An Overview of the Hawaii Geothermal Resources Assessment Program

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ABSTRACT

The Geothermal Resource Assessment Program of the Hawaii Institute of Geophysics began an evaluation of the geothermal resources of the State of Hawaii in February 1978. The first phase of the assessment program consisted of the compilation and evaluation of existing geological, geophysical, and geochemical data having relevance to a potential geothermal resource. The data acquired suggested that twenty separate locations on the five major islands had some evidence far a geothermal resource. During the second phase of the program thirteen of the identified potential geothermal areas were studied using a variety of geophysical and geochemical techniques. The results of the surveys strongly substantiated the existance of a geothermal resource in four areas, provided moderately positive evidence in three areas, and gave contradictory or negative data in five others,

INTRODUCTION

The Hawaii Geothermal Resource Assessment Program of the Hawaii Institute of Geophysics was undertaken in 1978 for the purpose of identifying and evaluating all potential geothermal resources in Hawaii. The faur year program consisted of two phases: an initial regional survey based on the evaluation of existing data relavant to detection of a geothermal resource followed by site specific field studies in selected locations identified in the earlier work as having a significant probability for a geothermal reservoir.

Phase I

Data gathered during the regional survey included all available geological, geophyisical, or geochemical data on the Hawaiian Islands that might provide insight into the geothermal potential of individual areas on each of the five major islands (Kauai, Oahu, Molokai, Maui, and Hawaii).

Regional and local geology were considered to be of primary importance because of the structural constraints on the location of a geothermal reservoir in Hawaii. The information of greatest interest in this regard was the locations of magma chambers and rift zones on the volcanoes and the age and duration of volcanism on each island. During the last sixty years detailed field mapping and structural studies have been done on all of the islands, and, thus, the major portion of the required data was readily available. The age of volcanism on each island, however, was substantially less accessible. Even though the general age of progression of volcanic activity along the chain is well known, records of volcanic events extend only to about 200 years before present. As a result there is very little reliable information regarding geologically recent volcanism in Hawaii prior to about 1790.

The existing geophysical data base for Hawaii proved to be substantially less useful in identifying potential geothermal areas. This was primarily because the majority of the available data of direct relevance to geothermal exploration (resistivity, heat flow, spontaneous potential and electromagnetic soundings) were collected in an area of already proven geothermal potential, the Kilauea Volcano East Rift Zone. More broadly based data (seismic, gravity and high altitude aeromagnetic data), although not directly applicable to geothermal resources evaluation, were useful, however, in confirming the geologic mapping and Structural data.

Groundwater geochemistry and temperatures provided the third major data base used for the regional geothermal assessment work. Since the majority of Hawaii's drinking water supplies are municipally owned well and shafts, a substantial amount of this type of data was available. The information initially considered to be of most use in identifying a potential geothermal area was groundwater temperature, major cation concentrations, and dissolved silica concentrations. Above ambient water temperatures usually indicate higher than average heat flow for a given area, whereas silica and cation geothermometer calculations have been widely used to identify thermally altered groundwaters that have subsequently cooled to ambient temperatures.

DATA COMPILATION AND CALCULATION

Geologic data gathering work consisted largely of mapping the outlines of calderas, rift zones, and post erosional volcanic centers of individual volcanoes on the major islands of the chain. Identification of these areas was based on both the geologic mapping data and any available supporting geophysical information. Ages of volcanism from historical records as well as carbon - 14 and potassium-argon dating were also compiled, Evaluation of the available groundwater data turned out to be far more difficult than initially anticipated. Although numerous groundwater temperature measurements had been made the data were extremely unreliable having no documentation of where or how the measurements were made. Analysis of the chemical data was also complicated by the fact that most of the major ion analyses were incomplete or were done using techniques that are not presently considered to be reliable. In addition, cation geothermometry calculations, using the more reliable data sets, were found to yield totally unreasonable temperatures even in areas of known geothermal potential. (It is currently believed that mineral equilibria controlling cation ratios in continental geothermal systems are not applicable for the rock types found in Hawaii). Application of silica geothermometry was similarly handicapped by very high rates of meteroric recharge to basal water supplies in some areas and by secondary addition of silica in irrigation return water in others. Thus none of the existing quantitative chemical geothermometers were of significant use in assessing the geothermal potential of groundwaters in Hawaii. Evaluation of water chemistry analyses conducted for geothermal and shallow groundwaters in the one proven geothermal resource area in Hawaii (the Kilauea East Rift Zone) indicated, however, that there is a strong correlation between the magnesium ion concentration and the degree of thermal alteration a groundwater has been subjected to (Cox and Thomas, 1979a). The correlation is especially good if the ion concentrations are normalized for sea water (chloride ion) contamination in the groundwaters. Normal (unaltered) groundwater has a chloride to magnesium ion ratio ranging from 2 to about 8 whereas the thermal fluids from the Kilauea East Rift Zone have values from about 12 to as high as several thousand, Thus, even though there does not appear to be a quantitative relationship between the temperatures to which groundwaters have been exposed and the magnesium ion concentration, the Cl/Mg ion ratios seem to be reliable indicators of thermal alteration of shallow groundwaters.

The procedure used for evaluating groundwater data began by screening all available data in order to obtain a median value for groundwater temperature and silica concentration for each island. The data were then rescreened, and all water sources having temperatures more than 5°C or silica concentrations more than 30% above the respective median values were identified as "anomalous," The water chemistry data for all water sources so designated were then re-evaluated for their chloride-magnesium ion ratios. Locations of those groundwater sources identified as having individual or multiple temperature, silica, or Cl/Mg ratio anomalies were then plotted on the geologic data map along with any available geophysical data directly relevant to a geothermal resource.

The primary objective of the regional assessment program was to identify all possible geothermal resource areas for future field evaluation; therefore the criteria set for identifying an area as potentially having a geothermal resource were very broad on the basis that it was better to include false positives, which could later be elimiated, than to exclude false negatives that might never be evaluated. Thus, any area on the data map that had two or more coincident indications of a geothermal anomaly was identified as a potential geothermal resource area, Approximately twenty potential geothermal resource areas were identified (Fig. 1) using this method.

The second step in the evaluation process was to rank each of the twenty resource areas according to its probability for having a resource. Data on which the rankings were based included the age of most recent volcanism in the area, the number of different coincident anomalies (e.g. an area having temperature, silica and Cl/Mg anomalies would normally be ranked higher than one having only a silica and Cl/Mg anomaly), and the strength (i.e., deviation from the median) of the identified anomalies in each location.

Phase II

During Phase II of the program, field surveys were conducted in a selected set of locations identified in the Phase I work in order to confirm the preliminary evaluation as well as to define more completely the characteristics and magnitude of the identified resource. The field study sites were chosen on the basis of estimated potential (i.e. ranking) as well as the projected probability for future development of a resource should one be confirmed in that location. The latter projection was made on the basis of its proximity to a market for the resource as well as its accessibility, potential environmental impacts, and potential land use conflicts.

Field surveys have been conducted, to a greater or lesser extent, in thirteen of the twenty identified potential geothermal areas. The field techniques used included groundwater temperature measurements and chemical analyses, soil mercury and radon mapping, passive seismic monitoring, resistivity and time domain electromagnetic soundings, and spontaneous potential surveys. Although no single individual survey technique was found to be able to unequivocably confirm the existance of a geothermal reservoir in a given location, each was able to provide data that were useful in assessing the probability of there being a resource within the tentatively identified area. A summary of the data acquired from the field surveys performed during the second phase of the geothermal assessment program follows:

Kilauea East Rift Zone

The Kilauea East Rift Zone has been the site of frequent eruptive activity throughout recorded history. Numerous geophysical and geochemical studies (Cox, et al., 1980; Druecker and Fan, 1976; Furomoto, 1975; Kauahikaua and Klein, 1978; Kroopnick, et al., 1978) have been conducted in the East Rift Zone during the current as well as prior geothermal exploration work. Results from

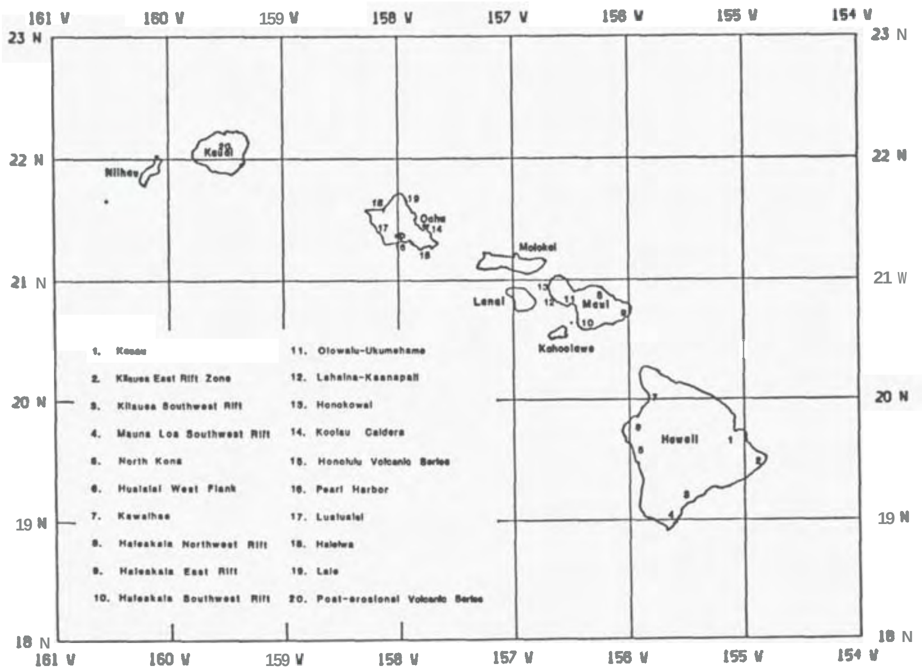

Fig. 1 Identified Potential Geothermal Resource Areas in Hawaii.

the earlier surveys led, in 1976, to the drilling and testing of a deep (1966 m depth) geothermal well in the lower East Rift which discovered a high temperature (>360°C) geothermal resource. A wellhead generator facility installed on the well is currently producing approximately 2.8 MWe on a continuous basis, During the last three years, four privately financed geothermal wells have been drilled along the East Rift Zone and are presently undergoing testing and evaluation. More recent geophysical surveys (Godson, et al., 1981) suggest that a geothermal resource may be present along the entire length of the Kilauea Rift Zone and, thus, the resource discovered in this area may have a capacity sufficient to produce from 500 to 3,000 megawatt-centuries of electrical power.

Kilauea Southwest Rift

Eruptive activity on the Southwest Rift of Kilauea has been far less frequent than that along the East Rift; however recent intrusive activity suggests that a substantial amount of heat may be stored in the southwest flank of Kilauea. Although there have been a very limited number of field surveys conducted along the rift, both aeromagnetic (Godson, et al., 1981) and resistivity (Hussong and Cox, 1967, and Kauahikaua and Mattice, 1981) data suggest that a thermal anomaly is associated with the rift zone; isolated areas of steaming ground and low temperature thermal springs tend to substantiate this conclusion as well. An overall evaluation of the data suggests that a substantial thermal resource is present along the Kilauea Southwest Rift; however, no estimate of the magnitude of the resource can be made with currently available data.

Mauna Loa Southwest Rift Zone

Mauna Loa Volcano has not been as active as Kilauea Volcano during the last three decades; however, during the last 150 years, 38 eruptions have occured in the summit and flanks of Mauna Loa. Fourteen eruptions have occured during the present century and, of these, five have been along the Southwest Rift Zone. The only geothermal field surveys conducted in this area have been resistivity soundings along the lower Southwest Rift; the surveys were unable to detect evidence of resistivity anomalies within 1 km of the surface (Kauahikaua and Mattice, 1981). Nonetheless, the frequency of activity along the rift zone would suggest that further investigations are warranted.

North Kona

Aerial infrared surveys (Fisher, et al., 1966) initially identified warmer than expected temperatures in the coastal waters near North Kona and more recent grounwater data suggest that some thermal alteration has occured in the water chemistry, Mercury and radon surveys (Cox, 1980) have also identified anomalies that are inferred to be associated with a thermal source located on the southwest flank of Hualalai Volcano. Geophysical. surveys (resistivity and electromagnetic soundings) of limited extent were, however, unable to detect significant resistivity anomalies along the North Kona coast. The current assessment of this district is that, if thermal fluids are present, they are probably the result of a heat source within Hualalai Volcano.

Hualalai West Flank

Recent geologic mapping conducted on the western flank of Hualalai (R. Moore, personal communication) indicates that the frequency of eruptive activity on this volcano has been much higher than earlier studies indicated. Soil mercury and radon mapping (Cox, 1980) have been conducted along the lower west flank of Hualalai and have been identified only very weak anomalies within the diffuse western rift zone. Resistivity soundings near the summit detected low resistivities at 500 to 1000 meters depth that could be associated with dike or ash bed-perched thermal fluids. Although further evaluation work should be conducted on Hualalai, presently available data suggest that there is a significant probability that a thermal resource is associated with this volcano.

Kawaihae

Groundwater temperature and chemistry data (Epp and Halumen, 1979; Thomas et al., 1979; Cox and Thomas, 1979a, 1979b) strongly suggested that a thermal resource was present near Kawaihae. More recent soil mercury and radon mapping (Cox, 1980) indicates that some form of anomaly extends to the east from near Kawaihae Bay and resistivity soundings have identified an apparent intrusive body that may be associated with an 80,000 year old eruptive vent on Kohala Volcano. It is highly probable that a low to moderate temperature resource is present near Kawaihae Bay.

Keaau

Keaau is located near the inferred lower East Rift Zone of Mauna Loa Volcano and was initially identified as a potential geothermal site on the basis of groundwater chemistry data acquired during the Phase I study (Thomas, et al., 1979). Reanalysis of the water chemistry did not confirm the earlier data; and follow-up time-domain electromagnetic soundings did not detect any significant resistivity anomalies within 3 km of the surface. More recently acquired data suggests that the probability for a thermal resource near Keaau is very low.

Haleakala Northwest Rift

Post-erosional eruptive activity along the Northwest Rift of Haleakala has been much more limited than that along the East or Southwest Rift zones. Groundwater geochemical data, soil mercury and radon mapping initially suggested that a thermal resource was in this area; however, neither Schlumberger soundings nor spontaneous potential surveys (Mattice and Lienert, 1980; Mattice, 1981) were able to confirm the geochemical data. The present assessment of the potential of this area is that the probability that a viable geothermal resource is present is considered to be moderate to low.

Haleakala Southwest Rift

The Haleakala Southwest Rift Zone was the site of the only historical eruption, in 1790, on Haleakala. Although only a limited number of field surveys have been conducted along the lower Southwest Rift Zone, soil mercury and radon surveys and electromagnetic soundings all give positive indications of a thermal resource in this area. These data are very encouraging, however further studies on the Haleakala Southwest Rift are required to confirm the existance of a resource.

Olowalu-Ukumehame

Temperatures of more than 10°C above ambient and highly altered chemical compositions of groundwaters near the mouth of the Ukumehame Valley strongly suggest that a thermal resource is present within the West Maui complex. Schlumberger resistivity soundings along the coastal plain (Mattice and Lienert, 1980a; Mattice 1981) have mapped a warm water lens within a few hundred meters of the surface, and electromagnetic sounding data indicate that the source of the thermal fluids may be located near the inferred caldera boundary of West Maui Volcano. A low to moderate temperature resource in the West Maui complex is considered to be almost certain although a high temperature resource is thought to be unlikely as a result of the one million year age of this volcanic system.

Lahaina-Kaanapali

Lahaina, located near several of the post-erosional vents of West Maui Volcano, was initially identified on the basis of weak groundwater chemistry anomalies. Although soil mercury and radon surveys tended to substantiate the groundwater data, Schlumberger soundings around Lahaina have not been able to detect significant resistivity anomalies. The age of the West Maui post-erosional volcanic centers (20,000 to 80,000 years before present) and the absence of any strong confirming evidence for a thermal anomaly suggests that the probability for a geothermal resource in this area is rather low.

Lualualei Valley

Numerous geochemical and geophysical surveys were conducted in Lualualei valley (Cox, et al., 1979) which encompasses the caldera area of the Waianae Volcano on Oahu. Groundwater temperature and chemistry data as well as soil mercury and radon results strongly suggest that thermal fluids are being channelled to the surface along the boundaries of the inferred caldera. In addition, Schlumberger resistivity soundings detected lower than expected resistivities at less than 1 km depth that are interpreted to be due to thermal fluids. Thus, while available data strongly suggest that a thermal source is present within Lualualei valley the age of the volcanism for this caldera (approximately 2.5 million years before present) suggests that the temperatures are likely to be relatively low.

Mokapu Peninsula

The Mokapu Peninsula is located on the northern edge of the Koolau Volcano and is made up of as well as adjacent to several Koolau post-erosional volcanic vents. While numerous geochemical and geophysical surveys have been conducted throughout the peninsula in a detailed geothermal 'field study (Cox, et al,, 1982), only a very few weak mercury and radon highs were identified, and Schlumberger resistivity soundings were unable to detect any evidence of a heat source. It is considered to be very unlikely that a resource is present within the immediate vicinity of Makapu Peninsula.

CURRENT PROGRAM STATUS

The Hawaii Geothermal Resource Assessment Program has concluded the major part of its field exploration effort and is presently preparing final reports on the work completed and the assessments of geothermal potential in each of the geothermal areas evaluated. Although considerably more geothermal work will be required to prove out the potential geothermal resources identified, the results of the program to date suggest that there are abundant geothermal resources, of varying temperatures, within the State of Hawaii.

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