quickly dissipate electricity which is directly monitored in DC soundings; whereas the primary and secondary EM waves of an inductive survey have a greater ability to penetrate resistive rock. Depth penetration in an inductive survey increases by lowering the frequency of the primary EM field, with lower resistivity of underlying rock structure, and as the distance between the source and sensor increases.

Self-Potential (SP) Surveys

In Hawaii, SP anomalies have been associated with subsurface thermal anomalies at Kilauea Volcano. The precise reason for the SP anomalies is not well understood. However, it is thought to be associated with an electrokinetic phenomenon. In contrast to most electrical methods, no artificial power source is used. Instead, as thermal convection carries hot brackish fluids upward it causes a displacement of ions along the flow path which can be distinguished from the predominately laterally flowing



LOOP SOURCE WITH LOOP AND/OR ELECTRODES RECEIVER



LINE SOURCE WITH LOOP AND/OR ELECTRODES RECEIVER

Figure 11. Inductive survey systems. Qualitative schematic illustrating the relationships between magnetic fields and induced earth currents for various inductive source-receiver configurations on a uniform, horizontal conducting layer (Klein and Kauahikaua, 1975).

basal (fresh) waters. This can result in a significant electric potential gradient which can be measured by a millivoltmeter. Although SP surveys directly test potential gradients of shallow groundwaters, an SP anomaly may reflect hot water flowing through a permeable vertical fracture connected to a broad heat source at depth. However the precise location of the deep heat source cannot be identified with certainty. Conversely, some geothermal resources, e.g. those not having a fluid discharge to the surface, may not be detected by this method.

The usual SP detection method involves placing electrodes into the ground and "leap-frogging" them over the area to be surveyed. The electrodes are connected by cable to a millivoltmeter which indicates the electric potential gradient. As with other electrical methods, care must be taken to avoid or account for conductive mineral deposits and cultural fixtures (pipes, buildings, powerlines) and activities (irrigation, agricultural chemicals) as these could distort electrical patterns.

Several SP anomalies have been identified in the summit region and along the Lower East Rift Zone of Kilauea Volcano. However, deep exploratory geothermal wells drilled into these anomalies have not always encountered success; e.g. Ashida Well #1, where hot fluids were encountered at 2000 meters, but low permeability prevented flow rates needed for commercial production.

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APPENDIX C

Geothermal Technology

GEOTHERMAL TECHNOLOGY

GEOTHERMAL WELLS

Drilling Depth

In Hawaii, geothermal reservoirs are expected to occur 4,000-8,000 feet below sea level. The rotary drilling rigs likely to be used in Hawaii are rated for drilling to a maximum depth of about 16,000 feet. Some mainland oil-rigs can drill to 22,000 feet but are not considered economical when applied to geothermal development here. The basic elements of a rotary drilling rig are shown in figure 1.

Directional Drilling

A geothermal rig can drill a hole perpendicular to the ground surface or directional holes to almost any desired angle from ground surface. A moderate curve in the drill route can also be achieved. Directional drilling can reduce both environmental and economic costs by allowing multiple holes to be drilled from one drill site. However the most economic and shortest route for a drill hole is usually straight and perpendicular to the surface.

Drill Hole Casing

Figure 2 depicts a typical well profile. The drilled hole has a 26-inch diameter for the first 250 feet, tapering to an eight inch diameter bottom hole in the production zone. The usual casing program includes a conductor pipe (surface to 250 feet), surface casing (surface to 2500 feet), intermediate casing hung from the end of the surface casing (2500 to 4000-6000 feet), and possibly a production liner hung from the end of the intermediate casing to bottom hole. All joints should be cemented and joined to ensure casing integrity into the production zone. Available well control techniques and blow-out prevention equipment can substantially reduce the risk of well blow-outs.

Drill Site Surface Area

A 2/1 ratio of good to bad wells is expected in a proven resource area. Once a successful well is drilled, six closely spaced wells (four expected successful) may be drilled within a radius of 2000 feet of the drill site. Two acres of land would be cleared for an exploratory hole. Approximately five acres of land would be cleared on a proven drill site. Four successful wells (three and spare) may be needed for a 12.5 megawatt (MW) plant. Generation capacity can vary from three to ten MW per well depending on the output rate and type (water or vapor dominated) of geothermal resource. The HGP-A test well is producing about three MW; however commercial wells are expected to have a larger capacity. Unsuccessful or expended wells would be abandoned unless used for injection of geothermal effluent.

Drilling Emissions and Effluents

Depending on geologic structure and capability of drilling equipment, either "drilling mud" or air will be used to remove cuttings and lubricate the drill bit. Drilling activities may use 2000 barrels of water per day per well. The mud and cuttings are disposed of at a drill site sump but can be removed to an approved disposal site if required. In the production zones, air drilling (instead of mud) may be used to avoid reduction of permeability in the production zone. While in the production zone, the return-air will contain cuttings and geothermal gases (most significant being H_2S). A caustic soda (NaOH) injection system and cyclone muffler can be used to abate hydrogen sulfide (H_2S), particulates, and noise during drilling (see figure 3). After completing the well, four to eight hours of unabated venting may be required to clear the hole of rock debris. Completed wells will be subjected to flow testing to determine reservoir characteristics. Emissions must meet Department of Health (DOH) standards. If the well is water dominated, a flash separator may be used at the well site to return brine to either a nearby percolation pond or reinjection well.

Injection Wells

One injection well may be needed for the three active wells which may be required to fuel a 12.5 MW plant. The number of injection wells will vary depending on the permeability of the injection well and the quantity of brine flowing from the production wells. The initial injection wells (specifically drilled for injection) are likely to be close to the plant to limit brine piping distance. Nonproducing or expended production holes may also be used for injection. Geothermal effluents will be injected into a geothermal aquifer having similar characteristics. Drill casing intergrity through overlying fresh water aquifers is essential if usable water supplies are to be protected. Injection wells are subject to standards and regulations of the State Department of Land and Natural Resources and Department of Health.

STEAM PIPING

The steam piping from well-head to plant is likely to be 16 to 22 inch diameter carbon-steel pipes. Piping may be placed four to six feet above ground-level on "saddles" which may be fortified to accomodate pahoehoe lava flows. Alternatively, piping may be buried for safety and aesthetics. The piping will have expansion joints which will allow for thermal expansion and some ground movement. Surface area needed for a pipeline corridor is discussed in "roads" section below.

GEOTHERMAL POWER PLANTS

Operation

Figure 4 depicts a simplified geothermal power generation system, emphasizing emissions and effluents. Before a plant becomes operational the Department of Health must issue permits regarding the quality of the air and fluids discharged from the plant. Components of this system are described below.

The characteristics of the geothermal fluid may vary from site to site. It may be liquid or vapor dominated. A vapor dominated system provides more steam for power generation per hole while reducing the hamount of brine which must be injected back into the ground. HGP-A is a water dominated system. Kapoho wells #1 and #2 have been reported to be vapor dominated.

As the geothermal fluid enters the power plant the steam and brine components are separated in the "separator". The compostion of the HGP-A brine is given in figure 5. Various heavy metal concentration such as arsenic, lead, and mercury are very low and should remain in the brine that is eventually reinjected. The steam phase leaving the separator consists of primarily water vapor and noncondensable gases. These gases as found at HGP-A are listed in figure 6. The two most significant noncondensable gases are H_2S and Radon 222. As described below, the level of H_2S can be almost completely abated. Outdoor concentration levels of emitted radon, if properly abated by dilution in the cooling tower, are lower than most indoor levels; since cement emits some radon in most buildings. Again, the composition of fluids and gases are likely to vary a bit with each reservoir.

The steam phase from the separator enters the turbine, turns the rotors, and exhausts into the condenser. Electricity is produced as the turbine spins the generator. The steam flow and resultant turbine-rotor turning is enhanced by the vacuum created in the condenser as the steam is condensed into liquid. This liquid (condensate) returns with the warm condenser cooling water to the cooling tower where it is cooled by evaporation. The size of the steam plume will vary with the size and efficiency of the plant, the cooling tower design, and the ambient weather characteristics.

Emission Abatement

The gas phase which exits the condenser consists primarily of the same noncondensable components which left the separator, most notably H_2S. An abatement system is utilized at this point to reduce the H_2S content to an acceptable level (see figure 4). A report recently prepared for the U.S. Environmental Protection Agency, Evaluation of BACT for and Air Quality Impact of Potential Geothermal Development in Hawaii, analyzes most available H_2S abatement systems. These include the iron catalyst primary system; the iron catalyst secondary system; the hydrogen peroxide, caustic, iron catalyst (HPCC) primary system; burner-scrubber system; and the Stretford system. The report recommends the Stretford system as the primary on-line abatement system. This system can remove over 99% of the H_2S contained in the noncondensable gases. By-products of the Stretford system include marketable elemental sulfur and sludge which requires disposal.

A geothermal plant is expected to be on-line 90-95% of the time. Contingency abatement systems can be utilized in the event the plant is "down" for maintenance or emergency. If maintenance is required on either the turbine or generator, the geothermal steam can be routed directly into the condenser utilizing the primary abatement systems. Since the turbine does not dissipate any heat or energy in the bypass mode, the cooling system must be over-designed to accomodate the extra heat during "turbine bypass". If the primary abatement system is not operational, a secondary abatement system such as NaOH (caustic soda) scubbing can be used in combination with a rock muffler to achieve 92-95% H_2S removal (see figure 4). In emergencies, well throtting may be accomplished by manual valve turndown or automatic valve control. Throtting must be slow (at least 15 minutes) and can reduce flow to a fraction of the well's maximum flow rate. The degree of throtting possible will depend upon the characteristics of each well. However, there is a danger that the additional stress with increased pressure could damage the well-bore, casing, or well-head equipment. If a geothermal development has more than one power plant, the wells could be moderately throtted and diverted to an operating plant. If all the above contingency abatement options are not available, a geothermal well may have to be free vented through a silencer without H_2S abatement until the required maintenance is completed or such time as the well can be shut-in completely.

The abated gases, condensate, and warm water are circulated through the cooling tower. Cooled water from the cooling tower is recirculated through the condenser; any excess water (blowdown) is piped into an injection well. It is expected that a wet, mechanical draft, cooling tower will be applied to geothermal development. Warm water enters the tower near the top, while a fan forces air through slats designed to maximize the surface area of the falling warm water. Use of drift eliminators significantly reduces the chance that any water droplets will exit with the steam plume. This falling water also scrubs any particulates from the gas exiting the abatement system. At "The Geysers" geothermal development in California, small amounts of boron from the condensate has been emitted with cooling tower drift (small water droplets entrained in the the steam plume) having some adverse effects on nearby vegetation. Based on the characteristics of the HGP-A reservoir fluids and the emission abatement which will be required by the DOH, cooling tower emissions from Hawaii's geothermal resources should not be toxic to flora and fauna in the vicinity of the geothermal power plant. Data available from the HGP-A indicates that the plume from the cooling tower should consist entirely of water vapor. The proposed DOH regulations require 98% H_2S abatement and a concentration of no greater than 25 parts per billion H_2S at the property line of a development.

In addition to cooling tower blowdown, brine leaving the separator will be piped into the injection well. If the rate of silica deposition in the brine is high, a silica-dropout system will be utilized between the steam-brine separator and the injection well. Otherwise, silica deposition within the injection well might cause it to become plugged. The silica deposits will be removed periodically and disposed of in an acceptable manner.

Plant Site Surface Area

The surface area required for a power plant varies with its megawatt output. Figures 8 through 13 depict the dimensions of the 12.5 and 55 MW capacity power plants. By using these units in tandem a 25 MW or 110 MW facility can be constructed without increasing the land area of the plant site significantly. Generally, a 12.5 or 25 MW plant will have structure dimensions of 90 feet x 40 feet x 54 feet high (per 12.5 MW unit) sited on a surface area of about 7 acres. A 55 or 110 MW plant will have structure dimensions of 350 feet x 80 feet x 75 feet high (per 55 MW unit) sited on a surface area of about 15 acres.

ROADS

Roads must be constructed to accomodate geothermal exploration, development, and production activities. Their placement should avoid volcanic hazards as much as possible. The extent of road building activities at a particular location will be influenced by the existing road infrastructure. Figure 14 depicts the design of access, well field, and power line roads. Road designs must be submitted to the counties for construction permit approval. Approximate road dimensions are given below.

	Width	Height	Description
Initial access	20'	-	One lane with shoulders.
Main access with transmission lines	78'	76'*	Two lanes, shoulders, & transmission lines on both sides.
Well field road	30'	4-6'**	One lane, shoulders, dual pipeline corridor on one side.

ELECTRIC TRANSMISSION LINES

Construction of a new transmission line corridor is required to connect the geothermal power plant to the existing power grid. By referring to figure 15, which depicts the existing power grid on the island of Hawaii, it appears that the need for new power line corridors will be minimal. However, existing lines may need to be upgraded. Figure 16 shows the clearance needed for 69 kilovolt (68' wide-67' high) and 138 kilovolt (78' wide-76' high) power line corridors. Dual lines will be used to assure reliability.

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*electric transmission line poles

**steam piping height

NOISE LEVELS AND ABATEMENT

During the initial phases of field development, persons in the immediate vicinty of a geothermal site may be exposed to noise levels varying from 40 to 125 decibels, depending upon the distance from the well site. High noise levels are produced during well drilling, production testing, and bleeding before connection to the generator. Drill rig noise varies from 60 to 98 decibels with muffler. Initial venting noise varies from 90 to 125 decibels which may be mitigated using a stack pipe insulator or cyclone muffler. Periodic operational venting noise is about 50 decibels using a pumice filled muffler. While most operations can be effectively muffled by acoustical baffling and rock mufflers, some emit unavoidable noise. Above noise levels apply to the immediate vicinity within 100 feet of the source.

The County of Hawaii geothermal noise level guidelines state that a general noise level of 55 decibels during the daytime and 45 decibels at night may not be exceeded at existing residential receptors which might be impacted.

The design standard for the HGP-A Wellhead Generator Project specifies that the noise level one-half mile from the well site must be no greater than 65 decibels. Construction of a rock muffler at the facility has reduced noise levels to about 44 decibels at the fence line of the project. A chart is provided in figure 17 which describes the noise levels from geothermal operations at "The Geysers" in California. Noise will vary with weather conditions and topography. Technology exists which should abate noise to acceptable levels.

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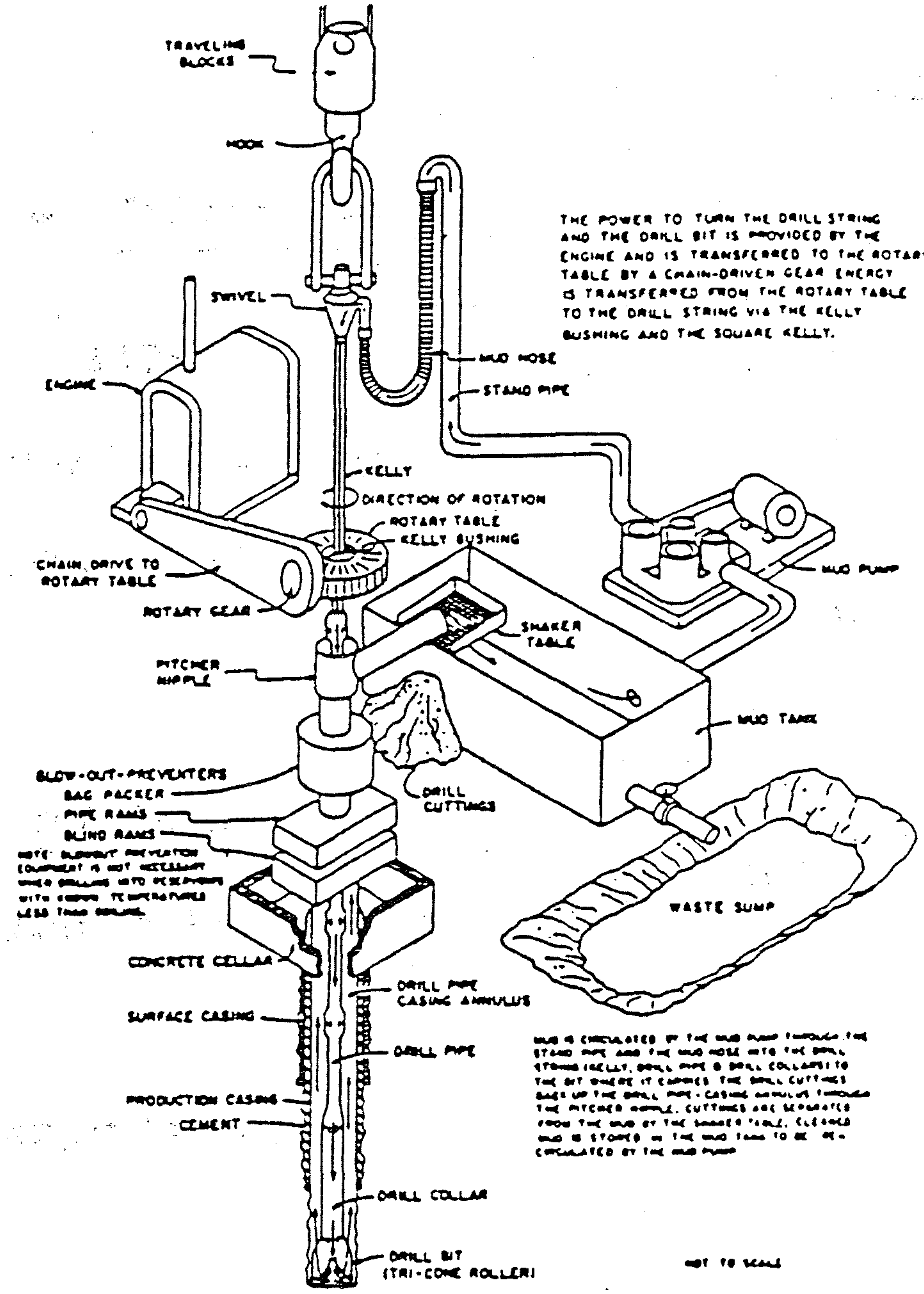


Figure 1. Basic Elements of a Rotary Drilling Rig.
(Source: Geothermal Power Development in Hawaii, 1982)

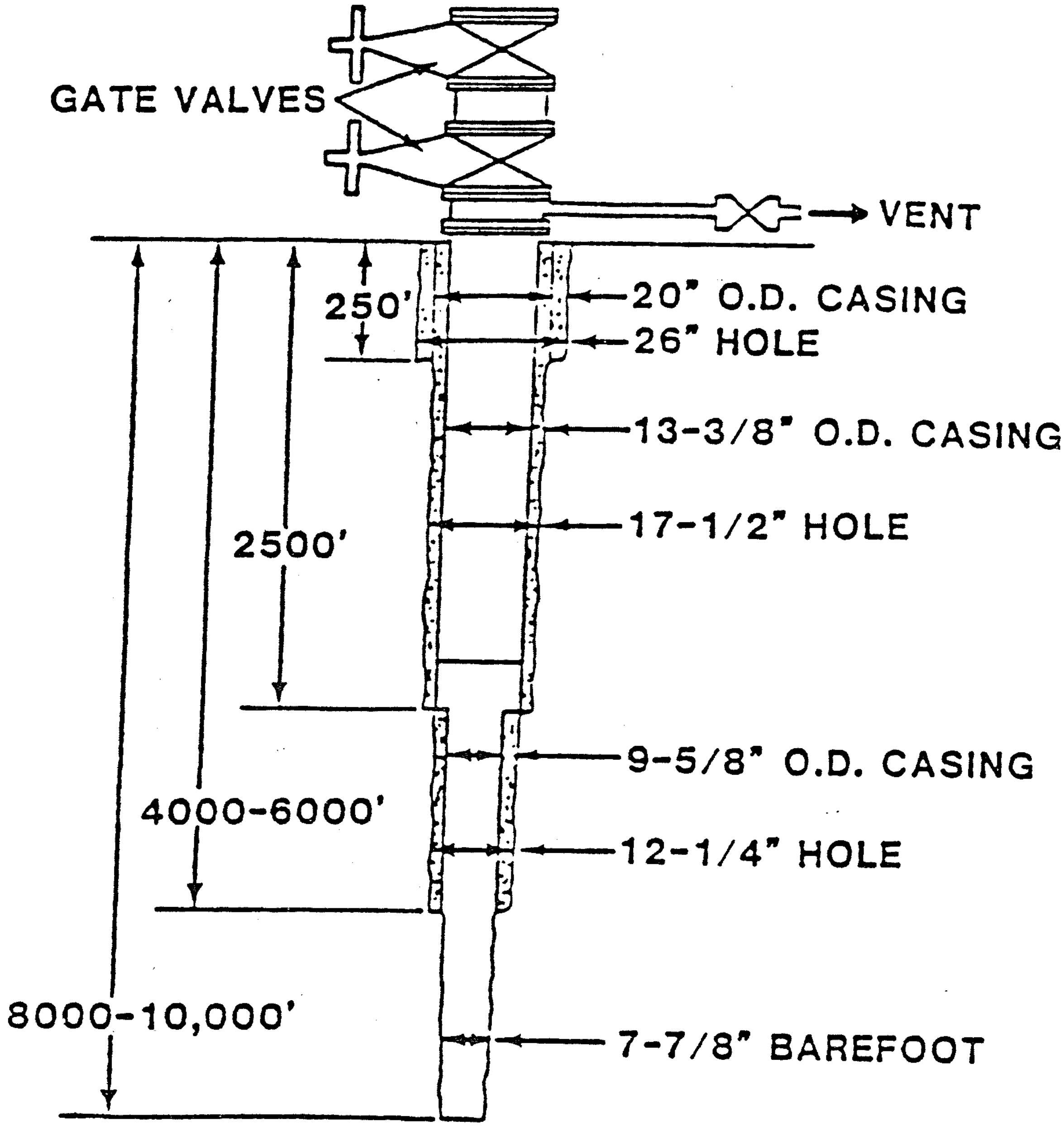


Figure 2. Typical Well Profile.
(Source: Kahaualea EIS, 1982)

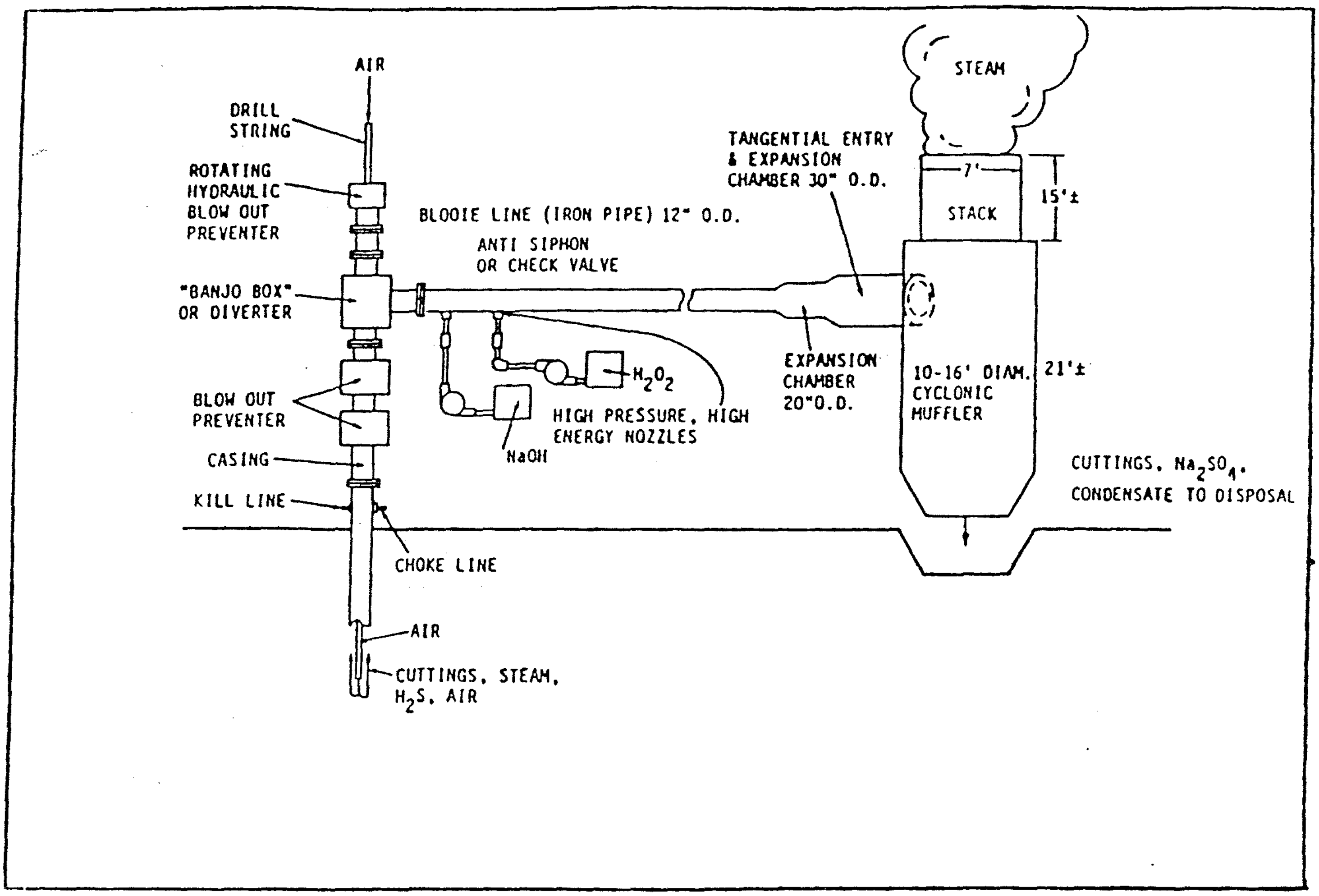


Figure 3. H_2S Removal During Well Drilling.
(Source: Dames & Moore, 1984)

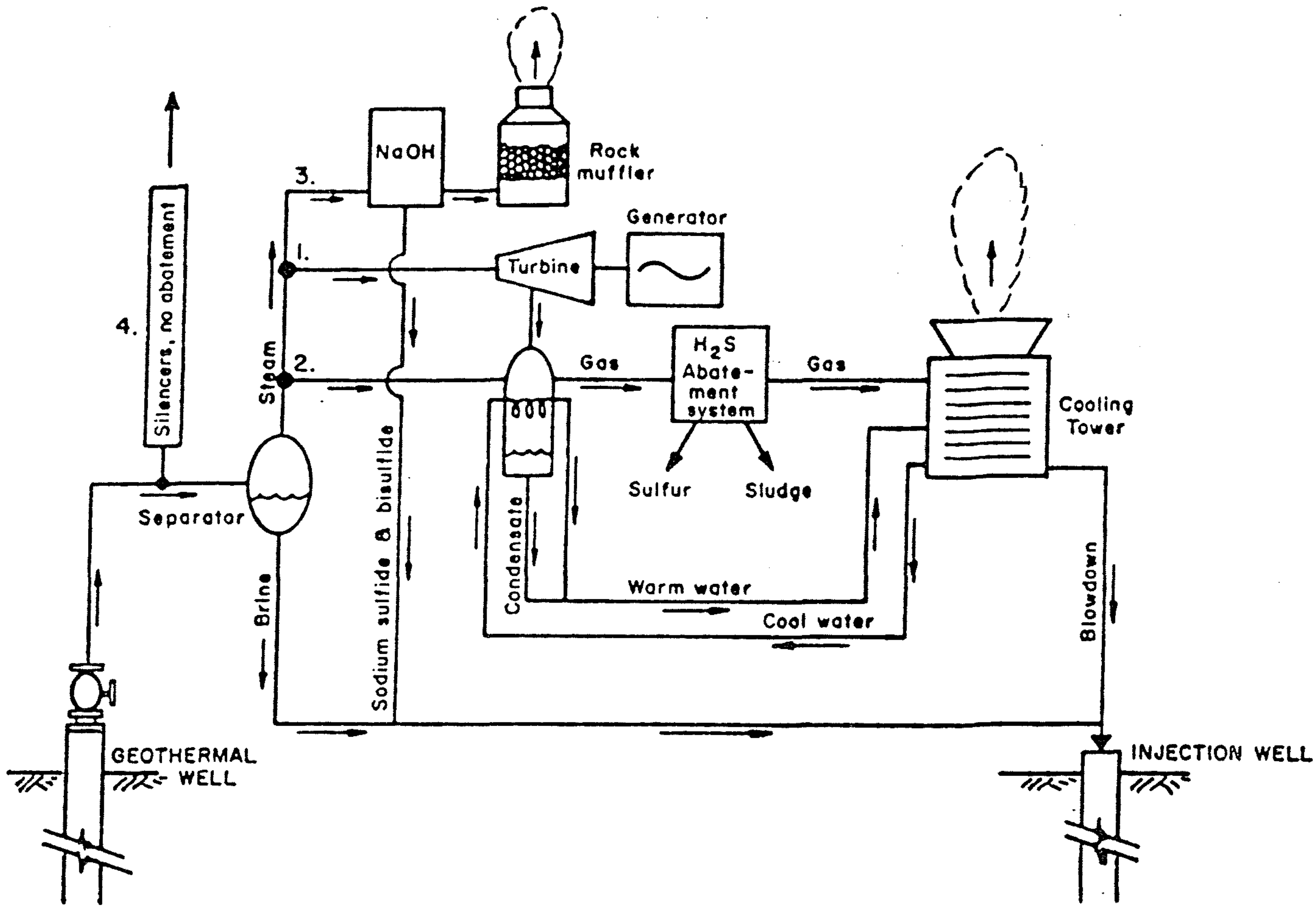


Figure 4. Hydrogen Sulfide Abatement During Power Plant Operation.

1) using primary abatement system (sulfur and sludge are byproducts of the Stretford abatement system);
2) using "turbine bypass" gas still abated through primary abatement system;
3) using contingency caustic (NaOH) abatement system;
4) unabated flow in emergency situations.

Element	Concentration, ppm[a]
Arsenic	0.01 - 0.001[b]
Barium	2
Boron	2
Calcium	218
Cadmium	<1.0[c]
Carbonate	75
Chloride	7200
Cobalt	0.014
Copper	<0.004
Gold	<0.00004
Iron	0.02
Lead	<1[c]
Lithium	0.034
Magnesium	0.131
Manganese	0.034
Mercury	<0.001
Molybdenum	0.067
Nickel	<0.02
Niobium	<0.4
pH	7.4[d]
Phosphorous	0.2
Platinum	<0.006
Potassium	600
Silica	800
Silver	<0.02
Sodium	3700
Strontium	2.0
Sulfate	50
Sulfide	17
Tantalum	<0.001
Thallium	<1[c]
Tin	<0.2
Titanium	0.006
Uranium	0.16
Vanadium	0.016
Zinc	0.012

[a] Liquid samples taken from cyclone separator (Thomas, 1983a).
[b] Rough estimate based on preliminary analysis, Thomas, 1983b.
[c] Thomas, 1982b. 'Less than' signs indicate detection limit of analyzer.
[d] Before atmospheric flashing, Thomas, 1982a.

Figure 5. Particulate Composition of HGP-A Brine.
(Source: Dames & Moore, 1984)

Gas	Concentration (ppmw in steam)	
	Geysers[a] (dry steam)	HGP-A[b] (separated steam)
CO_2	3260	1200
H_2S	222	900
NH_3	194	0
CH_4, C_2H_6	202	NR[c]
N_2	52	125
H_2	56	56
He	NR	0.5
Total (ppmw)	3985	2237
Total (wt%)	0.40	0.22
Rd^{222} nCi/lb steam	6.1	1.5

[a] Source: NCPA, 1981; Squire and Robinson, 1981.
[b] Source: Thomas, 1983a.
[c] NR - not reported.

Figure 6. Geothermal Noncondensable Contents.
(Source: Dames & Moore, 1984)

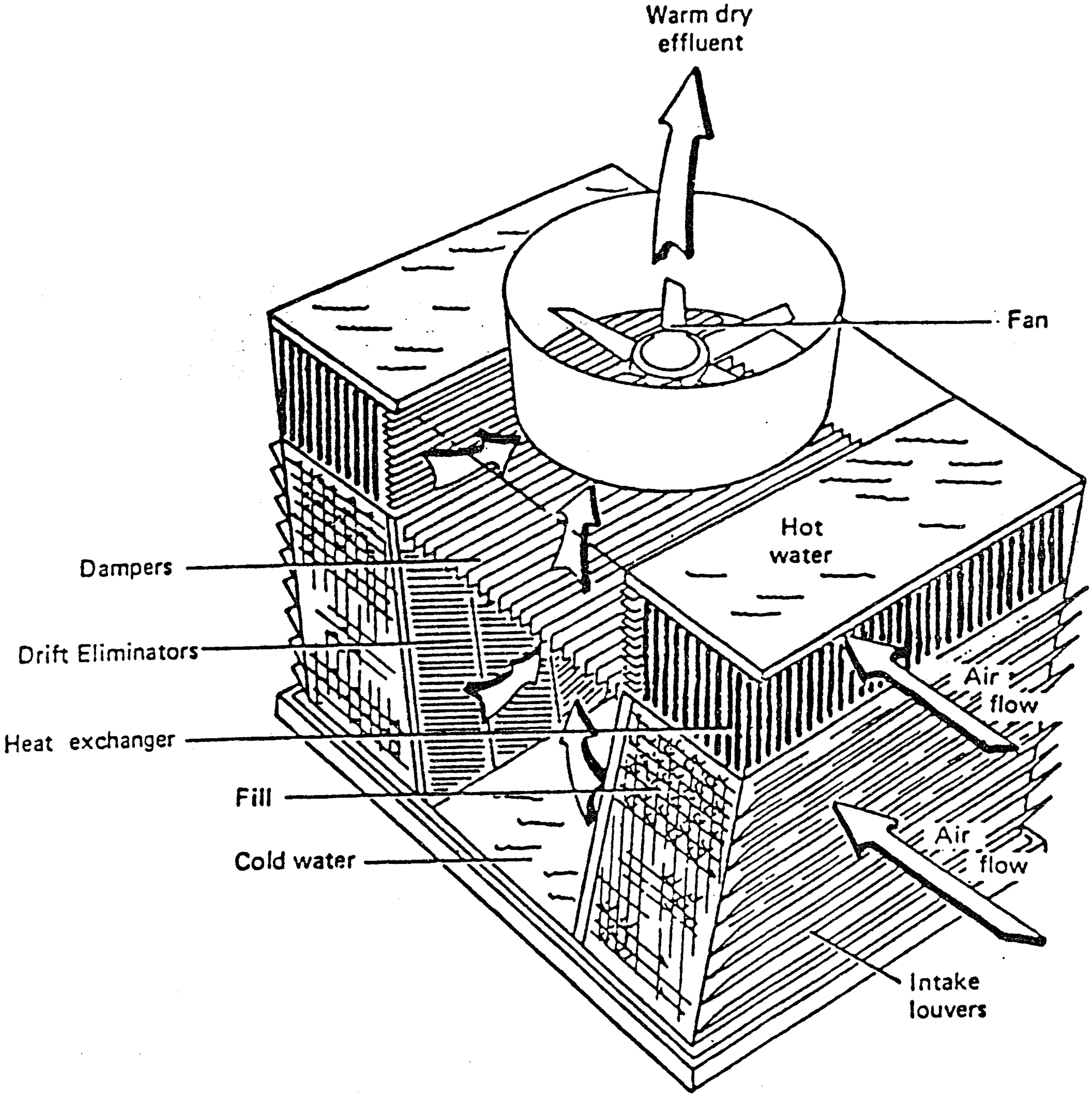


Figure 7. Cross-flow Mechanical Draft Cooling Tower.
(Source: Molenkamp, 1979)

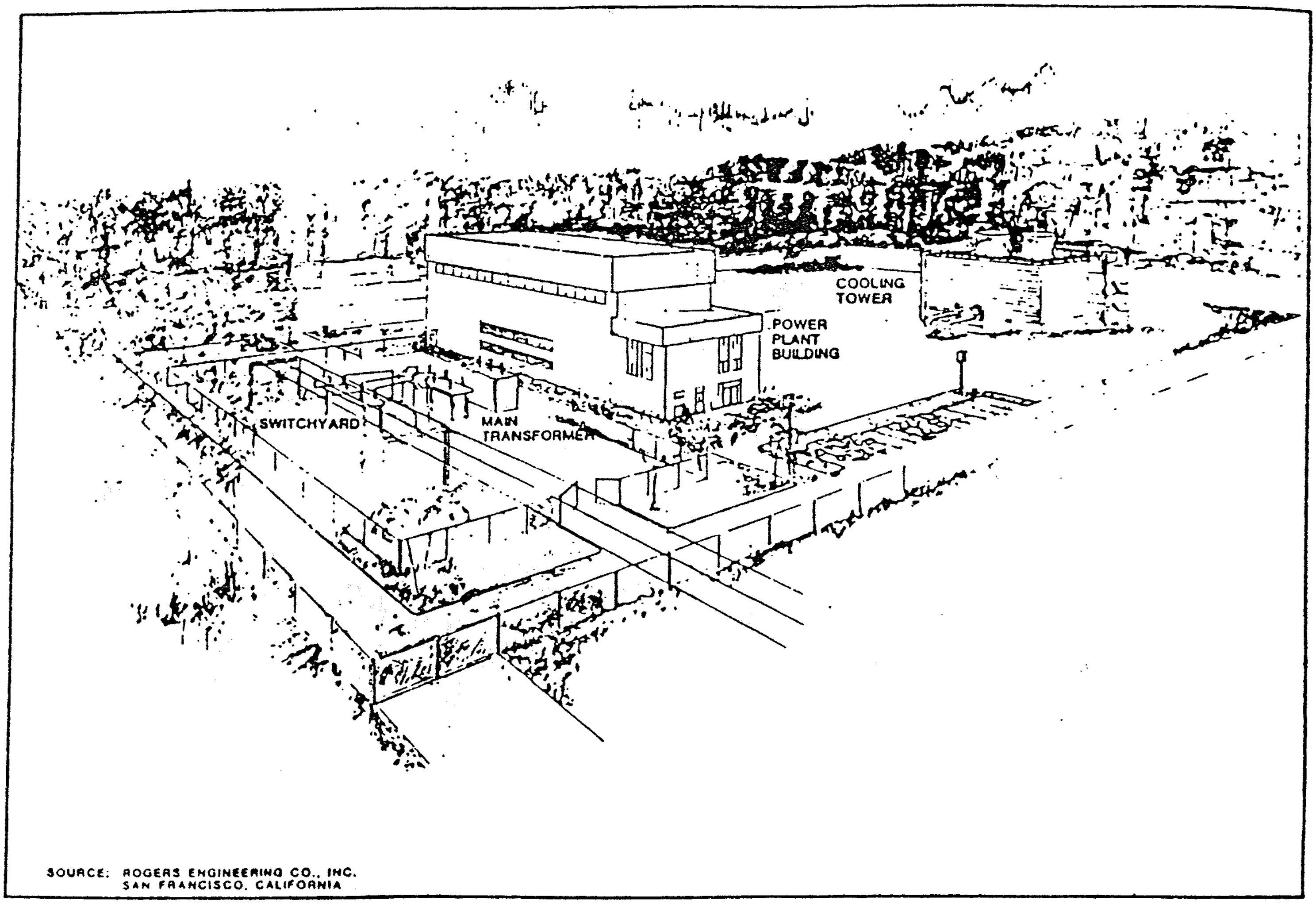
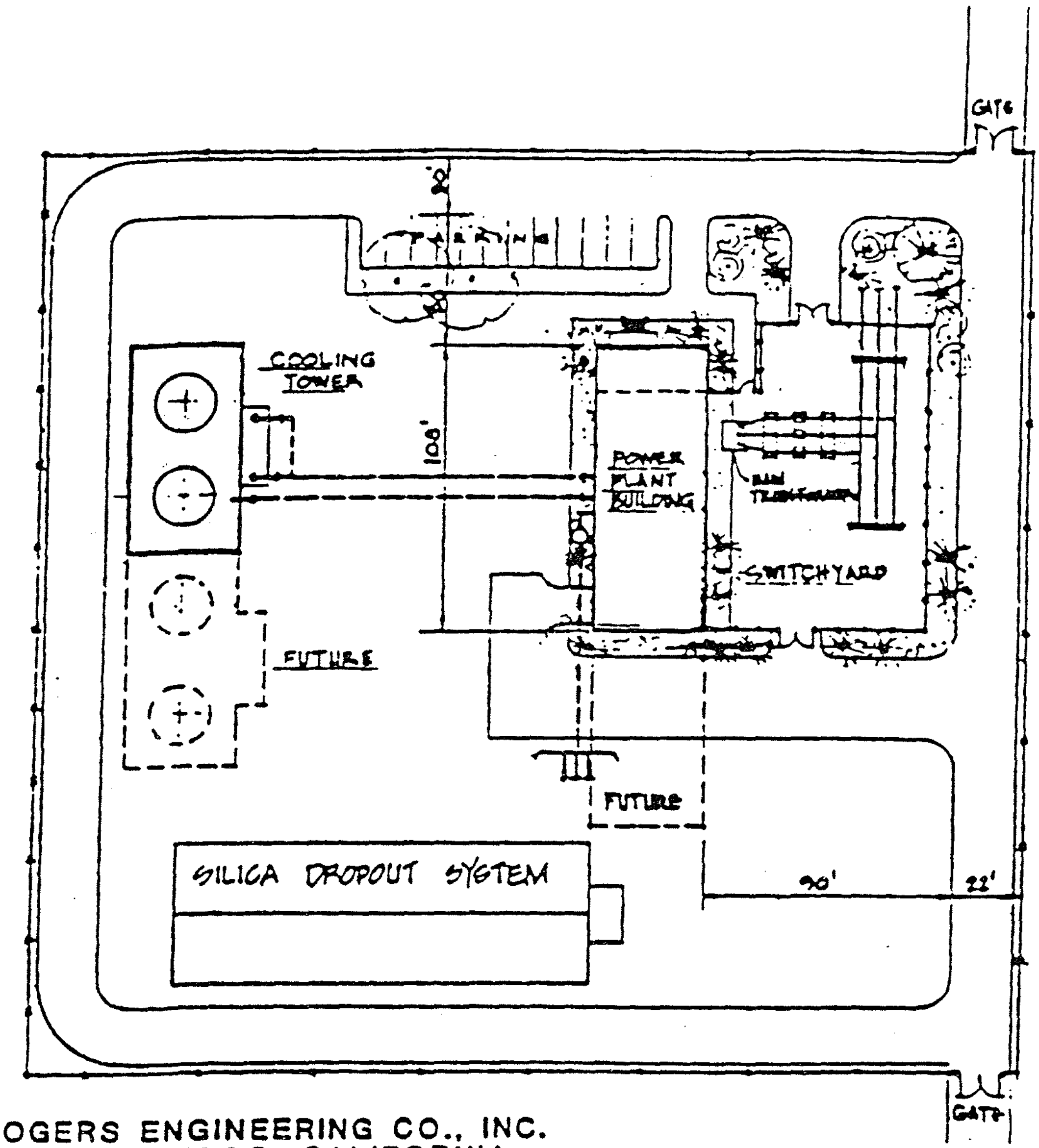


Figure 8. Perspective - Initial 12.5 MWe Power Plant.



SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

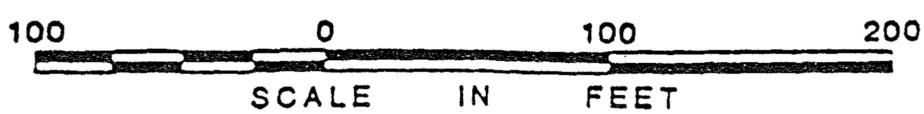


Figure 9. Site Plan - Initial 12.5 MWe Power Plant. (With Expansion to 25 MWe)

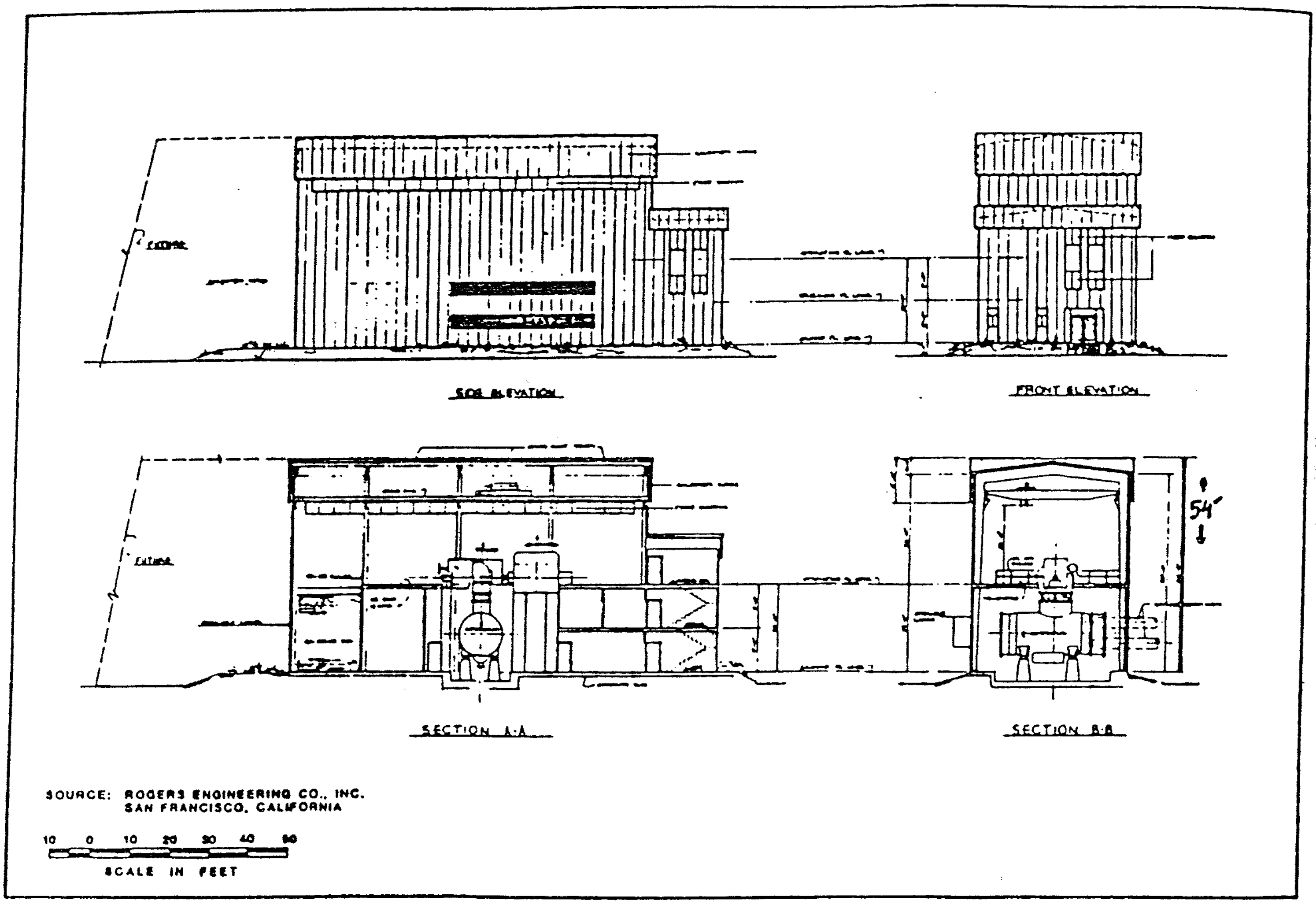


Figure 10. Elevations and Sections - Initial 12.5 MWe Power Plant.

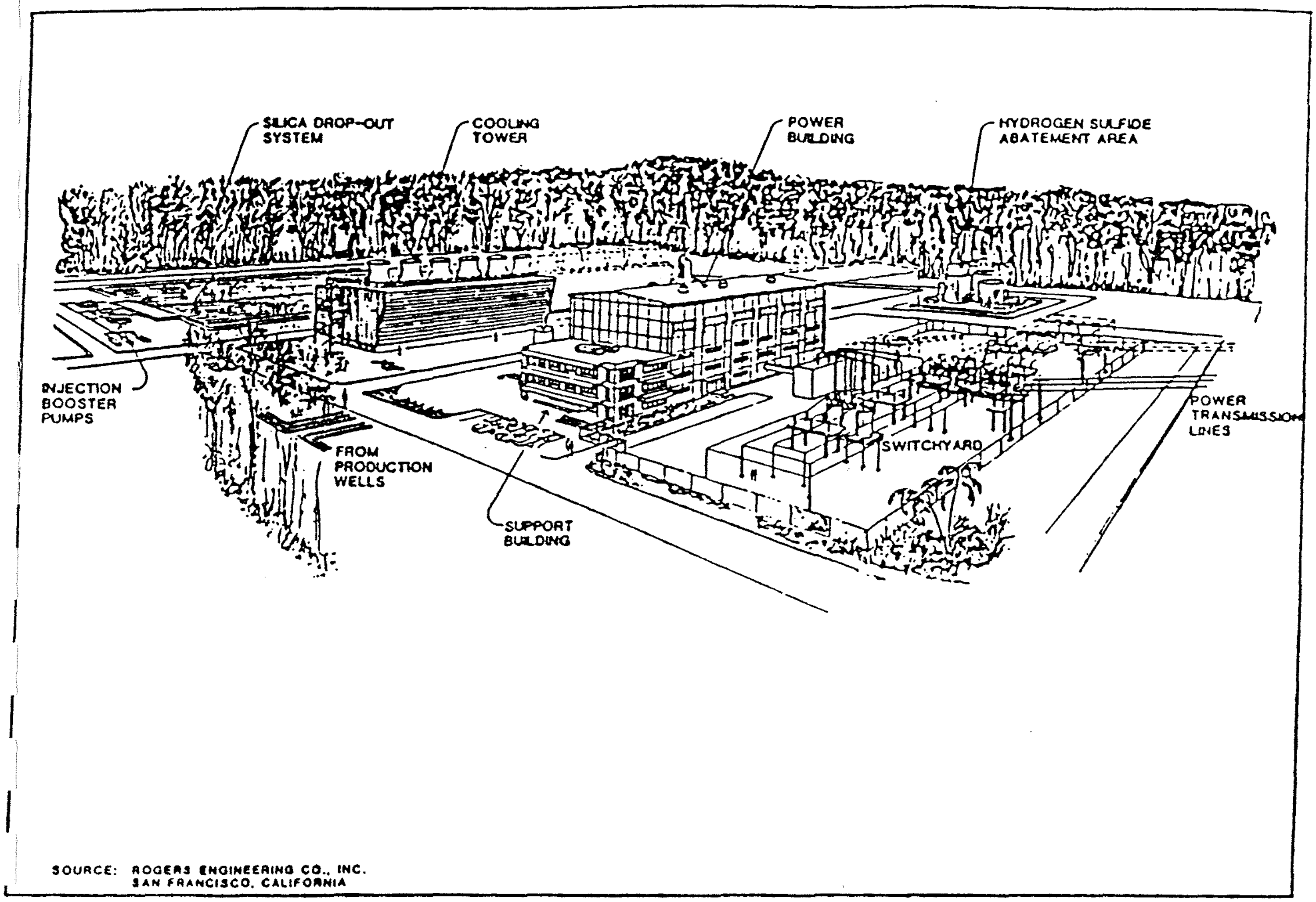


Figure 11. Perspective - 55 MWe Power Plant.
(With Expansion to 110 MWe)

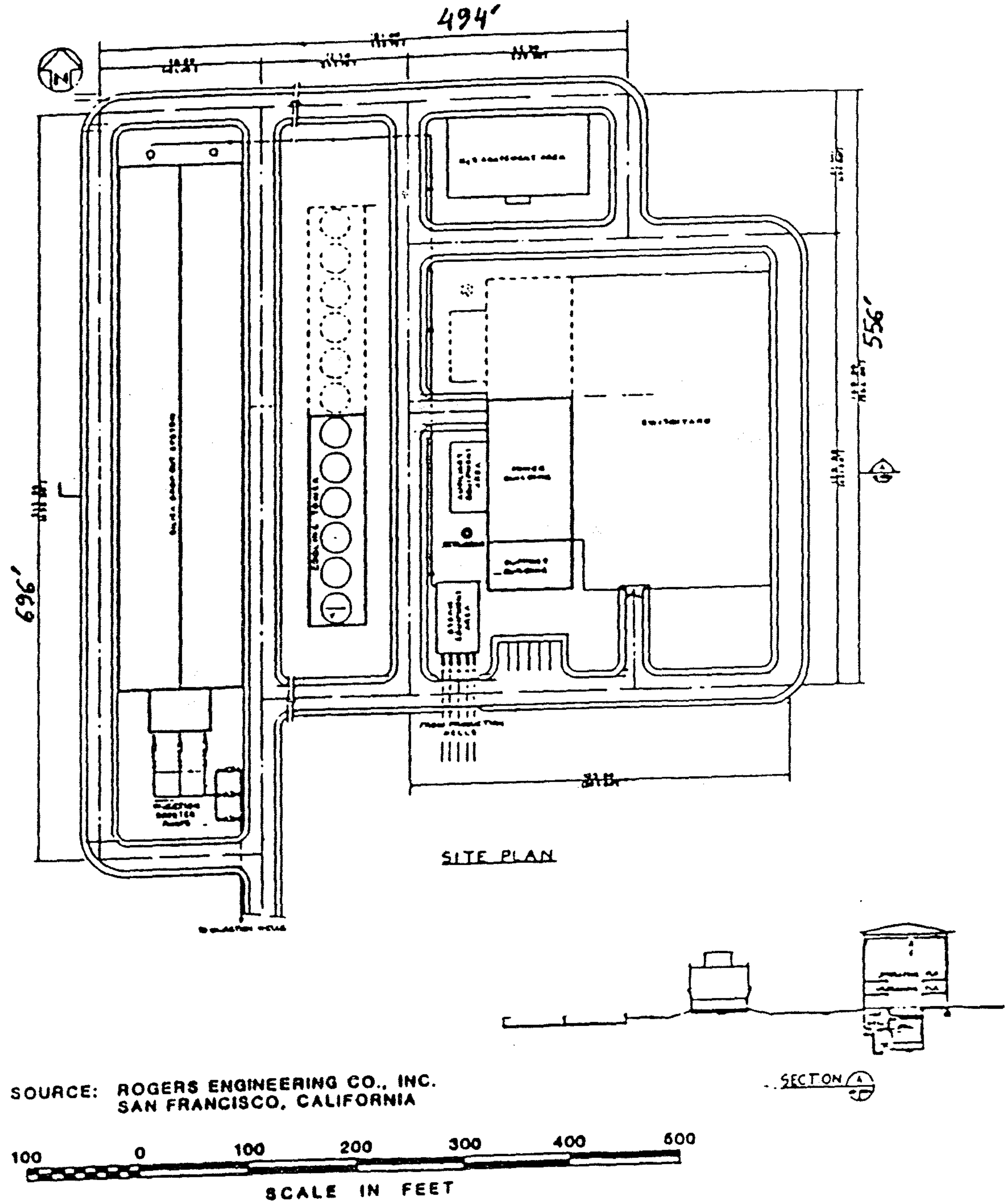


Figure 12. Site Plan and Section, 55 MWe Power Plant. (With Expansion to 110 MWe)

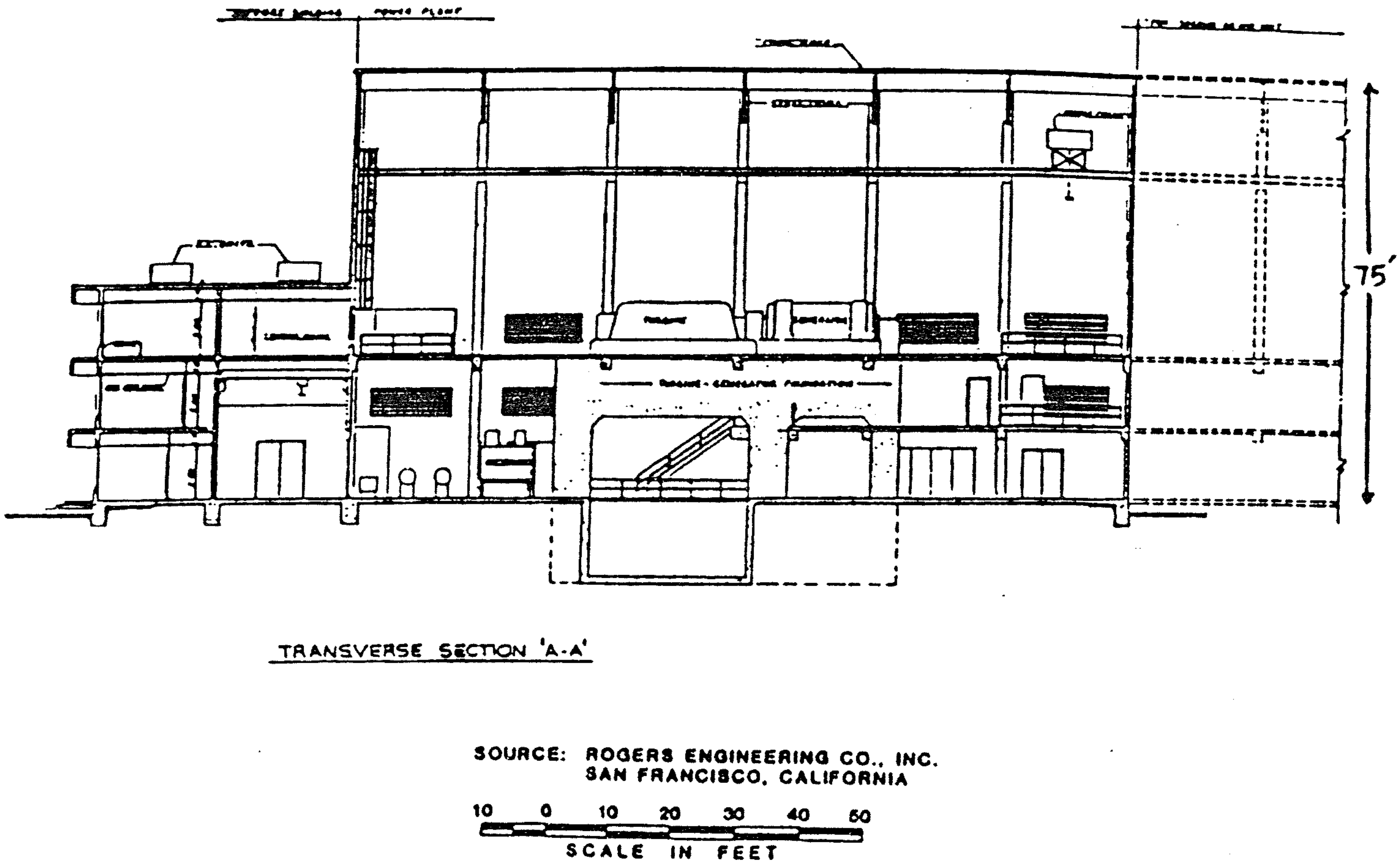


Figure 13. Transverse Section, 55 MWe Power Plant. (With Expansion to 110 MWe)

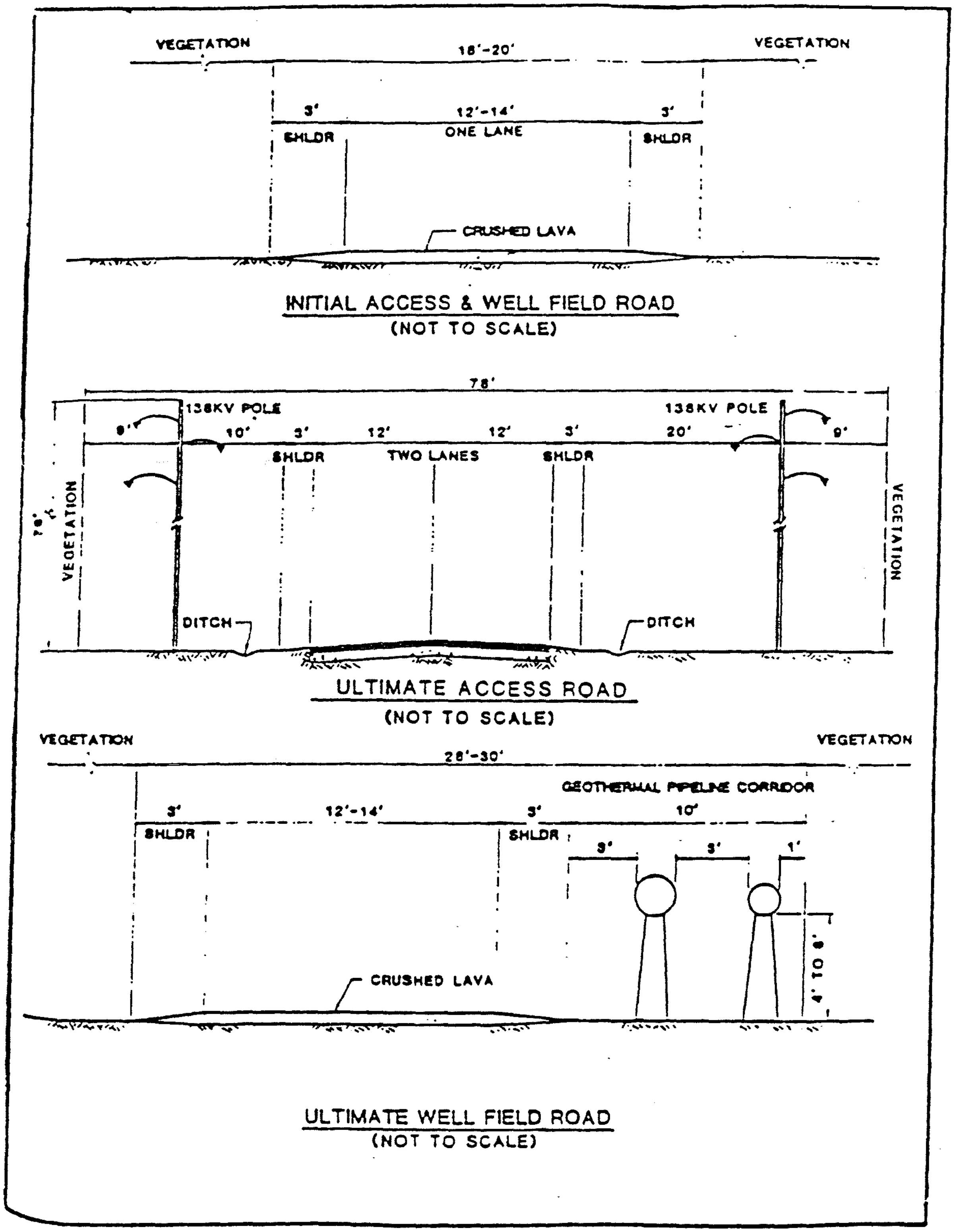


Figure 14. Road Design.
(Source: Kahaualea EIS, 1982)

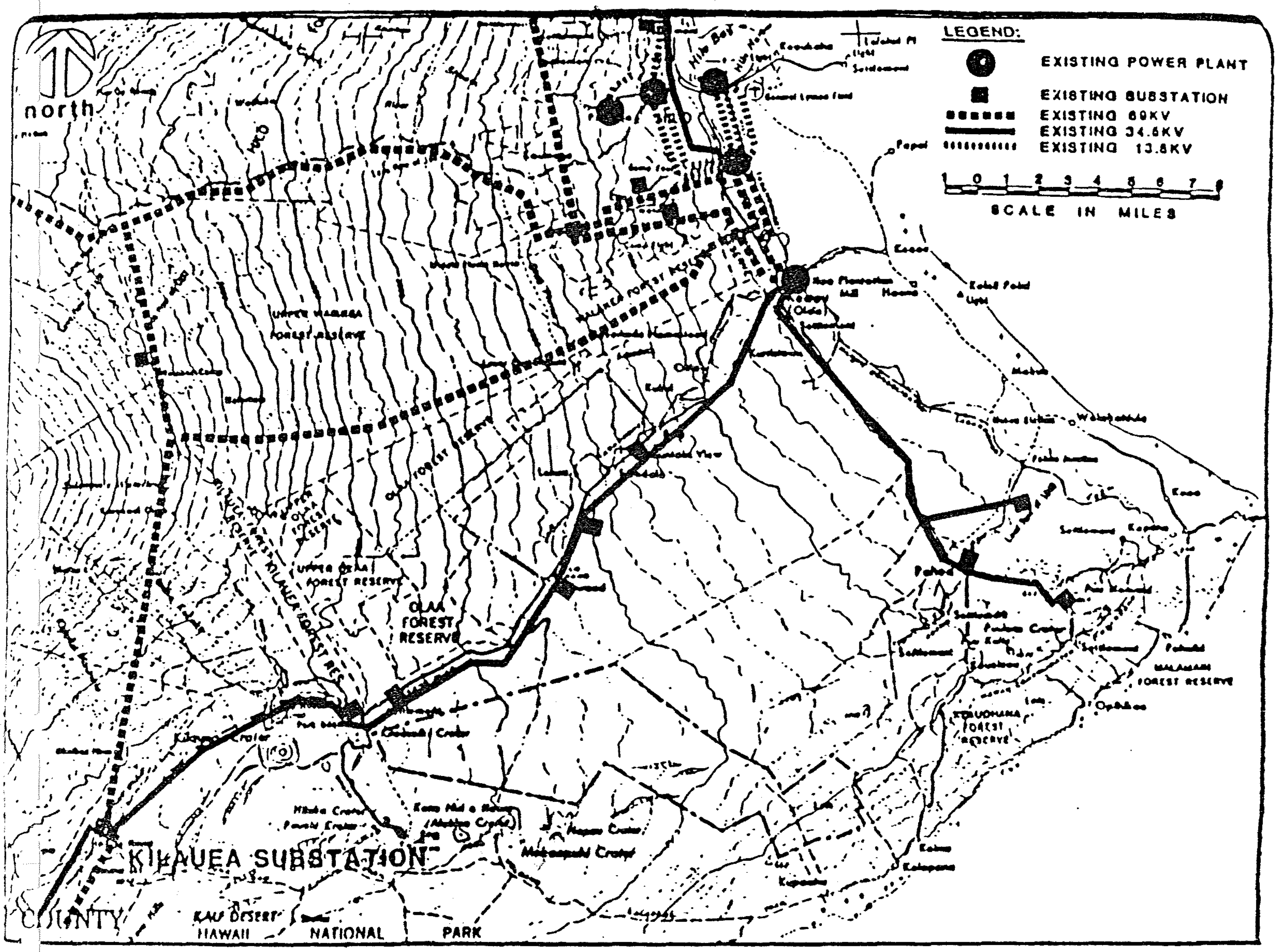
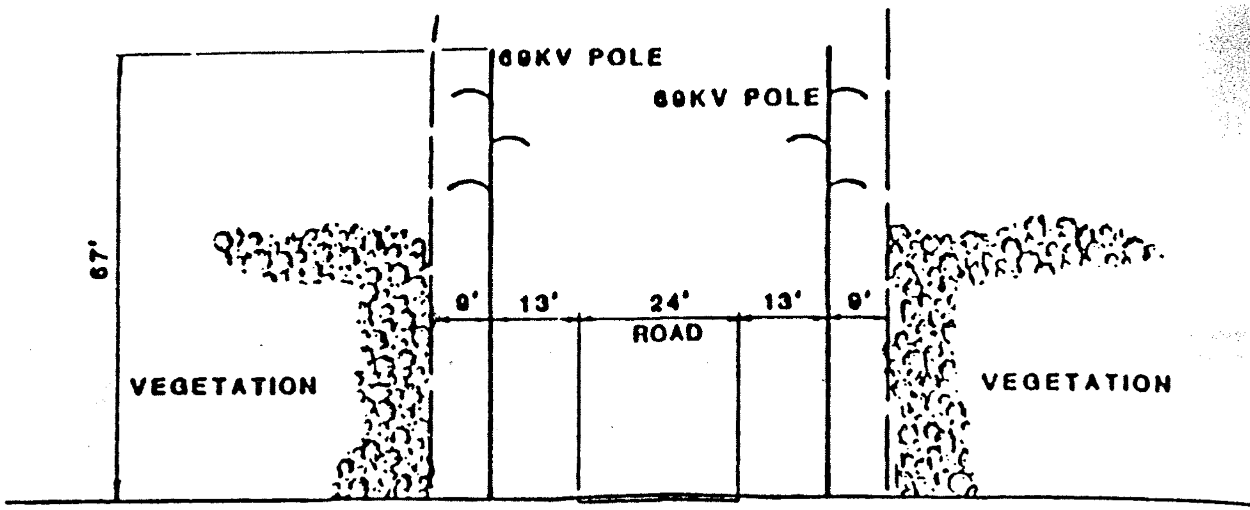
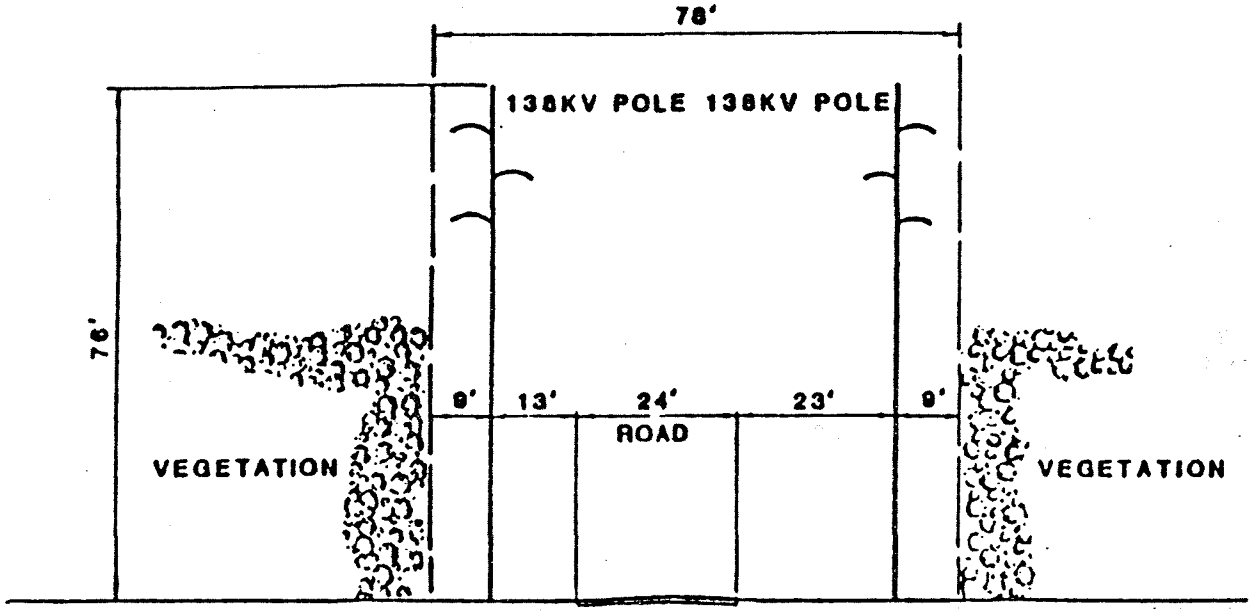


Figure 15. HELCO Power Transmission System.



69KV POWER TRANSMISSION LINE CORRIDOR
(DETAIL "A")



138KV POWER TRANSMISSION LINE CORRIDOR
(DETAIL "B")

SCALE: 1" : 30'

Figure 16. Power Transmission Line Corridors.
(Source: HECO)

Operation	Duration	dBA at 100'
WELL DRILLING		
Mud Drilling	60 days/well	69-74
Air Drilling, Including	30 days/well	
blow line		108
blow line w/air sampler		83
blow line w/air sampler & water injection		73
Well Cleaning; Open Well	3-6 days	112
Well Testing; Open Wells	14 days	112
Rock Muffler		77
Well Bleeding Before Connection to Generator	Variable	
open hole		60
rock-filled ditch		39
blowouts	Variable (infrequent)	112
CONSTRUCTION		
Operation of Construc. Machinery (Trucks, Bulldozers, etc.)	1-2 yrs.	64-84
PLANT OPERATION	20-30 Years	
Steam Line Vent (Muffled)	Intermittent	90
Jet Gas Ejector	Continuous	
unattenuated (old design)		97
with acoustical insulation		64
Steam Line Separator	Continuous	68
Steam Line Breaks	Brief, Infrequent	94
Cooling Tower	Continuous	60-70
Turbine-Generator Bldg.	Continuous	

Figure 17. Noise Levels of Geothermal Operations at The Geysers. (Source: Kahaualea EIS, 1982)