GEOTHERMAL ENERGY

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Ia1. The History of Geothermal Exploration in Hawaii

The recognition and use of geothermal energy in Hawaii has been recorded well back into the history of the Hawaiian Islands. Early explorers identified numerous fumaroles and thermal features on Kilauea and Mauna Loa volcanoes as early as 1827.[1,2] The use of the Kilauea summit fumaroles for a variety of cooking and heating purposes extends back into the times of the pre-contact Hawaiians[1] and has been virtually continuous up to the present time.[3] However, largely as a result of the relatively small number and low temperatures of Hawaii's surface thermal features, very little serious geothermal exploration or research was conducted until the early 1960's.

In 1961, four privately financed exploratory wells were drilled into the Kilauea east rift zone (Figures Ia1 and Ia2) by Hawaii Thermal Power Company.[4] Although all of these wells encountered temperatures well above that expected for normal groundwater (Table Ia1), due to their shallow depth none were of sufficient temperature to be considered economically exploitable and thus all were capped and abandoned. Subsequent to this effort the majority of the geothermal exploration done in Hawaii, until very recently, has been government sponsored research into the nature and occurrence of geothermal systems in Hawaii.

In 1973 the National Science Foundation sponsored a geothermal research project conducted at the summit of Kilauea volcano by Dr. George Keller of the Colorado School of Mines. A research well, located 1.1 km south of Halemaumau Crater, was drilled to a depth of 1262 m (approximately 160 m below sea level).[9] The maximum temperature encountered at the bottom of

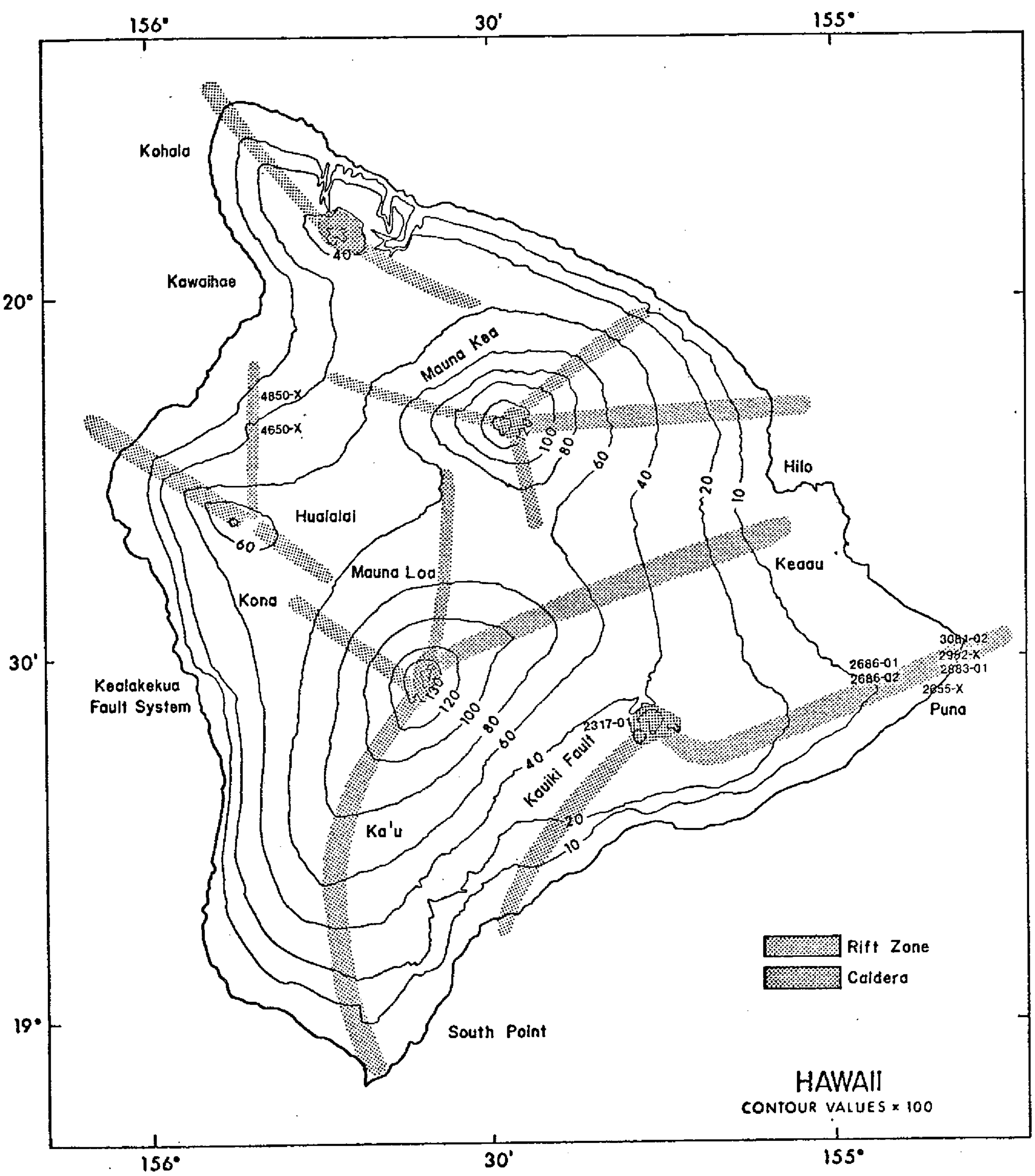


Figure Ia1. Map of the island of Hawaii with approximate locations of geothermal exploratory wells.

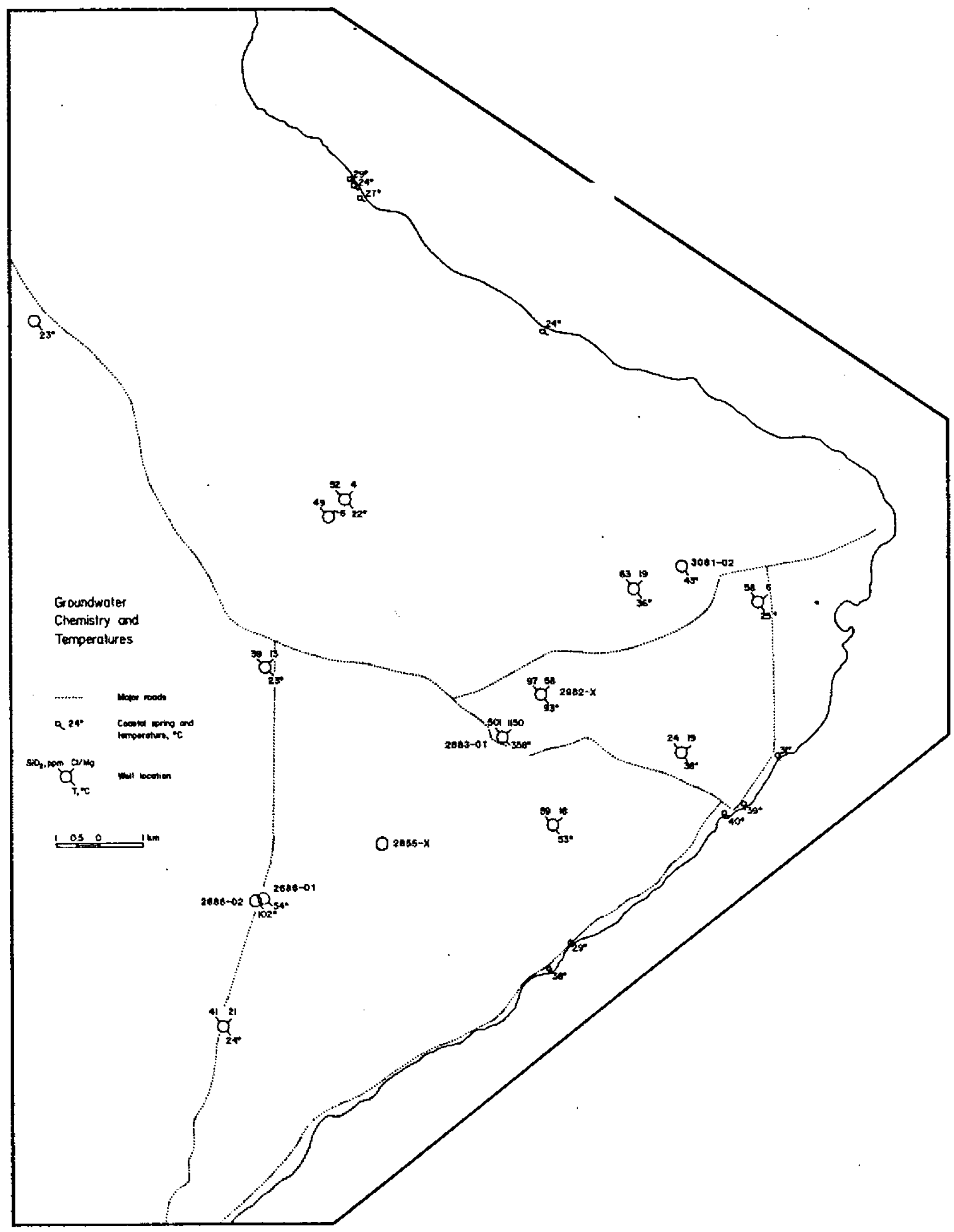


Figure Ia2. Map of the Puna district with approximate locations of exploratory wells.

Table Ia1

Geothermal Exploration and Research Wells in Hawaii

U.S.G.S. Well No.	Name	Depth/ Elevation (meters)	Maximum Temp (°C)	Year Drilled	Drilled By	Status	Reference Number
2686-01	Geothermal 1	54.3/307.5	54^{o}	1961	Hawaii Thermal Power Company	abandoned capped	4
2686-02	Geothermal 2	169.5/315.5	102^{o} (97.1^{o})	1961	Hawaii Thermal Power Company	abandoned capped	4 (5)
2982-X	Geothermal 3	210.3/171.6	93^{o} (92.5^{o})	1961	Hawaii Thermal Power Company	abandoned capped	4 (5)
3081-02	Geothermal 4	88.4/76.2	43^{o}	1961	Hawaii Thermal Power Company	abandoned plugged	4
2317-01	NSF-Kilauea	1262.2/1102.2	137^{o}	1973	Colorado School of Mines/GEDCO†	abandoned plugged	6
2883-01	HGP-A	1967.5/184.1	358^{o}	1976	University of Hawaii/GEDCO†	producable	7
4650-X	Steamco 1	1889.8/777.2		1979	PuuWaawaa Steam Company/GEDCO†	abandoned capped	8
4850-X	Steamco 2	2072.6/725.4		1979	PuuWaawaa Steam Company/GEDCO†	abandoned capped	8
2655-X	Ashida 1	*/244.8	*	1980	Barnwell Industries/ GEDCO†	*	8

†GEDCO = Geothermal Energy Development Company

*Data is not publically available

the well was 135^{o}C and the temperature gradient (the increase in temperature with depth) observed over the last 150 meters of the well was approximately 370^{o}C/km.[9] If drilling had continued to only slightly greater depths much higher temperatures almost certainly would have been encountered. However, in that the objectives of this well were directed toward basic research, the project was considered to have achieved its goals and thus no subsequent efforts have been made to deepen the well.

It was also during this period that the University of Hawaii, under a research grant from the National Science Foundation and the State of Hawaii, began an exploration program for a second geothermal research well. Although geophysical and geochemical surveys were initially conducted in several parts of Hawaii island, it rapidly became apparent that the east rift zone of Kilauea volcano had the greatest potential for success and thus the majority of the detailed exploration work was confined to this area.[11] A substantial quantity of data was obtained throughout the largely geophysical exploration program. From this data several areas were identified along the lower east rift zone which were interpreted to have conditions indicative of a geothermal reservoir. However, no single site could be positively identified as having a geothermal resource.

Despite some disagreement in the various interpretations of the subsurface conditions, a decision was made to drill a single deep research well into the lower east rift approximately 1 km west of the prehistoric cinder cone Puu Honualua. This location was chosen primarily on the basis of numerous shallow warm water wells in the vicinity, nearby resistivity and self-potential anomalies, and the availability of land for a drilling site.[12] Drilling was initiated in December, 1975 and was completed by late April 1976. Downhole temperature measurements made after the well was completed indicated that the well (named HGP-A[13]) was definitely hot, and on July 2, 1976, the well was artificially induced to discharge a mixture of steam and hot water. Numerous tests conducted on HGP-A since 1976 have shown that it is by far the hottest well in the United States, having a maximum bottom hole temperature of approximately 358^{o}C, and that the well is capable of producing over 45,000 kg/hr of steam (55%) and water (45%).[14,15]

Construction of a 3 megawatt wellhead generator facility is presently underway as a proof of feasibility project, and is jointly sponsored by the U.S. Department of Energy and the State and County of Hawaii. The installation of the generator is expected to be completed in early 1981 with production of electric power scheduled to begin in mid-1981. The objectives of the Wellhead Generator Project are to identify and surmount both the real and the perceived barriers to the production of power from the Kilauea east rift and thereby stimulate private interest in the development of the discovered resource.

Subsequent to the successful drilling of the HGP-A well a major exploration effort, jointly sponsored by the U.S. Department of Energy and the State of Hawaii, has been directed toward the identification and the characterization of other potential geothermal resources throughout Hawaii. The initial phase of this work consisted of a compilation of available data relevant to the identification of potential geothermal areas. On the basis of the initial reconnaissance survey, twenty areas within the State were selected as targets for more extensive detailed field surveys.[17]

This exploration effort is presently underway and a detailed summary of the results obtained to date are presented in section Ia2 below.

Private interest in geothermal exploration and development in Hawaii increased substantially subsequent to the successful completion of HGP-A in 1976. Privately financed exploration drilling was undertaken on the northwestern flanks of Hualalai volcano on the western side of Hawaii island in the early part of 1978 by the Puu Waawaa Steam Company. Prior to drilling, several geophysical surveys were conducted around the Puu Waawaa cinder cone by a mainland-based exploration group; several geophysical anomalies were observed in this area and, on this basis, two exploratory wells were drilled.[8] Neither well encountered significantly elevated temperatures to depths of more than 2000 m and thus both were abandoned shortly after completion.

More recently, several permits for exploratory wells in the immediate vicinity of HGP-A have been obtained by other private groups. One of these wells has been completed and is believed to have encountered high subsurface temperatures. However, in that this well is a private venture, virtually no information is available concerning subsurface temperatures or the nature of the resource encountered.

Although several other private groups have expressed interest in conducting exploratory drilling, both in Puna and in other parts of Hawaii, legal and jurisdictional conflicts have arisen that may prove to be more difficult to overcome than the technological problems encountered in earlier drilling efforts. Some of these issues are detailed below in subsequent sections of the present report.

Ia2. Nature and Occurrence of Geothermal Resources in Hawaii

The initial steps required in the development of any natural resource are, first, the acquisition of basic knowledge of the nature and occurrence of the resource and, second, the collection of specific information concerning the surrounding environment.

Geothermal energy, very simply defined, is that energy which can be obtained from heat within the earth. It is generally understood that the solid, relatively cool crust of the earth is underlain by several progressively hotter and denser layers of material. The source of the earth's heat is a combination of both the energy released by the decay of the small concentration of radioactive elements trapped within the earth as well as the thermal energy released when the original protonebular dust cloud coalesced to form the earth. If one were able to drill through the crust of the earth the temperatures encountered would gradually increase with depth; the temperature gradient observed through the crust would average $20^{o}C$-$30^{o}C$ per kilometer in depth.[18] Thus under most circumstances exploitable temperatures would not be reached above 5-10 km depths in most areas of the earth. In several places, however, the normal stability of the mantle and crust has been upset resulting in the formation of bodies of molten rock (magma) which migrate upward into the crust. When this molten magma reaches the surface of the earth, volcanic eruptions occur and the heat energy carried up from the earth's mantle is very rapidly dissipated into the atmosphere.[19] However, if the molten magma body begins to solidify before it reaches the surface, its thermal energy is slowly released to the near-surface rocks and groundwater. Under favorable conditions a relatively long-lived (thousands to millions of years) geothermal system can be formed by the interaction between slowly cooling magma bodies and near-surface groundwater.

There are several types of geothermal systems that have been identified in relation to volcanic and subvolcanic processes.[20] The most common type is the water-dominated system which is characterized by a reservoir of warm to very hot water confined by a low permeability cap rock or by the hydrostatic pressure of an overlying layer of cooler groundwater. If sufficiently high temperatures are present both hot water and steam can be recovered from these systems by drilling into the reservoir. Such liquid-dominated geothermal systems are known to exist in several parts of the United States (including Hawaii) as well as in New Zealand, Japan, and numerous other countries around the world.[20]

A second, less common, type of thermal reservoir is the vapor-dominated system; it is characterized by both a high heat flow and a low groundwater permeability. Geothermal fluids in a vapor-dominated reservoir are often nearly 100% steam with only very small amounts of liquid water (and other naturally occurring volatile compounds). Vapor-dominated systems are known to occur in only a few places around the world such as Larderello, Italy, and Geysers, California; however none are presently known to exist in Hawaii.

A third major class of geothermal resource is the hot dry rock system. These areas are similar to the vapor-dominated type in that they are also characterized by a low groundwater permeability, however, they have so little groundwater present and their permeability is so low that in order to extract heat from them, it is necessary to artificially induce permeability by fracturing the rock strata and then circulating water through the induced fractures from the surface. Development of the technology necessary for exploitation of this type of resource is still in the experimental stage. The extraction of heat from molten magma bodies (a subclass of the hot dry rock system) is also being considered. Large quantities of heat are contained in such near-surface bodies; however, even though they are known to exist in Hawaii (e.g. Kilauea east rift zone), the technology for economically exploiting this type of heat source is still several years away.

The formation of geothermal systems in Hawaii is controlled to a large degree by the processes which formed the volcanoes of the Hawaiian island chain. It is presently believed that a thermal instability, or "hot spot", is present in the earth's mantle beneath the crustal plate which forms most of the north Pacific basin. This "hot spot" has existed for several millions of years and, as the "plate" has moved northward over it, molten magma has leaked out onto the floor of the Pacific Ocean forming the chain of volcanic islands that extends from Hawaii at the south end, to Kure atoll to the northwest. This process is occurring even now, both on the island of Hawaii and on Loihi seamount south of the Big Island.[21] As one moves northward along the island chain and away from the inferred "hot spot" the age of the volcanism which formed the islands becomes progressively older.

Each major island in the Hawaiian chain is made up of one or more volcanic systems and each volcano evolves through a relatively well defined life cycle (Figure Ia3).[21] Initially, magma is erupted onto the floor of the Pacific Ocean. Sea water, at very high pressure, rapidly cools this

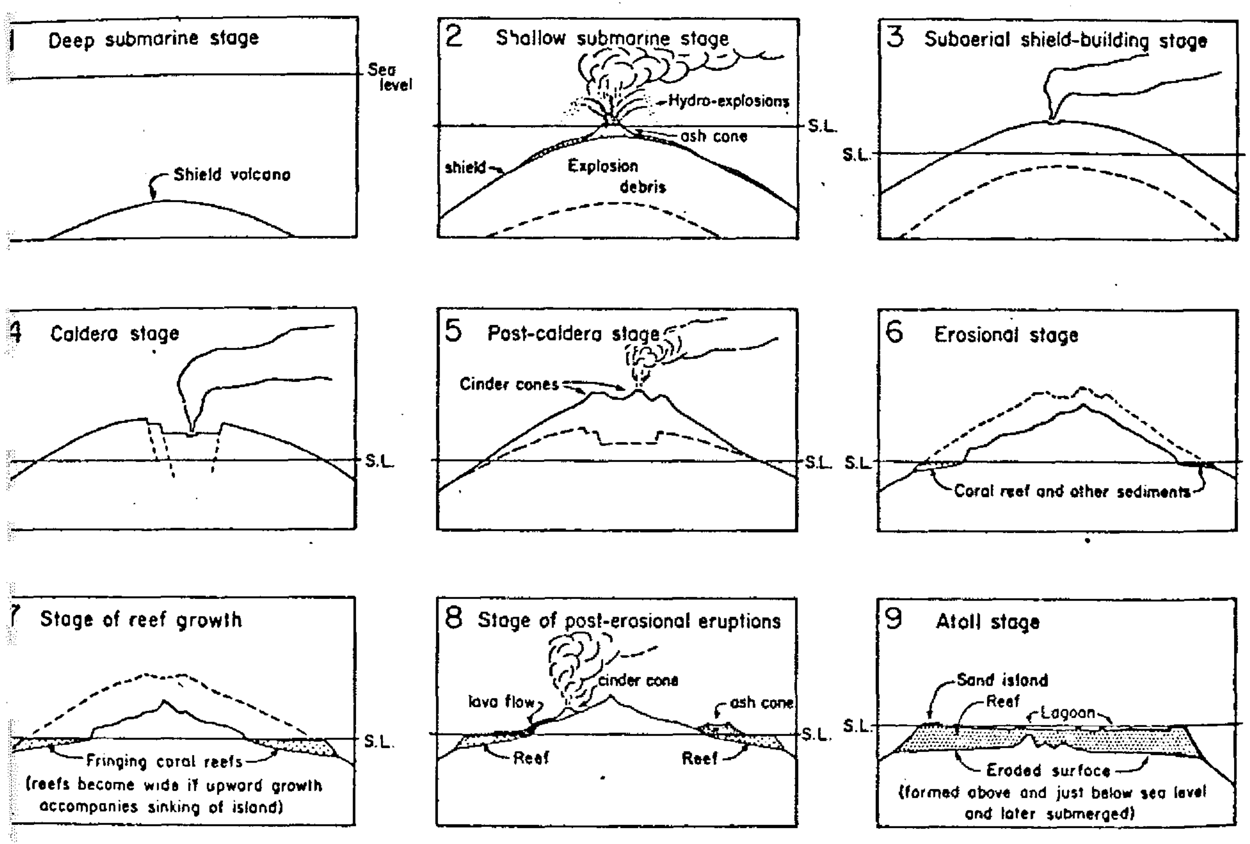


Figure Ia3. Life cycle of a mid-oceanic volcanic island; From Macdonald and Abbott, 1970.

basaltic magma which forms very dense and impermeable lavas. As magma continues to migrate to the surface a well defined plumbing system evolves within the volcanic cone. A roughly cylindrical conduit and magma chamber are formed near the center of the volcanic edifice; radiating outward from this conduit are usually two or three well defined fracture systems, or rift zones (Figures Ia4, Ia5, and Ia6). As the volcano continues to grow, magma migrates first up into the near surface magma chamber at a depth of 2 to 4 kilometers beneath the summit, and from there is erupted at the summit or is injected into the rift zone where it may either remain and slowly solidify or rise to the surface on the flank of the volcano.

The initial activity or extrusion rate from a young volcanic system is usally quite high. However, after a mature volcanic edifice has formed, activity tapers off over a period of several thousand years. During the final stages of activity the nature of the eruptive process changes markedly; individual eruptions become much smaller and more scattered and it is believed that the erupted magma rises very rapidly to the surface from a great depth beneath the volcano. Thus the later stages of activity may have relatively little relation to the magma chamber and rift zone structure of the younger volcano.

During the entire eruptive life of the volcano a substantial amount of thermal energy is brought into the near surface environment. This heat energy is dissipated very rapidly in the lava flows that are erupted in the submarine and subaerial environment. Generally within a matter of a few hours to a few years the temperature of these flows is equal to that of the groundwater or seawater that circulates through them. However molten

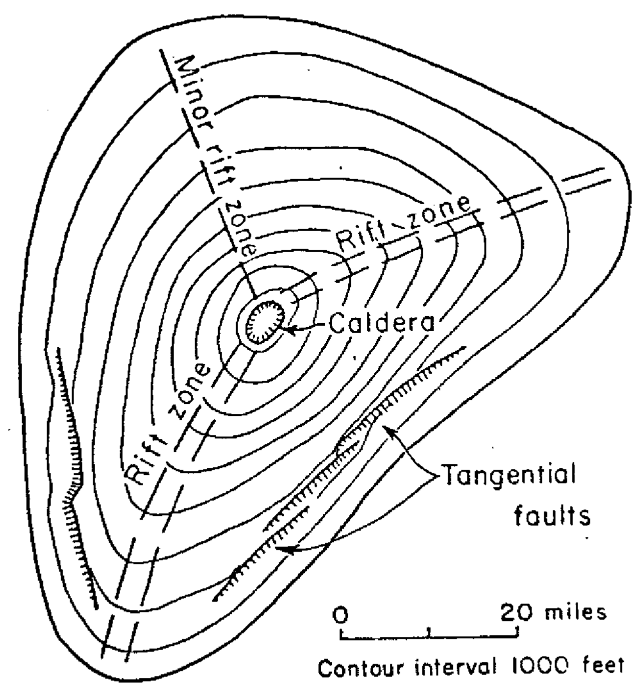


Figure Ia4. Plan view of typical oceanic shield volcano and associated rift zones. From Macdonald and Abbott, 1970.

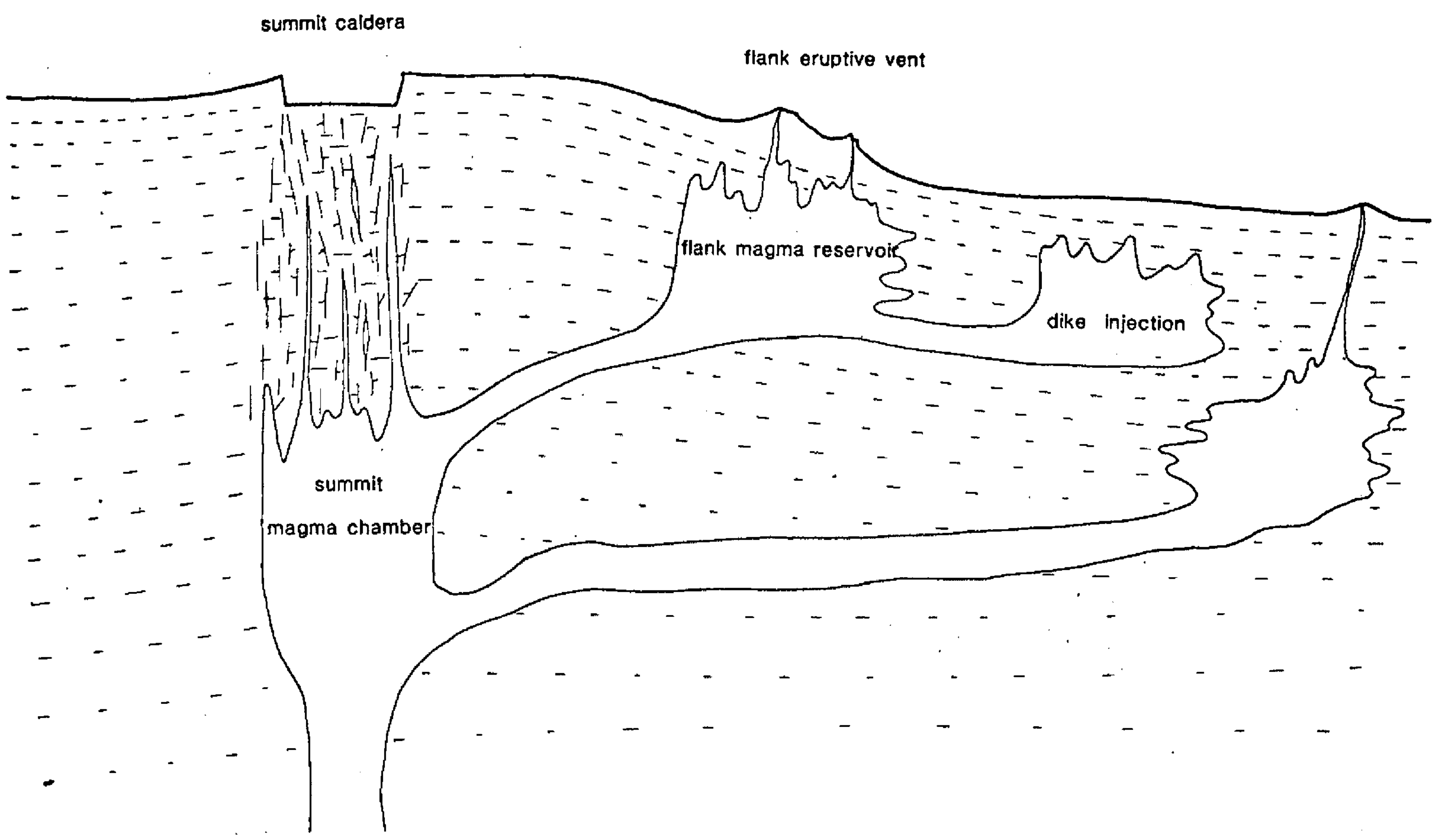


Figure Ia5. Cross section, parallel to the strike of the rift, of a magma chamber-rift zone system.

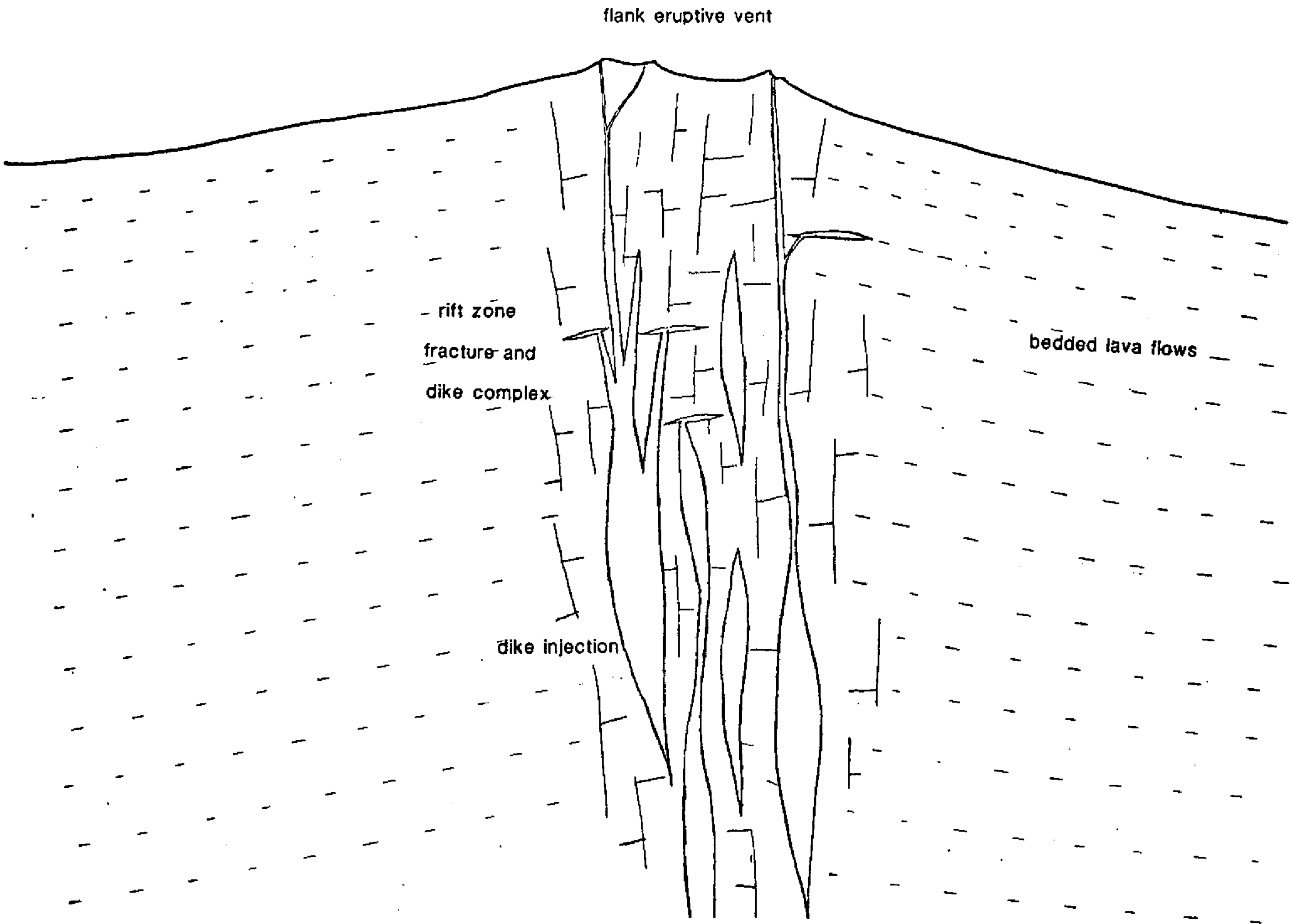


Figure Ia6. Cross section, perpendicular to the strike of the rift, of a rift zone fracture and dike complex on the flank of a shield volcano.

material in the magma chambers and material that has intruded into the deeper parts of the rift zones retains its heat for a much longer period of time. It is these areas that have the greatest potential for development of geothermal systems.

The Nature of Hawaiian Geothermal Systems

As mentioned briefly above, there are known to be at least two types of geothermal systems in Hawaii: molten magma and water-dominated systems. Molten magma is known to be present near the summit of Kilauea volcano both in the summit magma chamber and in the rift zones radiating out from the central caldera. Even though vast quantities of heat are stored in these bodies of molten rock, exploitation of this heat directly is not presently considered to be technically feasible. However, as these magma bodies cool, their heat is transferred out into the surrounding rocks which are often saturated with water. In rocks of high permeability the heat can be dissipated in a very short time to rapidly circulating groundwaters; however, if the cooling magma is surrounded or overlain by rocks of low permeability the heat loss occurs much more slowly. In cases where the heated groundwater is well below the surface of the local water table (1-2 kilometers), the weight of the overlying water (hydrostatic head) may be sufficient to prevent this heated water from boiling and dissipating the available thermal energy even more rapidly. Under some conditions the deeply circulating groundwaters dissolve minerals from rocks in the highest temperature zones and redeposit them as thermal fluids enter the cooler rock strata.[22] This process can obstruct the flow channels in the cooler rocks and thus confine the heated waters in a self-sealed thermal reservoir (Figure Ia7). It is not presently known whether this type of system exists in the Hawaiian geologic

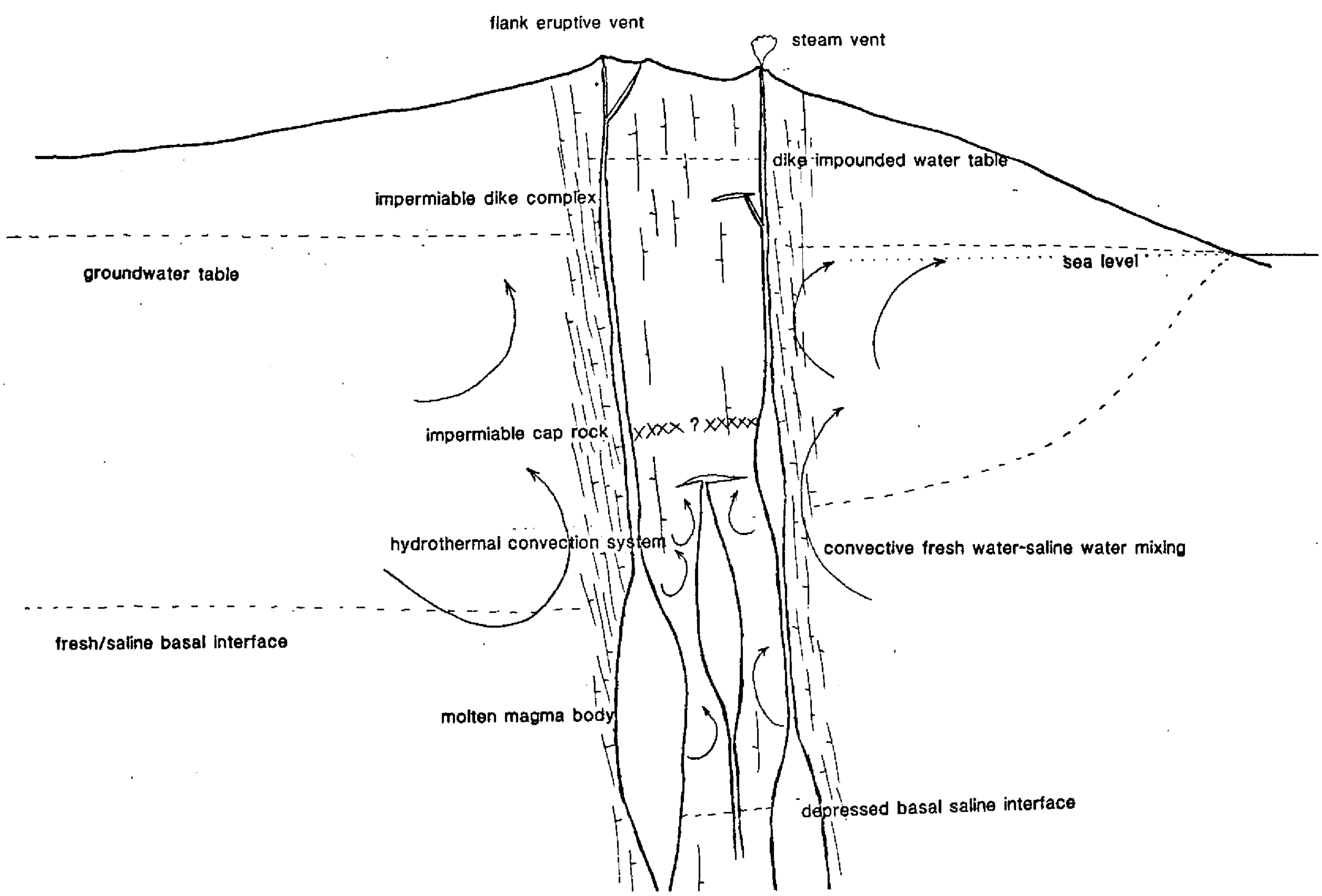


Figure Ia7. Cross section of an idealized geothermal system which might form on and around a rift zone dike complex.

environment. However, it is known that high temperature hydrothermal systems do form at depths at least as shallow as 2000 meters.[7,12,15]

A major concern regarding these hydrothermal systems in Hawaii is their longevity. The lifetime of a thermal system is controlled to a large degree by the size of the cooling magma body as well as the rate at which heat is removed by circulating thermal fluids or by conduction through adjacent rock. A thin dike injected into cold near-surface rock would lose most of its heat in a matter of weeks or months; a massive body of molten rock such as a magma chamber, in the core of a volcano, could take thousands to possibly even millions of years to cool to ambient temperatures. Thus it is highly possible that most high temperature geothermal systems in Hawaii will be located deep within recently active rift systems or in the slowly cooling magma chambers of the younger volcanic systems. The older volcanic systems, such as those on Molokai, Oahu, and Kauai, may still have thermal energy within their magma chambers, however, with the increasing age of these systems, the probability for finding useful heat at economically viable depths decreases substantially.

There are several methods by which a geothermal resource can be identified. Drilling, the only certain method, is extremely expensive and therefore is usually done after the completion of other, considerably less expensive and less certain, surface exploration techniques. The application of these techniques is based largely upon the unique features of a geothermal reservoir. The geologic conditions for a reservoir have been discussed above and are the initial constraints placed upon site selection for exploration work. Several geophysical and geochemical exploration techniques and the features each is attempting to identify are presented in Tables Ia2 and Ia3. Although each of these techniques has proven to be useful for indicating a geothermal reservoir, each is subject to difficulties of interpretation or to interferences which prevent any one technique from unambiguously confirming the existence of a thermal reservoir. Therefore it is usually necessary to apply a number of techniques in any potential resource area in order to ascertain whether anomalies observed by one method can be substantiated by other techniques.

Although geophysical and geochemical exploration work is not yet complete for most survey areas in Hawaii, substantial amounts of data have been acquired on the geothermal potential of Hawaii's volcanic systems. An initial compilation of existing geophysical and geochemical data completed in 1978[17] identified approximately twenty areas throughout the State (Figure Ia8, Table Ia4) in which further, more detailed, field investigations were warranted. Geochemical and geophysical exploratory investigations have been completed in some of the identified target areas and are currently underway in several others; a summary of the presently available data from this work is presented below.

The island of Kauai (Figure Ia9) was formed by one large volcano of approximately 3.5 to 5.5 million years age. Numerous post-erosional volcanic vents, which were active 1 to 2 million years before present, are scattered over the eastern and southeastern half of the island. Only a few groundwater geochemical anomalies have been identified on Kauai and, even though it is presently believed that the potential for discovering a viable thermal resource on this island is quite low, field surveys in the vicinity of the post-erosional volcanic centers will be necessary to confirm this preliminary conclusion.

Table Ia2

Geophysical Exploration Methods

Gravity	Very precise measurements of the gravity field at the ground surface can identify (1) very dense bodies of rock required for the existence of a longlived reservoir, (2) areas in which hydrothermal alteration has filled in fractures and pores normally found within the rock strata, or (3) areas in which hydrothermal mineral alteration has removed significant quantities of the denser material originally present.
Resistivity	The electrical resistivity of subsurface rock strata is strongly affected by the salt content and temperature of the groundwaters circulating through them. Thus rocks saturated with warm saline geothermal fluids have a lower resistivity than those saturated with colder groundwaters.
Magnetics	Rocks at very high temperature, or that have been altered by circulating thermal fluids, have a substantially lower magnetic susceptibility than do normal rock strata. These changes are reflected in slight changes in the earth's magnetic field above and around thermal areas.

Table Ia3

Geochemical Exploration Methods

Groundwater Chemistry	Water at high temperatures tends to dissolve selected minerals out of reservoir rocks and thus thermally altered groundwater has chemistry substantially different from cool groundwaters
Trace Element Chemistry	The leakage of geothermal fluids into the near surface tends to create anomalous concentrations of trace and volatile elements (e.g. mercury and radon) at or near the ground surface either by injection or by causing anomalous migration patterns around the areas of leakage
Isotope Chemistry	Geothermal fluids often have a unique isotopic character due either to high temperature isotopic exchange between groundwater and reservoir rocks or by the unique character of the minerals and gases dissolved from the reservoir rock (e.g. methane or helium)

Passive Seismic

Geothermal reservoir rocks (either because of cooling and contraction or a lowering of their mechanical strength) tend to fracture more readily than cold rock strata and thus generate more seismic noise than colder rocks.

Self Potential

The exact mechanism of the generation of self potential anomalies (natural voltages at the earth's surface) in Hawaii is not clearly understood. However, self-potential anomalies have been found to be strongly correlated with known thermal anomalies at the Kilauea summit and along the Kilauea east rift.

Temperature/ Heat Flow

Geothermal systems often leak high temperature fluids into the near surface environment creating anomalously warm ground or shallow groundwaters. These thermal anomalies can be detected by direct measurement or by airborne infrared imaging.

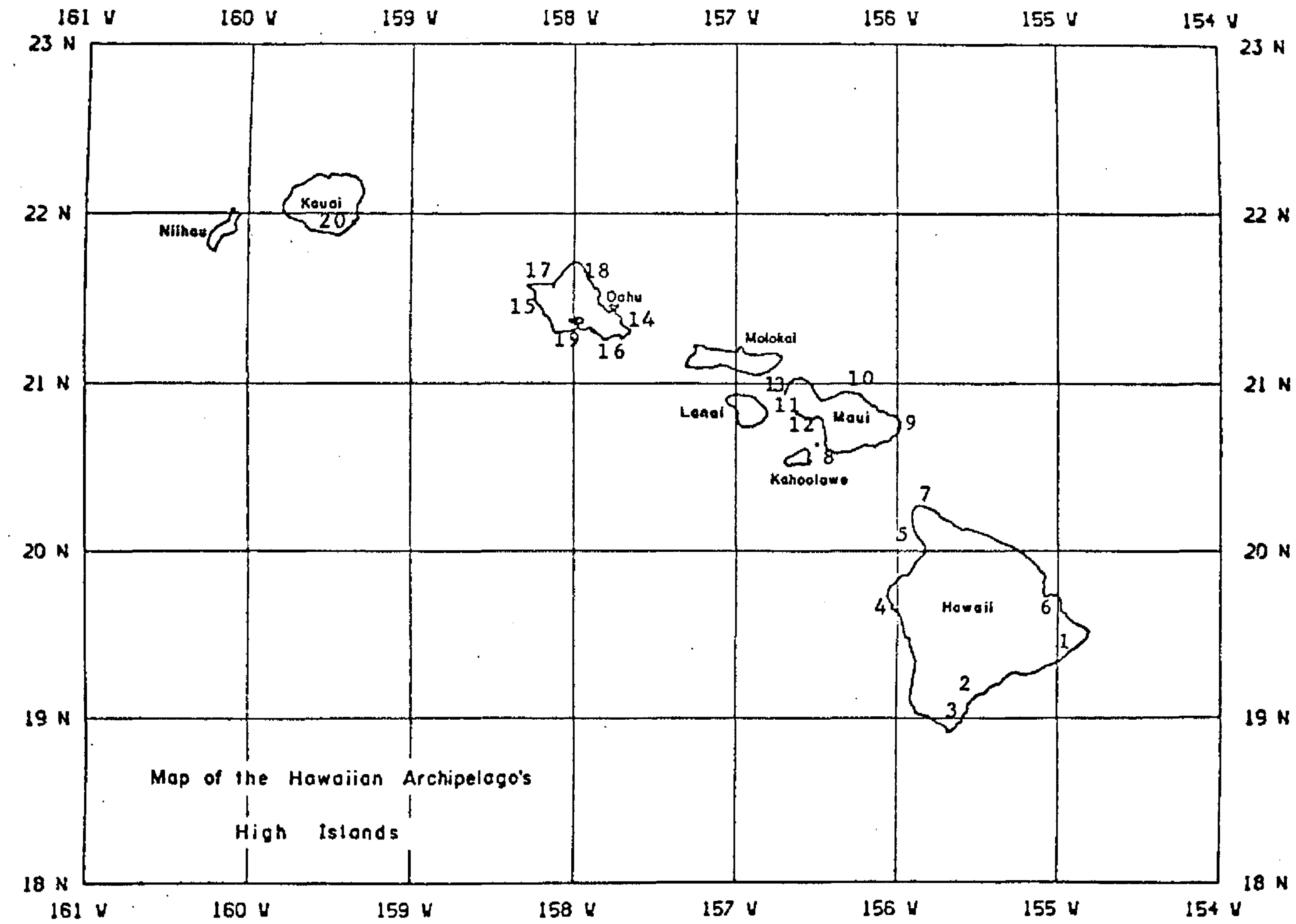


Figure Ia8. Map of the approximate locations of identified potential geothermal resource ares in Hawaii. From Thomas, et al., 1979.

Table Ia4

Location	High Temp. Resource	Low Temp. Resource	Probability for Development
Hawaii			
1. Puna	1	1	3
2. Ka'u	2	1	7
3. South Point	3	2	3
4. Hualalai-North Kona	5	3	1
5. Kawaihae	5	3	1
6. Keaau	6	4	1
7. Kohala	7	5	8
Maui			
8. Haleakala-Southwest Rift	3	2	5
9. Haleakala-East Rift	3	2	6
10. Lahaina	3	1	1
11. Olowalu-Ukumehame	3	1	2
12. Honokawai	5	4	2
Oahu			
13. Waimanalo	7	5	1
14. Lualualei	8	6	1
15. Honolulu Volcanic Series	8	7	2
16. Haleiwa	9	7	3
17. Laie	9	7	3
18. Pearl Harbor	10	9	1
Kauai			
19. Post Erosional Volcanic Series	10	8	5

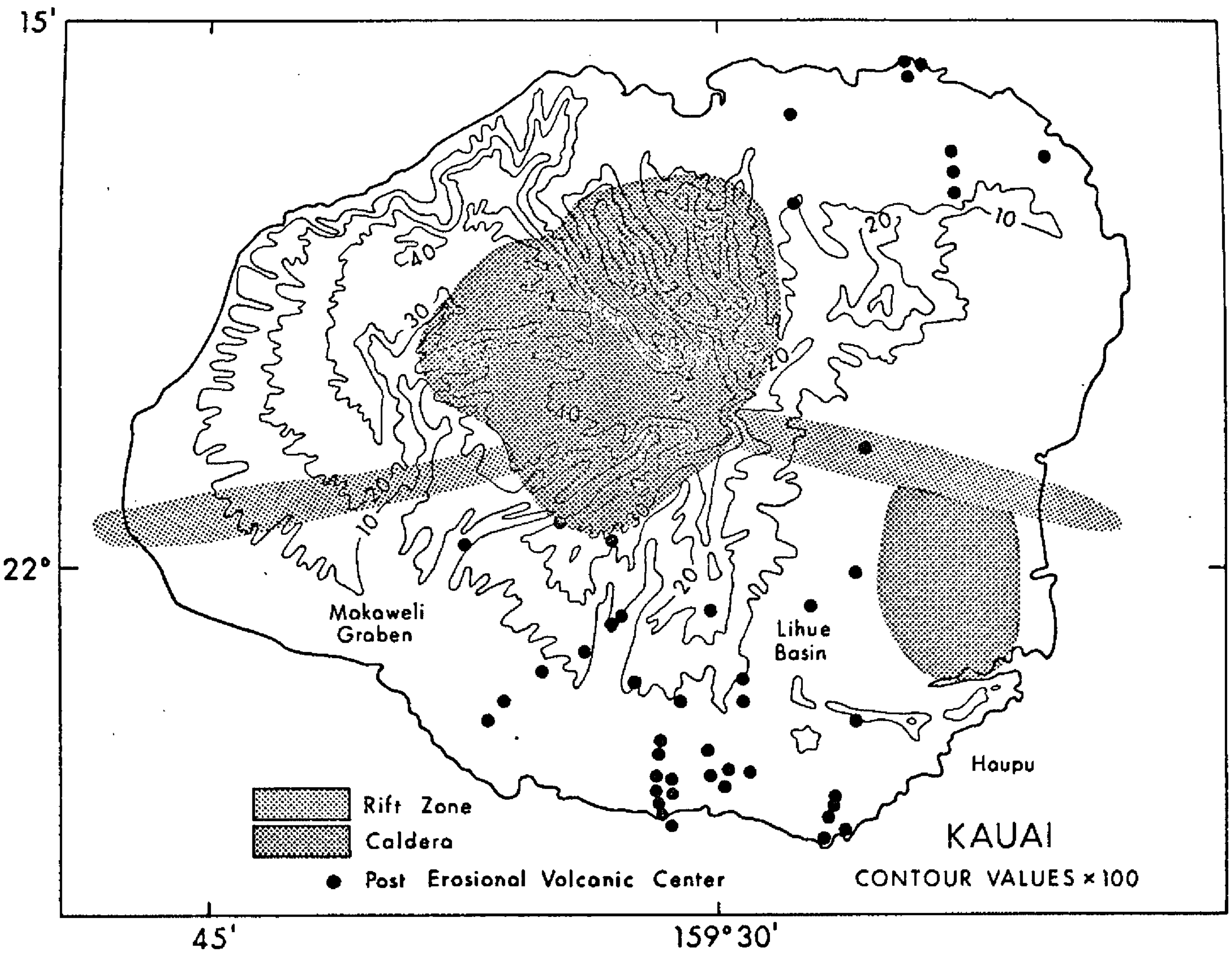


Figure Ia9. Map of the island of Kauai

The island of Oahu (Figure Ia10) is made up of two major volcanic edifices: the Waianae shield formed approximately 2.5 to 3.5 million years ago and the Koolau shield which was active from 2.5 million to 20,000 years before present. The latter age includes numerous post-erosional eruptive centers scattered across the southeastern end of Oahu. The preliminary assessment of Oahu's geothermal potential identified six separate areas on the island which warranted further investigation. Although the overall appraisal of the island's potential is generally low due to the relatively great age of both of the major eruptive centers, field investigations conducted in the vicinity of the Waianae caldera in 1978 were much more encouraging than initially expected.[23] The geophysical and geochemical techniques applied in the Waianae caldera (Figure Ia11) included resistivity, groundwater chemistry and temperature, soil mercury and radon, structural and petrological mapping, and alteration mineralogy. The results of these surveys identified several areas around the inferred caldera boundary where anomalous conditions were indicated to be present (Figure Ia12). Although several alternative explanations are possible for the data, the most reasonable interpretation of the coincident anomalies is that they are arising from at least a low level heat source within the Waianae caldera system. On the basis of the results obtained five sites were identified for future exploratory drilling. The U.S. Navy (the present land owner) has taken these recommendations under advisement, however, no exploratory drilling is presently planned.

None of the other identified potential geothermal areas on Oahu have been investigated to date, however a detailed survey of the Mokapu peninsula, near Kaneohe, is planned for early 1981. Even though this area is on the

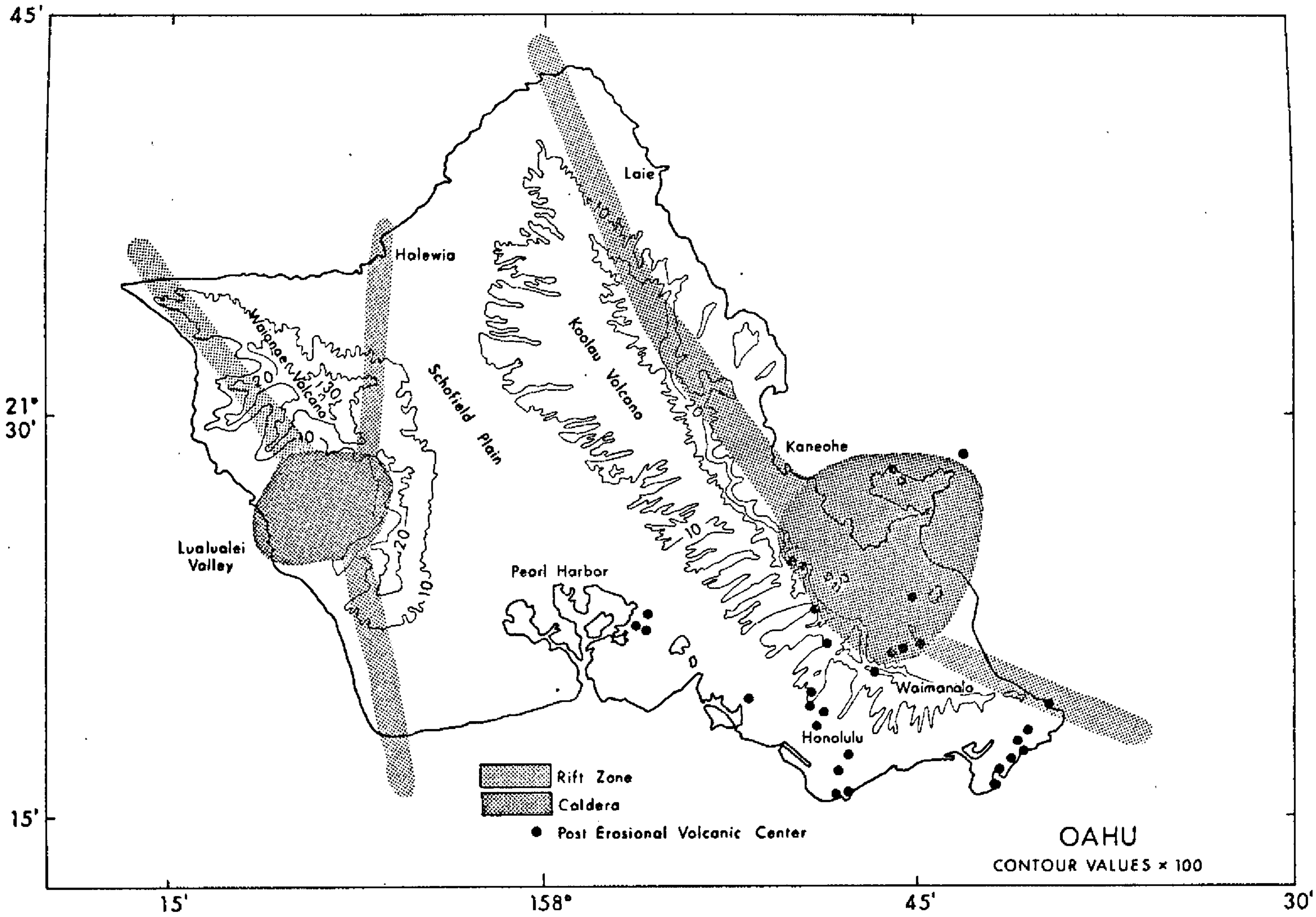


Figure Ia10. Map of the island of Oahu

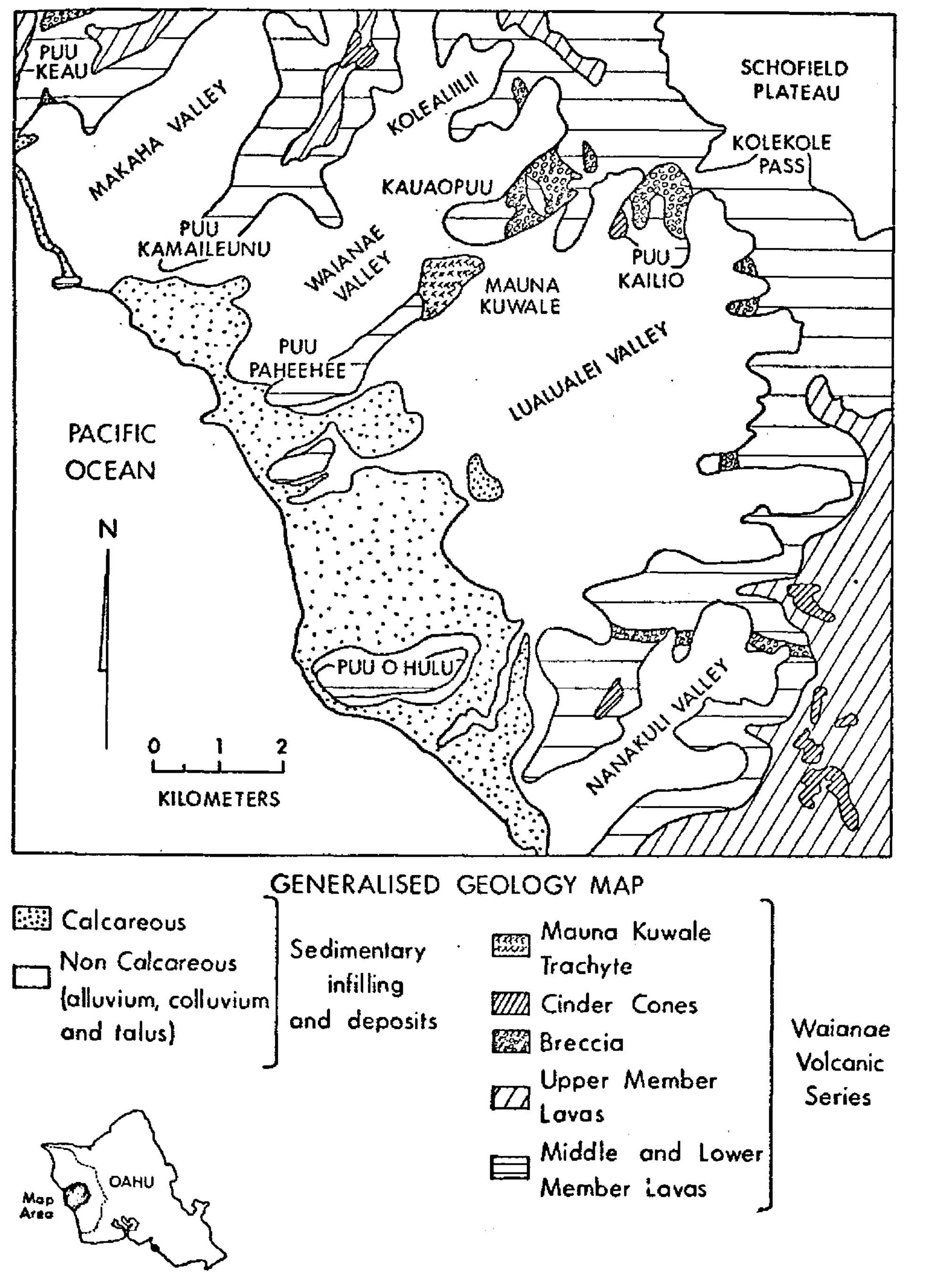


Figure Ia11. Generalised geology map of the Waianae Caldera in Lualualei Valley, Oahu. From Cox, et al., 1979.

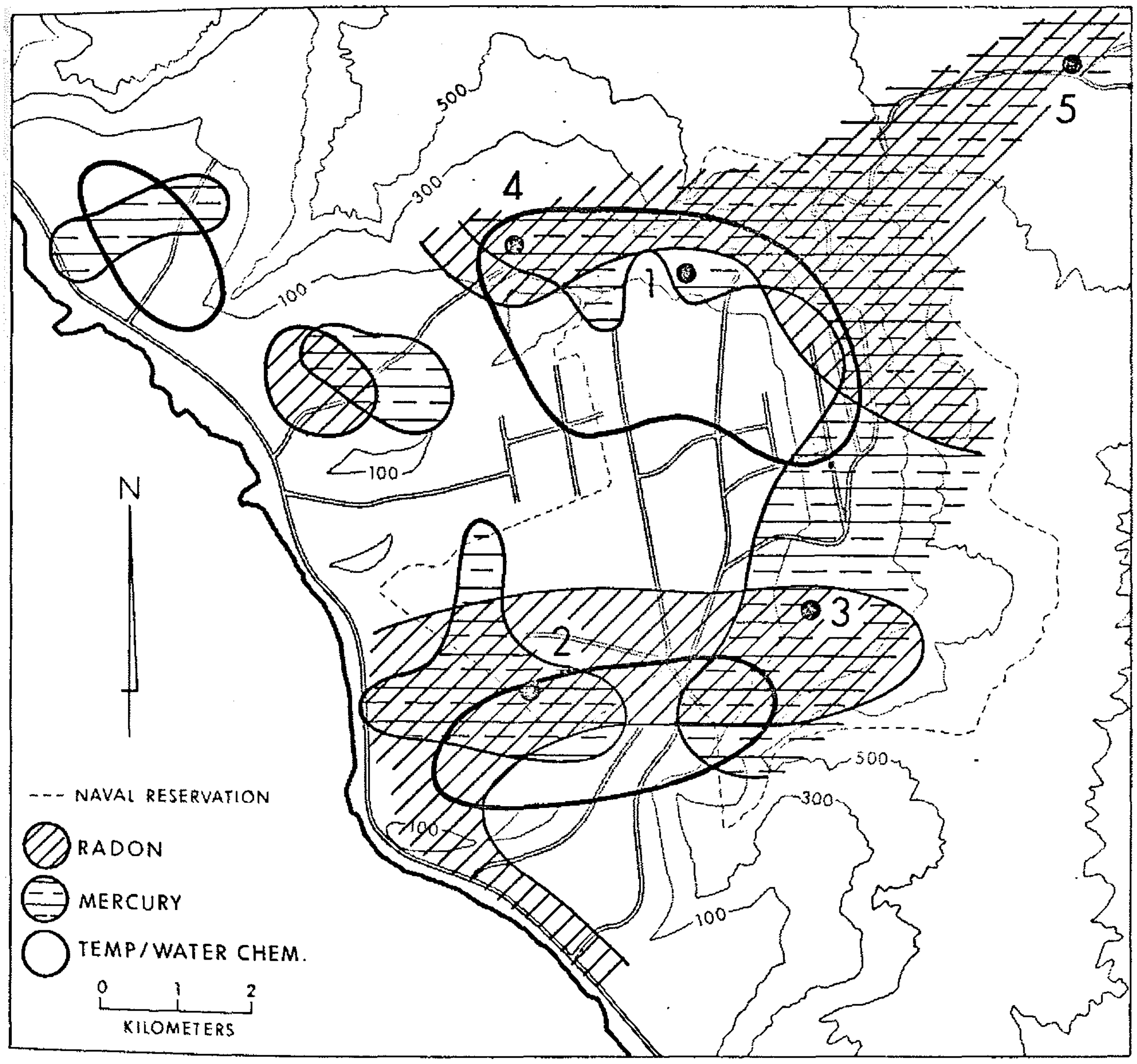


Figure Ia12. Map of Lualualei Valley, Oahu, summarizing areas having anomalous characteristics and identifying recommended exploratory drill sites. From Cox, et al., 1979.

outer edge of the inferred boundaries of the Koolau caldera it is the site of relatively recent post-erosional activity and therefore may have some potential for a heat source. Detailed exploration surveys in other parts of the Koolau caldera and in the other identified potential areas on Oahu have been forestalled for the present primarily due to a combination of the limited potential for finding a high temperature resource and the rather high population density and resultant difficulty in conducting field surveys in these areas.

Molokai (Figure Ia13) is made up of two major volcanic centers: the west Molokai volcanic series of 2.25 to 1.75 million years age and the east Molokai series of about 2 million to 1.25 million years age. The large post-erosional Kalaupapa series on the north coast of the island is thought to have an age of between 30,000 and 500,000 years. The initial assessment of Molokai's potential identified one documented warm water source on west Molokai and several other groundwater geochemical anomalies in other parts of the island. The general assessment of Molokai's potential was that a low temperature resource may well be present on west Molokai, however, due to the relatively small market for geothermal energy on Molokai, no further detailed field surveys have been conducted on the island.

The island of Maui (Figure Ia14) is made up of two major volcanic systems. West Maui is the older and smaller of the two having an age of from at least 1.25 million years to about 600,000; post-erosional activity occurred between about 80,000 and 20,000 years before the present. Haleakala volcano (east Maui) is substantially larger and younger than west Maui; the bulk of the Haleakala shield was built between 1.5 and 0.5 million years ago. Post-erosional volcanism on Haleakala has continued up until the

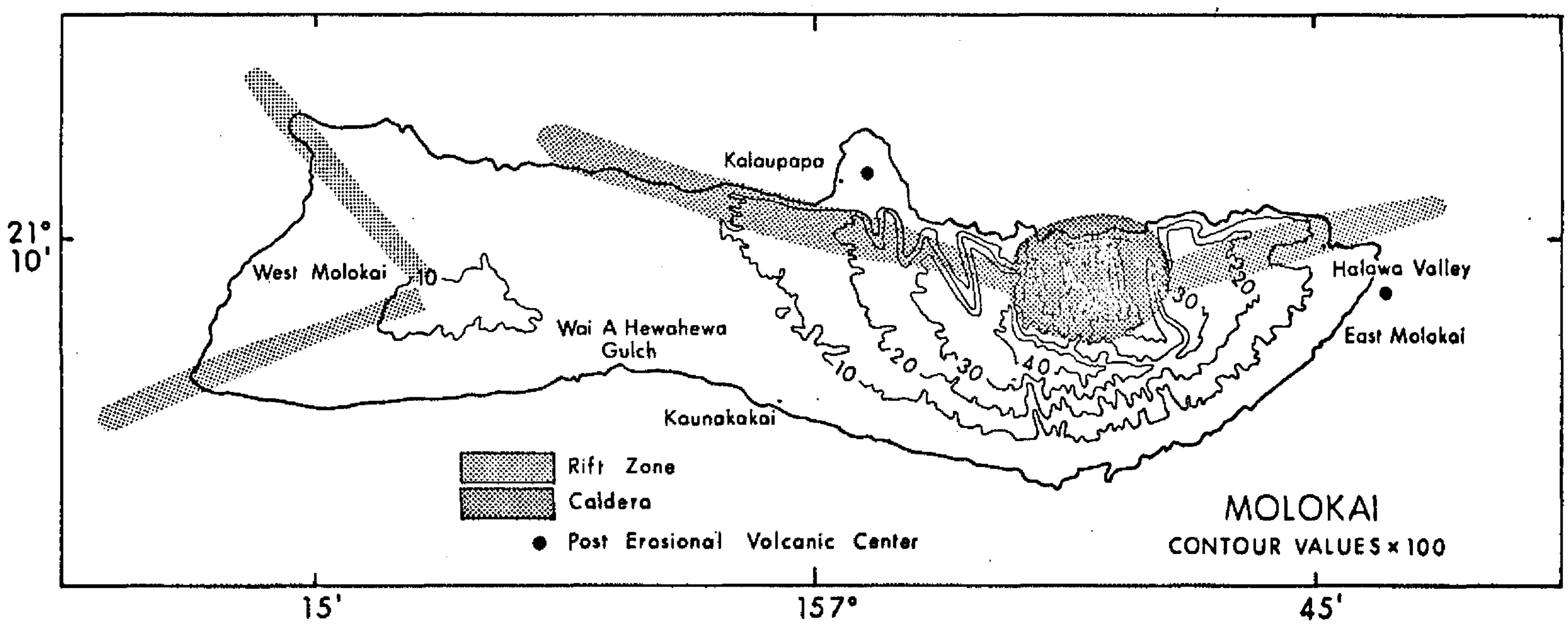


Figure Ia13. Map of the island of Molokai

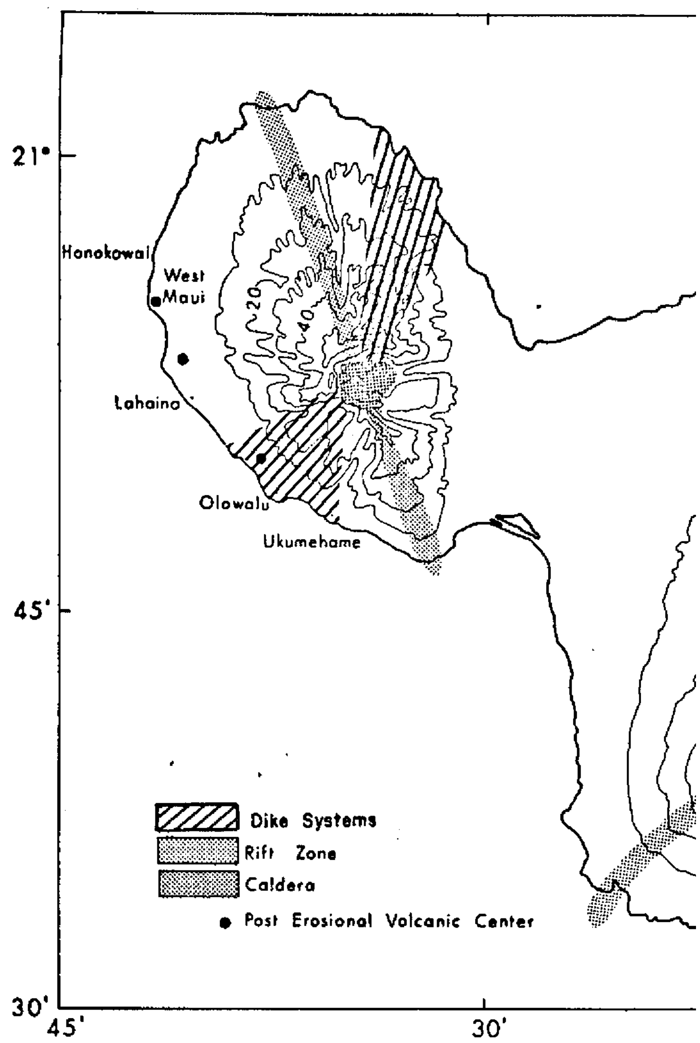
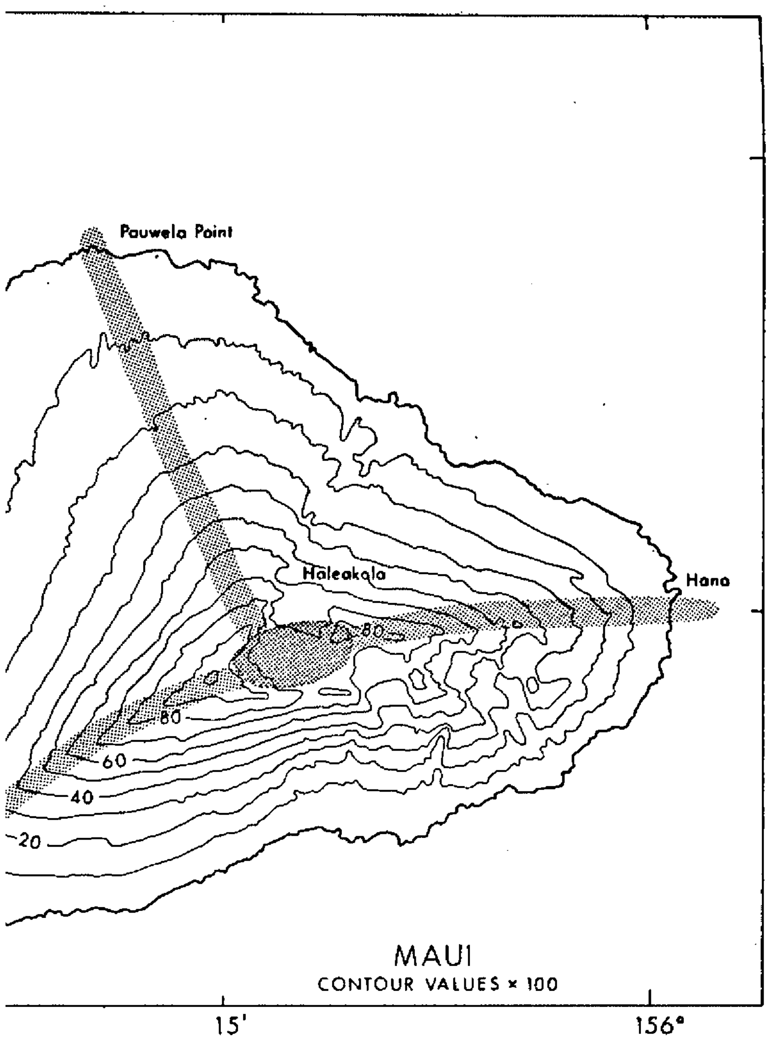


Figure Ia14. Map of the island of Maui.



Pauwela Point
Haleakala
Hana
80
80
60
40
20
MAUI
CONTOUR VALUES × 100
15'
156°

present time, the most recent eruptive activity having occurred in 1790 along the lower southwest rift system.

The preliminary geothermal assessment of Maui identified six areas which were indicated to have some potential for a geothermal resource. These potential areas were identified on the basis of groundwater geochemical and temperature data as well as location and age of most recent volcanism. Three of these areas (Lahaina-Kaanapali, Ukumehame-Olowalu canyon, and Haleakala northwest rift) are presently under intensive investigation and one other (Haleakala southwest rift) is targeted for field surveys in the near future. The presently available results for the areas being surveyed are as follows:

Lahaina-Kaanapali: low level groundwater chemical anomalies have been identified in two locations east of Kaanapali. Roughly coincident with these are anomalous soil mercury and radon concentrations possibly associated with nearby post-erosional eruptive centers. Geophysical surveys in this area, however, have been less encouraging. Resistivity soundings and self-potential surveys both indicate normal or near normal subsurface conditions. Further, more detailed,work using other geochemical and geophysical techniqes will be necessary in this area before the apparent conflict in the data can be resolved.

Olowalu-Ukumehame: groundwater geochemical and temperature data strongly suggest that a thermal anomaly is present in or near Ukumehame canyon; one Maui type water tunnel near the mouth of the canyon has encountered groundwater with a temperature of 33°C (significantly above the expected ambient groundwater temperature) which also has a substantially altered chemical composition. In addition, geophysical surveys conducted in this area have identified apparent resisitivity and self-potential anomalies. Although it is not presently possible to uniquely assign a temperature to the source of the inferred geochemical and geophysical anomalies, the estimated resource temperature may range from about $60^{o}C$ to as high as $170^{o}C$. Geophysical surveys are continuing in this area in an effort to further characterize the nature of the observed anomaly.

Haleakala Northwest rift: initial data acquired in this area indicated that both groundwater chemistry and temperature anomalies were present. More recent soil mercury and radon data have tended to substantiate the initial anomalous interpretation, however, limited geophysical surveys as well as more recent groundwater studies suggest that the earlier geochemical evidence may be the result of other, non-geothermal, processes associated with the northwest rift zone. Further geochemical and geophysical surveys, as well as detailed hydrologic modelling of this area are underway in an effort to confirm this preliminary evaluation.

Preliminary data acquired for both the east and southwest rift systems on Haleakala indicate that these rift systems may have a greater potential for a geothermal resource than any of the other identified areas on Maui. This evaluation is based primarily on the geological evidence of eruptive activity along these rift systems; a large proportion of the post-erosional activity on east Maui occurred along the southwest and east rift systems of Haleakala. The most recent activity on Maui occurred in 1790 on the lower southwest rift of Haleakala and it is presently believed that several of the other cinder cones on the Haleakala flanks are less than a few thousand years old. Although relatively little other geophysical and geochemical data are available for these areas, more detailed field surveys for both the east and southwest rift systems are planned for the near future.

The island of Hawaii (Figure Ia15) is both the youngest and the largest of the Hawaiian Chain. The island is made up of five volcanic systems: Kohala is the oldest and is considered extinct; Mauna Kea is the next oldest and is considered dormant; Hualalai, Mauna Loa and Kilauea have all had eruptive outbreaks during the last two centuries and thus are considered to be still active. The approximate range of ages for each of these volcanic systems are as follows: Kohala, 1.0 million to approximately 0.080 million years before present; Mauna Kea, 1.0 million years to approximately 3000 years; Hualalai, 750,000 to 180 years; Mauna Loa, 900,000 years to the present; Kilauea, 100,000 years to the present.

The preliminary survey of the geothermal potential of Hawaii island identified seven areas which had some evidence for potentially exploitable geothermal resources. Of these seven areas, one, the Kilauea east rift zone, was studied intensively prior to the siting of the University's well HGP-A; three others, Keaau, Kawaihae and North Kona, are currently being investigated. Based on the data presently in hand, the appraisal of the geothermal potential of each of these areas is as follows:

Kilauea east rift: geophysical and geochemical data acquired on this area during the Hawaii Geothermal Project's exploration program identified several marked anomalies along the surface trace of the rift zone (Figure Ia16). The University sited well, HGP-A, penetrated an extremely hot (358^{o}C) reservoir at a depth of approximately 1900 meters and has thus proven that

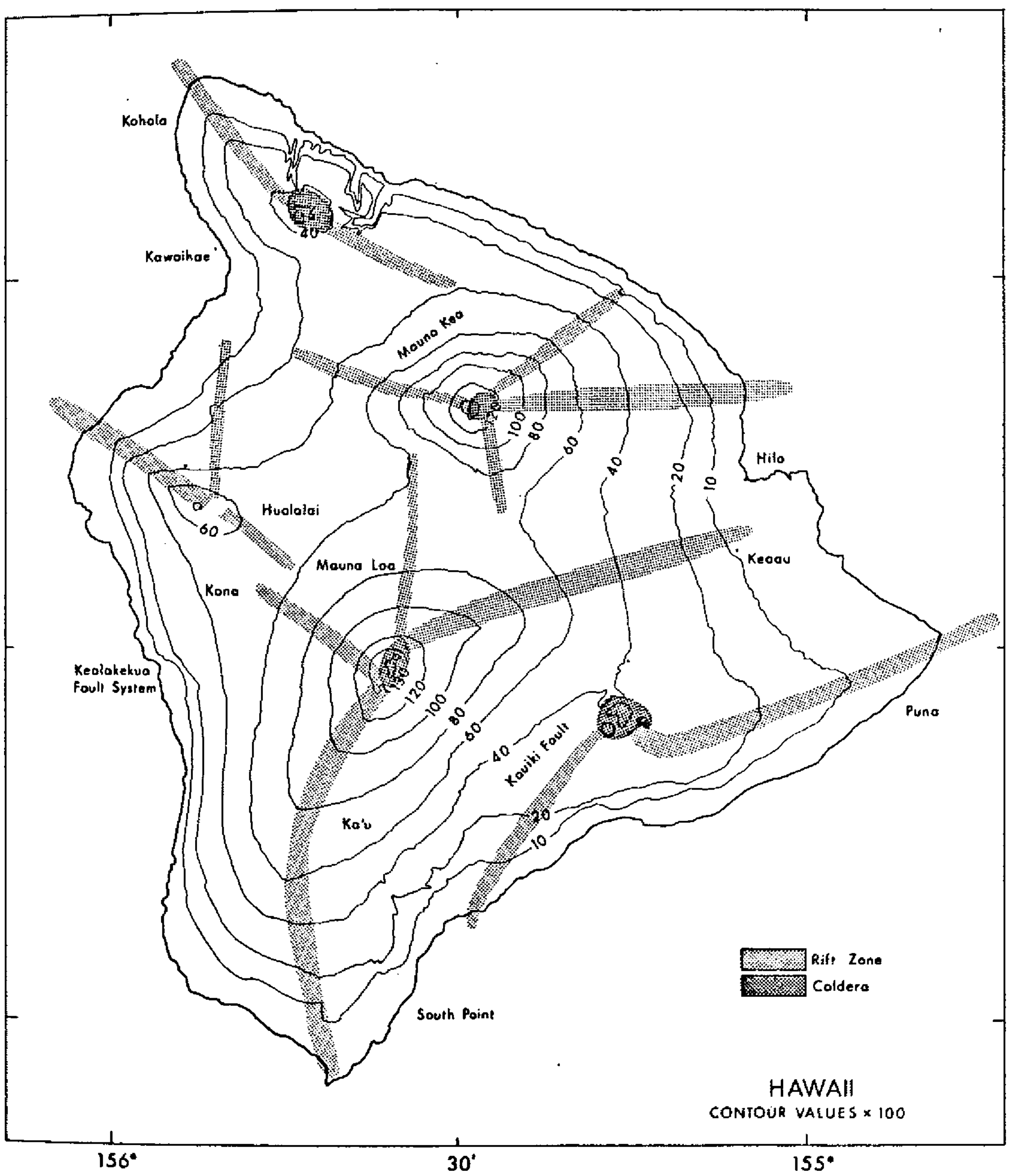


Figure Ia15. Map of the island of Hawaii.

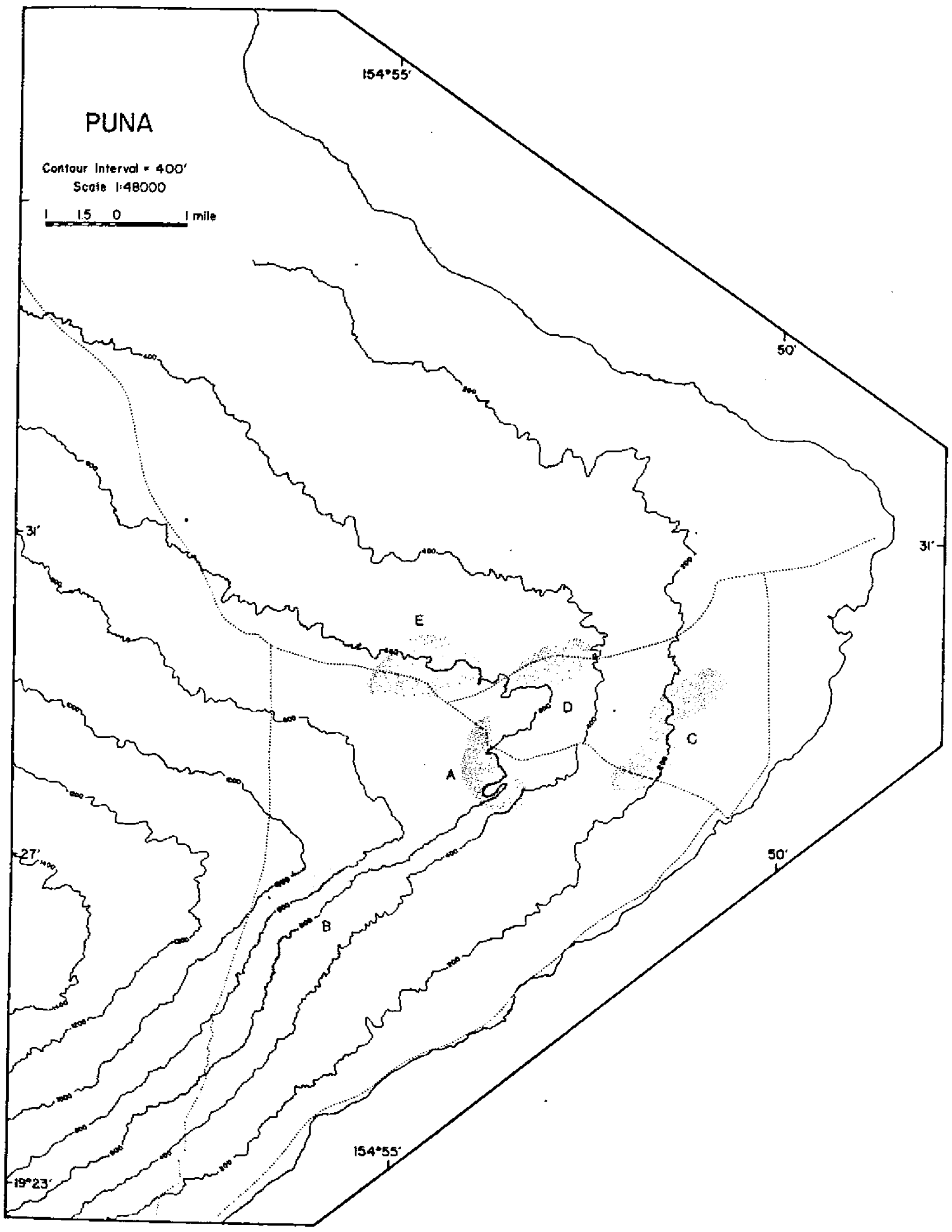


Figure Ia16. Map of the Puna district with approximate locations of anomalies identified during geophysical exploration conducted for the Hawaii Geothermal Project, modified from Suyenaga, et al., 1978.

a resource is present in the lower Puna area.[15] Further, more recent, geophysical surveys [25,26] suggest that subsurface high temperatures may exist along the entire length of the Kilauea east rift. The results of this work indicates that the entire rift zone could be a geothermal resource area if the other necessary conditions for the formation of a reservoir are present (groundwater, permeability, etc.). The actual extent and long term viability of the resource, however, can only be proven by further and much more extensive exploratory drilling and long term production. Presently available estimates of the geothermal potential of this east rift range from 100 MWE centuries[27] to more than 3000 MWE centuries.[28]

Keaau: initial groundwater chemistry data collected near Keaau indicated that thermally altered groundwater, possibly associated with the Mauna Loa east rift, might be present in this area. Subsequent more extensive geophysical and geochemical field surveys conducted around Keaau indicate that the anomalous groundwater chemistry may be the result of other, non-thermal, processes. The presently available data on Keaau strongly suggest that no thermal resource is present in this area.

Kawaihae: this area was originally identified as a potential geothermal area on the basis of groundwater chemistry and temperature data from wells to the east of Kawaihae Bay. More recent surveys have confirmed the original data obtained and have tentatviely located a possible source of the thermal anomaly; geophysical surveys identified a highly resistive layer at a depth of a few hundred meters below sea level that is interpreted to be an intrusive body associated with Puu Kawaiwai, a cinder cone associated with the Kohala post-erosional volcanic series. More extensive geophysical and geochemical surveys are presently underway in this area in an effort to both confirm this interpretation and to more fully characterize the inferred resource.

North Kona-Hualalai: preliminary surveys of North Kona district identified both water chemistry and thermal infrared anomalies along the coastal areas. More extensive trace element geochemical surveys near Kailua Kona have also identified apparent anomalies thought to be associated with Hualalai volcano. Although geophysical exploration in the North Kona area has been severely hampered by cultural interferences (power lines, buried pipes, etc.), detailed geophysical surveys conducted to the north of Kailua, near the Hualalai summit, have indicated that a conductive zone is present a few hundred meters below the surface. This has tentatively been identified as a layer of warm, possibly geothermally altered groundwater. In addition, a second subsurface low resistivity zone has been identified along the lower northwest rift of Hualalai near the cinder cone Puu Mau. Although both of these areas are thought to have a potential thermal anomaly present, considerably more exploration work is required to confirm their existence.

Relatively little recent data are available for the other areas on Hawaii that may have some potential for a thermal resource: South Point, Kilauea southwest rift, Mauna Kea and Kohala. Both South Point and the Kilauea southwest rift are thought to have a higher probability for a resource since both have been volcanically active during recorded history (Mauna Loa in 1890 and Kilauea in 1920) and thermal manifestations have been reported along both rifts.[21,29,30] However, few detailed geophysical surveys have been conducted over either area and virtually no geochemical data are available for soil or groundwater on either rift systems. Thus even though the geothermal potential in both areas is considered probable geologically, it is not yet possible to provide a more precise estimate of their potential.

Both Mauna Kea and Kohala volcanoes (compared with Waianae or west Maui) are relatively young and on this basis, may be considered to have some geothermal potential. However, until more geophysical and geochemical studies are conducted on these volcanic systems, no valid appraisal of their potential can be made.

In summary, it is apparent that several of the volcanic systems within the Hawaiian island chain have some evidence for the existence of a geothermal resource. Although only one of these areas can be considered to have a proven geothermal reservoir (the Kilauea east rift zone) recent field surveys have provided data strongly suggestive of a geothermal anomaly in several others. Evaluation and characterization of these identified anomalies are currently underway and exploration in other potential geothermal areas is continuing. The production capacity of one proven geothermal reservoir in Hawaii, the Kilauea lower east rift zone, has been initially estimated to be of the order of 100 to 3000 megawatt centuries, however, the actual production capacity of this area, as well as of all other identified geothermal resources in Hawaii, will be determined only by much more extensive exploratory drilling and production from each individual reservoir.

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deep geothermal wells exploratory on Oahu is attractive. In addition, the likelihood of volcanic activity on Oahu interfering with or damaging geothermal development appears to be less of a potential problem than it is on the Big Island.

ENVIRONMENTAL, SOCIAL, LEGAL AND CULTURAL ISSUES

Although geothermal energy offers one of the most promising developments of alternate energy resources for the Hawaii Island, there are many attendant issues which, if not dealt with successfully, could cause delays and other problems in the commercialization process. They cover a wide range of environmental and social concerns as well as legal and cultural barriers.

The demand for energy and the distribution of energy within the state are strongly influenced by the geography of the Islands. Each island currently forms an isolated energy market for which energy planning and development has generally proceeded indenendently. The island of Oahu, furthermore, overwhelmingly dominates the energy picture: the city and county of Honolulu represent 82% of the state's energy demand. Such concentration of demand is an important constraint in planning for geothermal resources development because the most promising sites for development are presently thought to lie on the geologically younger and volcanically more active islands of Hawaii and, perhaps, Maui -- not on Oahu. For geothermal energy resources on Hawaii and, perhaps, Maui to be fully exploited, energy demand must either shift dramatically to these islands or the energy produced must be transported to Oahu (assuming, for now, that Oahu will never prove to have any significant geothermal resources.)

Geothermal energy can meet requirements for baseload electricity, and direct heat applications are also possible. Planning for development is very much influenced, however, by concern with production of electricity. Two alternative strategies for geothermal development have emerged as a consequence of the existing supply/demand pattern and the presently perceived prospects for geothermal resources development: 1) island self-sufficiency, and 2) creation of a statewide, interisland electricity grid.

ISLAND SELF-SUFFICIENCY

According to an island self-sufficiency strategy, each island would continue as an independent energy system. Geothermal energy, along with other indigenous sources, would be developed to meet demands created on a given island. This approach would undoubtedly limit full exploitation of geothermal resources on the Big Island of Hawaii unless very large new customers were introduced; and extensive use of geothermal energy has been proposed for the Big Island. Sugar processing and large scale pumping of irrigation water to the semi-arid western side of the ~~Big~~ Island have been suggested. Serious consideration has been given to the possibilities for establishing energy-intensive chemical and mineral industries such as manganese nodule processing and aluminum smelting. Such developments would have a major impact on Hawaii and would require extensive pre-development planning to minimize dislocating community values and ways of life.

An obvious problem with this strategy is that Oahu is currently believed to have very little geothermal energy. Consequently, developing geothermal energy would not appreciably reduce the state's overall dependence on imported energy. Even if the islands of Hawaii and perhaps Maui attracted some of the state's current economic activity, and a higher proportion of its future economic activity, Oahu's needs would still have to be satisfied by foreign energy resources.

AN INTERISLAND ELECTRICITY GRID

The second strategy involves transmitting electricity from the outer islands to Oahu, allowing fuller exploitation of geothermal energy resources to replace imported petroleum. However, creating an interisland electricity grid by cable connection requires resolution of important technical and political issues.

An Oahu-Maui cable is technically feasible, but resource assessment does not suggest there is sufficient capacity to justify the cost of installing such a cable. A cable that can withstand the deeper waters between Maui and Hawaii has never been built, although the technology is considered obtainable within the next 10 to 20 years if the amount of transmission could justify the effort.

At present, attempts to construct an interisland transmission network could also face serious political problems. Traditional concern by people on the outer islands of economic and political exploitation by Oahu would be exacerbated. These concerns could be reduced by increasing local benefits; i.e., by compensating localities for adverse impacts with rewards such as higher employment, higher average wages, and a greater tax base. Resolution of such conflicts would properly involve county officials and local residents.

As we have noted, the first successful geothermal well drilled in Hawaii is located in the Puna district of the Island of Hawaii. Other test wells are scheduled for drilling in the same area. This part of Puna is a remote, almost wilderness area, with small farms and some sub-divisions which, although large in size, are sparsely settled. It is a rural community and, except for the geothermal development, totally free from industrial activities. The residents of the area include many Hawaiian and part-Hawaiian families, some of whom are living on lands that have been in their families' possession for five or six generations. Some residents are young people and retirees who have deliberately chosen to live in this isolated area for the peace and freedom it offers from urban noise and crowding. Development of a large geothermal complex at Puna is regarded by some as the first step in bringing in a large industrial development with associated construction, heavy equipment, traffic, increased population, noise, urban bustle and pollution. Development of geothermal resources in the Islands in general raises environmental, sociological, legal, and cultural issues which are illustrated by concerns expressed over development of the Puna reservoir. These concerns are discussed below with Puna in mind. However, the concerns at Puna are a guide to concerns wherever geothermal resources development might occur in the Islands.

<u>Sociological Sources</u>

Dramatic changes in the life style of the residents of the Puna could follow the development of geothermal resources, especially if an industrial complex is built. And, as certain residents pointed out in a public hearing* most of the sacrifices would be made by the residents -- and many of the benefits would accrue to others.

There are several community groups actively engaged in studying development plans and providing advice to residents on the impact of proposed geothermal development in Puna. The "Puna Hui Ohana" is an umbrella organization for four Hawaiian groups: Puna Hawaiian Organization, Hawaiian Parents Society, Hui O'Pio, and Young Hawaiians of Puna. The Leilani Community Association represents the residents of the nearby Leilani subdivision and publishes a monthly newsletter for its members in which a "Geothermal Update" appears.

Testimony presented at the August, 1980 hearings and other meetings and the Leilani Community Associaton newletter indicate that most of the organizations, families, and individuals who are expressing concern are not opposed to geothermal power as such. They see the need for lessened dependence upon imported petroleum and they prefer geothermal power to nuclear power. However, they do want orderly development of geothermal power, they appreciate the problems development will bring to the area and its residents, and they want a genuine effort to mitigate the negative effects of development.

In the state of Hawaii, public and private officials enjoy a certain lack of credibility. Their assurances of the benefits of

*Public Hearing of the Planning Commission, County of Hawaii, August 7 and 8, 1980 on the application of the Geothermal Exploration and Development Corporation, Hilo, Hawaii.

development to the residents and their promises of proper attention to the concerns of environmental damage and loss of access to recreational areas have been met with skepticism. Hawaiian people have heard these assurances many times in the past thirty years. Practically every developer or mainland company wishing access to Hawaiian resources has made the same promises. From many, performance regarding these assurances has been very disappointing.

The economic impact of development, in addition to the social impact, could have both positive and negative aspects for residents. More jobs will certainly be created, but residents are asking specifically "What kinds of jobs?" and "Who will get the jobs, local people or mainlanders"? Others point out that after the drilling and construction phases, relatively few full-time and part-time jobs may remain. On the positive side, assuming that geothermal development will lead to an expanded economy, it is anticipated that more public facilities such as roads, schools, police and fire protection, and medical facilities will become available. However, these positive effects will occur in conjunction with increased population and its problems. Land values usually increase with development, but this too can also be a mixed blessing as increased values may bring about increased property taxes.

Several studies of the sociological implications of the development of geothermal power in Hawaii are being made, including one by Dr. Penelope Canan of the University of Hawaii (Canan, 1980). Another is being conducted by the Puna Hui Ohana on the social impact of geothermal developments in New Zealand upon the lives of the native Maoris. The results of this study, (which is being done by a group of Puna residents and involves the Maoris who, like the Hawaiians, are a Polynesian people) could have an important influence upon geothermal development and residents of the Puna district.

Environmental Issues

In addition to concern about social changes anticipated from the emergence of industrial development in a formerly rural area, environmental concerns have been expressed by many people. While geothermal power is a more environmentally benign source of energy than fossil fuel and nuclear power, there are a host of worries associated with it (cf. SRI international pp. V1-4 to V1 10). Noise, H_2S, and loss of recreational areas are probably most important.

Health, safety and general nuisance problems are feared from drilling of wells. Pollution from hydrogen sulfide and other gases and the possibility of danger from steam and hot water have been mentioned as concerns. Some felt the noise from the HGP-A well was excessive and even damaging to the health of nearby residents as well as bothersome to native bird populations. Additional noise from possible construction of access roads, use of heavy equipment and increased traffic in the area is anticipated by residents.

Hydrogen sulfide ("rotten egg" gas) was obviously present in the first emissions of the well at Puna. Technological changes and the addition of a "scrubbing" process to the system have eliminated 90% of the problem (see Chen, et al, 1980), but fear exists that it could occur again with each new well that comes into production. Fears have also been expressed that the chemicals present in the steam would cause a "fallout" with resultant damage to cultivated and wild plants in the area and possibly to people and livestock eating them.

Although many of these concerns were answered by specialists who had made baseline environmental studies of the area, doubts concerning the completeness of these studies and the effectiveness of the proposed regulation system were expressed. One witness raised specific questions on the proposed environmental monitoring system. Who would be doing the monitoring? How frequently and how accurately would measurements be taken? To whom would anomalies be reported? By whom would corrective action be taken? How long would corrective action take?

Loss of recreational facilities in the area is also feared. Fishermen are afraid that ocean waters will be polluted, damaging traditional fishing areas; hunters fear that development will drive away the animals they have hunted for many years; families are afraid that recreational facilities in general will become overcrowded or made inaccessible to those who have always used and enjoyed them.

Legal Issues

Legal questions surrounding the development of geothermal resources in Hawaii have many ramifications. Property boundaries in Hawaii often have to be traced back through early records, many of which are written in Hawaiian. Since the time of the Great Mahele (1843), Annexation of Hawaii to the United States (1898), Territorial status (____), and then Statehood (1959), have added other statutes affecting private and public holdings and the interpretation of property rights.

The basic determination of ownership of geothermal resources is clouded by uncertainty over whether the legal ownership of geothermal resources is vested in the state, the surface property owner, or the native Hawaiians. Municipal control has also been suggested.

Dr. Robert Kamins, in a study of the ownership of geothermal resources in Hawaii, described some of the causes of this uncertainty. Although the Hawaii State Legislature passed a law in 1974 declaring that geothermal resources are "mineral" and therefore included with the mineral rights expressly reserved by the Hawaiian government in land grants made during the monarchy and prior to annexation, the first government claims were not uniformly expressed in land transfers to private owners during many of the early years.

Another legal constraint is the claim recently put forward that the Native Hawaiian people have paramount rights over geothermal resources. A brief for Ho'ola Kanawai in Robinson vs. Ariyoshi (obtain correct citation __________) asserts that the State holds mineral resources, including geothermal reservoirs, in trust for Hawaiians. A study of this claim, including a survey of case law on land and resource claims of American Indians, has been proposed to help resolve some of these ambiguities.

State and county regulations require permits and environmental impact statements, but they do not at present serve as real barriers to development of geothermal resources.

Cultural Issues

The cultural concerns of the people of Puna are very important factors in the development of geothermal resources both in the Puna area and in other parts of the state where geothermal resources may be found.

Puna is a district where a large majority of the residents are of Hawaiian or part-Hawaiian descent. Even the relatively recent residents who may or may not have Hawaiian ancestry, identify strongly with the Hawaiian culture and history and life style.

The love of Hawaiian people for their land is deep and has religious aspects. The land, the aina, has power and is regarded as the giver of food and substance to its people. The preservation of agricultural lands are important not only for preservation of a desired Hawaiian life-style and the cultivation of the usual crops and livestock, but also for the preservation of the old Hawaiian herbs and medicines which are part of the Hawaiian history and culture.

The need for surveying and preserving archeological and religious sites apply here, as well.

A unique cultural and religious factor in the development of geothermal resources in Hawaii is the legendary goddess, Pele, who is the patroness of--and by many considered the embodiment of--all the volcanoes of Hawaii. Although Christianity has been embraced by most Hawaiians, they and many others of different ethnic and cultural groups, believe strongly in the spirit of Pele, a goddess who can be benign or vengeful as she chooses. The legends of Pele are many; the supporting evidence startlingly precise: and belief in the goddess is not restricted to Hawaiian people or the normally superstitious. While it is not suggested in any way that outside developers have to join in this belief, it would be unwise of them to deny the right of belief to others.

Benefits

Although a variety of environmental, social, legal and cultural issues are recognized in connection with geothermal resources development, it should also be remembered that in the minds of many people significant benefits may also be realized. Developing geothermal resources on the Big Island will contribute to the state's goal of reduced dependence on imported fuel. In the near term, electricity generated from geothermal resources will help maintain a lower rate structure in the Island's electricity grid than electricity generated from fossil fuels. Over the long term, if geothermal electricity is transmitted off-island to Oahu to meet baseload electricity requirements, it will have a significant impact on the state's balance of payments problems and will lessen the vulnerability now associated with dependence on imported oil. Geothermal resources may also contribute to the competitiveness of goods and services produced in Hawaii by providing a reliable source of energy at stable, relatively low prices. Geothermal development may create additional local personal income from direct employment, and should have additional multiplier effects on the state's economy. The multiplier effect is estimated to be about 2.3 (Humme and others, 1979, p. 9-25.)

THE ECONOMICS OF GEOTHERMAL DEVELOPMENT

An issue of fundamental interest in geothermal resource development is the question of its economic viability. Uncertainty is involved in estimates of economic viability and competitiveness inasmuch as uncertainty is associated with underlying fundamental parameters characterizing a resource. Although each reservoir must be considered on its own, the Puna reservoir appears to be competitive economically as a means to support a combination sugar processing-electric generating operation.

Earlier we briefly noted one "test" that geothermal fluids must pass: costs for recovery must be less than a reasonable price one might expect to receive for the sale of the fluid as a substitute for fossil fuels (Howard, 1980). Costs depend largely on depth to the resource but are also strongly influenced by ultimate recoveries per well. Selling price, on the other hand, depends largely on the temperature of the fluid, because hotter fluids contain more useful energy on a pound mass basis. They can, so to speak, substitute for more fossil fuel. In a simple way, then, one can conclude that - in principle - the Puna Reservoir is hot enough to be economically exploitable for its particular depth of occurrence. This same kind of reasoning would have to be applied to every resource defined in the Islands. However, the resource could be shallower and less hot; deeper but hotter, and so on.

Economic viability and economic competitiveness are different concepts: and for geothermal resources development to occur in Hawaii, competitiveness as well as viability must be demonstrated.

A recent study by the Amfac Company is a model for economics analysis. It concludes in particular that a portion of the Kilauea East Rift could be economically competitive if developed for sugar processing needs and for electric power. Furthermore, it implies, as explained below, that development for electric power generation alone in the East Rift ought to be competitive.

Before explaining the implications of the Amfac study to developments of the East Rift for electric power generation alone, it would be useful to make several general statements. First, the economic competitiveness of each reservoir has to be evaluated on the basis of its own parameters such as temperature, depth, etc. Second, each evaluator must decide on a criteria for competitiveness, e.g., 15% rate of return. Third, there are unknowns that must be recognized; and it should be realized that the actual profitability of development depends significantly on the reliability of the estimates of these unknowns.

The Amfac Study of a Cane Sugar Processing Plant

The Amfac study of a cane sugar processing plant addresses all aspects of economics including depletion and depreciation. It includes some features that are not general features of geothermal resources development, e.g., income from the sale of SO_2. Nevertheless, it supports the conclusion that geothermal from the East Rift is competitive in the sense that an acceptable return on investment is possible.

The Amfac analysis strictly applies to a project calling for the production of geothermal fluid from the East Rift, transportation to an existent sugar mill 16 miles from the Rift, and use of the geothermal fluid to process sugar and produce electricity. The study also implies, however, that electric production from the East Rift is competitive.

Study of the Amfac analysis shows that $1.3M would be required to retrofit an existing turbogenerator to yield 12.3 MW of electric generating capacity; $17.7M would be needed to transmit the resource 16 miles to the sugar plant/electric plant. Our reasoning is that these capital funds ($19M) could just as well have been directed into construction near the wells of a new 12.3 MW power plant. In other words, funds equal to $1544 per kilowatt of installed capacity could have gone into a new plant for generation of electricity - still realizing to a first approximation a return on investment of 15%.* Inasmuch as installed capacities for flash systems, such as would be used here, run about $1200/kw, ~~(see Table 4)~~ electric generation from the Rift should clearly be competitive. Costs for installed capacity of the first 3 MW unit now under construction are expected to be about $2000/KW ($6M for 3000 KW). The reason that these costs are so high is not fully known, but in part they are due to the experimental nature of this plant. Competitiveness should improve as costs per installed kilowatt of electricity are presumably reduced in the future.

STET

Units of such small size can be as cheap as $330/KW (Sverrir

*To a first approximation because there are details in the financial analysis that differ. For instance, an 18-year depreciable life was assumed for the retrofit power plant; a new plant should have a longer life, etc.

Thorhallsson, Engineer in Charge, 8MW Svartsengi field, Iceland, pers. comm.) The average costs of the geothermal power plants built in the U.S. to date is $247 per kilowatt, although flash plants planned in the future average more than this (i.e., $1200/kw) (See Table 4).

CONCEIVABLE SCENARIOS FOR GEOTHERMAL RESOURCES DEVELOPMENT

Development of indigenous resources in Hawaii to offset fuel oil imports requires the retention of a host of environmental and social impacts which are now exported to energy producing countries. It would also change the environmental effects of energy consumption as oil is replaced with indigenous fuels. Development of an energy industry requires the creation of technical and administrative competence to ensure that in-state production of energy is a positive contribution to the society. The choice of any fuel/energy source implies direct and secondary impacts which must be evaluated in the context of the land constrained island environment.

Once a decision is made to commercialize geothermal energy resources, the pace will be limited by the rates at which supply and demand can be matched at different locations, and at which economic, environmental and social concerns can be resolved. It is difficult to overstate the care needed in energy development in island communities to avoid rapid and complex changes that may overwhelm or alienate people and institutions. Assuming that appropriate institutions to address identified problems exist or can be created, probable scenarios for geothermal development in the state can be projected.

Geothermal Electric Pla

State	Area	Developer	Utility
CA	Brawley	Union Oil	SCE
CA	East Mesa	Magma power	SDG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Union-Magma-Thermal	PG&E
CA	Geysers	Thermogenics	PG&E
CA	Geysers	Aminoil USA	PG&E
STATUS TOTAL			

Average Cost = $273/kw.

ınts on Line

Plant	Plant Type	Net Output MWe	Year on Line	Plant Cost ($) x 1000
SCE Pilot	Flash	10	1980	10,040
	Binary	10	1980	16,093
Unit #1	Steam	11	1960	2,005
Unit #2	Steam	13	1963	2,005
Unit #3	Steam	27	1967	3,085
Unit #4	Steam	27	1968	3,805
Unit #5	Steam	53	1971	6,378
Unit #6	Steam	53	1971	6,378
Unit #7	Steam	53	1972	5,760
Unit #8	Steam	53	1972	5,760
Unit #9	Steam	53	1973	6,760
Unit #10	Steam	53	1973	6,706
Unit #11	Steam	106	1975	19,666
Unit #12	Steam	106	1979	27,580
Unit #15	Steam	55	1979	25,530
Unit #13	Steam	129	1980	52,800
		812		201,125

ble 4. PROPOSED FLASH GEOTHERMAL ELECTRIC PLANTS

tate	Area	Developer	Utility	Plant Name	Net Output	Year	Cost $M	Cost/Kw
A	East Mesa	Republic	SDG&E	–	50	82	80	1600
A	Heber	Chevron	SCE	SCE#2	100	86	110	1100
A	Niland	Magma	SDG&E	SDG&E#1	24	83	30	1250
A	Niland	"	"	" #2	49	85	50	1020
T	Roosevelt	Phillips	UP&L	UP&L#1	20	83	20	1000

verage cost = $1194/kw

From Geothermal Progress Monitor, Progress Report 4.)

This section outlines an optimistic schedule for development, proceeding through four definable stages, as follows.

Development on Hawaii for Island Needs

Geothermal resource and technology development activities are presently confined to the island of Hawaii. If they proceed as planned, commercial electricity and direct heat applications will be on line within a few years. These activities should proliferate rapidly from present sites in Puna to supply a broad range of demands. Hawaii seems likely to follow the typical development pattern in which small scale applications are followed by larger and more ambitious projects as confidence and practical experience accumulate. This first generation should last five to ten years.

Development on Maui for Island Needs

Maui is the second island believed to contain sizeable high temperature geothermal reservoirs. Some field activities are underway at present, and The Hawaii Institute of Geophysics plans to conduct more surface exploration activities in the Northwest zone of Haleakala (Haiku-Paia) and the Lahaina-Kaanapali area within the next two years. A geothermal developer has already expressed interest in the latter area. Resource, technology, and market development should parallel that projected for Hawaii, following a few years behind. Success with resources on Hawaii would probably accelerate the pace of development on Maui by creating a pool of private sector experience and confidence. However, the potential market on Maui is even smaller than on the Big Island, so development will be constrained by lack of demand unless links are established to other islands or the economy of Maui is altered by the growth of new business.

Maui-Oahu Cable

If large-scale geothermal resources are identified on Maui, a transmission cable could be laid to Oahu. The cable is technically feasible now and awaits a commercial reason for construction. A Maui-Oahu link would allow full exploitation of Maui's energy resources (geothermal and otherwise) while replacing some of the imported petroleum Oahu now needs. If testing and development proceed as planned, work could begin on the cable before 1990.

Oahu-Hawaii Cable

Hawaii's resource base is believed to be larger than Maui's, but the island is separated from Oahu by deeper waters (down to 2000 meters) that have never been crossed with present cable technologies. This development may be delayed beyond 1990 to allow time for both resources assessment and technological development.

At the close of this fourth generation of geothermal commercialization, the state will have geothermal electricity and direct heat production on Maui and Hawaii, and the major islands will be part of a single electricity transmission network connected by inter-island cables. These cables can be sized to transport as much electricity as can be produced from all indigenous sources. These links should allow Hawaii to greatly reduce its present dependence on oil imports.